Land use: Reducing emissions and preparing for climate change

Committee on Climate Change
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Executive Summary

Executive Summary

This is the first of two reports on how to improve our use of land to meet climate goals. This report identifies areas where changes can enable land-owners to deliver climate change mitigation and adaptation objectives, among the other priorities for land use. In our second report next year we will carry out a deeper assessment of the policy framework to mitigate climate change through land use, to inform the development of the government's new land management system.

Land is a critical natural asset. It provides us with the fundamentals of life: clean water, food, timber, and the natural regulation of hazards such as flooding. Key to the effective functioning of these is biodiversity. Land is also an essential resource to mitigate climate change, naturally sequestering and storing carbon. Over the rest of this century and beyond, climate change combined with other social, economic and environmental pressures will present significant risks to the services provided by the land. Unless land is managed more effectively over this transition, its essential functions will not be maintained for future generations.

Past policies on land use have been fragmented and incomplete. Land use in the UK has been highly influenced by a complex set of national, EU and international policies. These have, to date, rewarded food production over the other services that land can provide:

- Since the mid-1940s, the Common Agricultural Policy and its predecessors in the UK have provided the main strategic framework for agriculture, driving the uses of land we now see. These policies have contributed to low innovation and slow productivity growth in UK farming compared with other countries. They have also resulted in a large variation between the best and worst performing farms; the average performance of the top 25% of farms in England was almost twice that of the worst in 2016/17.[1]
- While this approach has supported food production, it has not rewarded other services, including adaptation to climate change and carbon sequestration and storage. Important services provided by the natural environment have been degraded: loss of soil fertility through intensive monoculture farming; biodiversity losses resulting in reduced functioning of semi-natural habitats; loss of peatlands; and forests that have become unproductive through lack of management.

The current approach to land use is not sustainable. If land continues to be used as it has been in the past, it will not be able to support future demand for settlements[2] or maintain current per capita food production; nor will we be prepared for the warming climate:

- The UK population is predicted to increase by nine million by 2050. Based on our analysis, the area of land required for settlements could increase from 8% of UK land area currently to 12% by 2050. If trends in farming practices continue, the available land will not be able to support these basic needs and maintain the current level of per capita food production. It will also lead to higher emissions and other environmental problems.
- Climate change is already altering the use of land, changing the timing of natural events such as the flowering of plants each year, and enabling the greater uptake of crops previously grown only in warmer climates, such as grapes. Average UK temperatures have

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[1] Measured by the ratio of average output costs to average input costs for the whole farm business.

[2] Settlement covers housing, other urban development, and other infrastructure (roads, railways, windfarms, agricultural buildings etc.)

risen by 0.8°C since the period 1961 - 1990. Nine of the ten warmest years for the UK have occurred since 2002 and all of the 10 warmest years have occurred since 1990. Projections of future UK climate suggest further warming, periods of heavier rain leading to greater risks from flooding, as well as reduced water availability in summer. The potential negative impacts for soils, water, vegetation and wildlife are likely to be significant. There may continue to be some opportunities from climate change such as longer growing seasons, but the net effect is expected to be negative.

There is now an opportunity to define a better land strategy that responds fully to the challenge of climate change. The Government's Agriculture Bill and proposed Environment Bill will set the future direction of policy for the use of land. This is an important moment to influence the design of a set of policies that have been largely out of scope for decades. It is essential that the key objectives of the Climate Change Act: achieving deep emissions reduction; and adapting to the impact of a changing climate, are at the heart of reforms.

A future land strategy that delivers the UK's climate goals whilst balancing other pressures will require fundamental changes to how land is used. Incremental changes will not deliver climate goals, but bold decisions can ensure land continues to supply essential goods and services and plays a bigger role in meeting climate objectives:

- Implementing low-carbon practices within the current pattern of land use can offer some emissions reduction. Improved farming practices such as better soil and livestock management could deliver up to 9MtCO₂e[3] of emissions reduction by 2050, but would still leave agriculture as one of the biggest emitting sectors.

- Deep emissions reductions entail releasing agricultural land for other uses. Our analysis suggests that emissions reductions of as much as 35 - 80% (20 - 40 MtCO₂e) by 2050 compared with 2016 levels are possible while maintaining current per capita food production. Afforestation (increasing forest cover from 13% of all UK land today to up to 19% by 2050), restoring 55 - 70% of peatlands, catchment-sensitive farming and agricultural diversification can contribute to meeting these reductions.

- Changes in farming practices and consumer behaviours will drive the release of land, but these can build on a number of government initiatives already taking place. These include: improving sustainable agricultural productivity; promoting healthy eating through government nutritional guidelines which could reduce consumption and production of the most carbon-intensive foods; reducing food waste along the supply chain; and increasing forest productivity. Land released through these measures can be used for afforestation, peatland restoration and biomass production, where environmental risks are managed.

- Land use will have to alter due to climate change impacts. In some places, early action to change land use before these impacts occur would enable land managers to maximise the resulting economic benefits, through enhancing the land's ability to maintain the delivery of essential services, and reducing the risk of higher management costs. Acting early is also important to give the best chance of avoiding irreversible damage, such as the loss of upland peat due to warmer, drier conditions. Anticipatory action to improve resilience of land to climate impacts was shown to improve total net benefits across four case study locations in England, analysed in this report.

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[3] See Chapter 2 for details

- The changes that are needed will vary across the UK, requiring careful policy implementation. The impacts from climate change will be different in different locations and local choices will be needed to determine the best adaptation approach. The best use of land to support climate change mitigation will also vary across the UK. In Scotland for example there is greater capacity to switch land use to create natural stores of carbon through afforestation and peatland restoration – requiring new devolved policies to maximise mitigation UK-wide.

Many of the measures analysed in this report have clear, multiple benefits across climate change mitigation, adaptation and government's wider goals. Areas where there are multiple benefits include:

- New technologies and farming methods, essential for releasing agricultural land whilst maintaining food production, would raise productivity and improve the sector's competitiveness.
- A shift in diets towards government nutritional guidelines would improve health.
- Diversifying agricultural land, afforestation, peatland restoration and catchment management have positive impacts on the condition of natural habitats, and habitat creation.

Potential risks can be managed with careful planning. Biomass production for energy use has the potential to reduce emissions in other sectors, provided environmental risks are carefully managed. The Committee's accompanying report 'Biomass in a low-carbon economy' considers these wider sustainability issues in detail, and makes recommendations for improved governance to realise the potential benefits from biomass.

Barriers to transitioning to different patterns of land use and management will need to be addressed. These include inertia in moving away from the status quo and lack of experience and skills in alternative land uses; long-term under-investment in research and development and bringing new innovation to market; lack of information about new low-carbon farming techniques; high up-front costs of new farming methods and alternative land uses; uncertainty over future markets for new products; and little or no financial support for public goods and services provided by land that do not have a market value. There is also a problem with land ownership; 30-40% of UK farms are tenanted, with the average tenancy less than 4 years. This could affect tenant farmers' ability to make significant changes in land use, or to realise the benefits.

The Committee's initial recommendations for the development of policy to address these barriers are listed below. These will be followed by a more detailed assessment of the most appropriate framework for land to contribute to emissions reduction goals next year.

Recommendations

1. New land use policy should promote transformational land uses and reward land-owners for public goods that deliver climate mitigation and adaptation objectives. New policies should also reflect better the value of the goods and services that land provides. The key measures that have clear, multiple benefits are: afforestation and forestry management; restoration of peatlands; low-carbon farming practices; improving soil and water quality; reducing flood risks and improving the condition of semi-natural habitats. These measures should be rewarded if they go beyond a minimum standard that land-owners should already be delivering.

2. Support should be provided to help land managers transition to alternative land uses. This includes help with skills, training and information to implement new uses of land, and support with high up-front costs and long-term pay-backs of investing in alternative uses. It should also include action to address barriers to the take-up of innovative farming practices, which will drive productivity improvements. A structured approach to incorporating the potential impacts from a changing climate into long-term planning is essential for land managers to adapt successfully to climate change. The government should provide support and information through the National Adaptation Programme or the new Environmental Land Management System, to allow this planning to take place.

Committee on Climate Change

The benefits of changing the way we use our land

Land is a critical natural resource. How it's used and managed is vital to the UK's ability to deliver deeper emissions reductions and improve resilience to the effects of climate change over the long-term

Decisions need to be made quickly

The UK's goals for addressing climate climate are unlikely to be met without fundamental land reform. Proposed new UK laws on agriculture and the environment means there is now a one-off opportunity to define a new land strategy.

Nationally, action is required to do the following:

26-36%
Reduction in grasslands and rough grazing by 2050

(up to) 1.5 million hectares
of new woodland to store carbon by 2050

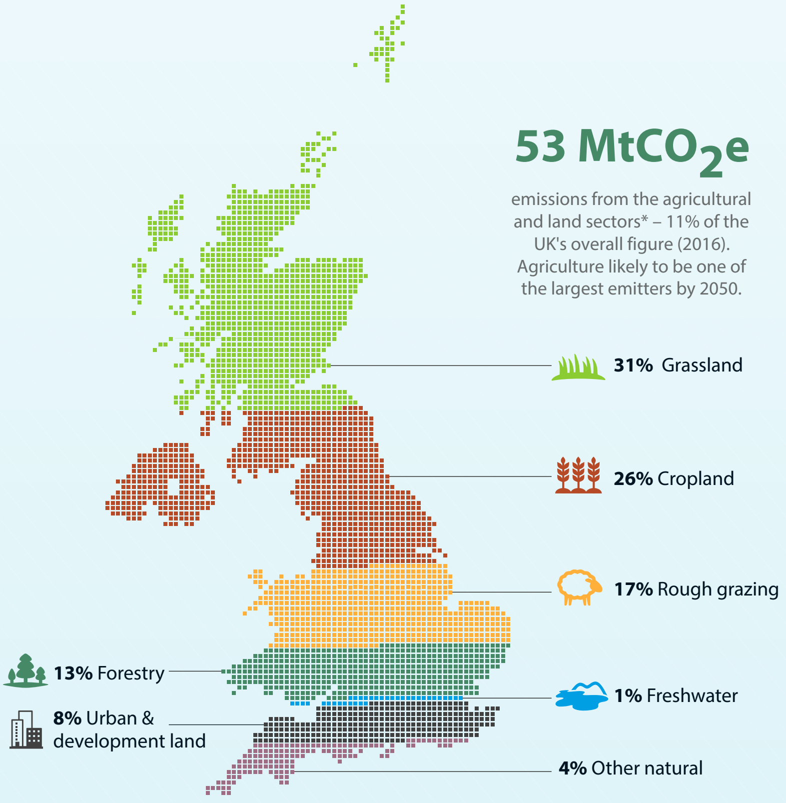
(up to) 1.2 million hectares
for bioenergy crops by 2050

Locally, addressing the risks early could bring multiple benefits:

✓ Can insulate against rising costs of climate change

✓ Supports sustainable benefits through long-term resilience

✓ Protects the natural environment against irreversible decline



How our land is used today

It needs a national, coordinated approach

Freeing-up agricultural land and converting it to alternative uses can help achieve deep emissions reductions. It can also prepare us for the impacts of climate change, while preserving food production and land for development.

Better information for land managers will:

- Help people who manage the land to understand the impacts of climate change (local level)
- Help farmers implement low-carbon farming practices
- Help identify other appropriate land uses such as planting trees or restoring peatlands

Financial support for those affected by:

- A potential loss of income when switching to e.g. new crops or planting trees
- Actions that have higher costs (e.g. planting energy crops such as Miscanthus)

Investment in innovation and technology can:

- Increase agricultural productivity in a sustainable way
- Improve crops and livestock health by breeding and species selection
- Reduce the cost of producing synthetic sources of meat and diary

Real action from individuals can:

- Reduce the amount of household food waste (70% of overall UK food waste)
- Lead to more healthier diets which can also help reduce emissions and protect natural land

The emissions benefits of acting now by 2050

The combination of measures required to reduce emissions can lead to long-term benefits. Many of these accrue over time:

4-11
MtCO$_2$e Saved
By restoring peatlands

8-18
MtCO$_2$e Saved
Increased woodland and hedgerow planting

(up to) 9
MtCO$_2$e Saved
Emissions saved annually from better soil and livestock management

2
MtCO$_2$e Saved
Planting bioenergy crops

20-50%
Reduction in UK food waste

35-80%
Potential overall reduction in MtCO$_2$e by 2050

*53 MtCO$_2$e is based on modelling work done for this report

Chapter 1: Introduction

Key messages

- **Land provides a flow of ecosystem goods and services that are essential to economic activity and societal well-being.** The value of these is enormous and often underappreciated. Unsustainable land use practices damage the natural assets that provide these goods and services, and the degradation of ecosystems ultimately results in a cost to society.
- **The effective use of land will be key if the Government is to achieve its long-term policy goals for climate change mitigation, adaptation and environmental quality.** Successfully achieving the ambitions set out in the Climate Change Act and the government's 25-year Plan for the Environment will require careful planning to incentivise measures that maintain and enhance the provision of public goods, including carbon sequestration, water and soil quality and quantity, and hazard regulation. There are many opportunities to build better land use into policy and practice, including a current important window of opportunity through the proposed new environmental land management system.

1.1 Aims of this report

In this report, we set out why a new, integrated strategy on land use is needed and how it can deliver our key objectives on climate change: achieving deep emissions reduction; and maintaining (at the very least) the critical goods and services currently provided by the land as the climate changes.

- Our analyses will help to inform decision makers in considering the relative benefits and trade-offs of alternative actions to deliver on both adaptation and mitigation, as part of the development of the post-Common Agricultural Policy (CAP) Environmental Land Management system.
- Box 1.1 sets out definitions of the key terms used throughout this report.

Box 1.1. Glossary of terms used in this report

A number of technical terms are used in this report that have different meanings in different applications. This glossary sets out how we used them here.

- **Agronomic practices** - Farm management systems that improve agriculture productivity and other environmental factors such as soil quality, water use and better fertilizer management.
- **Carbon sequestration** - The process by which carbon sinks remove carbon dioxide from the atmosphere.
- **Carbon sink** - A natural or artificial reservoir that accumulates and stores some carbon-containing chemical compounds for an indefinite period.
- **Cost-effective** - Where an intervention has a positive net present value (NPV), taking account of all costs and benefits. Cost-effective against a carbon price is a measure of the cost of abating one tonne of carbon dioxide (equivalent) and is assessed against the time-specific carbon value.
- **Hazard -** The potential occurrence of a physical event that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. We class heatwaves, cold snaps, flooding, drought, windstorms and wildfire as hazards.

Box 1.1. Glossary of terms used in this report

- **Land/ land use sector** - 'Land' in this report refers to land outside of urban areas. The land use sector comprises land use, land-use change and forestry (LULUCF) and agriculture, sometimes referred to as agriculture, forestry and other land use (AFOLU).[4]
- **Land cover** refers to the physical land type covering the landscape (i.e. grassland, woodland, water or built environment) and metrics are area-based.
- **Land use** identifies how people use the land e.g. for housing, transport, recreation, agriculture, conservation. There are different ways to measure this which include area, condition of habitats, types of farming, conservation areas etc.
- **Low-regret adaptation** - Adaptation actions that are cost-effective to implement today; where the benefits are less sensitive to precise projections about the future climate; and where there are co-benefits or no difficult trade-offs with other policy objectives.
- **Natural capital** - those elements of the natural environment which provide valuable **ecosystem goods and services** to people, such as the stock of forests, water, land, minerals and oceans (this is the definition used by the Natural Capital Committee).
- **Paludiculture** - the practice of growing crops or raising livestock on re-wetted land.
- **Public goods -** In economic terms, a public good is a commodity or service that is provided without profit to all members of a society. In the context of the government's 25-year plan and this report, the main public goods of interest relate to environmental enhancement.
- **Risk** - Combines the likelihood that a hazard will occur with the magnitude of its outcome. Consequences may be defined according to the economic, social or environmental impact. In some literature, risks can be classed as either **threats** (negative impacts) or **opportunities** (positive impacts). The CCC tends to use the word risk and threat interchangeably, with opportunities separate from threats.
- **Settlements** - Land used for housing, other urban development, and other infrastructure such as roads, railways, windfarms, agricultural buildings.
- **Silvicultural** - the practice of controlling the establishment, growth, composition, health, and quality of forests.
- **Silvo-arable** - the practice of growing trees within an arable agricultural system.
- **Silvo-pastoral** - the practice of growing trees within a livestock agricultural system.
- **Surface albedo** - The proportion of the solar radiation that is reflected back into the atmosphere from the earth's surface.
- **Transformational adaptation** - Adaptation actions that fundamentally change the system or systems in question. Transformational adaptation tends to occur once the limits of low-regret adaptation have been reached.
- **Volatile organic carbon compounds (VOC)** - Compounds that easily become vapours or gases. These can be from burning fuels, or from other applications such as pesticides and adhesives.
- **Yield class** - An index used to measure the potential productivity of even-aged stands of trees. It is based on the maximum mean annual increment of cumulative timber volume achieved by a given tree species growing on a given site and managed according to a standard management prescription.

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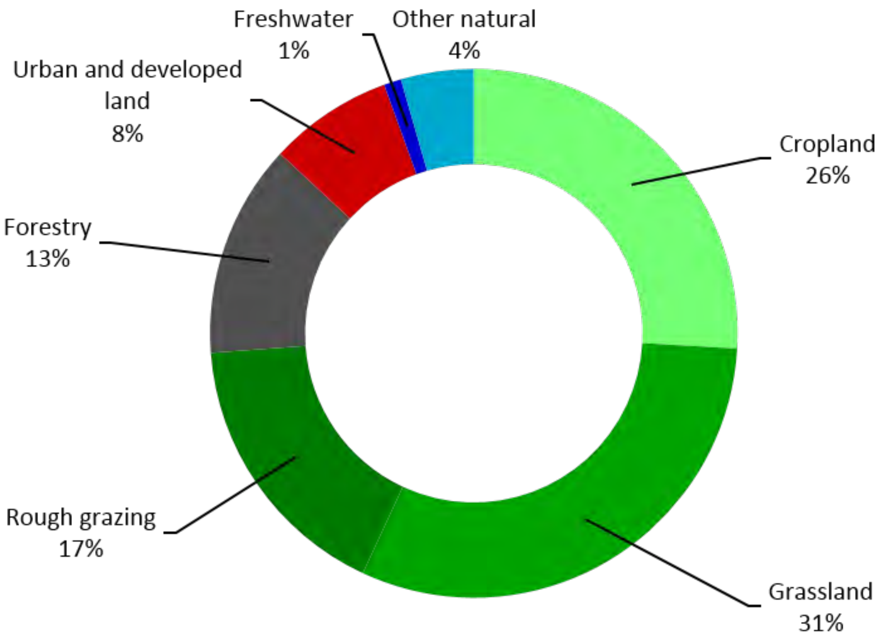
[4] UNFCCC (2014) *Understanding land use in the UNFCCC*

1.2 How land is used in the UK

Land cover in non-urban areas of the UK is made up of a mix of highly-managed and semi-natural habitats.

- This report focusses on land outside of built up urban areas. This includes farmland, woodland, wetlands, freshwater and other semi-natural habitats across the UK.
- Figure 1.1 gives a breakdown of how land is used currently. Agriculture is the largest land use class across the UK, occupying just over 70% of land area, and includes land used for crops and livestock.
- Just under one-fifth of land is semi-natural land covering forestry, freshwater and other natural land such as mountain, moor and heath, and coastal margins.
- The remaining, roughly 8%, is built-up urban and developed land.

Figure 1.1. Current land use in the UK



Source: CCC estimates based on *Agriculture in the UK, 2017*, ONS Experimental physical assets accounts for the UK and 2015 Corine land cover map data
Notes: Whilst the Corine land cover map provides detailed information for the UK, there is no standard or consistently applied classification for reporting of land use. This chart shows an approximation of how land is used in the UK based on three different sources.

There are a wide range of economic, social and environmental factors that influence decisions on the way land is used in the UK.

- The local climate, quality of the soil, topography and other environmental features have a considerable influence on decisions determining the suitability of land for a range of uses. In England and Wales, the suitability of agricultural land for different uses is divided into a number of land classes using the Agricultural Land Classification (ALC) System. The classes, from 1 to 5, represent the suitability of the land, ranging from high-grade agriculture (class 1) down to low-income rough grazing (class 5). Scotland and Northern Ireland have similar classification systems.[5] In England, the grade is derived from multiple criteria including site (gradient, micro-relief, flood risk), soil (depth, structure, texture, chemicals, stoniness), and climate (temperature, rainfall, aspect, exposure, frost risk). Chapter 3 sets out in more detail how climate change has, and is projected to, affect land use in England.

- Markets for different products derived from the land are an obvious driver of land use and land management decisions.
  - The markets for many products from the agriculture sector – many food types, wood and timber – are global. Farmers and land-owners are price takers, with prices determined by global supply and demand. Prices of agricultural products can be volatile as they vary with weather and impacts from pests and diseases, as well the scale of demand and exchange rate fluctuations.
  - Membership of the European Union (EU) has been a major driver of land use decisions across the UK, particularly in the agricultural sector under the CAP. Direct payments under the CAP have buffered many of the financial risks that would otherwise be associated with price volatility.
  - Overall, however, the CAP and its predecessors have caused significant environmental damage.[6] While the policy has supported food production, it has not rewarded other services, including adaptation to climate change and carbon sequestration and storage. Important services provided by the natural environment have been degraded: loss of soil fertility through intensive monoculture farming; loss of peatlands; and forests that have become unproductive through lack of management. Biodiversity has also declined across a number of different species groups.
- Future pressures from climate change, a growing population, increasing and competing demands for space and natural resources will continue to drive land-use change. Population growth, income growth and associated dietary changes are expected to increase the demand for food and other agricultural outputs globally over the next 30 years.[7] As these pressures intensify, so will the demands we make on our land. Climate change poses significant risks to global food security[8], but may also give the UK a comparative advantage over food-producing regions at lower latitudes. This could increase the importance of the UK as a food-producing nation.[9]

How land is used and managed has impacts across society, as those choices impact on the provision of ecosystem goods and services to people.

- Some ecosystem goods and services such as those for food, energy and timber have a market value and are referred to as private goods. Other ecosystem services generated from land such as nutrient cycling, flood alleviation, water purification, and carbon sequestration and storage are provided through public policy or private land users and owners, and are referred to as public goods (Box 1.2). Only the provisioning services are traded in

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[5] E.g. http://soils.environment.gov.scot/maps/capability-maps/national-scale-land-capability-for-agriculture/

[6] Defra (2018), A Green Future: Our 25 Year Plan to Improve the Environment

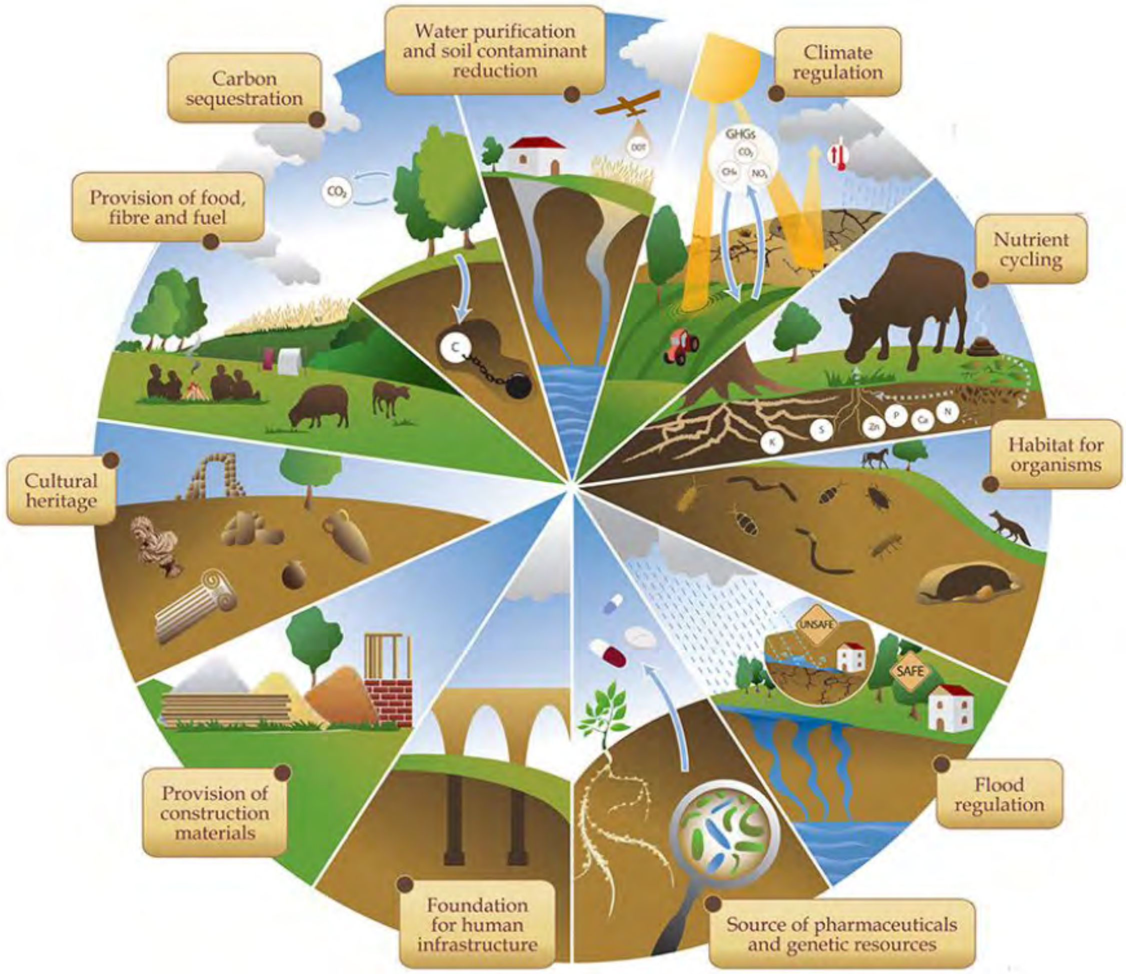
[7] Alexandratos, N. and J. Bruinsma (2012) *World agriculture towards 2030/2050: the 2012 revision*. ESA Working paper No. 12-03. Rome, FAO

[8] CCC (2016) *UK climate change risk assessment synthesis report: priorities for the next 5 years*. Committee on Climate Change

[9] CCC (2013) *Managing the land in a changing climate*

conventional markets. The rest is, essentially, provided for free and any negative impacts on them are not compensated for. In other words, markets fail to recognise the value of these public goods and fail to compensate for damage (or indeed reward efforts for improvement).

Box 1.2. Ecosystem goods and services provided by land



Source: JBA Consulting (2018) for the CCC

Notes: Ecosystem services can be classified according to their function and divided into four categories. These include:

-Provisioning services include the products that are obtained from ecosystems, such as: food, fibre, bioenergy, genetic resources, pharmaceuticals, water, and building materials such as timber

-Regulating services are the benefits to society that result from ecosystem processes, often moderating human impacts, such as: carbon sequestration and storage, water regulation and purification, erosion control, pollination, and protection from extreme weather and climatic events

-Cultural services are nonphysical benefits that humans obtain from ecosystems. Benefits include: knowledge systems, recreation, education, inspiration, aesthetic values, social relations, sense of place, cultural heritage and wildlife conservation

-Supporting services are the ecosystem processes and functions that are necessary for all other ecosystem services. They differ from other services as their impacts on humans are indirect, or occur over a long time period, making their valuation and protection even more difficult. Supporting services include: production of atmospheric oxygen, soil formation and retention, nutrient cycling, water cycling and provisioning of habitat for species

- The value of ecosystem services provided from the natural environment to society is enormous and often underappreciated. A partial[10] value of ecosystem service flows was estimated around £24 billion per year in 2015.[11] Over half of this, around £14 billion a year, was related to goods and services that have a market (including crops, timber, and renewable energy) - not a surprising finding given that market data on economic value is the easiest to calculate. Yet, the public goods considered which are provided for free (carbon sequestration, air pollution removal, recreation) was around £9 billion. Considering many other ecosystem services are not included in this estimate, including biodiversity, it is clear that markets underappreciate the value of nature.
- As public goods do not have a (financial) value that is incorporated into decision-making on land use, activities that unintentionally disrupt or degrade public goods can proceed without any obvious consequence. It is important, therefore, for land use decisions to be based on a careful consideration of the full range of ecosystem services.
- In addition, a number of classification schemes have been developed for classifying and recording land use and the monitoring of land-use change. No standard classification has been adopted, and a number of different sources exist (Figure 1.1).

1.4 The role of government land use policy in meeting climate change goals

How land-use change is managed will be critical to whether the government achieves its targets on reducing greenhouse gas emissions and managing the risks and opportunities from climate change.

- Meeting future carbon budgets and the UK’s 2050 target to reduce emissions by at least 80% of 1990 levels, as set out in the UK Climate Change Act, will require existing progress in the land use sector to be supplemented by more challenging measures. Emissions from the agriculture sector have not decreased over the past 5 years, and current policies are insufficient to meet the ambition set out in the Committee’s trajectory to meet the fifth carbon budget.[12] The existing policy framework involves an industry-led voluntary approach to emissions reduction in agriculture, combined with an afforestation target to plant 27,000 hectares per annum across the UK by 2030. Neither of these are on track to deliver the required levels of ambition.
- Unlike for climate change mitigation, the Climate Change Act does not contain specific targets related to adaptation. The government's second National Adaptation Programme sets a vision for *"[A] natural environment with diverse and healthy ecosystems, resilient to climate change, able to accommodate change, and valued for the adaptation services it provides. Profitable and productive agriculture and forestry sectors take the opportunities from climate change, are resilient to its threats and contribute to the resilience of the natural environment by helping to maintain ecosystem services and protect and enhance biodiversity"*. The Committee's most recent progress report on adaptation concluded that despite some areas of progress, the level of risk from climate change has increased for a significant number of

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[10] Ecosystem services included within the scope of estimates comprise: provisioning services (agricultural production, fishing, timber, water, minerals extraction, oil and gas, renewable energy); regulating services (carbon sequestration, pollution removal); and cultural services (recreation)

[11] ONS, 2018, *UK natural capital: Ecosystem service accounts*, 1997 to 2015

[12] CCC (2018) *Progress Report to Parliament*

adaptation priorities; including habitat condition and extent, soil health and carbon sequestration, and surface water flood alleviation.[13]

- The government's 25-Year Environment Plan sets out an aim to *"be the first generation to leave the environment in a better state than we inherited it"*. This is an ambitious vision for future environmental quality. Notably, the plan contains commitments to recognise good practices that build up and bolster natural assets, such as soil, water and biodiversity, while also taking account of the negative effects of a range of current land uses and activities. Achieving the ambitions outlined in the plan will require a balance of incentives and regulations – influencing decisions on the way land is used.
- Linked to the ambitions of the 25-year Plan, the government's Agriculture Bill sets out the major policy proposals on how farmers and other land managers will be paid for public goods following the UK's departure from the EU. Replacing the current subsidy system under the EU's CAP with a system of support that delivers a better quality of environment, sustaining food production, and other economic, social and environmental benefits presents a significant opportunity to meet the aims of the 25-year Plan and the Climate Change Act.

The rest of this report sets out the Committee's analysis and initial findings on what is needed through land-use change to meet the government's climate change goals.

- Chapter 2 considers how land can be used to deliver more ambitious greenhouse gas emissions reduction. We set out existing evidence on opportunities to move to less carbon intensive farming practices while preserving other essential functions of land such as food production, land for housing, economic activity and preserving natural capital. We do not set out a particular strategy that should be followed, but instead raise a number of important questions and highlight key insights that should steer policy development. We will build on this groundwork in a further report on appropriate strategies and policies to follow in 2019.
- Chapter 3 focuses on decision-making about land use in response to climate change. We recap on the current and future risks and opportunities from climate change, and adaptation actions taking place in the land use sector. We summarise our previous reports that have looked at how land management can improve resilience to climate change; including agricultural management but also restoration and recovery of semi-natural habitats. The analysis then explores how anticipatory action to change land use where needed in order to manage the risks from climate change, can reduce costs, increase benefits and limit the risk of irreversible damage to the natural environment. We set out a framework for considering the costs and benefits of planning to change land use and use this in four specific case study locations in England to draw some overarching conclusions.
- Chapter 4 draws together the evidence on mitigation and adaptation from the previous chapters to highlight co-benefits, trade-offs and risks associated with alternative land use strategies. We present initial evidence on barriers associated with transitioning to these pathways and make recommendations for how these could be removed.

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[13] CCC (2017) *Progress in preparing for climate change: 2017 Report to Parliament*

Chapter 2: How land can be used to achieve greenhouse gas reduction goals

Key messages

The way land is used is crucial to meeting the 2050 climate objective and the greater ambition of the Paris agreement. In this chapter we aim to develop understanding of the land-based options that deliver deep emissions reductions.

We set out existing evidence on how land can be used to deliver deeper emissions reduction, covering greater use of low-carbon intensive farming practices and releasing agricultural land for carbon reduction. This needs to happen while preserving other essential functions of land such as food production, housing and economic activity, and maintaining other goods and services that land provides.

Our key messages are:

- **Fundamental changes in how land is used are needed to deliver significant emissions reduction to meet climate goals.** Incremental change will not meet basic needs for food and settlements[14] given future population growth. The UK population is projected to increase by nine million by 2050 and the area of land required for settlements could increase significantly. Based on our analysis, if current trends in farming practices continue, land will not be able to support these basic needs and maintain current per capita food production. It will also lead to higher emissions and other environmental issues.
- **There are immediate opportunities to implement cost-effective, low-carbon practices which go some way to reduce emissions, but their scope is limited.** Options aimed at increasing the take-up of low-carbon farming practices (e.g. better soil and livestock management) could deliver up to 9 $MtCO_2e$[15] emissions reduction annually, but would still leave agriculture as one of the largest emitting sectors by 2050.
- **Achieving significant cuts in land based emissions rests on strong ambition to release agricultural land for alternative uses.** There are options to achieve this while preserving other essential goods and services of land, including levels of food production. Many of these build on government initiatives already taking place. These include: improving sustainable agricultural productivity; promoting healthy eating through government nutritional guidelines which could reduce consumption and production of the most carbon-intensive foods; reducing food waste along the supply chain; and increasing forest productivity. We set out evidence on these and develop a framework for assessing impacts, risks and uncertainties.
- **Our analysis shows that using land released from agriculture for carbon sequestration and restoring natural habitats can deliver deep emissions reduction to 2050**. Alternative uses of land could lead to emissions reductions of as much as 35-80% (20-40 $MtCO_2e$ per annum) by 2050. The key measures to deliver this are: afforestation (increasing forest cover from 13% of all UK land today up to 19% by 2050) and better management of existing forests; restoring 55-70% of peatlands could reduce emissions by 4-11 $MtCO_2e$ annually by 2050; sustainable energy crops representing up to 5% of land where wider environmental risks are managed; and more diverse uses of land that include trees on farms and hedgerow planting. Afforestation and restoring peatlands would also provide a range of additional benefits, including increased biodiversity, improved water quality and flood alleviation.

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[14] Settlement covers housing, other urban development, and other infrastructure (roads, railways, windfarms, agricultural buildings etc.)

[15] Under a 'High Ambition' scenario

- **Barriers to transitioning to different patterns of land use and management will need to be addressed.** These include: overcoming inertia, lack of experience or skills in alternative land uses; long-term under-investment in research and development and bringing new innovation to market; lack of information about new low-carbon farming techniques; high up-front costs of new farming methods and alternative land uses and uncertainty over future markets for new products; and little or no financial support for public goods and services provided by land that do not have a market value. There is also a problem with land ownership; 30-40% of farms are tenanted, with the average tenancy less than 4 years. This could affect tenant farmers' ability to make significant changes in land use, or to realise the benefits of any actions taken.
- **Addressing these issues is crucial for land to contribute to climate goals.** Many of the measures we consider have multiple benefits across climate change mitigation, adaptation and the government's wider goals. Diversifying agricultural land, afforestation and peatland restoration have positive impacts on the condition of natural habitats and habitat creation. But there are choices to be made. By setting the groundwork now to uncover these issues we expose the choices that need to be made in developing an integrated land use strategy. In our second report next year we will carry out a more detailed assessment of policy framework to mitigate climate change through land use to inform the development of the post-CAP framework.

We set out the analysis that underpins these conclusions in the following sections:

1. Land use today and in the future with current policies.
2. Measures that release land from current uses.
3. Options to deliver emissions reduction on land.
4. Key modelling insights and results.
5. Transitioning to alternative land use pathways.

Supporting evidence is provided in our technical annex[16] and a report by the Centre for Ecology and Hydrology (CEH) and Rothamsted Research,[17] the consultants involved in this project, published alongside this report.

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[16] CCC (2018) *Technical annex - UK land use: preparing for climate change and reducing emissions*

[17] Centre for Ecology & Hydrology and Rothamsted Research (2018) *Quantifying the impact of future land use scenarios to 2050 and beyond*

1. Land use today and in the future with current policies

As set out in Chapter 1, 74% of land in the UK is used for agriculture (26% is cropland, the remainder is grassland and rough-grazing), and a further 13% is forested. Peatlands account for 12% of land area and are under various land uses including agriculture and forestry. Settlements including housing account for 8% of UK land.

In 2016, agriculture emissions (46.5 $MtCO_2e$) accounted for 10% of UK greenhouse gas emissions. Their level has hardly changed since 2008. The land use, land-use change and forestry sector was a small net carbon sink, sequestering over 14 $MtCO_2e$, equivalent to abating around 3% of UK emissions. The ability of existing forests to absorb carbon is expected to weaken in the future due to the ageing profile of trees.

As well as providing a diverse range of essential functions including food, housing and other ecosystem services, land can sequester and store carbon in soils and biomass (e.g. trees). Therefore the way land is managed and used is vital to contributing to GHG emissions reduction goals:

- Our previous work[18] estimated that a set of farming practices and afforestation could deliver GHG emissions reduction of 9 $MtCO_2e$ by 2030 and 17 $MtCO_2e$ by 2050.
- This level of ambition is relatively modest compared with other sectors, which are expected to decarbonise much faster. Based on the cost-effective path set out in our fifth carbon budget report, agriculture would be one of the largest emitting sector by 2050.

The non-developed land sectors (agriculture, forestry and peatland) have potential to achieve more stretching reductions than we have currently identified. Increased effort will become even more pressing once all sources of peatland emissions are fully accounted for in the GHG Inventory, expected by 2021/22. This could increase reported emissions by a further 18 $MtCO_2e$, and abatement of these emissions will need to be reflected in the setting of future carbon budgets.

Current Defra and devolved administration (DA) policies are insufficient to meet the ambition set out in the Committee's trajectory to meet the fifth carbon budget. The existing policy framework focuses on an industry-led voluntary approach to emissions reduction in agriculture and an ambition to afforest 27,000 hectares per annum across the UK by 2024.[19] Neither of these are on track to deliver the stated ambition.

Under the current policy framework, important services provided by the natural environment have been degraded: loss of soil fertility through intensive monoculture farming; biodiversity losses resulting in reduced functioning of semi-natural habitats; and forests that have become unproductive through lack of management (Chapter 3).

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[18] CCC (2015) *Sectoral scenarios for the fifth carbon budget*

[19] BEIS (2018) *Progress Against Meeting Our Carbon Budgets– The Government Response to the Committee on Climate Change*

Other pressures on land are also increasing. Land will need to provide food, housing and area for economic activity to support a growing population, projected to increase from 66 to 75 million between 2017 and 2050.[20] Our analysis suggests continuing to use land along existing trends and policies will lead to higher GHG emissions than today, and there will be insufficient land to provide for settlement growth and to maintain current per capita food production:

- Land required for settlements[21] is expected to increase from 8% of UK land area to 12% (over 2.8 m hectares) by 2050 based on government projections for settlement growth.
- If current trends in agricultural productivity and diets continue, the area of cropland required to maintain current levels of per capita UK food production could increase by 15% by 2050.
- These two factors together would demand 3% more land by 2050 than is available, assuming national parks and other natural habitats continue to be protected.
- Without further action, GHG emissions would also rise by 9.5 $MtCO_2e$.

Furthermore, current policies and low-regret adaptation actions are not sufficient to counter the risks of the warming climate to the natural environment and the economic activity that depends on it, e.g. the condition of natural assets such as soil health; terrestrial and freshwater habitats; and biodiversity in the farmed countryside (Chapter 3).

Delivering the current level of services from land as well as deeper emissions reduction cannot be achieved under current trends and policies. In the next section we assess the extent to which land can be released from its current use. In Section 3 we set out options to use that land to reduce emissions, sequester carbon and provide biomass outputs for use in the rest of the economy.

2. Measures that release land from current uses

On current trends we will need more land for food and housing. But there is also a need for emissions reduction which will require changes in land use. Some brownfield sites and urban land may be available, but most land would need to come from agriculture. This has implications for food production, so we need to consider options to allow the set of requirements for services from land to be balanced.

The options we consider combine technological advances with measures that change behaviour:

- Improving agricultural productivity.
- Moving horticulture indoors.
- Shift of diets towards healthier eating guidelines.
- Food waste reduction.

The evidence used to underpin our analysis was gathered from a number of sources. These include an assessment of latest data and academic literature, stakeholder engagement and workshops, and expert advice and modelling set out in the consultants' report. For each of the above measures we develop a low, medium and high level of ambition that could be feasible by

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[20] Office for National Statistics (2017) *2016-based National Population Projections*

[21] Settlement covers housing, other urban development, and other infrastructure (roads, railways, windfarms, agricultural buildings etc.

2050. In Section 4 we use these in scenarios to develop insights and highlight risks in how they could contribute to emissions reduction.

Improving agricultural productivity

We use agricultural productivity to cover optimising the use of agricultural inputs to maximise outputs of both crops and livestock.

A number of current government initiatives aim to increase agricultural productivity. These include the Agri-Tech strategy, which aims to improve innovation and productivity through collaboration and data sharing, the Industrial Strategy Challenge Fund (Transforming Food Production) and the Countryside Productivity Scheme,[22] which both provide funding for farmers to invest in new technology, and to reduce costs or improve product quality.

Current evidence indicates that rates of productivity and profitability vary considerably across different farming systems and within them (Box 2.1).

An international comparison shows UK productivity growth lagging behind other developed countries. Between 2000 and 2015, average annual growth in total factor productivity of UK agriculture was 1% compared with 1.5% in the US, 1.7% in Germany and 2.4% in France. Innovation has played a major role in recent productivity improvements in Dutch agriculture (Box 2.2).

Box 2.1. Farm income and productivity

There is a wide range in farm income and productivity in England. In 2016, a small number of large farms (7%) produced 55% of output with just 30% of farmed area, with output per hectare nearly three times higher than among the smallest farms.

Across the sector as a whole there is wide variation between the top and bottom economic performing farms:

- In England in 2016/17 the average performance of the top 25% of farms was 1.8 times that of the bottom 25%. The largest gap was among horticulture and grazing livestock, the lowest among poultry and dairy.
- There is also a wide distribution in farm profitability, with poultry farms making the highest average profit (£112,000 in 2015/16) and grazing livestock in lowland and least favoured areas the least (less than £20,000).
- The wide distribution of income also exists within farm types, so while around a fifth of dairy and poultry farms had an income of more than £100,000, a fifth of dairy and 30% poultry farms did not make a profit in 2016/17 (Figure B2.1)

Farms rely heavily on direct payments from the Common Agricultural Policy. Across the sector as a whole 61% of farm income comes from direct payments. Pig, poultry and horticulture have the lowest share of direct payments (less than 20%), whilst grazing livestock farms rely on direct payments for almost all of their income and mixed farms for over 100%.

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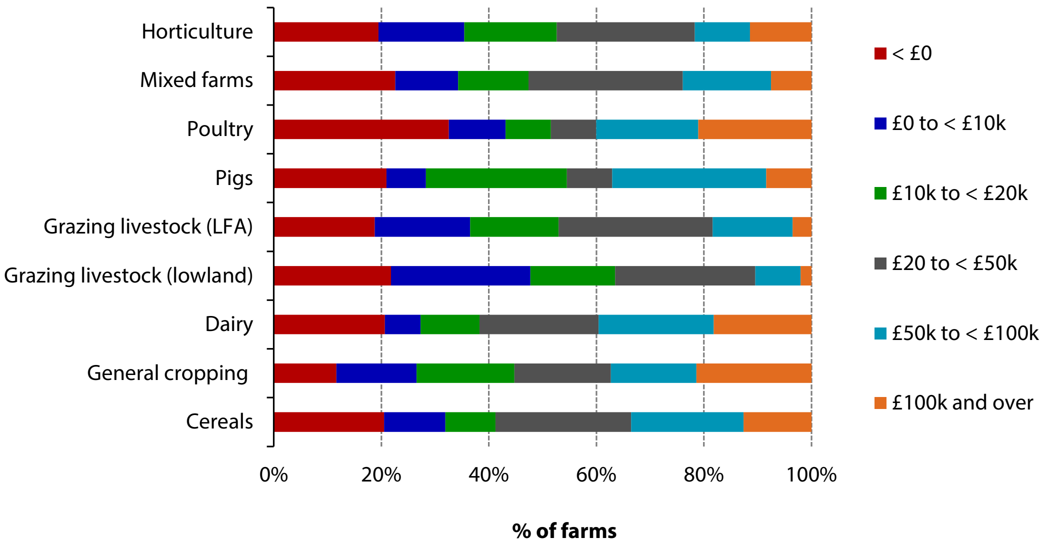
[22] The Rural Development Programme's CPS provides funding for projects in England only.

Box 2.1. Farm income and productivity

Figure B2.1. Distribution of farm business income by farm type income in England (2016/17)



Source: Defra (2017) Farm Business Income by type of farm in England, 2016/17

Source: Defra *Farm Business Survey*

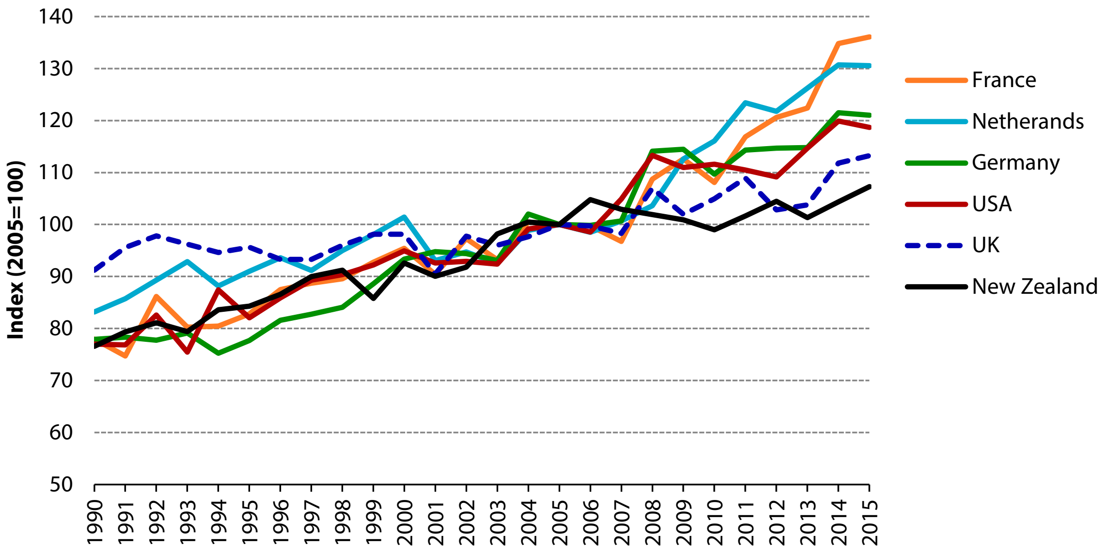
Box 2.2. An international comparison of productivity growth in agriculture

An international comparison shows UK productivity growth lagging behind other developed countries. Between 1990 and 2000 growth in total factor productivity in the UK was flat, whereas it increased among all other countries shown in Figure B2.2. Since 2000 it has lagged behind increases in all these counties apart from New Zealand.

In the Netherlands, the widespread and continuous adoption of innovative agricultural technologies has enabled it to significantly improve productivity for all crop types sustainably, while reducing the emissions intensity of output:

- Driven by a national commitment to produce 'twice as much food using half as many resources' almost two decades ago, the Netherlands ranks as the second largest food exporter in value terms, behind the USA, but with only a fraction of the land.
- Innovative practices include the use of drones over potato fields to monitor soil, nutrient and water conditions, and growing most of its horticultural products in climate controlled greenhouses. This has reduced the need for water, soil, pesticide and inorganic fertiliser and produced high yielding crops.

Figure B2.2. International comparison of agricultural total factor productivity (1990-2015)



Source: United States Department of Agriculture (2018) *International agricultural productivity.*
Notes: Total factor productivity is a measure of how well inputs are converted into outputs giving an indication of the efficiency and competitiveness of the agriculture industry.

The evidence suggests there is scope for the sector as a whole to raise productivity in line with the best performing farms, and move towards international best practice. There are a number of measures that can help to boost productivity, covering both livestock and crops.

Livestock

Improved animal health can reduce emissions intensity by increasing feed conversion rates; improving fertility and reducing mortality; and increasing growth rates and milk yields. Of the endemic diseases and conditions that impact productivity, it is estimated that Bovine Viral Diarrhoea (cows), mastitis (cows) and intestinal parasites (sheep) cost the agriculture sector over £300 million per annum.

In our assessment, we take account of improvements in livestock health as options to reduce non-CO_2 emissions within current agricultural practices. However, we have not considered the potential reductions in land area that could result from improving health and reducing mortality, which is an area for further exploration.

We have assessed the impact of increasing the stocking density of livestock on grasslands and rough grazing, a measure that can release land. The levels of livestock intensification explored in this project are relatively modest, and imply:

- An increase in stocking density from just over 1 livestock unit (LU) /ha[23] in 2017 (assuming cattle is 1 LU and sheep 0.1 LU) to a maximum of around 1.5 LU/ha by 2050. This is within the industry 'low' stocking density range (1-1.5 LU/ha), and well below the 'high' indicative range of 2-2.5 LU/ha.
- The increase in stocking density is achieved by assuming rough grazing land (which tends to be the least productive land) is freed up, with livestock moving to other types of grasslands.

A similar approach has been adopted in other studies, for example, a report by ADAS[24] for the Energy Technology Institute, which assumed grassland was spared for bioenergy crops through improved utilisation.

Sustainably increasing stocking density accompanied by a good grazing management system can also maximise grass utilisation rates (i.e. the grass that is eaten). Moving from set stocking or continuous grazing systems (where livestock have unrestricted movement over a large area) to paddock grazing, where livestock are moved frequently to select parts of the field, can increase grass utilisation rates from around 50-60% to 80% utilisation, while also increasing yields of dry matter per hectare.[25]

Crops

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. This compares with substantial increases in the 20 years before this where yields more or less doubled to around 8 tonnes/hectare for wheat. Within this, there has been some seasonal variation with favourable weather conditions in 2015, for example, resulting in record wheat yields averaging 9 tonnes/hectare.

Evidence indicates that yield improvements rely on good agronomy practices such as optimising fertiliser application, soil management, crop rotation, and development of crop varieties resistant to pests and diseases and other stresses, including climatic factors[26] (Box 2.3). The

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[23] A livestock unit attempts to define livestock by metabolise energy requirements and weights different types of livestock accordingly

[24] ADAS (2016) *Refining estimates of land for bioenergy*

[25] AHDB (2016) *Planning grazing strategies for better returns*

[26] Knight et al (2012) *Desk study to evaluate contributory causes of the current 'yield plateau' in wheat and oil seed rape. Project no. 502, AHDB*

impact of climate change on crop production will vary across the UK: drier summer conditions in the south and south east may result in lower yields without irrigation, but production could increase in northern and western areas with warmer temperatures, if water is not limited.

Reflecting the range of uncertainty in the future development of these factors, our analysis adopts a wide range of assumptions on future yields:

- These range from no increase from the current average of 8 tonnes/hectare for wheat (and equivalent rates for other crops, including horticultural crops that use arable land) to 10-20 tonnes/hectare by 2050.
- The top range is very stretching and would rely on significant advances in science and technology. The 'Designing Future Wheat' project is one example of the work that is being undertaken to boost yields (Box 2.3).

Our analysis takes account of the potential regional variation in yields at the NUTS1 level,[27] but more work is needed to assess the extent of improvements possible at a more localised level.

Box 2.3. Measures to improve crop yields

Cereal yields in the UK are higher than the EU average, but are lower than key competitors such as France, Germany and the Netherlands.[28] There is also considerable regional variation in cereal yields, of around one-quarter to one-third between the highest and lowest productive areas in 2016.

Options to deliver sustainable improvements in arable crop yields cover improved management techniques and developing new varieties that are better able to withstand pests, diseases and the impacts of a warming climate:

- **Agronomic practices.** In recent years record global wheat yields achieved in New Zealand of 16.8 tonnes/hectare, and the UK record yield of 16.5 tonnes/hectare in Northumberland provide good examples of the impact of adopting best practices, coupled with favourable weather. This relies on selecting crop varieties that are consistently strong performers, having good soil structure and fertility, selecting the optimum planting period, and ensuring good crop nutrition and protection from weeds and pests. Good nutrition involves not only optimum fertiliser use throughout the growing period, but an adequate supply of trace elements (e.g. zinc and copper) to ensure good plant health.
- **Crop breeding.** Funded by the Biotechnology and Biological Sciences Research Council (BBSRC), work under the 'Designing Future Wheat' multi-institute programme is focused on developing new improved wheat germplasm, or living tissue that contain key traits that allow the next generation of wheat to be more sustainably productive and resilient to disease and the warmer climate. Launched in 2017, the programme aims to develop traits that will be made available to commercial breeders that are higher yielding, require fewer inputs such as fertiliser and water, contain essential nutrients and increase resistance and susceptibility to pathogens and pests.

Source: Knight et al (2012) *Desk study to evaluate contributory causes of the current 'yield plateau' in wheat and oil seed rape*. Report for the AHDB

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[27] NUTS1 is a geographical classification that sub-divides the UK into the following regions: Scotland, Wales, Northern Ireland and within England, there are eight regions, North West, South East. West Midlands etc.

[28] Eurostat (2017)

Moving horticulture indoors

A more widespread use of indoor horticulture could also reduce GHG emissions and release land for other uses. This method of production which takes crops 'off-farm' is currently being used in the UK, although at a small scale, for mainly high value salad crops, some of which are based on hydroponic and vertical production systems using LEDs.

Making this system available to a wider range of horticultural crops including vegetables and soft and top fruit has the potential to release more land through the use of vertical stacking systems. We test the impact of using this system by assuming 10-50% of horticultural products are moved indoors, but find that this releases a relatively small amount of land (reaching 83,000 hectares in the higher case) given that the area of cropland used for horticulture is just 3.5%.

Greater land sparing benefits from this production system could occur if arable crops could be grown indoors at scale. We have not included this in our analysis at this stage given more work is required on technical feasibility and the financial and environmental costs. Current evidence suggests a significant reduction in electricity costs would be required before this production system could be considered a serious option (Box 2.4).

Box 2.4. Indoor horticulture

Indoor horticulture requires use of artificial light, water, humidity, temperature, and nutrients all of which are carefully controlled in order to maximise plant growth and avoid losses that could occur when grown on land due to adverse weather conditions and pests.

This system is being used to trial growing wheat indoors and to 'speed' breed crop varieties:

- With the development of short wheat varieties, Rothamsted Research is experimenting with growing wheat indoors. Using LED technology to mimic solar radiation, the stacked method employed under a controlled environment is producing quicker harvesting, after 80 days, which could on average produce four to five crops a year. This compares to one to two crops when grown outside. As well as the sparing of cropland, the use of recycled water and nutrients on a controlled basis reduces water and fertiliser needs. The controlled environment reduces the risks that outdoor wheat may be more susceptible to as the climate warms, such as reduced water availability and pests and pathogens. Although the technology for growing crops under such conditions is proven (e.g. salad crops), the high electricity costs of the LEDs currently makes this system uneconomic for the lower value crops such as wheat and grains.
- The John Innes Centre is using the LED indoor system to improve its crop breeding programme. As the indoor system provides 22 hours of light, plant growth is much faster compared to outdoors (e.g. up to six generations a year is possible) thereby allowing the 'speed' breeding of crop varieties, getting them to market faster.

Source: Rothamsted Research and John Innes Centre

Shift of diets towards healthier eating guidelines

The production of beef, lamb and milk is a large source of agricultural emissions in the UK. In 2016, cattle and sheep directly accounted for around 58% of agriculture emissions,[29] while there are additional soil emissions associated with growing their feed (e.g. grass and cereals). Changes

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[29] Methane and N_2O emissions from enteric fermentation and manure and waste management

in people's diet, if this leads to reduced UK production of these products, could therefore have a significant impact on emissions.

The 'Eatwell Guide'[30] is the government's official guide to achieving a healthy and balanced diet. Its primary purpose is to promote healthy eating through the provision of readily available advice to both householders and those working in the food supply chain (e.g. catering and hospitals). Endorsed by the Department of Health and Social Care, the Guide advises on the level of different food groups adults should eat. Following the guidance would have significant impacts on the average adult diet compared with current eating patterns (Box 2.5):

- There would be a large reduction in the consumption of red meat, by 89% for beef and 63% for lamb, together with a 20% decline in dairy products.
- The amount of plant based food in the diet would increase, with meat protein being replaced with more pulses and legumes (up by 86%). Consumption of fruit and vegetables would also increase by around 54%.

In our analysis, we assess the impact on GHG emissions and the amount of land released out of agriculture from a reduction in demand for beef, lamb and dairy. We assume:

- A lower reduction in the consumption of beef and lamb compared to the 'Eatwell' guide, but we go further with dairy products, with a reduction of demand of 20% to 50% by 2050 across these products.
- As well as assuming an increase in the consumption of more plant based food, we also include a switch to other meat proteins (pork and chicken), and 'alternative' proteins:
  - Under the 20% reduction, beef and lamb is replaced by pork and chicken and dairy products by crops.
  - Under the 50% reduction, the additional 30% is met by the consumption of 'alternative' proteins produced 'off-farm'. These could comprise more innovative options such as lab-grown meat and synthetic milk, together with a higher uptake of more established non-meat and non-dairy protein sources such the fungi-derived mycoprotein.
- As the production of non-plant based 'alternative' proteins requires much less land, it could release land out of agricultural use, with benefits for mitigation and adaptation. However, without addressing public acceptability issues, uptake of more novel products could be limited. In the absence of demand for 'alternative' proteins, eating more plant based food would meet the dietary guidelines of the 'Eatwell' Guide, although more land would be required to grow the crops (Box 2.6).

There are also other aspects to reducing red meat and dairy consumption to be considered. There is a wide range of literature on the life-cycle analysis (LCA) of red meat and dairy production. But before decisions to switch can be made there is a need to assess the LCA and use of resources (e.g. water) for alternative dairy products (e.g. almond and soya milk); the LCA of feeds used for poultry and pigs compared with beef and lamb; and the full range of implications around 'alternative' protein production. We will consider these areas in more detail as we develop our advice next year.

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[30] Public Health England, in association with the Welsh Government, Food Standards Scotland and Food Standards Agency (2016) *The Eatwell Guide*

Box 2.5. The 'Eatwell' Guide

The dietary guidance issued by Public Health England implies a large reduction in the average consumption of beef and lamb, which fall by 89% and 63% respectively to 2.2 and 2.6 grams per day, and a 20% reduction in the amount of dairy products consumed. It is estimated that meeting the guidance, which involves rebalancing the diet towards more plant based food would deliver multiple health benefits, at no extra cost to the consumer:

- The Association for Nutrition has stated that following the guidance would help reduce the risk of developing long term illnesses such as heart disease, Type 2 diabetes and some cancers.
- Oxford University[31] modelled the costs of meeting the dietary requirements set out by the 'Eatwell' Guide, and concluded that it could be delivered at no extra cost to the householder.

Meat still makes up a staple of the UK diet, and the rebalancing in diets recommended by the Guide goes further than the change in consumption patterns since 1990, particularly for beef. According to the data from the UK Family Food Statistics,[32] consumption of beef and lamb/mutton has fallen by 24% and 72% respectively between 1990 and 2017. However, this has not been accompanied by a rise in the consumption of vegetables which declined by 8% over the period.

Official figures suggest that the proportion of the UK population that is vegetarian or vegan has increased from 1.6% in 2009 to 2.5% in 2015.[33] However, more recent surveys suggest much higher figures, as well as evidence of a trend towards a more 'flexitarian' diet (meat is consumed occasionally) with growing interest being shown by both retailers and consumers:

- A survey by Waitrose in 2018 found that 1 in 8 people are now vegan or vegetarian, with a further 21% flexitarian.
- An ING survey found that 15% of the UK population expects to eat less meat in five years' time, with health cited as the main reason for the change.
- Recent research by the Institute of Grocery Distribution[34] indicates that of 2,055 grocery shoppers questioned, just over half are either following or would be interested in following more of a plant based diet either as a flexitarian, vegetarian or vegan.
- Supermarkets are responding to the interest in plant based products. Earlier this year, Tesco announced plans to double its own range of plant based food in response to a 25% increase in demand for chilled vegan food. Waitrose has expanded its meat-free range to over 150 products citing that customers wanting to reduce their consumption of meat are driving the growth in this market.

Source: ING Europe (2017) *The Protein Shift: Will Europeans Change Their Diet?* Institute of Grocery Distribution (2018) *IGD Shopping Vista*

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[31] Scarborough P, Kaur A, Cobiac L, et al (2016) *Eatwell Guide: modelling the dietary and cost implications of incorporating new sugar and fibre guidelines*

[32] Defra (2018) *Family Food Statistics*

[33] Food Standards Agency and Public Health England (2018) *National Diet and Nutrition Survey*

[34] Institute of Grocery Distribution (2018) *IGD Shopping Vista*

Box 2.6. Lab-grown meat

As the production of some alternative proteins such as lab-grown meat and milk do not require agricultural land, future uptake of these products could release land for other uses. However, making this a viable food source requires reducing the costs of production to enable commercialisation, while securing public acceptability. There is evidence that costs have fallen significantly, while surveys indicate people are willing to try out this product:

- Lab-grown meat involves taking tissue from an animal in order to cultivate cells in the laboratory. The technical feasibility has been proven with the first lab-grown burger made in 2013 by the Dutch company, Mosa Meats, which have plans to launch a commercial product by 2021. Costs of production have fallen significantly from around £215,000 in 2013 to around £8 per burger patty,[35] although costs for more expensive cuts of meats such as steak are expected to be higher. More investment is entering the sector with the number of biotech start-up companies increasing, including investment from Tyson, the largest meat processor and supplier in the USA who want to position themselves as a provider of all forms of proteins.
- A survey of 2,000 UK adults conducted earlier this year indicated a high level of acceptance, with 40% believing they will be eating lab-grown meat and fish by 2028. The factors determining adoption were taste, texture, smell and appearance. Another survey found 30% of 1,000 people questioned in the USA and the UK would be willing to buy it, with the level of responsiveness rising to 60% of those who are vegan.

Source: Starcom UK Group (2018) Survey. Survegoo (2018) survey commissioned by Ingredient Communications

Reducing food waste

According to estimates by the Waste Reduction Action Programme (WRAP)[36] around 10 million tonnes of food downstream of the farm-gate is wasted each year. Householders account for the largest share (70%), while the supply chain comprising manufacturing (17%), hospitality and food service (9%) and retail (2%) make up almost all of the remainder.

Preventing waste is the best action for the environment in the 'waste hierarchy'. Reducing the level of food waste, particularly the amount that is deemed to be avoidable (or under the revised definition 'edible')[37] - five million tonnes for householders - would deliver savings along the supply chain. As well as contributing to a quarter of methane formation at landfill,[38] waste has associated emissions from growing crops and rearing livestock, through production and packaging of food products, and transport to food processors, supermarkets and to consumers. Waste represents an inefficient use of resources across the whole supply chain, including land.

The Government is expected to set out how it intends to deliver its ambition for England to work towards eliminating all avoidable waste, including food by 2050 in its Resources and Waste Strategy later in 2018. Wales is expected to consult on plans to halve food waste by 2025, while earlier this year Scotland set out a target to halve food waste by 2030.

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[35] Adam Smith Institute (2018) *Briefing paper: The prospects for lab grown meat*

[36] WRAP (2013) *Household Food and Drink Waste in the United Kingdom 2012*

[37] WRAP (2018) *Household food waste: restated data for 2007-2015.* This report restates previously published estimates which have been reinterpreted using the most recent international definitions and classifications relating to food waste

[38] Methane formation is higher than methane emitted at landfill due to flaring and capturing of methane for energy

Voluntary initiatives to reduce food waste have been led by WRAP. Key initiatives are:

- The 'Courtauld 2025' commitment has a voluntary target to reduce waste by 20% by 2025. This covers waste arising across the supply chain from food producer (post-farm gate) to end consumer.
- The UK Food Waste Reduction Roadmap launched this year by WRAP and the Institute of Grocery Distribution (IGD), targets a halving of food waste by 2030 in line with the UN's Sustainable Development Goal 12.3.

In contrast to 'Courtauld 2025', the new UK Food Waste Reduction Roadmap includes the targeting of on-farm food waste. There is currently a lack of reliable data on the scale of food waste in primary production at a national or regional level, either in the UK or EU. WRAP is currently working on developing a robust baseline to measure this.

We have assessed the impacts of a 20-50% reduction in food waste:

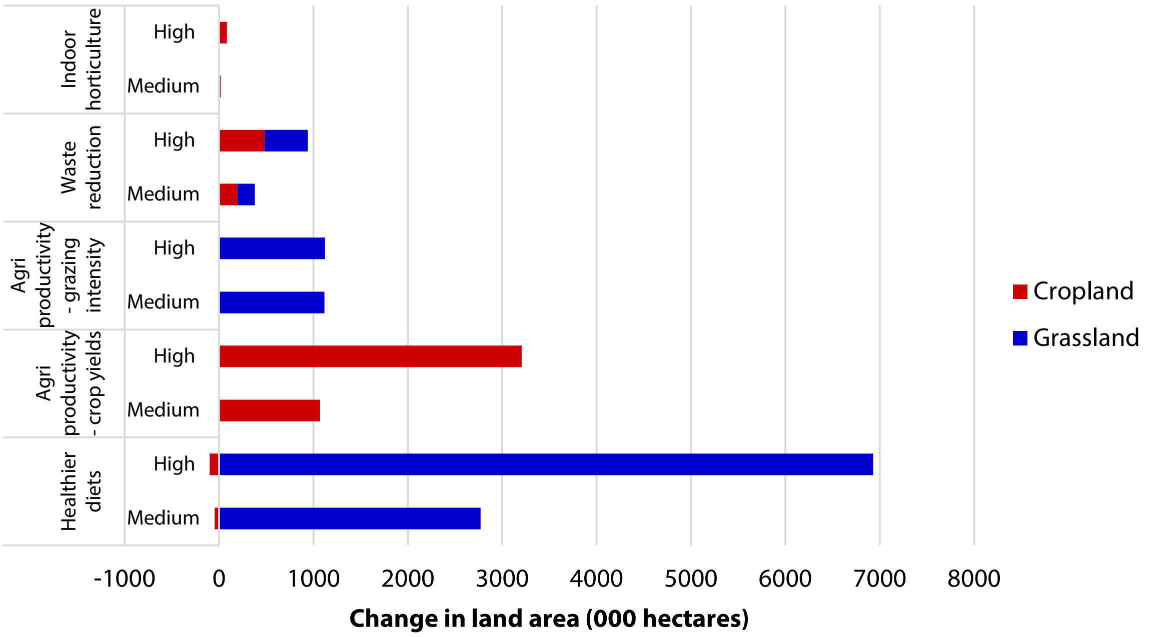
- In the lower case, our assumptions align with the 'Courtauld 2025' ambition, with no further improvement post-2025.
- The upper bound matches the UK Food Waste Reduction Roadmap, but is assumed to be achieved 20 years later.

Efforts to reduce the amount wasted on-farm could deliver additional benefits, in terms of reduced agricultural emissions, other environmental impacts and releasing agricultural land for alternative uses. Our analysis excludes a reduction in on-farm food waste due to a lack of reliable data.

Impact of measures to release land for other uses

Different levels of ambition on these technologies and behaviours could allow varying amounts of agricultural land to be released for other uses. Our analysis suggests that moves towards healthier diets and improving agricultural productivity could have the biggest impact.

Figure 2.1. Agricultural land area released by different factors compared with BAU, 2050



Source: CEH and Rothamsted Research (2018), CCC analysis
Note: The change in area of grassland due to grazing intensity is the same under "medium" and "high" ambitions

Figure 2.1 shows the change in cropland and grassland from each measure compared with a business as usual case in which current trends largely continue to 2050:

- A move to healthier diets would release the largest amount of land under both levels of ambition due to the reduction in beef cattle, dairy cattle and sheep numbers. The high ambition would reduce 2016 grassland area by over half by 2050. This is associated with a much smaller increase in cropland to grow crops for human consumption and for animal feed needed for the increased number of pigs and poultry. Beyond these estimates, there is scope to release more grassland if beef and lamb consumption decreased in line with meeting the 'Eatwell' Guide.
- Productivity measures aimed at improving crop yields release more than 50% of cropland under the high ambition. Increasing livestock stocking rates releases around 9% of grassland by 2050.
- Despite the ambition to halve food waste by 2050, the effect on land use is less significant. This reflects the foods that make up food waste. The 2013 WRAP report found that fruit, vegetables, salads and drink accounted for almost 40% of the avoidable waste by weight. Reductions of these products results in a small impact on UK land area:
  - Imports accounted for 84% of UK fruit demand in 2017.
  - Vegetables that are grown in the UK (and which supply 57% of UK demand) account for a small share of cropland (less than 0.5%).

  - Reducing the waste of bakery products (11% of food waste by weight) would be more significant, given the large area of land used to grow cereals, and the near self-sufficiency of cereal demand.

- Horticultural production accounts for just 3% of current UK cropland area, therefore moving even half of it indoors does not release much land.

In the next section we consider the different options for using land that could be released from agricultural production.

3. Options to deliver emissions reduction on land

In our previous reports,[39] we set out cost-effective options that can reduce emissions in agriculture and land use by 2050. Improved farming practices such as better soil management and improving livestock health and diets could reduce agricultural emissions by 9 $MtCO_2e$, while afforestation could deliver savings of 8 $MtCO_2e$. This would still leave agricultural emissions of around 35 $MtCO_2e$ while the LULUCF net emissions sink would reach -13 $MtCO_2e$.[40] Without further action, agriculture is likely to be the second biggest emitting sector by 2050.

Land released out of agriculture production presents an opportunity to encourage more diverse land use towards measures that can reduce non-CO_2 agricultural emissions and increase carbon sequestration, as well as provide wider environmental benefits. This would enable deeper emissions reduction than is possible through changes in farming practices alone.

In this section we present evidence on measures to reduce land based emissions and increase sequestration. They cover:

- Low-carbon farming practices.
- Afforestation and forestry management.
- Agro-forestry and hedgerows.
- Bioenergy crops.
- Peatland restoration.

Low-carbon farming practices

In 2016 agricultural emissions were 46.5 $MtCO_2e$ accounting for 10% of all UK GHG emissions. The main source of GHG emissions in agriculture are N_2O and methane from soils and livestock. In our advice on the fifth carbon budget, we estimated that cost-effective measures to tackle on-farm emissions could deliver around 9 $MtCO_2e$ annually by 2050.[41] These covered a range of options covering crop and soil management, livestock diets and health, waste and manure management and fuel efficiency.

We have assessed the impact of a different levels of ambition on low-carbon farming practices (Box 2.7):

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[39] CCC (2018) *Reducing UK emissions: 2018 Progress Report to Parliament*; CCC (2018) *An independent assessment of the UK's Clean Growth Strategy: From ambition to action*

[40] Excludes sources of peatland emissions not currently covered in the GHG inventory

[41] This represents the rescaled level of emissions savings that now takes account of the revisions made to the emissions factors under the GHG Platform Work

- **Nitrogen use efficiency.** We use a range of 20% to 30% improvement in the efficient use of nitrogen on cropland and a 10% improvement rate on grassland. The same set of measures are adopted for both levels of ambition, but uptake is assumed to be higher in the high level of ambition. There are also smaller savings from the use of low-carbon fertilisers.
- **Livestock measures.** Measures such as improving the feed digestibility of cattle and sheep, improving animal health and fertility, and improving the feed conversion ratio through the use of genetics can reduce methane emissions. Our analysis assumes these deliver a 5-10% reduction in enteric emissions per ruminant animal and a 5-10% reduction in volatile solids and nitrogen excretion for all livestock types by 2050. The use of feed additives and the genetic selection of animals could go beyond this, which we assume in the high ambition.
- **Manure management.** Practices such as better storage, management and application on land of animal wastes can reduce manure management emissions. Our analysis assumes an increase in the uptake of anaerobic digestion to treat 10-20% of cattle, pig and poultry waste by 2050 and better management of housed livestock manures (e.g. better floor design and use of air scrubbers). In the higher case we also include additional measures such as slurry acidification.

Box 2.7. Evidence on low-carbon farming options

The level of ambition assumed for reducing non-CO_2 emissions from soils and livestock is evidenced from a wide range of sources that illustrate the potential level of abatement that could be technically feasible now and in the future. Below we set out a few examples to illustrate how non-CO_2 emissions could be reduced further.

Nitrogen use efficiency

This could be achieved through a number of measures including loosening soil compaction on cropland, use of precision farming (e.g. variable rate fertiliser application and controlled traffic farming), more use of organic residues (e.g. anaerobic digestates), better accounting for nutrients in livestock manures, and increased use of legume crops. A higher uptake of these measures accounts for most of the increase in emissions savings by improving nitrogen use efficiency by 30%, with much smaller savings assumed by the use of novel fertiliser types such as controlled release fertiliser and use of urease inhibitors. This is consistent with the ambition of the Clean Growth Strategy, which will explore the mitigation potential of low-carbon fertilisers. These measures will also deliver co-benefits of reduced soil and water pollution from fertilizer use.

Genetic selection of ruminants for inherently low enteric emissions

The general aim of breeding is to select animals to produce offspring that ensure that each generation is genetically superior to its forerunners. The New Zealand Animal Selection, Genetics and Genomics Network (ASGGN) focuses on scientific research to reduce emissions from ruminant livestock through the use of animal selection, genetics and genomics techniques. It found that the trait for emitting methane is 20% heritable for sheep so by breeding lower emitters, it was possible to reduce the amount they produced after a few generations. Lower emitting sheep were found to produce 10% less methane than high emitting sheep. Furthermore, initial evidence suggests that the lower emitting sheep tend to produce more wool, with the feed energy lost in the methane retained by the animal.

Source: CCC (2015) *Fifth Carbon Budget*
Notes: The ASGGN networks is within The Livestock Research Group, which was established by the Global Research Alliance on Agricultural Greenhouse Gases

Afforestation and forestry management

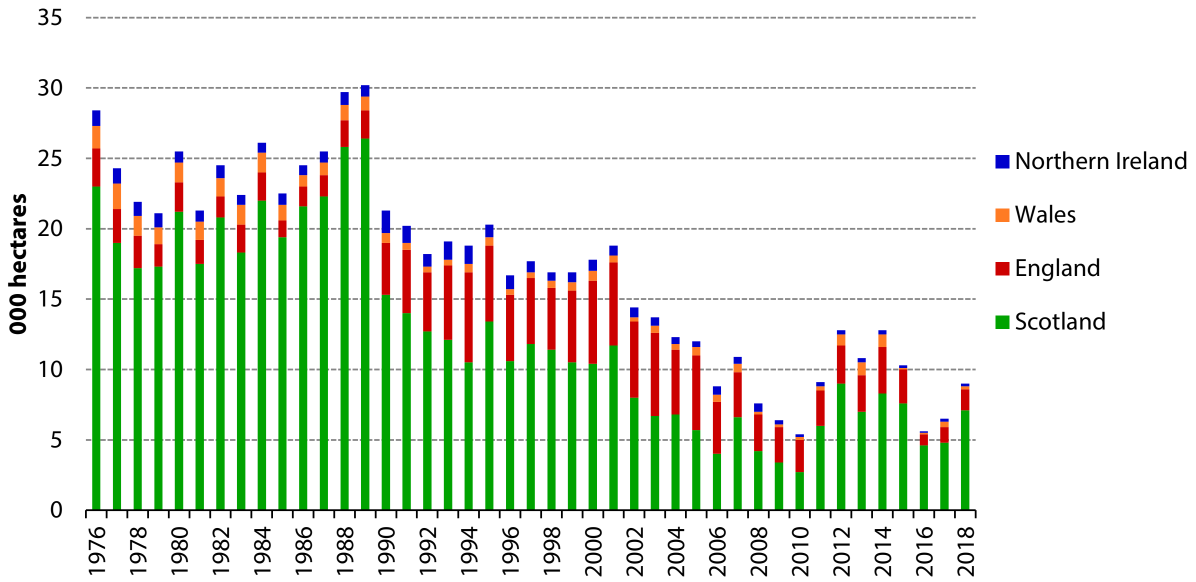
In 2018, 13% of UK land area is woodland, which is evenly distributed between conifers and broadleaves. On a country basis, Scotland is the most forested country (18.5% of its land area), followed by Wales (15%), England (10%) and Northern Ireland (8%). There are regional differences in forestry type, with conifers making up three-quarters of Scottish woodlands, while broadleaves are the dominant tree type in England (74% of woodland area). There is a more even distribution between conifers and broadleaves in Wales and Northern Ireland.

The area of woodland increased during the latter half of the 20th century (from 6% in 1947) as a result of a steady programme of afforestation throughout the UK. Planting rates reached a high of 30,000 hectares annually in the late 1980s, but have declined dramatically in recent years, averaging 9,000 hectares annually since 2010 (Figure 2.2).

Forests provide a range of ecosystem services such as recreation, fibre for fuel and timber, flood alleviation, biodiversity, and water filtration as well as carbon sequestration. The carbon cycle of forests is complex, and there may be wider impacts on the climate from trees (Box 2.8, Figure B2.3).

UK forestry is a net carbon sink.[42] The rate of absorption of UK forests is projected to decline given the ageing profile of the existing woodlands – which are unable to sequester more carbon once it reaches equilibrium – combined with a continuation of low tree planting rates.

Figure 2.2. Area of new tree planting for each country of the UK (1976-2018)



Source: Forestry Commission, Natural Resources Wales, Forest Service (2018), Forestry Commission statistics
Notes: Planting year ends 31st March

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[42] $-24MtCO_2e$ in 2016 according to the GHG Inventory, based on the CARBINE model. This differs to the level calculated by CEH for the analysis in this report ($-13.7\ MtCO_2e$) which was derived from its C-Flow model. Despite these differences in the results from the two models, the C-Flow model results provide indications of magnitude and change in direction of sufficient robustness for policy assessment based on fewer input requirements. These differences are set out in more detail in the Technical Annex and CEH report

Box 2. 8. The forest carbon cycle and other biophysical effects of forests

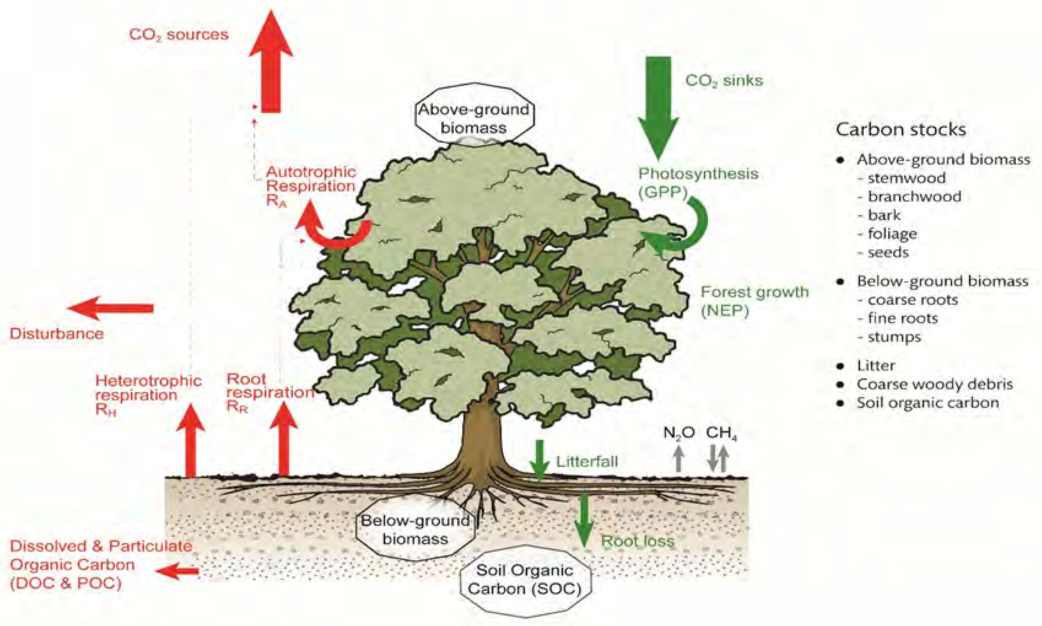
Through the process of photosynthesis, carbon is sequestered from the air and stored in the biomass of trees (e.g. stem, branches) above ground and the root system below ground, and in the soil. Simultaneously, carbon is released through respiration and from decaying wood and leaf litter. Other GHG emissions are also exchanged between forests and the air. For example, waterlogged soils can produce methane, but drier forest soils usually remove methane, while the exchange of N_2O is usually very small compared to agriculture.

Forests can also have additional important biophysical effects on regional climate through changes in surface albedo, evaporation, and transpiration:

- Surface albedo is the proportion of the solar radiation that is reflected back into the atmosphere from the earth's surface. Generally, the lighter the surface, the more solar radiation is reflected back. Changes in land use can therefore impact albedo. As evergreen conifers have permanent canopy cover that is dark in colour, with dense branching, more of the solar radiation is absorbed by the trees than would have been the case if the land had been used to grow arable crops, for example. This can have a warming effect that could potentially offset some of the carbon sequestration benefits, but the scale of the effect varies with broad climatic region, and the particular vegetation change.
- Forests can also have a cooling effect, as they intercept more rainfall than short vegetation, which then evaporates. Importantly, they transpire more water from deeper in the soil, particular during dry periods, which cools the air. The evaporation and transpiration can also lead to more cloud formation, depending on the weather conditions, which increases the reflection of solar radiation, and contributes a further cooling effect.
- Many forest tree species can release more volatile organic carbon compounds (VOC) than arable crops and grasses. These biogenic VOC affect atmospheric chemistry and can contribute to aerosol formation, which can act to increase cloud formation. The net effect of any biophysical and biochemical effects of land-use change vary with the nature of the change and the particular climate conditions.

Box 2.8. The forest carbon cycle and other biophysical effects of forests

Figure B2.3. The forest carbon cycle



Source: Morison, J., Matthews, R., Miller et al (2012). *Understanding the carbon and greenhouse gas balance of forests in Britain*. Forestry Commission Research Report, Forestry Commission
Notes: This a modified version of the chart used in the above report

The scale of potential carbon sequestration from new forests depends on a number of factors such as the type of trees planted and their productivity; planting rates and for existing forests also, management practices.

Types of trees and yields

Different trees have different growth rates and levels of productivity as measured by their Yield class (YC). Broadleaves are slower growing, typically taking around 90 years on average to reach maturity compared to around 60 years for conifers. This impacts both the time profile of carbon sequestration, and the harvesting of products.

The changing climate will present a number of different challenges for trees, and this will require careful management. Given the long life span of a tree, planting decisions taken today must take account of the tree's future resilience to the impact of the warmer climate. In deciding where and what to plant it is important to consider future susceptibility of different areas to drought and of different tree species to pests and diseases. For example a rise in temperature may increase growth rates as long as water is not a limiting factor, but can also lead to increased risks from pests and diseases. Issues around outbreaks of *Dothistroma* needle blight currently prohibit the planting of Corsican pine, and the risk is set to increase further with climate change.

For new woodland, higher yields can be achieved by better silvicultural (management) practices and from breeding. For the analysis, we assume:

- An average baseline YC12 for conifers and YC6 for broadleaves, which is maintained for the low ambition. This is a simplification of actual practice, which would cover a larger range of species, but was adopted for modelling purposes.
- An increase in productivity of between 10% and 20% for the medium and high ambition respectively.
- Improving yields enables trees to be more productive both in terms of the amount of CO_2 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 (Box 2.9).

Box 2.9. Factors influencing forestry yield improvements

Our assumptions on the scope to increase yields follow discussions with the Confederation of Forest Industries (Confor), and the Forestry Commissions in England and Scotland. A number of factors could deliver higher productivity rates e.g. improvements in management practices and the use of breeding and the CO_2 fertilisation effect that occurs from having increased levels of CO_2 in the atmosphere.

Silvicultural practices:

- The adoption of best silvicultural practice covers the nursery stage, choice of planting stock, establishment and on-going management as the tree grows. Measures would include site preparation to ensure the successful establishment of young trees and selecting the right trees and area to take account of the level of moisture and nutrients in the soil. For example, Sitka spruce does not tolerate drought. Once planted, on-going management could entail protection to prevent damage caused by deer, for example, while management of the surrounding vegetation may be required to reduce competition and ensure successful establishment.

Breeding:

- The use of breeding and genetics has a large role to play in improving both forest productivity and its resilience to the impacts of climate change. In the past, R&D was largely undertaken by the Forestry Commission and Forest Research. As a result of their breeding programmes around 94% of the current nursery stock of Sitka spruce is of 'improved' stock and has been bred to improve growth rates and timber quality. Breeding can also help deliver trees that are disease resistant.
- Today, research is being driven by the commercial sector within organisations such as the Conifer Breeding Co-operative, and the broadleaved focus Future Trees Trust. The latter is focused on enhancing the genetic quality of broadleaves to improve their growth rate, form and resilience to disease and a warming climate. The aim is to use conventional breeding in order to deliver a 40% increase in timber yields and CO_2 sequestration. In general, the choice of techniques available to breeders include controlled fertilisation, cutting and vegetative propagation, and hybridisation (where two different species are crossed). In the future, use of genetic modification could potentially lift yields even further.

In deciding what and where to plant it will also be important to take account of future resilience to the impact of a changing climate.

Source: Forestry Commission and Confor

Planting rates

England and the DAs have ambition to increase woodland cover amounting to annual afforestation rates of 20,000 hectares to 2020 and 27,000 hectares by 2024. If achieved, this could increase the area of woodland cover from the current 13% of UK land area to around 15% by 2050.

However, current rates are short of this ambition, with just under 9,000 hectares/year planted in the UK between 2014 and 2017. Our analysis assumes this continues to 2050 as a lower bound. In more ambitious scenarios, we assume annual planting rates of 31,000 and 50,000 hectares to 2050. The former rate corresponds to levels achieved in the late 1980s and matches our estimates for the fifth carbon budget under a stretching level of uptake. Afforestation rates of 50,000 hectares/year is much more ambitious and exceeds historic afforestation levels, but is not far off the levels achieved in 1971 for Great Britian, which included restocking of existing forested areas.

Meeting these planting rates would require significant scaling up across the sector, from research into the most appropriate species to plant across the country, scaling up the nursery sector to grow the saplings, to actual planting on site. Past performance has, however, demonstrated the supply chain's capability to deliver high rates of tree planting. In terms of suitable land area, England's Forestry Commission identification of 5 million hectares of low risk areas[43] for afforestation signals that there would be enough suitable land to meet a much higher level of afforestation, assuming all other barriers are overcome.

Forest management

Around 80% of broadleaved woodlands in England are in an unmanaged or under-managed state. To incentivise management compliant with UK Forestry Standards to meet the target for 67% of all woodlands to be managed in England, Defra is making grant funding available under the Countryside Stewardship's Woodland Management Plan Grant.

There are good reasons for bringing neglected woodland into management. These include increasing resilience to wind, fire and pests and diseases, the incidence of which could increase with a changing climate. Furthermore, low intensity management can help young and better quality trees to thrive, thereby aiding the sequestration of more carbon, while allowing light in can increase biodiversity. This has been recognised in the 25 Year Environment Plan, which is focusing on increasing the proportion of broadleaf woodlands that are sustainably managed. A wider and more detailed account of carbon impacts of forestry management is provided in a Technical Annex to the Committee's Biomass report.[44]

Our analysis considers the increased management of broadleaf woodland only. We assume that 67% to 80% of existing broadleaf woodland is brought into active management by 2030 under the medium and high ambition respectively, compared to the low ambition remaining at the current 20%. Our analysis assumes that all conifers are in some form of management, although not necessarily compliant with UK Forestry Standards:

Management allows for the harvesting of biomass, which can be used in other sectors to displace emissions (e.g. in energy generation and construction), and when used in the energy sector can generate negative emissions if used with carbon capture and storage.

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[43] Excludes Best and Most Versatile (BMV) agricultural land (Grades 1, 2 and 3a) and protected landscapes

[44] Ian Tubby (2018) *CCC Sustainable forest management and bioenergy annex*

Given the wood being harvested from existing neglected broadleaf woodland is of a poor quality, we assume most of the material is used as fuel wood. The adoption of best practices in silviculture practices and breeding for new planting could improve the quality of broadleaf timber for other uses such as construction.

Agro-forestry and hedgerows

Agro-forestry

We use the term agro-forestry to mean the integration of trees and/or shrubs on to cropland (silvo-arable: trees and crops) and grassland (silvo-pastoral: trees and animals). In addition to sequestering carbon in the biomass and soil, other benefits include non-CO_2 savings from reduced fertiliser use due to the recycling of nutrients that arises from leaf litter and the rooting system. Growing trees on farms can also improve water quality from reduced nitrate leaching into water courses, improve soil structure and fertility from litter fall and enhance biodiversity. For example, establishing rows of trees between alleys of arable crops can provide wildlife corridors. Trees also provide shade from the sun and shelter from the wind for grazing livestock, which could improve productivity and animal welfare.

Benefits of agro-forestry have been recognised at the EU level, and farmers in some member states are able to receive funding under Pillar II of the CAP while still being able to receive its Basic Payment. Take-up in the UK has been extremely low with incentives lacking, particularly in England. There are no official estimates on the amount of land used for agro-forestry practices in the UK, but a close proxy would be 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.[45] In our fifth carbon budget we estimated that a doubling of the area of agricultural land used to grow trees and shrubs to 2% could deliver 0.9 $MtCO_2e$ by 2050 (less than 2% of agriculture emissions in 2016).

Although governments in England and Scotland are now looking to encourage farmers to plant more trees (as set out in their respective reports, the Clean Growth Strategy and the Climate Change Plan), there is no specific planting target for agro-forestry. In our analysis, our level of ambition goes beyond our previous work and assumes 5-10% of agricultural land area could be used for agro-forestry by 2050:

- **Silvo-arable.** We assume that the area of cropland planted with trees increases to 5-10% for each country of the UK under the medium and high ambition respectively by 2050. This is equivalent to annual planting rate of 5,000 - 10,000 hectares. Tree density is assumed to be 188 trees/hectare. In England, which accounts for 85% of the area planted, trees are assumed to be poplar, and yields of YC12 are assumed to remain static.
- **Silvo-pastoral.** The same percentage of permanent grassland is planted with trees as with cropland, but annual planting rates are higher ranging between 7,500 to 15,000 hectares. The planting density is much higher at 400 trees/hectare but productivity of tree species is lower at YC6 (beech).

The level of carbon sequestration between the two types of systems will depend on the yield class of the tree, the planting density, planting rates and the type of land used to grow trees. Our analysis only considers the carbon sequestered in the soil and biomass, although additional

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[45] SRUC and Ricardo AEA (2015) *Review and update the UK Agriculture Marginal Abatement Cost Curve to assess the greenhouse gas abatement potential for the 5th carbon budget period and to 2050.*

benefits could accrue from a reduction in nitrogen use, and higher productivity due to improved soil quality.

Hedgerows

Historically, hedgerows were used to mark field boundaries. Under CAP, farmers are incentivised to retain and extend their hedges under mandatory 'cross-compliance' rules[46] and the voluntary agri-environment scheme (one such scheme provides grant funding for hedgerow restoration and creation).[47] Hedgerows can provide a similar set of benefits to those derived from agro-forestry in terms of carbon sequestration, improving farmland biodiversity and shelter for grazing livestock.

In our analysis, we include increased hedgerow planting and the introduction of some harvesting for use as fuel wood. The current length of hedgerows in the UK is around 120,000 hectares, and we assume increases of 30% - 40% by 2050. The lower bound corresponds to the level recorded in the 1984 Countryside Survey. Management is also assumed to increase so that 10-30% of hedges are managed.

Bioenergy crops

Bioenergy crops are specifically grown for use in the energy sector, and the emissions savings from displacing fossil fuels should be considered alongside any net carbon benefits that are derived while growing these crops. This life-cycle analysis and the wider sustainability issues of growing energy crops are set out in more detail in the Committee's Biomass report.[48]

Our analysis considers three types of energy crops grown in the UK: miscanthus, short-rotation coppice (SRC) willow and short rotation forestry (SRF). The first two energy crops are faster growing and harvesting can occur after two to three years following planting. SRF is conventional forestry and the slower growth rates means harvesting occurs much later, which can vary according to tree species.

Current levels of planting for miscanthus and SRC are very low (accounting for around 0.2% of UK arable area as of 2016),[49] while SRF for bioenergy is non-existent. The Government's previous Energy Crop Scheme suffered from low uptake and closed to new applicants in 2013. With no Government ambition on energy crop planting, we assume that a BAU scenario delivers no planting of these crops. Our higher levels of ambition are based on work by the Energy Technology Institute (ETI): [50]

- **Planting rates.** The planting area (evenly split across the three crop types) reaches 1.2m hectares under the high level by 2050. This is lower than the ETI central estimate of 1.4m hectares because our wider analysis shows there is not enough land for this higher level given other competing uses. The ETI only considers the sparing of land for bioenergy crops whereas our analysis covers a wider range of land demands. The medium level of ambition in our analysis is half of the ETI central estimate at 0.7m hectares by 2050.

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[46] Receipt of the Basic Payment subsidy under CAP requires farmers to adhere to mandatory 'cross-compliance' rules which includes the maintenance of hedges

[47] The Hedgerows and Boundaries Grant Scheme in England

[48] CCC (2018) *Biomass in a low-carbon economy*

[49] DEFRA (2017) *Crops grown for bioenergy in England and the UK in 2016*

[50] Energy Technologies Institute (2016) *'Insights into the future UK Bioenergy Sector, gained using the ETI's Bioenergy Value Chain Model'*

- **Yield improvements.** Improved agronomic practices and use of breeding are assumed to increase average yields of miscanthus and SRC from current levels of around 12 oven-dried tonnes (odt)/hectare to 15-20 odt/hectare by 2050. For the purposes of the modelling, poplar YC12 is selected for SRF and yields are assumed to remain static to 2050.

These energy crops are perennials and thus can deliver large carbon sequestration benefits if planted on arable land. The rooting system and the leaf litter fall can build up soil carbon and, once planted, there is little requirement to apply fertiliser, thereby reducing non-CO_2 emissions. The soil carbon gains are less if grown on grassland given that grassland stores more soil carbon than arable land.

Given the simplified assumptions used in the modelling for energy crops, our analysis could underestimate the carbon gains on cropland and overestimate losses on grassland. This is due to the assumptions used which, among other things, assumes full tillage when planting SRC and excludes SRC litter inputs which would add to soil carbon. Correcting for these assumptions is expected to give larger net carbon benefits particularly when planted on cropland. Other studies indicate miscanthus could increase soil carbon stocks by around 50 tCO_2/hectare after 35 years.[51] For SRF, the net carbon gains could rise to between 0.8 and 6.4 $MtCO_2e$ by 2050 under the medium and high level of ambition respectively.

SRC and miscanthus account for all of the harvested crop output by 2050 as it is assumed that SRF is planted from 2030 onwards. It is possible that alternative SRF species such as eucalyptus could be more appropriate in certain areas particularly as the climate warms and assuming there is sufficient water. As eucalyptus is higher yielding and rotation length is half the 26 years assumed for poplar, biomass output would then be much higher than our results indicate.

Peatlands

Carbon stocks contained in peatland in the UK are estimated at 3,200 ± 300 million tonnes.[52] In contrast to mineral soils, organic soils such as well functioning peatland[53] are able to 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.

Peatlands account for around 12% of UK land area, but only around a quarter is in a near-natural or re-wetted state and is therefore a small net carbon sink. The remaining peatlands are in various states of degradation due to a variety of practices such as moor burning for grouse shooting, afforestation, peat extraction for horticultural use and agriculture. Degradation severely limits the ability of peatlands to sequester carbon, and they then become a net source of emissions.

Currently, the GHG inventory only reports on 9% of emission losses from all peatlands and it does not take account of any emissions savings from restoration practices. All peatland emissions will be included by 2021/22. The estimates will be based on a new set of emission factors and activity data that reflect UK conditions from unpublished work[54] by CEH for the BEIS Wetland Supplement project. This work estimates net emissions from all peatlands sources of around 18.5 $MtCO_2e$ currently.

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[51] Richards et al (2017) *High-resolution spatial modelling of greenhouse gas emissions from land-use change to energy crops in the United Kingdom*

[52] Worrall, Chapman et al (2010) *Peatlands and climate change: scientific review for the IUCN UK peatland programme*

[53] Soils with more than 50% organic matter are defined as peats

[54] CEH (forthcoming), *Implementation of an emissions inventory for UK peatlands*

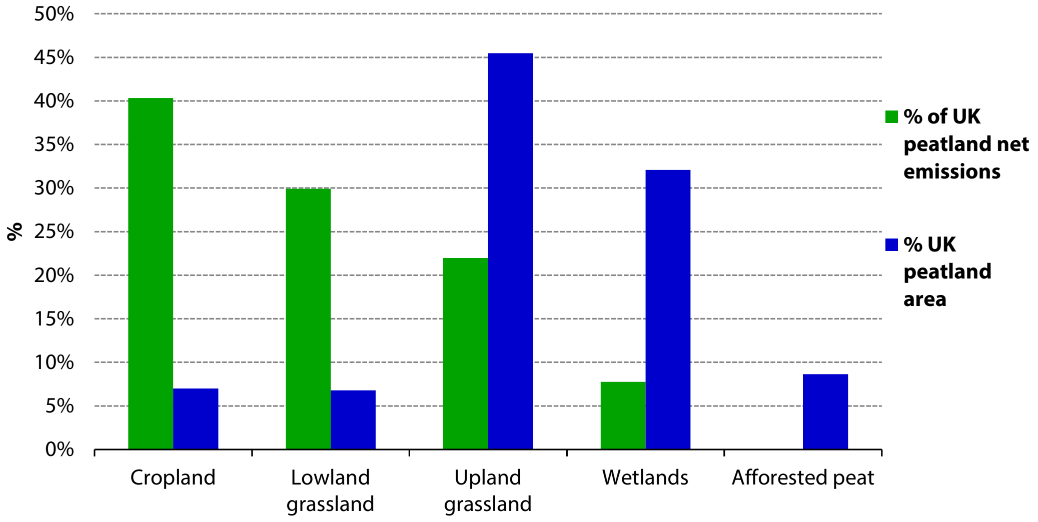
Emissions from peatlands[55] vary significantly by land type, largely determined by the level of peat disturbance. For example, historic and on-going drainage of lowland peat for crop and grassland use has resulted in significant peat loss and shrinkage. Coupled with the use of fertiliser, the lowlands are the largest source of peat emissions on a per hectare basis (Figure 2.3):

- Although lowland cropland accounts for only 7% of peatland area in the UK, it is responsible for around 40% (7.5 $MtCO_2e$) of UK peatland emissions. This is equivalent to an average of 39 tCO_2e/hectare due mainly to carbon losses from drainage for growing crops and some N_2O emissions from fertiliser use.
- Lowland grassland peat is the second most carbon-intensive (30 tCO_2e/hectare) accounting for around 30% of peat emissions and 7% of UK peatland area.
- 45% of peatland is categorised as upland grassland. Compared to the lowlands it has been subject to less disturbing practices so only accounts for just over a fifth of peatland emissions (equivalent to 3 tCO_2e/hectare).

Although England has one quarter of UK peatland by area, they account for 55% of emissions due the intensive management of lowland peat for agricultural use. Scotland, which has two-thirds of UK peatland, accounts for a third of the emissions as it has a higher proportion of upland peat which are in a less degraded state.

Both countries have ambitions to reduce peatland emissions. Scotland has an ambition to restore 250,000 hectares of degraded peat by 2030. England's 25 Year Environment Plan has a commitment to restore peatland and develop sustainable management practices for those lowland peatland areas that remain in agricultural production. Defra is scheduled to publish an England Peat Strategy later this year.

Figure 2.3. Share of UK peatland net emissions and peatland area by land type, 2016



Source: CEH and Rothamsted Research (2018), CCC analysis
Notes: Afforested peatland are assumed to be a small net carbon sink in the modelling. Wetlands includes extraction sites, rewetted peat and near-natural sites

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[55] This covers emissions from all peatlands, not just those in the GHG inventory

Our estimates of emissions and the abatement potential from restoring upland and lowland peat, which also includes taking less productive trees off afforested peatland, are based on the CEH work for BEIS. Efforts to restore peatland will reduce emissions losses and, assuming adequate restoration, allow the peat to eventually turn from a net source to a net sink in the long term. Given the time profile of our analysis however, we assume that the restoration of peatland delivers emissions savings by 2050 but does not start to sequester carbon until after this date.

Our assumptions imply that the area of UK peatland that is restored rises from 25% currently to a range of between 55% and 70% by 2050:

- **Upland peatland**. Around 87% of peat grassland is located in the uplands. We assume restoration of between 50-75% of this area.
- **Lowland peatland**. This covers both grassland and cropland that is intensively managed for agricultural use. The share of lowland peat that is cropland accounts for just 4% of total UK cropland but it is highly productive land. By re-wetting the land, conventional agricultural production is no longer viable. We assume a lower level of restoration of between 25-50% of lowland peat:
    - Our high scenario assumes that 50% of unrestored land is still in production by 2050. We estimate the additional abatement of partially re-wetting (i.e. seasonal raising of the water table when there are no crops on the field) of this area. Although partial rewetting does not release land for alternative uses it can deliver further GHG savings.
    - The loss of agricultural output that restoration entails could be partly offset by switching to paludiculture or 'wet-farming', that is food and non-food crops that can be grown in water (e.g. blueberries, reeds, sphagnum) and the rearing of water buffalo on rewetted grassland. However, with emissions factors yet to be developed for paludiculture, the impact of this has not been included in this project.
- **Afforested peatland.** Around 9% of UK peatland area has been afforested, mainly with conifer plantations. Of this, around 35% (84,000 hectares) is afforested with low productive trees of less than YC8. We assume that 25-50% of this area is deforested.
- **Peat extraction**. Extraction, mainly for horticultural use, currently accounts for about 1 $MtCO_2e$ of emissions each year. We assume extraction ceases with 100% restoration to semi natural habitats by 2030.

Defra is currently evaluating the viability of paludiculture as an alternative agricultural system on lowland peat, and the impact of managing the water table as part of a wider project that is exploring mitigation measures on agricultural lowland peatland.[56]

4. Key modelling insights and results

In this section we set out the modelling methodology used to bring together the different factors that could drive changes in land use discussed above and draw out key results and insights.

Scenarios are used to quantify the impacts of the options and levels of ambition set out in the previous sections. The key purpose of developing scenarios is not to aim for a particular land use

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[56] Defra (2018) *Managing agricultural systems on lowland peat for reduced GHG emissions whilst maintaining agricultural productivity*

future, but to increase our understanding of long-term pathways, to highlight risks and uncertainties and to help inform decision-making. They also demonstrate interactions between the different land use sectors and illustrate alternative uses that are internally consistent so that the amount of land required for alternative uses is not greater than the amount that is released out of agricultural production.

In developing the methodology underpinning this study, we considered a range of existing land use models and literature that could be used to answer the questions we are exploring. The modelling framework chosen has a detailed representation of all three land use sectors (agriculture, forestry and peatland) and is transparent in terms of inputs and outputs. A simplified representation of the modelling framework is in Box 2.10.

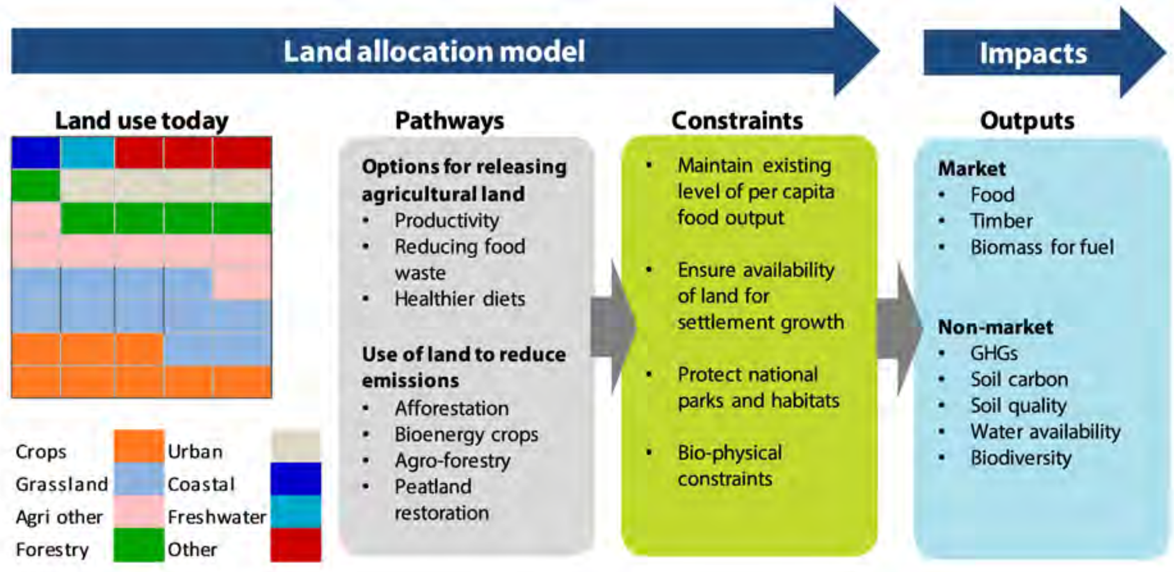
Box 2.10. The modelling framework

The modelling framework has a detailed representation of three land sectors: agriculture, forestry and peatlands, but also takes account of other pressures of land for housing and economic development.

It starts with a picture of land use today, and applies options to release agriculture land (e.g. productivity improvements, diet change), subject to a number of constraints (e.g. preserving current levels of food production). Through applying different levels of ambition of these factors, this gives alternative land pathways that deliver a range of different impacts (Figure B2.4).

The project also took account of the ecosystem services of land in the face of a warming climate, either within the modelling or as a narrative around key risks and future uncertainties.

Figure B2.4. The modelling framework



Source: CCC analysis
Notes: 'Land use today' is illustrative and does not correspond to actual share of land by each type of cover

Notes: See CEH and Rothamsted Research (2018) for more detail

The CCC technical Annex and consultants' report set out in detail the assumptions that underpin the scenarios developed. A high level description of these is provided in Table 2.1.

Table 2.1. Key elements of the CCC land use scenarios

Scenario	Description
Business as usual (BAU)	Existing trends in land use and management continue to 2050. Levels of agricultural productivity and innovation reflect past trends and little change in behaviour on diets and food waste.
High biomass/natural peatland (HBP)	Agricultural land released through higher agricultural productivity and some changes in behaviour on diets and food waste. Focus on high tree and bioenergy crops planting rates and productivity and peatland restoration.
Innovation and behaviour focus (IBF)	Maximum ambition for agriculture innovation and technology and high levels of change in behaviour towards healthy eating guidelines, and willingness to try novel food sources that could release more land. High tree planting and productivity rates helped by innovative techniques.
Multi-functional land use (MFLU)	Medium levels of ambition on innovation and behaviour to release agricultural land for other uses. High levels of hedgerows and trees on farms and areas of afforestation leading to a more diverse agricultural landscape.
Off-track	Land spared through higher agricultural productivity and technology used mainly for growing more food in the context of increasing global food demand. Focus on maximising agriculture output and exports, with low levels of ambition for afforestation and bioenergy.

Source: CCC analysis
Notes: See the CEH and Rothamsted Research report for a full explanation of the assumptions underpinning these scenarios

Key results and findings

An effective land use strategy needs to take account of a range of demands on land. We therefore applied a number of constraints to our modelling:

- Land currently designated as national parks and protected areas continues to remain so to 2050.
- The level of food production per capita is at least maintained at current levels by 2050. We also assume that the proportion of meat in imported food should not exceed current levels to avoid exporting emissions. Future exports are assumed to remain the same as in 2016 in absolute terms.
- Demand for settlements - for housing and other economic activity - is met before options to use land for emissions reduction.

The results presented below are shown at the UK level. A more detailed spatial disaggregation is given in the CCC Technical annex.

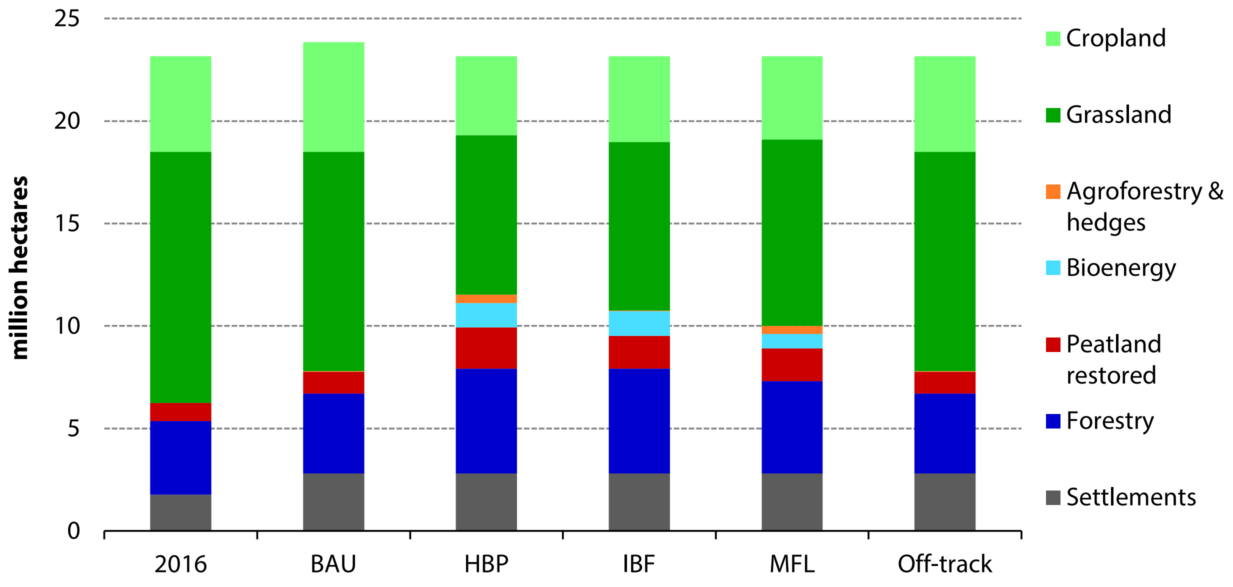
A key finding of our analysis is that **if land continues to be largely maintained and managed as it is today, GHG emissions will increase and there will be insufficient land to meet current levels of per capita food production**:

- If current agriculture trends continue, there could be around a 3% shortfall in non-developed land to maintain per capita food production at 2016 levels given population growth and increased demand for housing and other economic activity.
- Under a business-as-usual scenario there could be an increase in annual net emissions of 9.5 $MtCO_2e$ by 2050 compared with 2016 levels. This is driven by:
  - A 10% increase in agricultural non-CO_2 emissions to 46 $MtCO_2e$ by 2050. A growing population with no change in diets leads to higher livestock numbers and increased emissions from enteric fermentation and manure management, particularly from cattle and sheep.
  - The ageing profile of existing woodland and low rates of afforestation lead to a halving of the net forestry carbon sink by 2050. Woodland cover increases by just one percentage point to 14% of UK land area by 2050.

The modelling results show that significant changes in current land use patterns are needed to deliver deep cuts in GHG emissions:

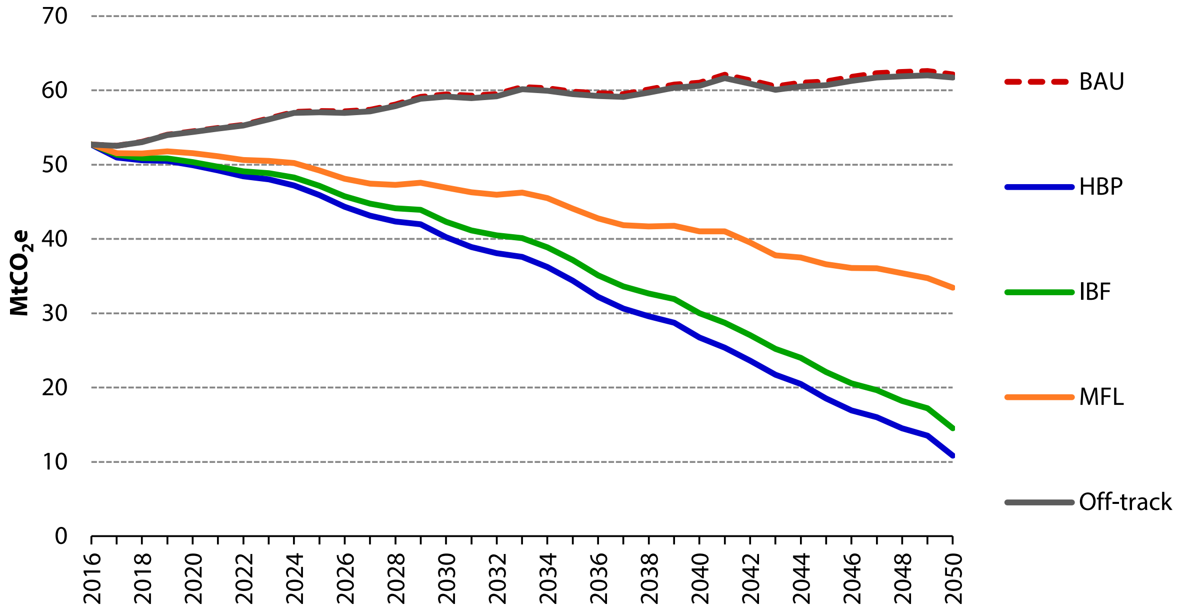
- Scenarios that deliver deep emissions reduction involve releasing 25-30% of land currently used for food production to other uses by 2050 (Figure 2.4).
- This could help deliver emissions reductions of between 35-80% by 2050 (Figure 2.5). How far these are realised in practice depends crucially on the extent to which the changes in technologies and behaviours that free up land are achieved.
- A scenario that focuses on maximising food production could see land-based emissions rise by 17% by 2050 and is not consistent with climate goals (Off-track).

Figure 2.4. Land use in 2016 and under alternative scenarios, 2050



Source: CEH and Rothamsted Research (2018) and CCC analysis

Figure 2.5. GHG emissions for different land use scenarios, 2016-2050



Source: CEH and Rothamsted Research (2018) and CCC analysis
Notes: Includes emissions from land-use change for settlement and urban expansion. A 2016 start date is illustrative only. In practice, pathways would start to diverge from BAU from the point at which land use drivers change

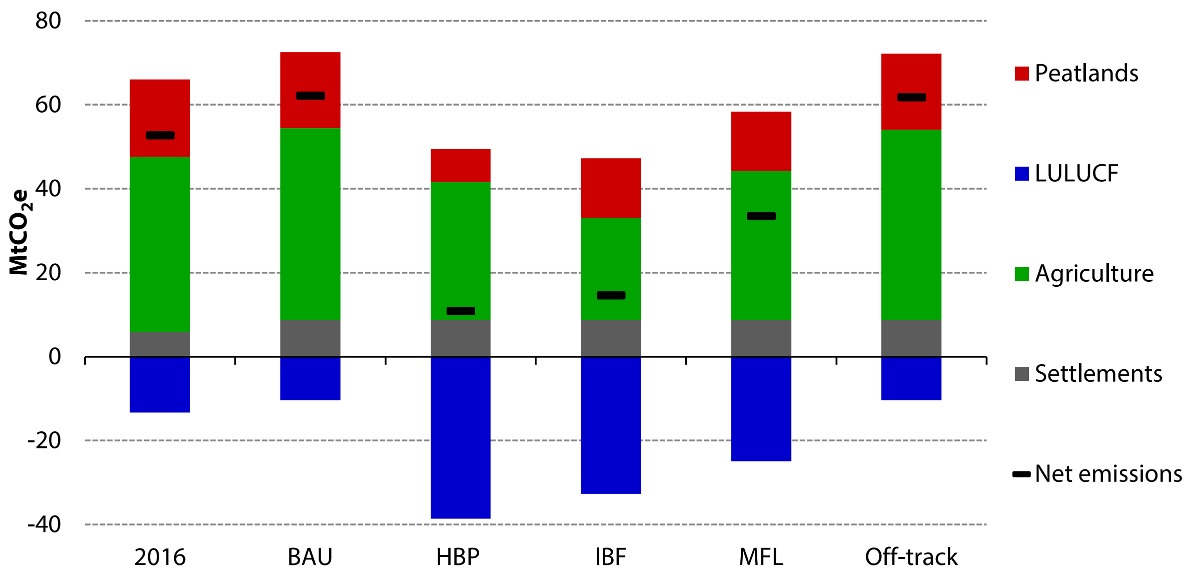
In the three scenarios that deliver emissions reduction, the **largest changes in land use result from the release of grassland currently used for grazing livestock (Figure 2.6):**

- Grasslands and rough grazing could reduce by 3.8-4.5 million hectares by 2050 (26-36%) through the adoption of healthier diets, reduced food waste and increased grazing intensity.
- Land area for afforestation and bioenergy could increase by 2.2-2.7 million hectares by 2050, which would increase woodland cover from 13% of UK land area currently to 17-19%.
- Peatland restoration could result in the re-wetting of an additional 0.7-1.1 million hectares by 2050. Around 80% of the area restored is upland grassland, which is mainly used for rough grazing. The remaining restored area is equally split between lowland cropland and grassland.

There is no single land use that can deliver significant GHG savings on its own. Actions in agriculture, forestry and peatlands are closely linked and inter-dependent. Maximising emissions reduction requires actions across all of these sectors:

- Pathways that deliver significant cuts in GHGs could reduce net agriculture and land emissions by 35-80% by 2050, resulting in residual emissions of 11-33 $MtCO_2e$, compared with 53 $MtCO_2e$ in 2016.
- All sectors contribute to this reduction: agriculture by 33 - 58%; forestry, biomass and agro-forestry by 34 - 48%; and peatlands by 11-26%.

Figure 2.6. Net GHG emissions under different land use scenarios, 2050



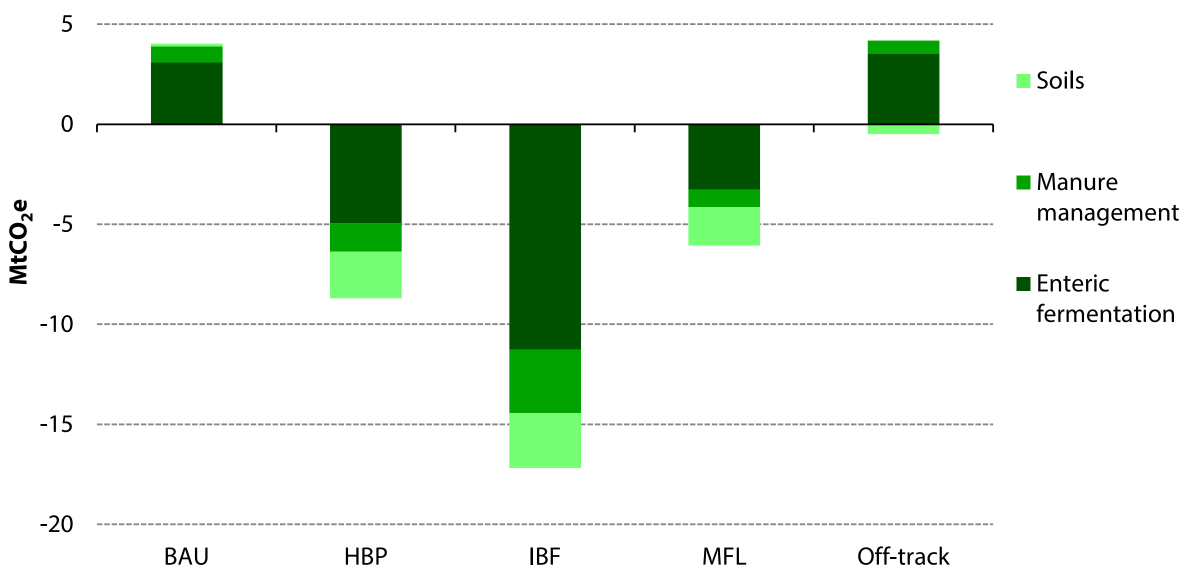
Source: CEH and Rothamsted Research (2018) and CCC analysis
Notes: The HBP scenario includes partial rewetting (i.e. seasonal raising of the water table) on the area of lowland agricultural land that remains in agricultural production. LULUCF includes forestry, bioenergy, agro-forestry, hedges, and agriculture land-use change

Without concerted action to free up agricultural land for alternative uses, there is a risk that GHG emissions could rise by just under 20% to 62 $MtCO_2e$ by 2050 (BAU and Off-track scenarios). Our analysis suggest that current low tree planting rates, coupled with a reduced ability of ageing forests to absorb carbon over time and continued peatland degradation, more than offsets any GHG savings in using lower carbon farming practices.

In agriculture, livestock offers the largest potential to deliver cuts in GHG emissions with annual emissions falling between 6-14 $MtCO_2e$ by 2050:

- Savings at the upper end of the range rest on a shift in production away from cattle and sheep, and improved productivity of livestock through better health, breeding and grazing practices. This would require consumers to switch diets away from beef, lamb and dairy products, and a focus on innovation and research and development to improve livestock productivity.
- The opportunity for cuts in soil emissions is lower, at 2-3 $MtCO_2e$ by 2050 across all scenarios. Measures for agricultural soils are less transformative. They arise from more efficient use of nitrogen and from the release of 10-17% of land out of cropland driven by increases in crop yields and waste reduction that reduces overall nitrogen use (Figure 2.7).

Figure 2.7. Changes in GHG emissions from agriculture by scenario, 2016-2050



Source: CEH and Rothamsted Research (2018) and CCC analysis
Notes: Results are for non-CO_2 emissions only

All biomass options[57] have the potential to deliver sizeable emissions reduction, around 7 - 20 $MtCO_2e$ annually by 2050 (Figure 2.8). Selecting appropriate biomass strategies – afforestation, bioenergy crops or agro-forestry - depends on location-specific factors such as soil type, climatic conditions and altitude, as well as factors associated with maximising other services, such as

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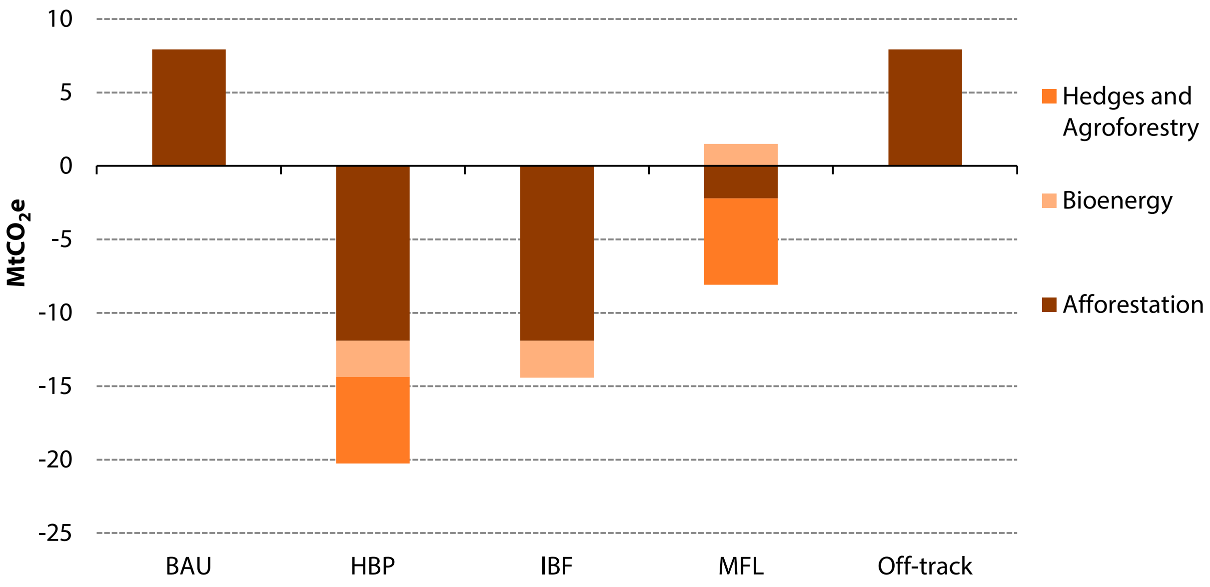
[57] Covering forestry, energy crops, SRF, agro-forestry and hedgerows

biodiversity, water regulation and recreation (which will also have a social dimension), as well as the time profile of emissions savings required. Setting out a highly spatially disaggregated picture of biomass options is beyond the scope of this project. However, key points in assessing the range of biomass options are:

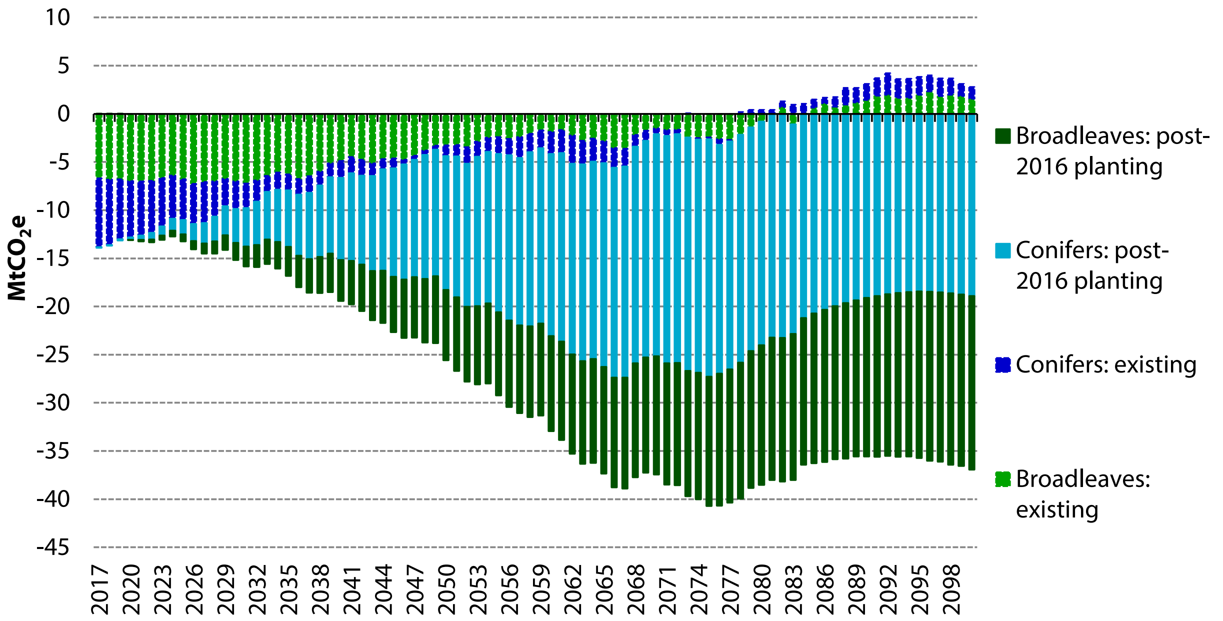
- Improving carbon sequestered from forestry relies on high planting rates, selecting appropriate species to improve productivity and active forest management. Planting a mix of trees consisting of native and non-native conifers and broadleaves, including trees for fuel and timber, is important for wider environmental and social impacts.
- The temporal profile is important, particularly for trees that are slow growing. To understand fully the time profile of net sequestration it is important to look beyond 2050 (Figure 2.9).
- Planting energy crops or trees on arable land can deliver GHG benefits through increased soil carbon and reduced nitrogen use by moving from annual to perennial crops. Whilst the soil carbon benefits are fully captured in our modelling for trees and SRF, our results for energy crops underestimate carbon savings (see Section 3). Our analysis also excludes the benefits from reduced nitrogen use for planting of all types of biomass.
- Planting trees within current agricultural systems (silvo-pastoral or silvo-arable) and hedgerows can enhance soil fertility and improve productivity as well as provide other benefits such as shelter for livestock. It could lead to additional GHG savings from reduced nitrogen application and agricultural productivity gains which have not been factored into our analysis.

Figure 2.8. Change in GHG emissions from forestry and biomass by scenario, 2016-2050



Source: CEH and Rothamsted Research (2018) and CCC analysis

Figure 2.9. Net carbon sequestration of high ambition of tree planting by type of forest, 2017-2100



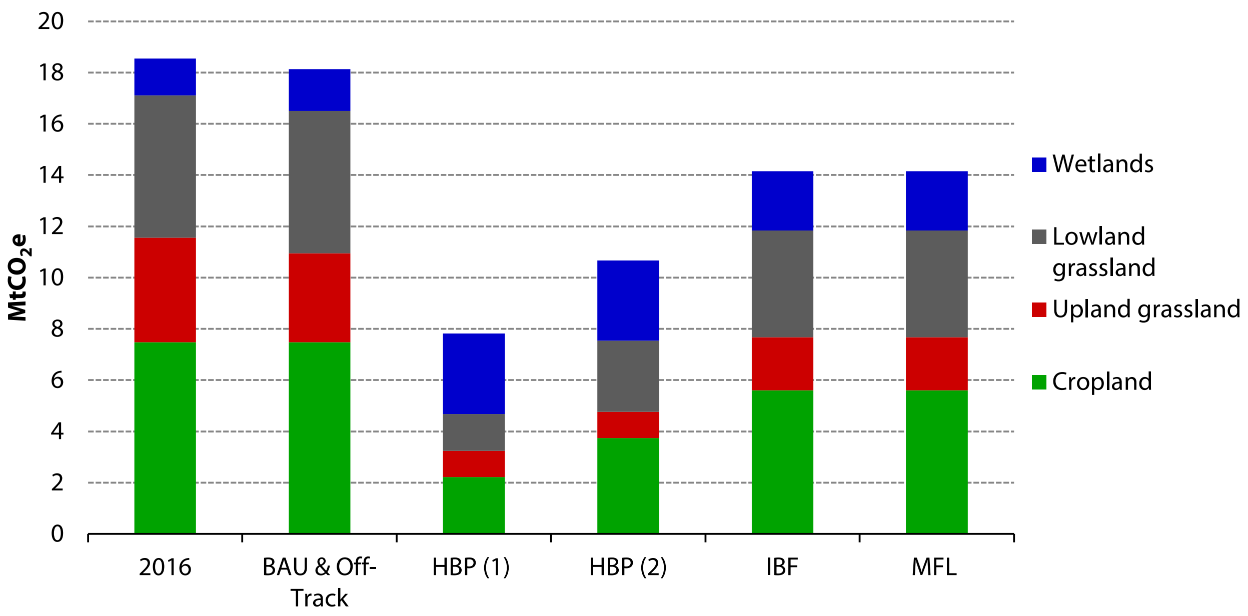
Source: CEH and Rothamsted Research (2018), CCC analysis
Notes: This is based on the high level of ambition for tree planting, forestry yield improvements and forestry management. 'Existing' refer to trees planted before 2017. Forestry net carbon sink is estimated using the C-Flow model

Peatlands currently emit around 18 $MtCO_2$ per year. Options to reduce this by 4-11 $MtCO_2e$ by 2050 are based on increasing the area of restoration from the current 25% to 55-70%. This includes upland restoration, lowland rewetting (with and without partial rewetting) and removing unproductive trees on afforested peat. Savings at the upper end of the range would involve the restoration of around 7% of agricultural land, and the partial rewetting of half of the remaining lowland area that remains in agricultural production (Figure 2.10). The breakdown by land use type shows:

- **Upland peatland.** Restoring between 50-75% of the area of upland peat that is degraded saves between 2-3 $MtCO_2e$ of emissions by 2050.
- **Lowland peatland.** Restoration of between 25-50% could deliver savings of between 2-3.7 $MtCO_2e$. Additional savings of 1.5 $MtCO_2e$ would be available from partially rewetting on a seasonal basis the land that continues to remain in agricultural production.
- **Afforested peatland.** Removing trees with a yield class of less than YC8 on 25-50% of the area with low productive trees results in little change in net emissions savings. The amount of timber for fuel wood reaches a high of around 20,000 odt by 2050.

In total, these practices reduce net peatland emissions by between 24% and 42% by 2050. This reduction increases to 58% if partial rewetting is included. Restoration of peatland could provide a range of additional benefits beyond emissions reduction including increased biodiversity, improved water quality, and flood alleviation. Restoration is also a key component in avoiding an irreversible loss of peatlands under warmer and drier conditions (Chapter 3).

Figure 2.10. 2016 net peatland emissions and by scenario, 2050

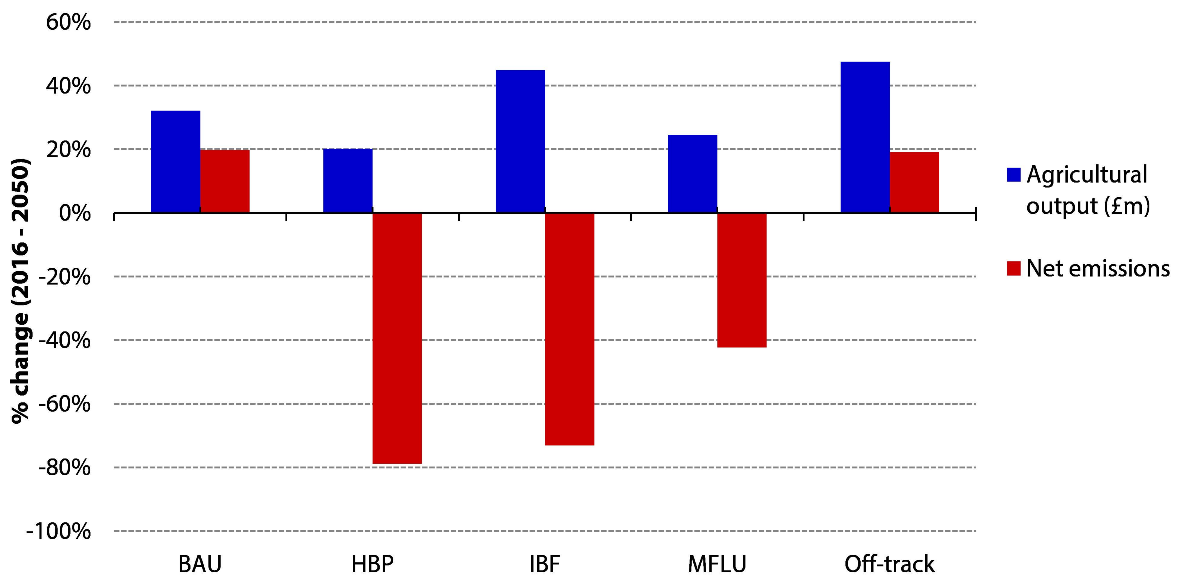


Source: CEH and Rothamsted Research (2018), CCC analysis
Notes: HBP (1) includes partial rewetting (i.e. seasonal raising of the water table) for the area of lowland agricultural land that is not restored under HBP (2). HBP (2) excludes partial rewetting of lowland agricultural land. Wetlands includes extraction sites, rewetted peat and near-natural sites

Deep cuts in emissions can be achieved whilst increasing food output. Agriculture output could increase by 20-45% by 2050 compared with 2016 levels on a gross value added (GVA) basis (Figure 2.11). Key drivers for a strong agriculture sector are: increasing productivity of crops and livestock underpinned by innovation and R&D to improve crop varieties and build resilience to climate impacts: maintaining healthy soils; and improved animal health. The modelling assumes that within agriculture, there is a shift away from red meat (beef and lamb) and dairy towards crops and white meat (pork and poultry):

- Although the area for growing crops reduces across the three transformative land use scenarios (HBP, IBF and MFL), output of arable crops, vegetables and other horticultural products could increase (ranging from a marginal increase of around 2% to more than doubling by 2050).
- Diet change away from the most carbon-intensive feedstocks would reduce dairy, beef and lamb numbers by up to 46% and increase poultry and pigs by around a quarter. These structural changes in agriculture away from red meat and dairy and towards other meat and crops leads to changes in the composition of agricultural output, which affects the value of total agricultural output to 2050.
- Novel protein sources such as lab-grown meat and insects for animal feed, together with paludiculture ('wet-farming') on rewetted peatland could provide additional value by 2050. However, the economic impacts of these have not been included in the estimates of agricultural output.

Figure 2.11. Change in agriculture output (£m) and change in net emissions by scenario, 2016- 2050



Source: CEH and Rothamsted Research (2018) and CCC analysis
Notes: The modelling assumes exports remain at 2016 absolute levels, and imports per capita remain as in 2016. The exception is the Off-track scenario where food output and exports are higher. The value of agricultural products is held constant in real terms.

Currently around 8 million oven-dried tonnes (M odt) of products are harvested from UK forests. This could increase to 18-29 M odt by 2050 under stronger ambition for forestry and bioenergy. The material can be used for timber or fuel, depending on the type of biomass planted and the quality of the material harvested. The type of biomass also dictates the time profile for harvesting:

- As fast growing energy crops such as SRC and miscanthus can be harvested two to three years after planting, they account for 35-50% of the harvested material in 2050. We assume SRF poplar can be harvested after 25 years but as planting begins from 2030 harvesting starts in the mid-2050s with around 1.8 M odt each year to 2100 (Figure 2.12).
- Conifers and broadleaves take around 60 and 90 years respectively to reach maturity on average, and only thinnings for fuel are available from any new planting by 2050. Fuel from management of existing woodlands is more important in the early decades, and accounts for all of timber volume and around 90% of fuel wood harvested from UK forests by 2050.
- A time profile beyond 2050 is needed to realise the harvested wood products from new tree planting. For example, the first rotation of conifers planted after 2016 does not occur until the 2070s. By 2100, new planting accounts for almost half the material taken out of forests for either fuel or timber, equivalent to 11.5 M odt under the high ambition (Figure 2.13).[58]

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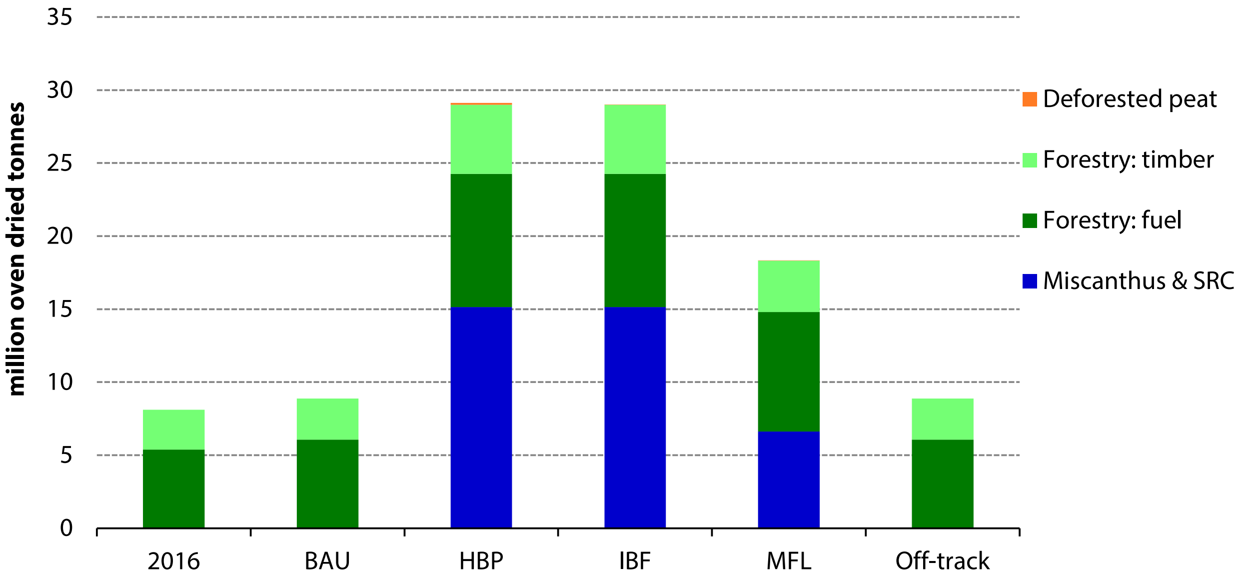
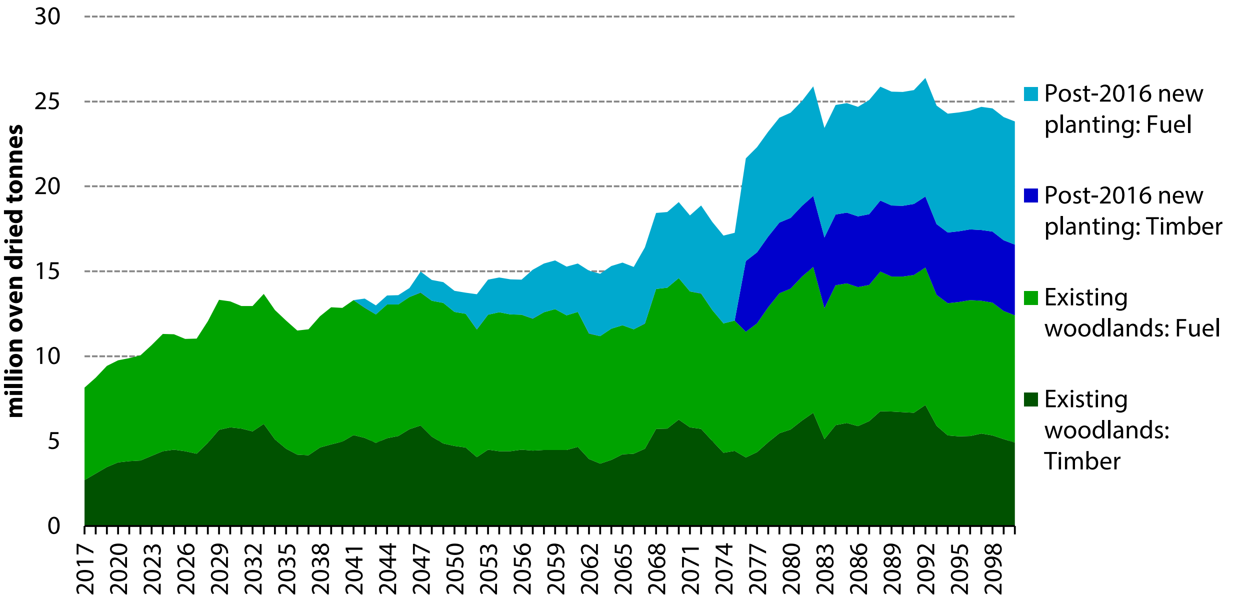
[58] This falls to 4.7 Modt under the medium ambition for tree planting and yield improvements

Figure 2.12. Harvested output from forests and bioenergy crops, 2050



Source: CEH and Rothamsted Research (2018) and CCC analysis
Notes: We assume planting of short rotation forestry starts in 2030 and therefore there is no harvesting by 2050

Figure 2.13. Harvested wood from existing and new woodlands, 2017-2100



Source: CEH and Rothamsted Research (2018) and CCC analysis
Notes: Output is based on the high ambition for new planting, yield improvements and management of existing broadleaf woodlands

Biomass can be used to provide additional emissions savings from offsetting fossil fuels used in the energy sector. Land used to grow biomass could compete with other land-based technologies that reduce fossil fuel use such as solar PV and onshore wind. An initial comparison shows that GHG savings from forest sequestration and use of products in the energy and other sectors would deliver higher savings than solar PV or onshore wind by 2050 on an annual average basis (Box 2.11). The level of GHG savings from solar PV and wind depend heavily on the carbon intensity of fuels that are displaced, and would be higher in earlier years before the grid is almost fully decarbonised. For forestry this is less of an issue because a large proportion of GHG savings are from soils and litter (around 90%), which do not change with end use of forestry products.

Box 2.11. Carbon savings from different uses of land, 2050

Whilst this report focuses on natural resources to sequester and reduce carbon emissions, land can also be used in other ways that reduce emissions. Technologies available today include solar PV and onshore wind. These could compete directly with land for forests but could also be used within agricultural systems e.g. raised solar panels on grassland.

The impact of growing forests or biomass and using their products to offset energy or products used in other sectors depends on a range of factors including: the type of land used to grow them and the management practices applied over the lifetime of the forest. Emissions savings from land used for solar PV and wind depend on how much energy is available from the wind or sun; the efficiency with which the technologies convert the available energy into power; and the carbon-intensity of the fuels or alternative uses they displace.

Figure B2.5 shows estimated carbon savings from one hectare of land used for forestry compared with using the land for solar PV and wind in 2050. The uncertainty ranges reflect:

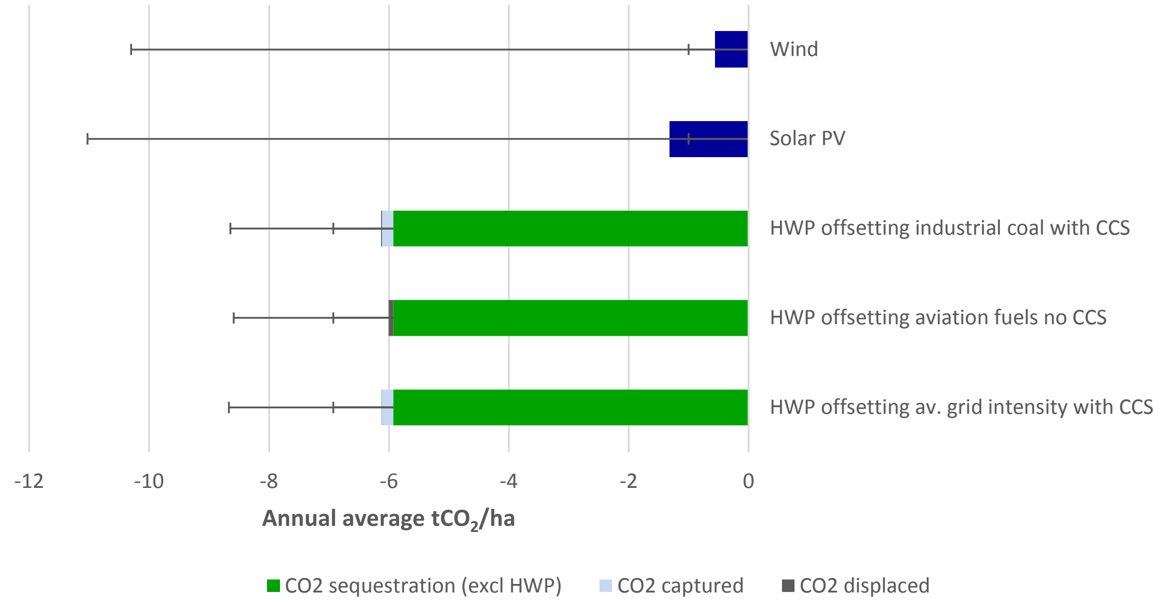
- Different types of trees and yield classes used in this study.
- Different values for the carbon intensity of the power sector, broadly reflecting a range from 2030 to 2050 in line with the Committee's previous work on the cost-effective path to achieve future emissions targets. Solar PV and onshore wind are assumed to be a part of this pathway.

The estimates are given in average annual terms over the lifetime of the forests, given the long time taken for trees to mature. Figure B2.5 shows a selection of potential applications for biomass products. For a fuller analysis see Chapter 5 of the Committee's Biomass Report.

The analysis does not take account of the important role played by woodlands in providing a range of ecosystem services, or of the private and social costs and benefits of these options.

Box 2.11. Carbon savings from different uses of land, 2050

Figure B2.5 Carbon savings from different uses of land, 2050



Source: CCC analysis
Notes: Carbon savings take account sequestration whilst growing and use of harvested products to offset energy use. Uncertainty ranges for forestry reflect the ranges used in this study. In practice they are likely to be larger than this. Average grid intensity is assumed to decline in line with the CCC cost-effective path. The estimates do not take account of other environmental benefits of woodland

A number of other recent studies have also looked at the potential of land to contribute to climate goals (Box 2.12). Both studies found an important role for afforestation and peatland restoration in reducing emissions. The Balmford et al study identified key drivers that release land in line in our study: productivity improvements in agriculture production, diet change away from red meat and waste reduction.

Box 2.12. Comparison of studies examining the potential of land to contribute to UK climate goals

A joint report by the Royal Academy of Engineering (RAE) and Royal Society (RS) considered how the deployment of greenhouse gas removal technologies could deliver net-zero carbon emissions in the UK by 2050. Their estimates for afforestation and peatland restoration are similar to our results:

- **Afforestation:** The RAE and RS estimate that increasing woodland cover from 13% currently to 18%, by planting 1.2 million hectares by 2050 could deliver annual savings of 15 $MtCO_2e$. These estimates are very close to our analysis. We assume 0.9-1.5 million hectares of afforestation by 2050 could deliver between 13-21 $MtCO_2e$. This would increase woodland cover to 17-19%.
- **Peatland restoration:** While the RAE and RA analysis assumes a similar area of peatland is restored as in our study, they assume net carbon sequestration occurs before 2050. This is a key difference to our work. We assume restoration delivers a reduction in emissions but that peatlands remain a net source of carbon emissions by 2050:

Box 2.12. Comparison of studies examining the potential of land to contribute to UK climate goals

  - The RAE and RS report assumes 1 million hectares of peatland is restored by 2050, which removes 1 $MtCO_2e$ from the atmosphere by 2050.
  - Our analysis assumes the restoration of around 0.7-1.0 million hectares, reducing carbon losses from peatland by 4-11 $MtCO_2e$ by 2050, but they remain a net source of carbon. Our analysis did not consider when restored natural peatland could become a net carbon sink.

The RAE and RS report also considered the sequestration potential of additional measures not covered in our analysis:

- **Soil carbon of agricultural land:** The REA and RS estimate that a range of management practices deployed on cropland and grassland could increase soil carbon by 10 $MtCO_2e$ by 2050. This is not line with CEH evidence[59] which found that management practices have a limited role in increasing the soil carbon of agricultural land.
- **Biochar:** Biochar is produced from organic matter using the pyrolysis process that makes it resistant to decomposition. It is therefore a potential store of carbon. The RAE and RS estimate that biochar could sequester 5 $MtCO_2e$ by 2050, but this technology has not been demonstrated at scale.

In contrast with our analysis, the RAE and RS report did not consider the factors (e.g. diet change, improving crop yields) that could release land from existing use (e.g. agriculture) for afforestation and peatland restoration.

A report by Balmford et al assessed the potential for land sparing to offset GHG emissions from agriculture. Whilst there were some difference in methodology between this study and our own the broad insights are similar:

- In some scenarios, projected farming capacity did not keep pace with demand growth, which resulted in increased agriculture imports. This also resulted in increased emissions by 2050.
- There was significant scope for reducing emissions through more efficient farming practices and active restoration of habitats on land spared. In the upper bound case this led to an 80% reduction in net emissions relative to a 1990 baseline.
- Their scenario could increase forest cover to 30% by 2050, compared with an upper range of 19% in our analysis.
- Changes in farming practices through crop yield improvements, livestock diet change and improvements in livestock feed conversion rates were key drivers for releasing land for natural uses.
- Reducing meat consumption has a larger impact than reducing food waste, but they could potentially be used to achieve greater than 80% GHG savings.

Source: The Royal Academy of Engineering and the Royal Society (2018) *Greenhouse gas removal*
Balmford, A et al (2016) *The potential for land sparing to offset greenhouse gas emissions from agriculture*, Nature Climate Change January 2016
Notes: The scope of GHG emissions in the Balmford et al study was wider than the CCC analysis and includes emissions from imported food and agriculture emissions reported in other sectors e.g. farm energy use and agro-chemical production

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[59] CEH (2013) *Capturing cropland and grassland management impacts on soil carbon in the UK LULUCF Inventory*

5. Transitioning to alternative land use pathways

Transitioning to alternative ways to use land will require overcoming inertia and long-standing traditions in farming and removing financial and non-financial barriers. We identify three areas where actions are needed to move towards land uses that deliver significant cuts in emissions:

- Innovation and R&D to improve agricultural productivity.
- Adoption of low-carbon farming practices and alternative uses of agricultural land.
- Addressing public acceptability of moves to alternative food sources.

We will return to assess these areas more fully in our follow-up report next year.

Innovation and R&D

Defra spending on agriculture R&D decreased by two-thirds between 2004 and 2017. While the Agri-Tech Strategy and Industrial Strategy Challenge fund go some way to address this historical under-investment, more needs to be done. Areas that are particularly important for delivering pathways for climate change mitigation and adaptation are:

- Research to identify high yielding crop varieties that are also resilient to climate impacts, including more extreme weather, drought, flooding, pest and diseases. This should cover research into genetically modified crops and other techniques.
- Investment in the livestock sector to improve animal health and diets and research into selective breeding.
- Research to develop low-carbon fertilisers, as set out in the Clean Growth Strategy.
- The use of breeding and genetics to improve forest productivity, both in terms of the CO_2 sequestration potential and the volume and quality of harvested products, while enhancing resilience to the impact of climate change.
- Assessing the role of novel food sources, the production of which does not require land, and the role they could play in the food sector in the future. These could cover 'alternative proteins' such as lab-grown meat and milk.
- How to bring innovative agriculture techniques from the lab to market.

As the UK prepares to leave the EU, greater competitive pressures are likely to be exerted on the sector. New ideas and practices will be essential to enable a move towards low-emission, high productive farming and land use.

Low-carbon farming practices and alternative use of agricultural land

Moves to low-carbon farming practices, and alternative land uses underpin pathways to deep emissions reduction. Our previous work has focussed on the former, while this report has identified options to use agriculture land differently. Key issues around these include:

- Identifying effective policies for farmers to take-up low-carbon farming practices, which could reduce emissions by around 9 $MtCO_2e$ by 2050. There has been no progress reducing agriculture emissions to date. New measures will need to address: lack of knowledge, experience and skills of using low-carbon farming techniques and practices that improve productivity; high up-front costs of new farming methods and alternative land uses; and uncertainty over future markets for new products. There is also a problem with land ownership where 30-40% of farms are tenanted, with the average tenancy less than 4 years. This could affect tenant farmers' ability to make significant changes in land use or to realise their benefits. We will consider options to address this in our follow-up report, including as part of the new Environmental Land Management Scheme that will replace the CAP.

- Assessing how best to intensify sustainable livestock production including appropriate grazing strategies. This should entail exploring the social and cultural importance attached to maintaining certain farming systems, such as upland grassland.
- Assessment of issues around scaling up of biomass production. There has been very little progress towards increasing the production of sustainable biomass in the UK over the last decade. This lack of progress is associated with a range of regulatory, economic and technical barriers, including high up-front costs, lack of knowledge and expertise, and policy uncertainty. These issues are explored in more detail in the Biomass Report.
- Action to restore degraded peatlands. Although Defra's 25 Year Environment Plan has a commitment to restore or develop sustainable practices on peatland, and Scotland has an ambition to restore 250,000 hectares of degraded peat by 2030, there has been very little progress to date. Defra is scheduled to publish an England Peat Strategy later this year, and we will assess this in our future report.

Public acceptability issues

Pathways that deliver significant cuts in GHG emissions rely, to some extent, on changes in current behaviours around food consumption and food waste. In Section 2 above, we set out recent trends towards vegan, vegetarian and flexitarian diets. A recent Waitrose study found that concerns for animal welfare, health and environmental impacts were key factors driving lower meat consumption in the UK. A Chatham House report[60] found that understanding of the link between red meat consumption and climate change was low, but once made aware, people said they would be willing to reduce their consumption of such food products.

Our scenarios imply a reduction in red meat and dairy products as part of a healthy diet which moves towards the government's own recommendations. However, a fuller understanding of how people could transition to healthier eating is needed to deliver the alternative land uses. Issues that we will be exploring in more depth include:

- Public attitudes and knowledge of food-related climate change issues.
- Acceptability of 'alternative' protein sources including other meats, dairy substitutes, and novel food sources, the last of which would not require land for production (e.g. lab-grown meat).
- Measures that could incentivise moves towards healthier diets, including information provision and 'nudge' strategies.

Reducing food waste also requires people to change current behaviours across the supply chain – from farmers to manufacturers, retailers and consumers. There is also a role for local and central government and food retailers to make it easier for consumers to reduce waste. In our next report we will review the Government's waste strategy due later this year, and assess whether this is sufficient to deliver the low-carbon alternative land use pathways.

The next chapter focuses on decision-making about land use in response to climate change.

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[60] Chatham House (2015) *Changing Climate, Changing Diets: Pathways to Lower Meat Consumption*

Chapter 3: Building resilience to climate change through land-use change

Key messages

- **Climate change will alter the long-term provision of goods and services that people obtain from the land.** Even if future global emissions of greenhouse gases fall rapidly, climate change will still have significant implications for future land use. Average UK temperatures have risen by 0.8°C since the 1970s. Nine of the 10 warmest years for the UK have occurred since 2002 and all the top 10 warmest years have occurred since 1990. Projections of future UK climate suggest further warming, periods of heavier rain leading to greater risks from flooding, as well as reduced water availability in summer. The potential impacts for soils, water, vegetation and wildlife are likely to be significant. There may be some opportunities from climate change such as longer growing seasons, but the net effect is projected to be negative.
- **Current policies and low-regret adaptation actions - as described in the National Adaptation Programme (NAP) and elsewhere - may not be sufficient to counter the risks from climate change in some places.** 'Low regret actions' are so called because they are cost-effective land management measures that would make sense in any future climate (e.g. soil and water conservation to maintain current land use such as agricultural production). These types of measures have been the sole focus of the government's National Adaptation Programme to date. The impacts from climate change may come at increasingly high financial and environmental cost if low-regret actions are the only way we adapt to change in the future. Transformational measures, including land-use change, have not been considered in detail to date.
- **Land-use change in the future is inevitable; although there will be short-term costs, actively managing adaptation to this change can bring much higher net benefits.** As the climate changes, use of land will have to alter. This is inevitable. In some places, particularly for higher levels of warming, land-use change in anticipation of future impacts is likely to be the option with the highest net benefits compared to relying on low-regret measures or waiting to change land use until after an impact has already occurred. Anticipatory action was shown to improve total net benefits by between £2,500 per ha and £8,400 per ha across four English case study locations analysed in this report; Norfolk and Suffolk Broads; Somerset; the Petteril; and Moor House and Upper Teesdale.
- **Widespread awareness of the potential risks from climate change to current land use, and a concerted effort for long-term planning are needed to encourage anticipatory decision-making.** A structured approach to incorporating the potential impacts from a changing climate into long-term land use planning is essential for land managers to successfully adapt to climate change. At present, there is no evidence that information about future impacts of climate change is taken into account sufficiently and that such long-term planning takes place. The government needs to own and supply the required information, and there needs to be a mechanism for land owners to use it. The government should implement this provision of support and information, which has been eroded over time, through the second National Adaptation Programme or the new ELM system.

The CCC's statutory role in assessing progress in adaptation as set out in the UK Climate Change Act relates to England only. The new analysis contained in this chapter therefore focusses on England, although the findings presented will be of interest to the devolved administrations.

3.1 Current progress in adapting to climate change

The climate in the UK is changing, leading to rising temperatures and sea levels.

- Nine of the 10 warmest years for the UK have occurred since 2002 and all the top 10 warmest years have occurred since 1990.[61] The most recent decade (2008 – 2017) has been on average 0.3 °C warmer than the 1981 – 2010 average and 0.8 °C warmer than 1961 – 1990. This recent warming is consistent with increasing greenhouse gases in the atmosphere.[62]
- Average UK sea levels have risen at a rate of 1.4 ± 0.2 mm/year since 1901, corrected for land movement.[63] This is close to the estimate of 1.7 ± 0.2 mm/year estimated for the global sea level rise.[64]
- There has been an increase in annual average rainfall over the UK in the past few decades, mainly driven by changes in Scotland. Seven of the ten wettest years in the UK have occurred since 1998, including 2015, 2014, 2012 and 2008. Furthermore, of the 17 record-breaking rainfall months or seasons since 1910, nine have occurred since 2000.[65] It is not clear yet whether or not trends in rainfall are attributable to climate change. There is higher variability in rainfall compared to average temperatures and sea level, so longer time series are needed to statistically analyse causation.
- Observed trends in storminess in recent decades are not considered unusual in the context of longer European records dating back to the early 20th century.[66] Wind speeds show a very slight decline across the UK in all regions except the south-east, which shows a slight increase.

Some impacts from climate change are already evident within the natural environment and agriculture sector in England.

- Warmer temperatures have resulted in changes in the timing of life cycle events (phenology), with long-term monitoring datasets indicating that spring in England is arriving earlier. Since 1999, the average date in the year for the 'onset of spring' has occurred around 6 days in advance of the average dates over the 1897 to 1947 period.[67]
- There is evidence that the earlier spring and delayed autumn seasons have impacted the delicate seasonal clocks of migratory birds, with many iconic species such as swallows - a bellwether of spring - arriving in England earlier each year and leaving later each autumn.[68] Others, such as the night heron, are breeding in the UK for the first time as their range expands north, while other species such as the snow bunting are in decline.
- The complex interaction between climate and crop growth along with the many other changes to crops and cropping practices makes it difficult to attribute changes in yield over

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[61] Kendon, M. et al (2018) *State of the UK climate, 2017*

[62] Karoly, D. and Stott, P. (2006) *Anthropogenic warming of central England temperature*. Atmospheric Science Letters, 7, 81-85

[63] Woodworth et al (2009) *Trends in UK mean sea level revisited*. Geophysical Journal International, 176, 19–30 and updated for the 2017 Climate Change Risk Assessment Evidence Report

[64] Church et al, (2013) *Sea level change*. Report for the European Environment Agency

[65] Kendon, M. et al (2018) *State of the UK climate, 2017*

[66] Feser. F. et al, (2014) *Storminess over the North Atlantic and north western Europe*. A review by the Royal Meteorological Society

[67] JNCC (2018) *UK Biodiversity Indicators 2018*

[68] Hayhow DB et al (2018) *The state of the UK's birds 2017*. The RSPB, BTO, WWT, DAERA, JNCC, NE and NRW, Sandy, Bedfordshire

the past 30 years to observed changes in climate.[69] There are some indications that higher temperatures in England are enabling greater planting of crops previously grown only in warmer climates (Box 3.2.). Over the past 40 years there has also been a shift towards a warmer, drier regime during the growing season in eastern parts of England, which has led to more land being classified as 'prime agricultural' in those areas.[70]

Box 3.2. How climate change is altering the way land is used in the UK: wine production

The amount of land used for wine production in the UK has more than doubled in the decade to 2015 (Figure B3.2). Wine producers in Britain planted a record one million vines in 2017, enabling growers to reportedly produce two million more bottles of wine a year compared to 2016.[71] Some anecdotal reports have suggested that warming temperatures are providing a later English growing season and making the wine industry more viable across the south east of England and as far west as Wales, though other factors are also likely to be playing a part in the expansion of the industry.[72] Further statistical work is needed to get a clearer picture of whether warmer temperatures are the main reason for the increase in UK-based wine production.

Figure B3.2. Wine producing vineyards in England and Wales

Source: ADAS (2017) *Research to provide updated indicators of climate change risk and adaptation action in England and Wales. A report for the Committee on Climate Change*

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[69] Brown, I. et al (2016) *UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets*. Report prepared for Committee on Climate Change, London

[70] NERC (2016) Agriculture and Forestry Climate Change Impacts Report Card

[71] FarmingUK website article (2017) *British wine industry to plant 1m vines as production set to double* https://www.farminguk.com/News/British-wine-industry-to-plant-1m-vines-as-production-set-to-double_46189.html

[72] CCC (2017) *Progress in preparing for climate change: 2017 Report to Parliament*

- There is evidence that higher average temperatures in recent years have had an adverse impact on production of certain fruit varieties by reducing the incidence of chilling temperatures that are necessary in some overwintering crops. Inadequate chilling interferes with the normal processes of bud formation, flowering and, consequently, yield. For example, blackcurrant has been identified as a fruit species that has a particularly high chilling requirement, and the recent warm winters have resulted in lowered yields and fruit quality in the UK, partly as a result of uneven ripening.[73] The observed decline in spring frost frequency has been linked with a reduced variation in blackcurrant yields in comparison with the 1960s and 1970s.[74] Recent spells of high temperatures in warmer summers have also caused reductions in yields and quality that have affected crops such as brassicas, some fruits and tomatoes.[75]
- While heatwaves like that England experienced in 2018 (Box 3.3) are expected to become a more frequent feature of summers by the 2040s, the precise nature of the changes in climate and the specific way that ecosystems will respond remains uncertain. However, there is robust evidence that the impacts of climate change will be more severe if ecosystems and the land that accommodates them is degraded.[76]

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[73] Jones, H.G., Gordon, S.L. and Brennen, R.M. (2014) *Chilling requirement of Ribes cultivars*. Frontiers in Plant Science 2014; 5: 767

[74] Defra website article, 2014 *Climate change explained:* https://www.gov.uk/guidance/climate-change-explained

[75] NERC (2016) Agriculture and Forestry Climate Change Impacts Report Card

[76] Lawton, J.H. et al (2010). *Making space for Nature: a review of England's wildlife sites and ecological networks*

Box 3.3. Reported impacts of the 2018 UK heatwave

The summer of 2018 was notable for heatwave and low rainfall conditions, with the UK experiencing its hottest, and fifth driest, first half of the summer since modern records began.

Food production

Dairy farming - the extended dry spell reduced the productivity of grazing land, resulting in a shortage of forage for livestock. Farmers were forced to dip into already depleted winter supplies of feed, following the late spring. Reported cases of heat stress in dairy cows also increased, reducing productivity, through delays to calving and milk production.

Crop production - the warmer, drier summer reduced crop growth in many parts of the UK. Salad, fruit and vegetable growers reported harvests and yields being severely affected. While improvements in agronomy and irrigation, embedded over the last 40 years, to some extent lessened the impact of the drought conditions, irrigation systems were reported to be under pressure, in some cases requiring additional water stocks to be ferried in at additional cost to producers. Most notably, yields were down for several staple UK crops including cereals, potatoes, carrots, cauliflowers and salads. This led to fears over reduced availability in stores later in the year.

The warmer conditions also provided the perfect breeding ground for specific types of insect pests such as the pea moth and bruchid beetle, which feed on both peas and beans during the summer months. Bruchid beetle damage to pulse harvests was worse than in previous seasons, especially in the South of England.

Water deficits

Water supplies came under intense pressure due to lower than normal rainfall and soaring temperatures. Some suppliers we forced to seek special exemptions from the Environment Agency to alter the usual flow of rivers to help shore up their dwindling reservoirs. United Utilities water company issued warnings for a ban on hosepipes and water sprinklers, for over seven million domestic customers.

Wildfires

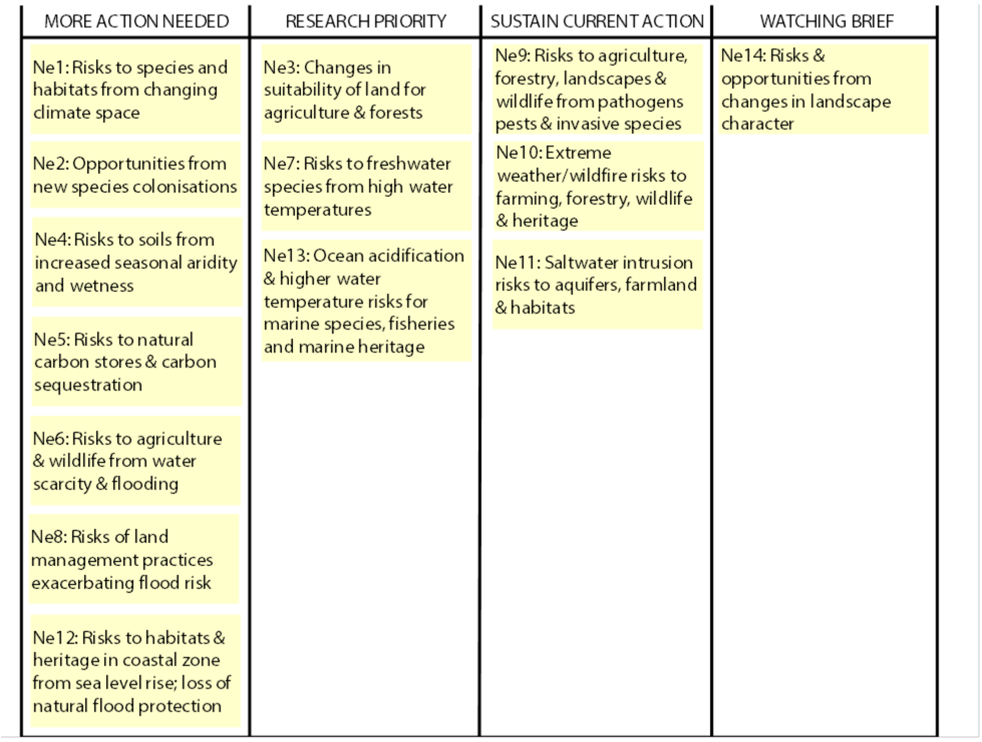
The dry conditions fuelled a spate of wildfires in northern England and Scotland, forcing the evacuation of people from their homes. The two largest fires, which were declared major incidents, resulted in over seven square miles of moorland being seriously damaged. The fire on Saddleworth Moor in Yorkshire burned for three weeks, with around 100 soldiers drafted in to support emergency services to limit its spread.

Source: AHDB (2018) *Agricultural drought impact summer 2018*;
BBC news website article: *Saddleworth Moor fire: Homes evacuated as blaze continues to rage*, 27 June 2018
https://www.bbc.co.uk/news/uk-england-manchester-44624021
Sky news website: UK weather: *How the heatwave will impact British life*, 2 July 2018
https://news.sky.com/story/uk-heatwave-vegetable-crops-and-insects-under-threat-during-long-british-summer-11424278
Guardian newspaper website: *Heatwave pushes up UK fruit and vegetable prices as yield fall*, 27 July 2018
https://www.theguardian.com/business/2018/jul/27/heatwave-pushes-up-uk-fruit-and-vegetables-prices-as-yields-fall

The UK climate change risk assessment presents a number of risks and some opportunities related to land use across the UK.

- Risks and opportunities for the natural environment, including agriculture and forestry, were set out in the most recent UK Climate Change Risk Assessment Evidence Report (Figure 3.1).

Figure 3.1. Risks and opportunities for the UK's natural environment from climate change



MORE ACTION NEEDED	RESEARCH PRIORITY	SUSTAIN CURRENT ACTION	WATCHING BRIEF
Ne1: Risks to species and habitats from changing climate space	Ne3: Changes in suitability of land for agriculture & forests	Ne9: Risks to agriculture, forestry, landscapes & wildlife from pathogens pests & invasive species	Ne14: Risks & opportunities from changes in landscape character
Ne2: Opportunities from new species colonisations	Ne7: Risks to freshwater species from high water temperatures	Ne10: Extreme weather/wildfire risks to farming, forestry, wildlife & heritage	
Ne4: Risks to soils from increased seasonal aridity and wetness	Ne13: Ocean acidification & higher water temperature risks for marine species, fisheries and marine heritage	Ne11: Saltwater intrusion risks to aquifers, farmland & habitats	
Ne5: Risks to natural carbon stores & carbon sequestration			
Ne6: Risks to agriculture & wildlife from water scarcity & flooding			
Ne8: Risks of land management practices exacerbating flood risk			
Ne12: Risks to habitats & heritage in coastal zone from sea level rise; loss of natural flood protection			

Source: CCC (2016) *UK Climate Change Risk Assessment 2017. Synthesis Report: Priorities for the next five years*
Notes: The urgency associated with each risk and opportunity (shown in top row) was determined by the CCC on the basis of the evidence presented in the CCRA chapter. See Chapter 2 of the CCRA Evidence Report (Warren, R., et al (2016) *UK Climate Change Risk Assessment Evidence Report: Chapter 2, Approach and Context)* for a description of the urgency scoring methodology

Specific examples of the risks and opportunities set out in the CCRA related to land use are:

- **Climate change will alter the magnitude, frequency and duration of flood events.** Using an indicative 1 in 75 year average risk level, flooding of high-grade agricultural land from fluvial, coastal and pluvial sources is projected to increase from 570,000 hectares (present day) to 750,000 hectares under a 2°C rise in global mean temperatures by the 2080s; and to 940,000 hectares in the context of a 4°C rise. Land that is regularly flooded is only capable of supporting lower-value crops, pasture or woodland.[77]

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[77] Brown, I. (2016) *UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets.* Report prepared for the Committee on Climate Change, London

- **Changing temperatures and soil moisture have the potential to lead to increased soil erosion and soil carbon loss, though there is uncertainty about exactly how soils will respond.**[78] Agricultural land use activities such as the use of lowland peat soils for intensive arable production have led to steep reductions in carbon stocks contained in soils and vegetation of peatland areas. If these rates of degradation continue, intensively farmed soils in the Fens could lose all of their peat top soil in 50 - 80 years under current land management conditions. With climate change, the rate of degradation could increase, resulting in a complete loss of the peat soil layer within 30 - 60 years.[79]
- **Soil moisture deficits are projected to increase in the future, which in particular may impact agricultural production in the south and east of England where dryness is already a constraint.**[80] Climate change will almost certainly require relocation of growing areas for some crops from one region of the UK to another. There is projected to be a regional shift in the areas deemed climatically suitable for crops such as potatoes and carrots (assuming no additional irrigation) (Figure 3.2). Based on a UKCP09 high emissions scenario, it is estimated that the volume of water for irrigation would need to increase seven-fold by the 2050s for present-day levels of potato production in England and Wales to continue.[81] If these costs become prohibitive or sufficient water for irrigation is not available, crop production may have to shift elsewhere.

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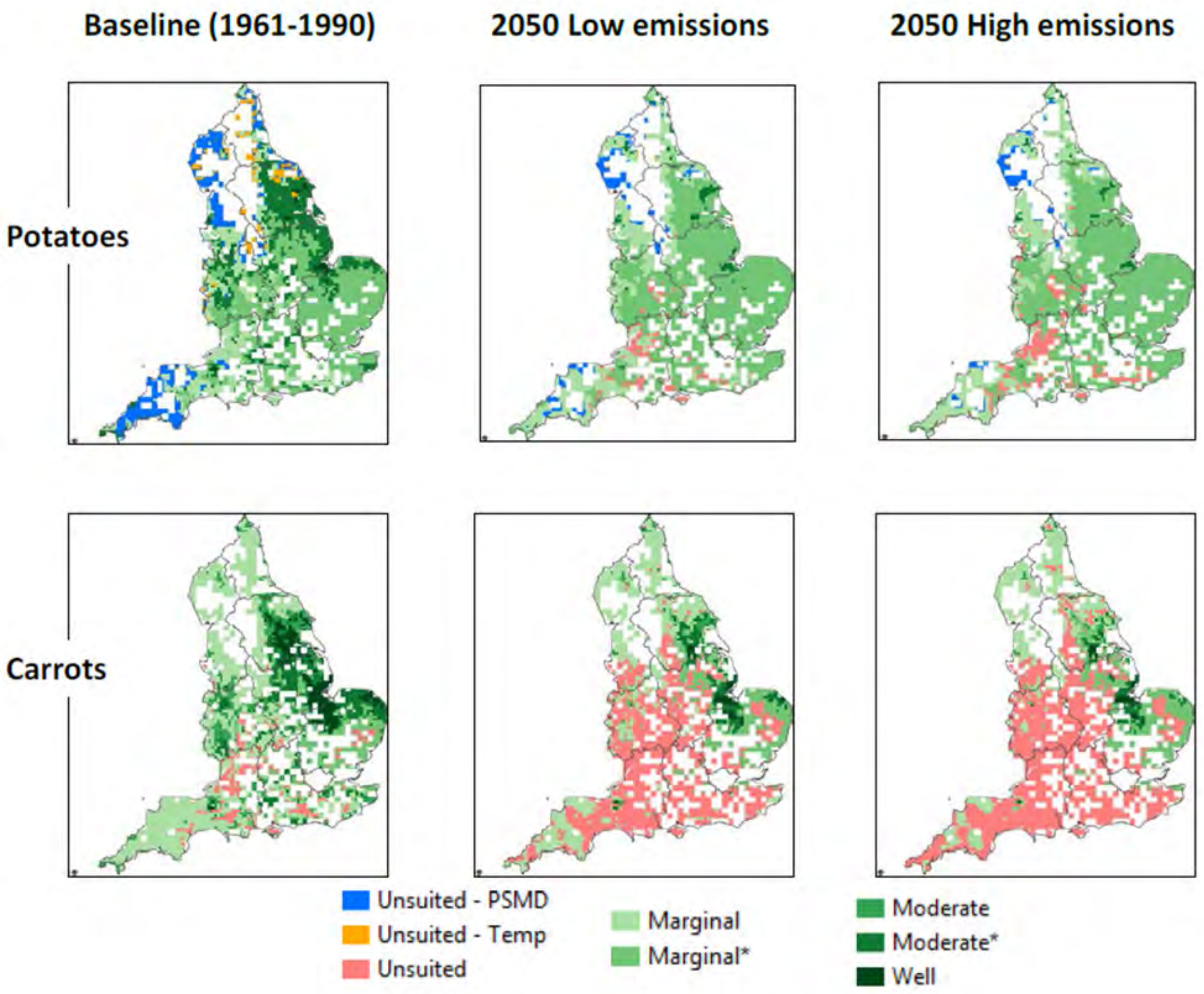
[78] *Ibid.*

[79] CCC (2013) *Managing the land in a changing climate*

[80] Brown, I. (2016) *UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets.* Report prepared for the Committee on Climate Change, London

[81] Keay, C. A. et al (2014). *The impact of climate change on the capability of soils for agriculture as defined by the Agricultural Land Classification.* Report to Defra. ADAS/University of Cranfield

Figure 3.2. Projected agricultural land suitability for potatoes and carrots in England under low and high UKCP09 emissions scenarios (2050s)



Source: ECI et al (2013) for the CCC
Notes: Agricultural land suitability for potatoes and carrots under three UKCP09 scenarios (Baseline, 2050 Low and 2050 High) for areas where crop was present in 2010 based on June Agricultural Census data. The UKCP09 low emissions scenario equates to a 2.1°C rise in average annual temperature in the 2050s compared to a 1961-90 baseline (central estimate). For the UKCP09 high emissions scenario the increase is 2.7°C[82]

- Woodland growth rates could benefit from warmer temperatures and increased carbon dioxide concentrations, particularly in cooler regions of the UK, if other factors such as water availability are not limiting. However this may not necessarily be beneficial for forestry as faster growth may reduce timber quality unless different species (or different genotypes) are used.[83]

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[82] Murphy, J.M. et al (2009) *UK climate projections science report: climate change projections.* Met Office Hadley Centre, Exeter, UK

[83] Brown, I. (2016) *UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets.* Report prepared for the Committee on Climate Change, London

- Milder and wetter winters are projected to result in more virulent pests, diseases and invasive species increasing the risks to trees, crops, livestock and native wildlife.[84] There is likely to be an increased risk to livestock production from endemic livestock diseases and a greater incursion of exotic diseases.[85] For trees, greater frequency of drought, heat stress and waterlogging is likely to exacerbate damage and deaths resulting from attacks by pests and diseases. Some insect pests that degrade valuable timber or kill mature trees are likely to increase.[86]
- It is expected that observed trends in species colonising more northerly and higher altitude locations will continue. At the same time, it is likely that species at the southern and low-altitude margins of their range will continue to decline or become extinct in the UK.[87]

In responding to climate risks and opportunities, the Intergovernmental Panel on Climate Change (IPCC) distinguishes between low-regret adaptation measures and transformational measures.

- Low-regret measures are defined as those that are cost-effective to implement today; where the benefits are less sensitive to precise projections about the future climate; and where there are co-benefits or no difficult trade-offs with other policy objectives.
- Transformational change is defined as actions that fundamentally change the system or systems in question. Transformational adaptation is necessary once the limits of low-regret adaptation have been reached.
- Table 3.1 sets out examples of low-regret and transformational adaptation. In the context of land use, transformational change is often associated with changing land use to different activities.

Table 3.1. Comparison of low-regret actions versus transformational land-use change

Type of adaptation	Low regret measures	Planned transformational measures
Soil management	Low-cost soil conservation measures – e.g. contour ploughing.	Restoring peatlands through revegetation, while re-orientating revenue generating activities away from potentially damaging activities (e.g. game hunting, sheep grazing) in upland peat areas, towards sustainable sphagnum moss production activities.

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[84] Brown, I. (2016) *UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets*. Report prepared for the Committee on Climate Change, London

[85] Skuce et al, (2015) *Livestock health and greenhouse gas emissions*. Report by ClimateXchange Scotland

[86] NERC (2016) Agriculture and Forestry Climate Change Impacts Report Card

[87] Brown, I. (2016) *UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets*. Report prepared for the Committee on Climate Change, London

Table 3.1. Comparison of low-regret actions versus transformational land-use change

Type of adaptation	Low regret measures	Planned transformational measures
Crop and livestock production	Low cost water conservation measures – e.g. improving water efficiency through irrigation scheduling.	Fundamentally changing agricultural production through new technologies e.g. indoor crop production, increase in novel foods, dietary change (see the 'innovation and behaviour focus' scenario in chapter 2).
Flood management	Works to improve land drainage systems, and employing equipment to pump water off waterlogged land.	Facilitated landscape scale expansion of grazing marsh and pasture from arable land area.
Forestry	Increasing the diversity of tree species planted to help reduce overall vulnerability to disease.	Landscape scale expansion of forest, replacing other land use types.

The focus of the government's first and second National Adaptation Programmes has solely been on 'low-regret' measures to increase climate change resilience.

- The Adaptation Committee in its 2011 and 2013 reports identified a number of low-regret measures for improving the resilience of land use to future climate change. These mainly focused on maintaining the productive capacity of the land for agriculture through land management measures such as conserving soil and water; improving the condition and size of semi-natural habitats; and increasing the diversity of the types of crops, livestock and trees produced for food and timber.
- The National Adaptation Programme (NAP), first published in 2013 and updated in 2018, sets out the actions government and others are taking in England to manage the increasing risks from climate change. Out of the 137 low-regret actions listed under these themes in the first National Adaptation Programme, the majority were delivered as planned (Figure 3.3). Examples of the sorts of measures implemented between 2013 and 2018 include:
  - Natural England developed and disseminated a vulnerability mapping tool to prioritise actions for increasing resilience across its range of work. It also produced an adaptation manual to include advice on species of conservation concern.
  - The Ministry of Defence undertook climate risk assessments across its priority sites for biodiversity, with over 100 sites assessed.
  - In response to a Committee recommendation,[88] Natural England conducted a review of how past agri-environment scheme delivery had contributed to climate change adaptation. It found that the greatest contribution to adaptation occurred where there

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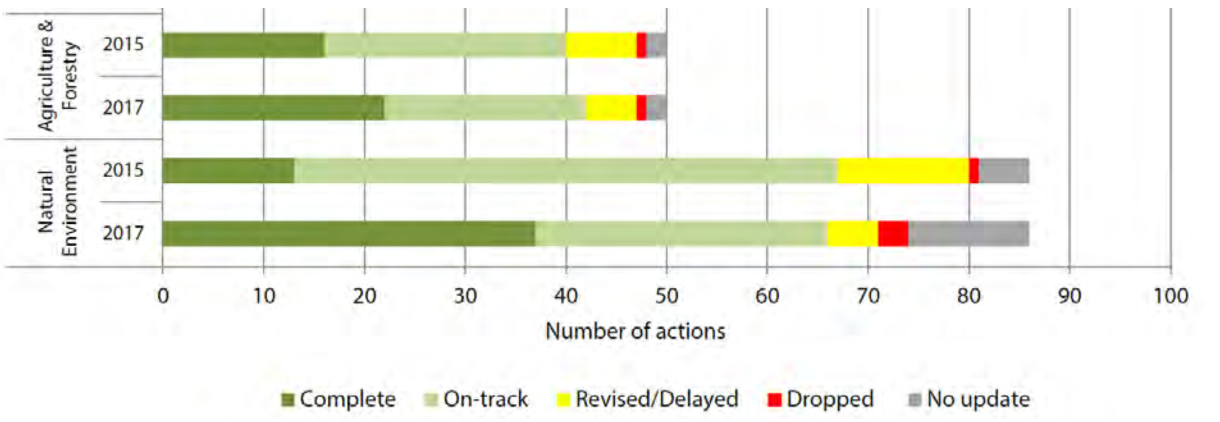
[88] 'Natural England should establish within a year of this report a monitoring scheme to assess the extent to which the new Countryside Stewardship scheme will help to deliver coherent ecological networks, and more broadly reduce the vulnerability of farmland wildlife to environmental pressures, including climate change'.

was overlap with other objectives, for example the maintenance of existing protected sites. Despite an increase in the amount of priority habitat being created under the schemes, there had been limited success in addressing habitat fragmentation. The study also found that the majority of blanket peat soils (~73%) were covered by agri-environment options whilst only 9% of other peat soils were covered .

- More recently, £10m of new funding has been announced that aims to help deliver the commitments in the 25 Year Environment Plan to enhance peatland restoration in England. The funds will be split across four projects in England, with a total area of 6,580 hectares of upland and lowland peatlands. The government has also announced it will be publishing an England Peat Strategy later in 2018.

Figure 3.3. Status of actions set out in the first National Adaptation Programme



Source: CCC (2017) *Progress in preparing for climate change: 2017 Report to Parliament*
Notes: CCC analysis of returns received from action owners, the majority commissioned through Defra (those relating to government departments and their agencies), with other organisations contacted directly by the CCC

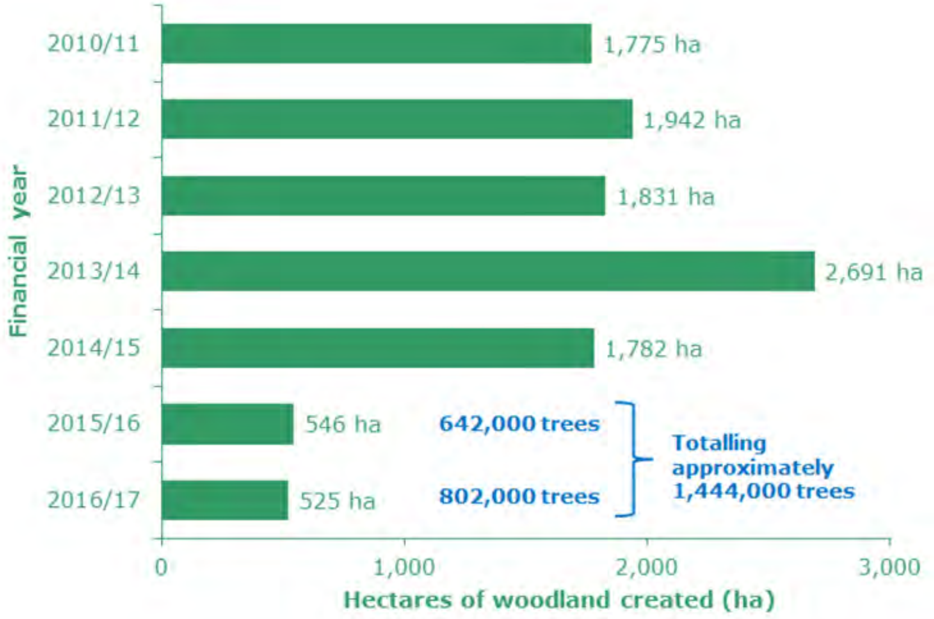
While there have been some individual success stories, the Adaptation Committee's assessment of the first NAP concluded that the measures within it have not been sufficient to reduce overall vulnerability to climate change in the land use sector.

- In order to build resilience, the second UK Climate Change Risk Assessment Evidence Report identified that more action was needed to manage vulnerability to climate change through reducing existing pressures on the natural environment, increasing the size and improving the condition of habitats, restoring degraded ecosystems, and delivering coherent ecological networks (Figure 3.1). These measures are in line with those set out in the Lawton Review (2010) to give the natural environment the best chance of adapting to a changing climate.

- Key areas which remain a concern in the natural environment in England mainly centre on the deteriorating condition of natural assets: soil health; the condition of terrestrial and freshwater habitats; and biodiversity in the farmed countryside. Examples of where government actions are falling short of its own targets (which if met would go a long way to improving preparedness for climate change) include:

- Farmland species continue to decline in abundance, with robust evidence that this is linked to poor condition of farmland habitats.[89] Farmland butterfly populations in England have fallen in abundance by 27% since 1990. The abundance of farmland pollinator species fell by 32% between 1980 and 2010. Farmland bat species have seen an increase, however.
- In 2013, the government set a woodland planting aspiration in England of 5,000 additional hectares per annum.[90] Despite some progress, annual planting rates from the Forestry Commission in England show that in no year has the annual target been reached, with hectares of woodland planted falling consistently between 2013/14 and 2016/17 from 2,691 hectares to 525 hectares (Figure 3.4). The government has, however, announced plans for a new Northern Forest as part of its 25 Year Environment Plan, which if implemented will span 120 miles across the north of England and comprise 50 million trees.[91]

Figure 3.4. Hectares of woodland created (Gross) in England, 2010/11 to 2016/17



Source: Forestry Commission, 2018
Notes: Area of woodland created with support from the Rural Development Programme for England: both the English Woodland Grant Scheme (EWGS) and the Countryside Stewardship incentives. Areas of private-sector funded planting or planting supported by other Government funding streams are not included

- The percentage of blanket bog sites of special scientific interest (SSSIs) in favourable condition declined from 19% to 10% between 2003 and 2016, though the percentage moving from unfavourable to unfavourable recovering condition (i.e. with a restoration plan in place, though not necessarily with any change in condition) rose from 16% in 2003 to 87% in 2016.

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[89] JNCC (2017) *The state of the UK's birds*

[90] The aspiration was based on private sector's contribution rising in line with assumptions

[91] Woodland Trust, 2018. *Plans unveiled for 50 million tree new Northern Forest*

3.2 Assessing the case for land-use change as a measure to improve resilience to climate change

For this report, the Adaptation Committee commissioned research to investigate the benefits of land-use change in a changing climate, and how land managers can assess the need for land-use change, using four case study locations in England.

- The Adaptation Committee commissioned research from JBA Consulting to examine how taking a long-term approach to considering the risks from climate change, and anticipating land-use changes to manage these risks, could deliver net benefits in terms of the maintenance of natural capital and the services it provides. An 'adaptation pathways' approach was used to develop understanding of how the need for planned transformational change can be understood and analysed.[92]
- Our analysis is further underpinned by evidence from other sources. These include an assessment of latest data and academic literature, stakeholder workshops and expert advice. While the focus of this research is on the natural environment, including extensive agricultural land areas, some of the findings may be relevant for other land use types such as urban areas.

Box 3.4 presents an overview of the case study locations scoped for this research.

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[92] See also CCC (2018) *Managing the coast in a changing climate* for examples of the benefits of using adaptation pathways approaches

Box 3.4. Overview of case studies

The location of the four case study areas used in the research analysis is presented in Figure B3.4.

Figure B3.4. Location of the four case study areas used in research analysis

Source: JBA Consulting (2018) for the CCC

The analysis considered impacts under different climate change scenarios over the period 2018 to 2100. Basic details for each case study location are given below:

- **Case study area 1. Norfolk and Suffolk Broads, East Anglia**

Location: The Norfolk and Suffolk Broads case study boundary is defined according to the Broadlands River Catchment plan[93] land area.

Current land use: Land use mapping of the area shows that at present 86% of the land is used for farming: 71% non-irrigated arable, of which cereals and horticultural crops dominate, and 15% pastoral, comprising of a mixture of dairy and grazing.[94] The remaining 14% is made up of urban area, woodland and coastal habitats.

Climate change context: Flooding resulting from an increase in the frequency and severity of coastal storm events.

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[93] Broadlands River Catchment plan (2014)

[94] Corine Land Cover map (2012)

Box 3.4. Overview of case studies

Climate hazard threshold identified: Combination of sea-level rise, higher intensity rainfall events, and a greater magnitude and frequency of storms (1 in 200 year events), resulting in small scale breaches of sea defences and extended periods of waterlogged agricultural land.

Threshold event point: Assumed to occur at 2050 for all scenarios, with impacts being experienced over a 5-year period following.

- **Case study area 2. The Petteril Catchment, Cumbria, Cumbria**

Location: The River Petteril is a tributary of the River Eden in Cumbria and is located in the North Pennines in the north of England. The Petteril catchment covers an area of 160 km^2 (16,075 ha).

Current land use: 91% of the land in the case study area is used for farming. Of this, 64% is used for pastoral livestock (beef and dairy), 24% for arable (cereals, horticulture and general cropping) and 3% grassland (grazing). The remaining land uses at the location are forestry (4%) and urban (3%), with the city of Carlisle located in the far north of the area.

Climate change context: Warmer and wetter winter seasons

Climate hazard threshold identified: Three seasons in five years of winter/spring waterlogging of fields and/or fluvial flooding causing crops and grassland to be submerged for more than 14 days at a time.

Threshold event point: Assumed to occur at 2030 for all scenarios, with impacts being experienced over a 5-year period following.

- **Case study area 3. Moor House and Upper Teesdale in the North Pennines**

Location: Moor House and Upper Teesdale comprises a 88 km^2 National Nature Reserve (NNR) in the North Pennines, in a remote Pennine dale forming the upper catchment of the River Tees. The whole area is part of the larger North Pennines Area of Outstanding Natural Beauty (AONB).

Current land use: The majority of the land in the case study area is upland peat (70%), farmed for sheep and grouse. This falls into the lower slopes and valley bottom with areas of in-bye grassland, scattered broad-leaved woodland and the river floodplain bordered by riparian woodland. Some key special areas for biodiversity are blocks of sugar limestone scattered across the hills, which support a rare upland calcicolous flora, and give the area its designations.

Climate context: Severe droughts and summer heatwaves

Climate hazard threshold identified: Low winter rainfall followed by spring and summer drought resulting in lower water tables in the peat soil. This is in the context of a gradual increase in summer mean temperatures of 3.5 to 4.0°C and a decrease in summer mean precipitation of 40-50% above the 1961-90 average by the 2080s, which are consistent with the UKCP09 high emission scenario. These gradual changes would cause a deterioration in the condition of the peatland over time, including a complete loss in peat-forming sphagnum by 2100.

Threshold event point: The event (low winter rainfall and summer drought) is assumed to occur in 2030 for all scenarios, with impacts being experienced over a 1-year period following it. Land use pressures would be further exacerbated by a gradual deterioration in suitable climatic conditions over the century.

- **Case study area 4. Somerset, including the levels**

Location: The case study area is approximately 2,500 square kilometres in size covering the catchments of the Parrett, Axe and Brue. Large urban settlements within the case study area include Weston-Super-Mare and Bridgwater to the north, and Taunton and Yeovil in the south.

Box 3.4. Overview of case studies

Current land use: The vast majority of the land in the case study area is allocated to farming: 53% is used for pastoral (sheep and cattle) and 36% supports arable farming (cereals, maize, oilseed rape and field beans). Urban development represents a further 5% of land area. The remaining land at the location comprises woodland (4%, primarily broadleaved), inland wetland (1%) and non-agricultural vegetated areas (1%).[95]

Just over 5% of the case study land area is designated as Sites of Special Scientific Interest (SSSI). The peat soils of the Levels and Moors (covering 20,000ha) are also a significant store of organic carbon.

Climate context: Sea level rise, warmer and wetter winter seasons

Climate hazard threshold identified: Tidal surges in the Bristol channel combined with periods of unusually intense rainfall in the upper catchment. Three seasons in five years of waterlogged fields and floods, causing the crops and grassland to be repeatedly submerged for more than 14 days at a time.

Threshold event point: Assumed to occur at 2050 for all scenarios, with impacts being experienced over a 5-year period following.

Source: JBA Consulting (2018) for the CCC

The analysis examined how taking a long-term approach to considering the risks from climate change, and anticipating land-use changes to manage these risks, could deliver benefits to the land managers in each case, in terms of improving resilience to climate change.[96]

- The research considered three different adaptation (decision-making) scenarios to test the effect of pursuing different long-term strategies: (i) a business as usual (BAU) scenario, assuming no land-use change interventions; (ii) an anticipatory scenario, assuming land-use change happens before a climate hazard threshold event occurs; and (iii) a reactionary scenario, assuming land-use change occurs after the climate hazard threshold event. A climate hazard threshold in this context relates to a given level of a climate hazard that, once reached, will make it cost-prohibitive to maintain the current land use and the ecosystem services it has provided to date (Box 3.4).
- Figure 3.5 presents a schematic of the decision framework developed.
  - Stage 1: Identify the current land use management strategy and quantify what is produced or provided by the land.
  - Stage 2: Determine what level of climate hazard acts as a risk to the current land use.
  - Stage 3: Assess the evidence for the plausibility and timing of these hazards occurring.
  - Stage 4: Estimating the costs and benefits of alternative decision-making scenarios, either taking a 'do nothing' approach (BAU), action taken before the threat is realised (anticipatory) or after it has happened (reactionary).

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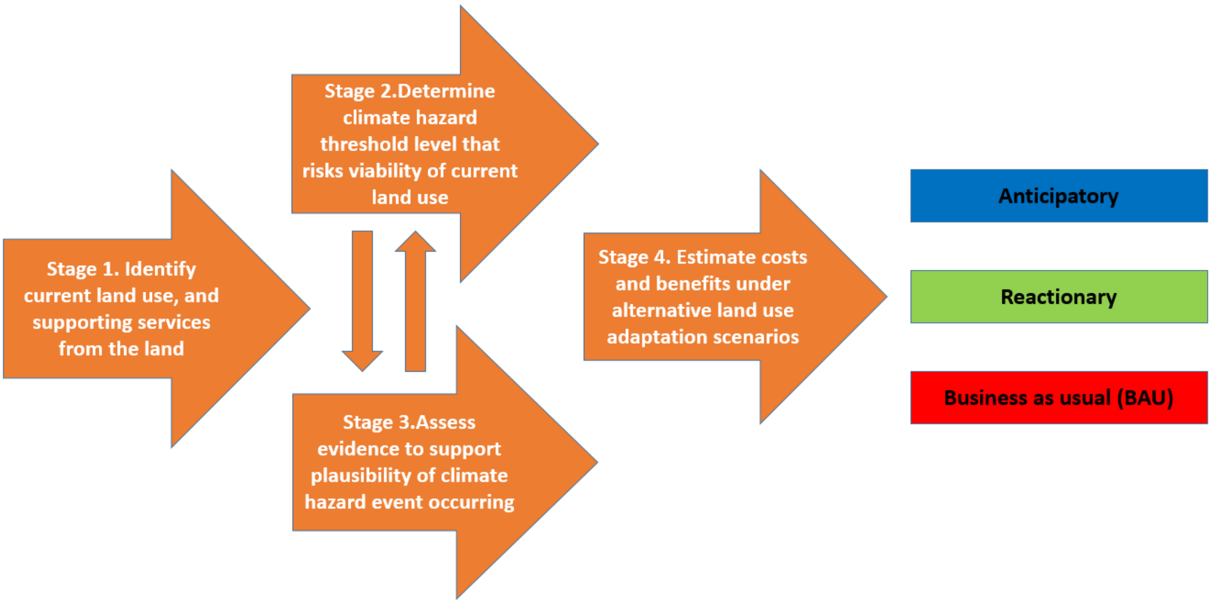
[95] Corine Land Cover dataset, 2012

[96] For all of the case study areas, different types of adaptation decision frameworks were tested, and the results of this analysis are presented in the supporting research to this report (JBA Consulting (2018) for the CCC).

Figure 3.5. Building resilience to climate change - Long term adaptation decision-making framework



Source: JBA Consulting (2018) for the CCC
Note: Stages 2 and 3 and are conducted concurrently and inform each other

The case studies demonstrate that in scenarios where climate change presents a threat to current land use, the use of adaptation pathways that consider land-use change in advance of the climate hazard event occurring deliver higher net benefits compared to waiting until the hazard has occurred.

- The potential gains centre on avoiding escalating costs, maximising benefits, and reducing the risk of irreversible change. Each of these three factors is illustrated in turn below.

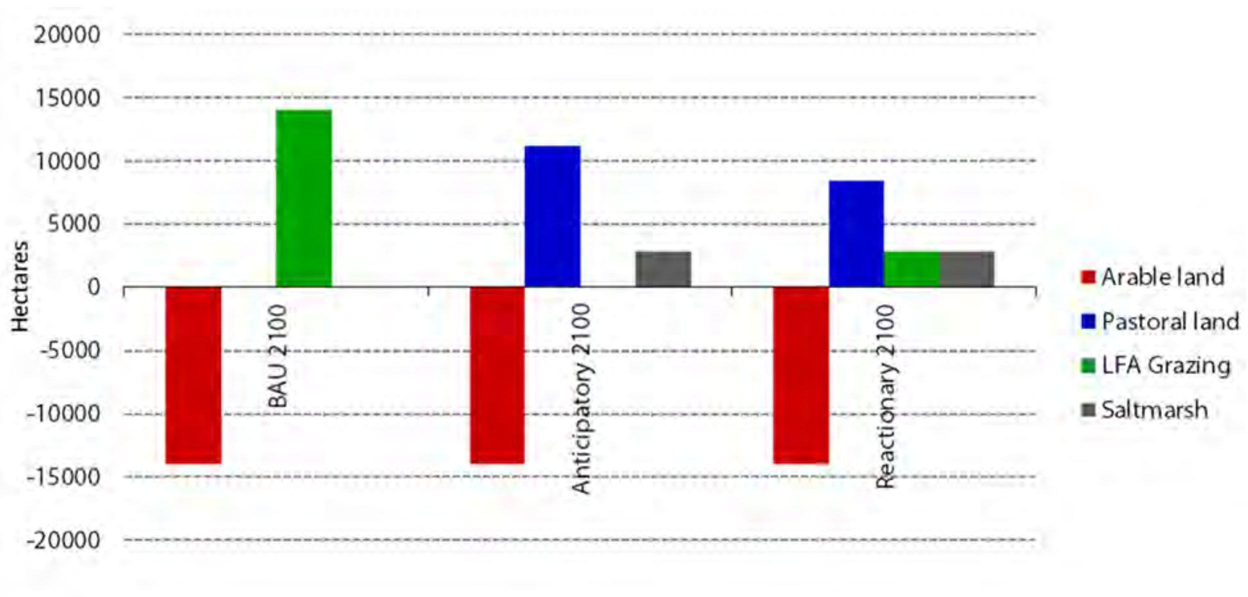
Early adaptation action avoids escalating costs

Acting in advance of a hazard threshold occurring to change land use limits the increase in costs in all of the case studies presented.

Here we illustrate this finding using the Norfolk and Suffolk Broads case study, where the majority of land is used for arable and livestock farming. The climate hazard threshold used related to coastal and inland flooding in 2050 (Box 3.4).

- Figure 3.6 presents the change in proportional land use distribution at the beginning and end of the reference period based on the three adaptation scenarios. The change in land use over the reference period in the anticipatory scenario involves a 5% (14,000ha) reduction in land used for arable production, with 11,200 ha (4%) converted to semi improved grassland, 2,800 ha (1%) converted to new saltmarsh habitat. The 1% (2,800ha) shift from arable land to less favourable area in the reactionary scenario, reflects a decline in the quality of some land resulting from the delayed implementation of adaptation actions.

Figure 3.6. Land-use change (ha) under the three adaptation scenarios for the Norfolk and Suffolk Broads case study



Source: JBA Consulting (2018) for the CCC

- Implementing anticipatory land-use change measures were shown in this case study to help avoid the higher costs associated with the BAU and reactionary approaches in response to the flood hazard threshold.[97] Conversely, postponing interventions until after the threshold occurred increased the level of restoration required to maintain natural assets over the long-term.
- In all scenarios, there is a short-term jump in costs in response to the climate hazard event in 2050 (Figure 3.7). Costs due to the impact from the flooding threshold on agricultural production include:
  - Waterlogged soils exceeding agricultural field capacities
  - Saline incursions into freshwater and farmland habitats
  - Increased soil runoff and erosion
  - Nutrient loading of water and sediments discharging into water systems
  - One-off cost of livestock feed resulting from temporary loss of grazing land
- These costs are lowest in the anticipatory scenario due to a switch to more flood-resilient land uses before the flood hazard threshold occurs (arable switching to pastoral and saltmarsh). Under the BAU scenario, in which only low-regret options are used for land management (mainly arable production), without any transformational adaptation actions in response to changing climatic conditions, the ongoing costs to sustain current land use

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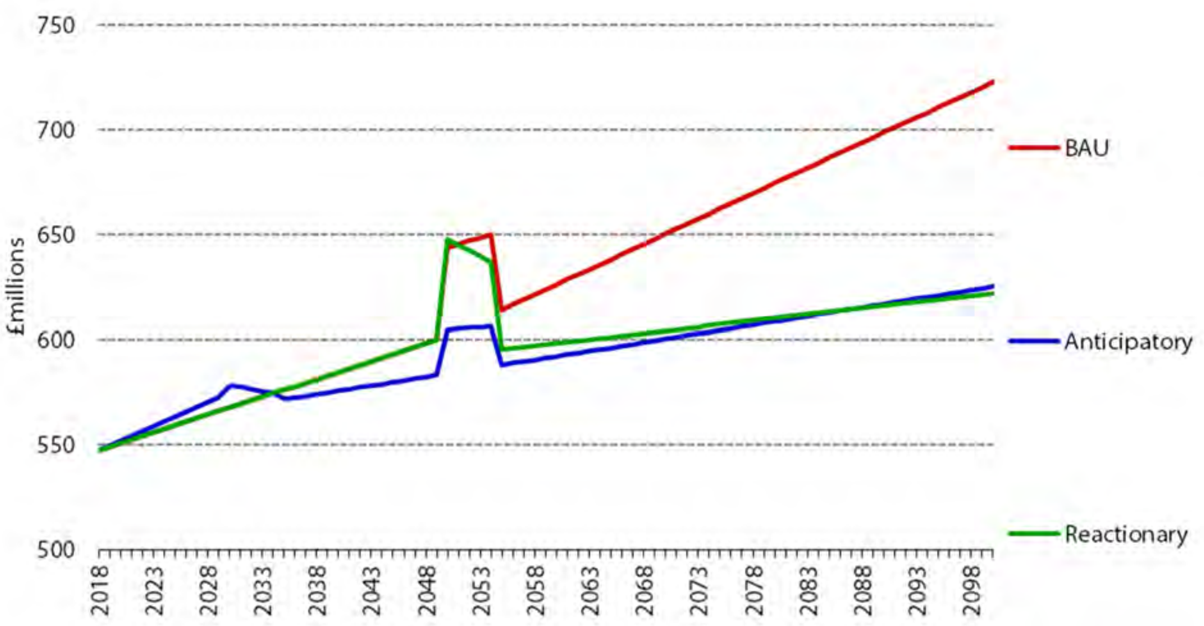
[97] Implemented at 2030 (pre-event) under the anticipatory scenario and 2055 (post-event) under the reactionary scenario

activities (mainly arable production) using only low-regret options increased at the highest rate. This is driven by higher and escalating maintenance costs, including:

- A sharp increase in expenditure owing to the recovery costs associated with flooding
- Additional application of fertiliser to address declining soil quality and support crop production
- Additional cost of livestock feed resulting from lower productivity of grazing land
- Works to improve land drainage systems
- Infrastructure to pump water off the waterlogged land.

Figure 3.7. Norfolk and Suffolk broads case study: Long-term pattern of costs (£m) under different adaptation scenarios



Source: JBA Consulting (2018) for the CCC
Notes: The jump in costs seen in 2050 relates to the recovery costs after the flooding event, plus an increase in short-term maintenance costs and expenditure to maintain production. Due to some degree of switching to more resilient land uses (arable to pastoral and saltmarsh), the costs during this period are lower under the anticipatory scenario than for the reactionary or BAU scenarios, but some impacts still occur due to negative impacts on the remaining arable land in particular. See the supporting research for more details. Values are quoted in nominal terms.

- The cost associated with the climate hazard event in the BAU scenario are estimated to be £63 million[98] over the five-year period of the threshold event, which equates to approximately 6% of total costs over the same period.

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[98] In present value terms. Costs over the period are discounted according to HM Treasury Green Book guidance

Land use adaptation actions to improve resilience for this case study in the anticipatory and reactionary scenarios involve a shift to a catchment sensitive farming approach and a reconnection of watercourses with the flood plain.

- Actions considered under this approach included:
  - Facilitated landward expansion of grazing marsh and pasture from arable land area
  - Managed extension of intertidal areas, increasing mudflat and saltmarsh areas
  - Overtopping of flood banks and an associated responsive drainage systems to minimise short-term impacts.
- Implementing anticipatory adaptation measures results in an increase in costs over the short-term. However, when compared to the BAU scenario, taking effective land-use change actions early, as demonstrated in the anticipatory scenario, reduces total costs by £490 million over the 80 year reference period, and reduces the risk of escalating costs over the long-term. Results under the reactionary scenario suggest that while total costs are lower relative to BAU under this approach (reduced by £380 million), it is not as efficient as the anticipatory approach over the long term.

Early action maximises benefits

Anticipatory adaptive decisions can lead to greater benefits (as well as more sustainable land uses) over time. Delaying adaptive actions in the case studies reduced the land's ability to accommodate change and hence reduces sustainability.

- The analysis conducted for this report suggests that for all four case studies, the benefits achieved in the anticipatory scenario are higher than in the BAU and reactionary scenarios over the reference period. Here we exemplify this using the Petteril case study. The hazard considered here is winter/spring waterlogging of fields and/or fluvial flooding of agricultural land (Box 3.4).
- The land-use changes in response to the flooding hazard explored for this case study comprised:
  - 20% reduction to arable land (780 ha) and a 7% reduction in pastoral land (680 ha),
  - an expansion in semi-natural grassland (530 ha), wet woodlands (390 ha) and land used for agro-forestry (540 ha).
- Under the anticipatory scenario for the case study, the initial transition between land uses results in a relatively sharp decline in benefits over the short-term. This is primarily due to the decline in incomes from agricultural production as a result of the reduction in the area of arable land.
- However, anticipatory adaptation measures deliver higher total benefits in the long-term due to the increased level of resilience to climate change achieved through the adaptation actions implemented (Figure 3.8). When totalled over the 2018 to 2100 reference period, the present value[99] of benefit gains over and above the BAU scenario are £41 million in the anticipatory scenario as opposed to £17 million in the reactionary scenario.

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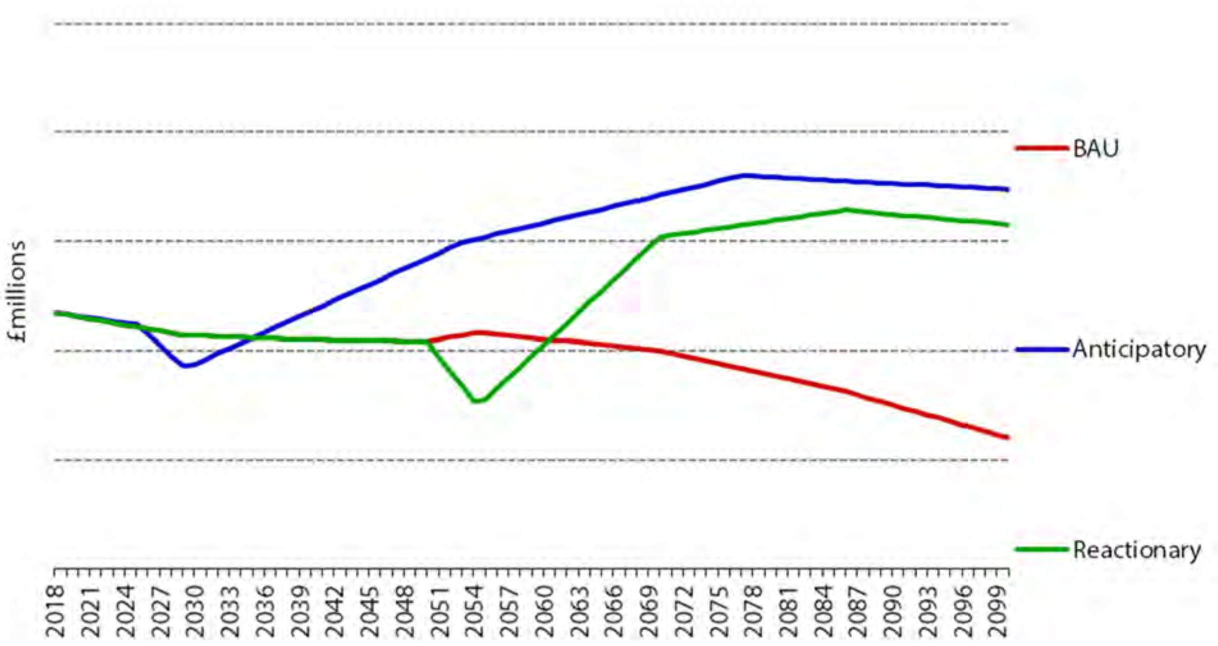
[99] Net present values for the flow of benefits over the period are discounted according to HM Treasury Green Book guidance

- The switch to agro-forestry and wet woodlands contributes to the increase in benefits in both the anticipatory and reactionary scenarios, through:
  - Carbon sequestration - increased carbon removal potential through conversion of arable land to agro-forestry, and pastoral land to a combination of wet woodland and semi-natural grassland.
  - Timber - increase in production supported by expansion in woodland areas.

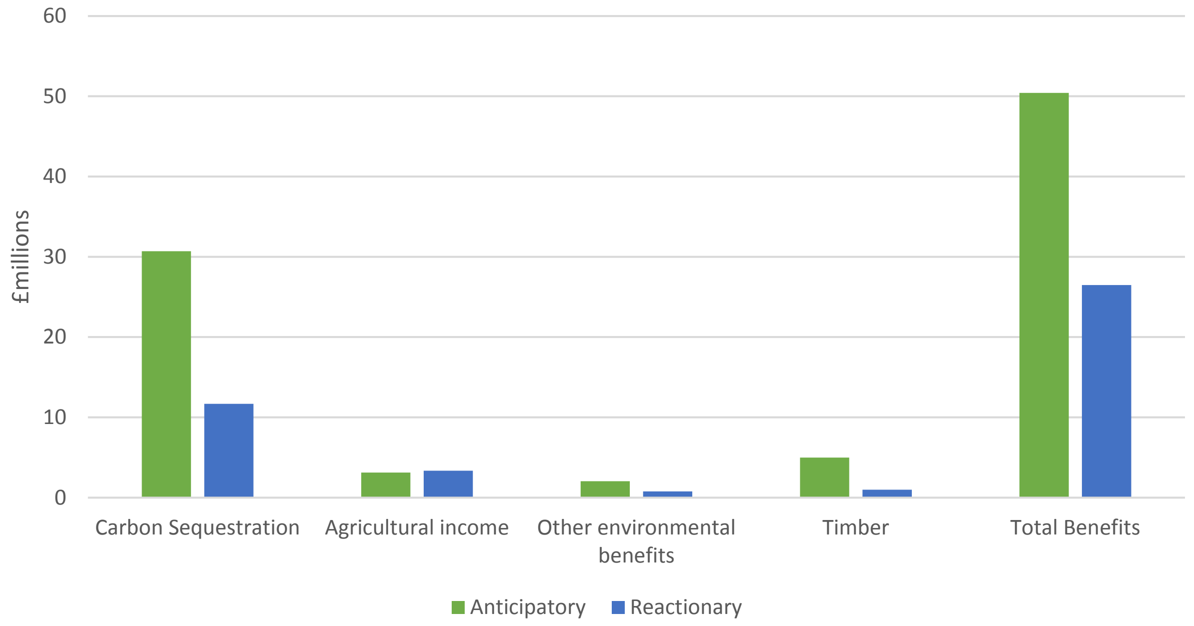
Figure 3.8. Petteril catchment case study: Long term pattern of benefits (£m) under different adaptation scenarios



Source: JBA Consulting (2018) for the CCC
Notes: Assumptions on incomes from agricultural production activities exclude government subsidies. Benefits identified include: timber production; carbon sequestration services; recreation; and other environmental benefits (see JBA (2018) for the CCC for a full breakdown). Values are quoted in nominal terms.

- Figure 3.9 presents a breakdown of the additional benefits in the anticipatory and reactionary scenarios, by type.

Figure 3.9. Early invention versus reactionary intervention: Difference in benefits (£m) above and over BAU for the Petteril study, 2018 to 2100



Source: JBA Consulting (2018) for the CCC

Notes: Estimates for 'Other environmental benefits' include values for water quality improvements, biodiversity and aesthetic amenity. They are determined using guidance set out in eftec (2010)[100] and eftec (2016)[101]

Early action reduces the risk of irreversible changes

Unless addressed in advance, some of the downside risks of climate change could be effectively irreversible and endanger the supply of essential ecosystem services from the natural environment.

- Climate change will place significant pressure on some of the UK's key natural assets, with upland peatland habitats in some areas of the country particularly at risk from a warmer, drier climate in the future.[102] The risks of irreversible change are higher for those natural assets in less favourable condition by the time those climate changes occur.[103] We exemplify this using the Moor House and Upper Teesdale case study. The climate hazard threshold considered in this case study was low winter rainfall followed by spring and summer drought, in the context of warmer, drier conditions in general (Box 3.4).
- The results from the Moor House and Upper Teesdale case study indicate that a complete cessation of damaging activities on peatland habitat at the location (starting from now and completing by 2030), together with adaptive interventions to restore damaged peat assets, could prevent a loss of the peatland area in the long-term.

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[100] eftec (2010) *Cost effectiveness of woodlands for CO_2 abatement*

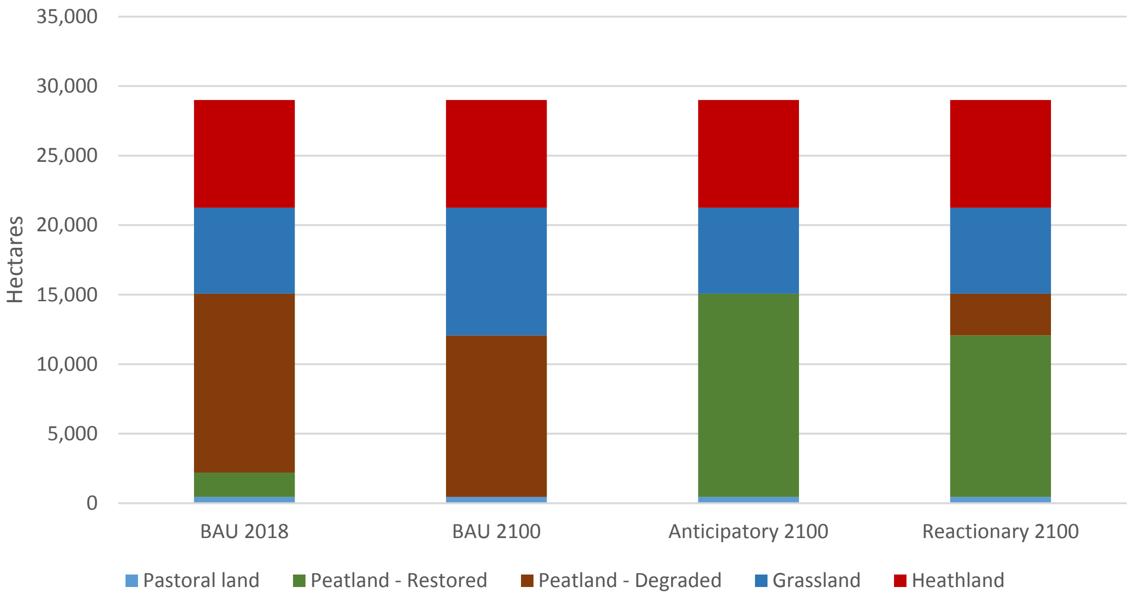
[101] eftec (2016) *Assessing the wider benefits of the Woodland Carbon Code*

[102] Brown, I (2016) *UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets.* Report prepared for the Committee on Climate Change, London

[103] Lawton, J.H. et al (2010) *Making space for Nature: a review of England's wildlife sites and ecological networks*

- Under the BAU scenario, which assumes no land use adaptation action, the projected warmer and drier climate results in colonisation of the peatland habitat by non-peat forming species (such as grasses) causing a loss in area covered by the peat-forming species (mainly Sphagnum) to grassland habitat (Figure 3.10). However, peatland restoration actions conducted in the anticipatory scenario facilitate the recovery of some areas of previously degraded peatland, to peatland in favourable condition. The improved condition then allows the Sphagnum to be maintained through natural succession to more resilient varieties as the climate changes.

Figure 3.10. Change in land use (ha) in the adaptation scenarios for the Moor House and Upper Teesdale case study

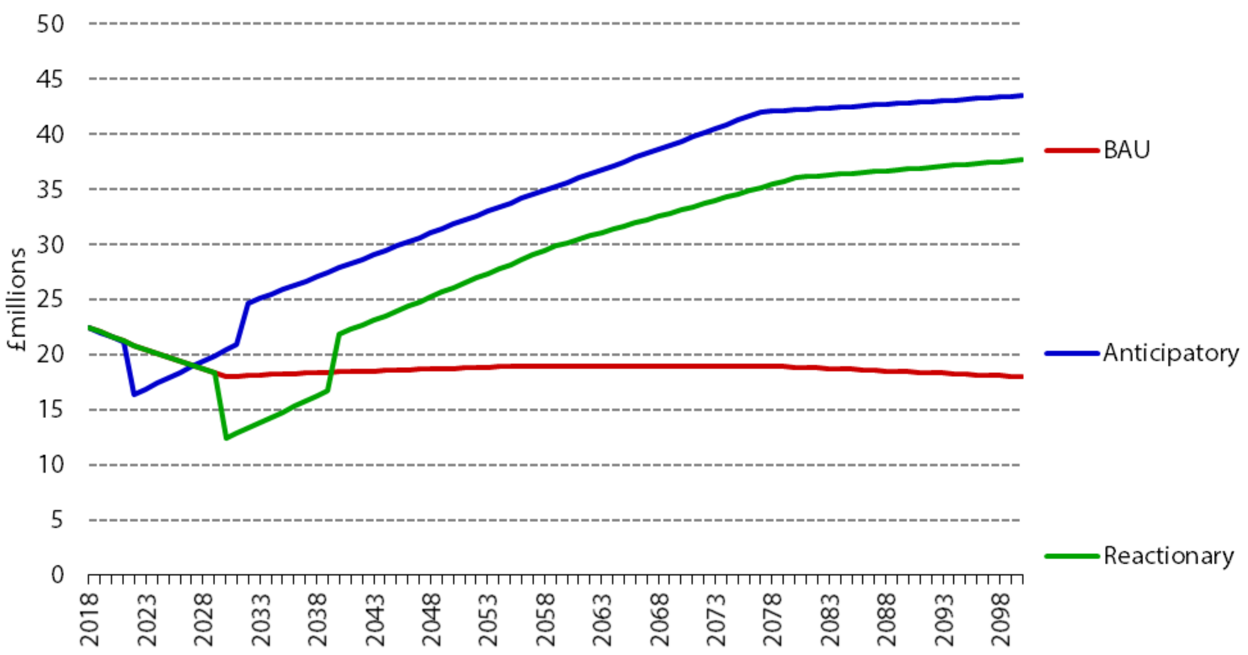


Source: JBA Consulting (2018) for the CCC

The longer that unsustainable land use activities are continued, the higher the potential level of degradation to the natural assets that support it.

- Figure 3.11 presents annual net benefits (benefits - costs) under the three scenarios for the Moorhouse and Upper Teesdale case study over the 2018 to 2100 reference period. The steep initial decline in net benefits under the anticipatory scenario reflects the higher initial costs related to restoration activities. However, over the long run, the higher level of net benefits (relative to the BAU and reactionary scenarios) demonstrates the land's improved resilience to climate change, facilitating an increased capacity to deliver ecosystems goods and services. Postponing interventions until after a climate change threshold event has occurred potentially increases the level of restoration required to natural assets and, in turn, negatively impacts net benefits received over the long-term.
- When compared to the BAU scenario, the total net present value of carbon sequestration services provided by the land at the case study location is £167 million higher in the anticipatory scenario, and £131 million higher in the reactionary scenario.

Figure 3.11. Moor House and Upper Teesdale case study: Long-term net benefits (£m) under different land use adaptation scenarios



Source: JBA Consulting for the CCC
Notes: Values quoted in nominal terms

In all scenarios assessed in this analysis, adaptation pathways that consider land-use change in advance of the event occurring have greater net benefits compared to waiting until the hazard has occurred.

- Analysis of findings from across the four case study locations assessed indicate anticipatory adaptation action can improve total net benefits by between £2,500 per ha and £8,400 per ha (Table 3.2).

Table 3.2. Total net benefits gain above and over BAU scenario

	Norfolk and Suffolk Broads		**Petteril Catchment**		**Moor House and Upper Teesdale**		**Somerset and the Levels**	
	Total Net benefit gain (£m)	Total Net benefit gain (per ha)	Total Net benefit gain (£m)	Total Net benefit gain (per ha)	Total Net benefit gain (£m)	Total Net benefit gain (per ha)	Total Net benefit gain (£m)	Total Net benefit gain (per ha)
Anticipatory adaptation scenario	930	2,500	70	4,580	240	8,400	650	2,600

Table 3.2. Total net benefits gain above and over BAU scenario

	Norfolk and Suffolk Broads		**Petteril Catchment**		**Moor House and Upper Teesdale**		**Somerset and the Levels**	
Reactionary adaptation scenario	650	1,750	30	2,000	120	4,080	210	860

Source: JBA Consulting for the CCC
Notes: Net present values are estimated according to HM Treasury Green Book guidance

Land managers need to take an anticipatory approach to land use adaptation if they are to best meet the challenges of climate change.

- Our analysis has highlighted that in cases where some land uses are projected to become increasingly unviable into the future because of climate change, land-use change to build resilience before threshold events occur provides greater net benefits than relying on low-regret measures to try to maintain the current land use activity. However, to build awareness of the potential risks from climate change to current land uses, land managers require relevant information about future impacts. The government needs to own and supply the required information, and there needs to be a clear mechanism for land owners to use it.
- Making land use interventions in advance of a specific climate-related risk occurring, will enhance the ability of land to accommodate the impact of climate change, and confer net economic benefits to society. The systematic approach to decision-making on land-use change demonstrated in the supporting research to this report[104] allows for land-use change to be implemented in a robust and evidence-based way.

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[104] JBA (2018) for the CCC

Chapter 4: Transitioning to alternative land uses

Key messages

- **The government's goals for climate change mitigation and adaptation are unlikely to be met without fundamental changes to the way land is used and managed.** The analysis in this report has shown that the government needs to consider land-use change as a core part of policies to deliver climate change mitigation and adaptation. There are three cross-cutting principles that will help to drive this change; the need to focus on measures that have co-benefits across multiple government objectives; the need for early action; and the need for an integrated, strategic framework to support change.
- **Transforming land use to deliver climate objectives can also deliver wider environmental benefits, though some potential trade-offs need to be managed.** As well as increasing carbon sequestration and reducing carbon losses, new tree and hedgerow planting, catchment-sensitive farming and peatland restoration have important benefits for building climate resilience and wider environmental goals set out in the government's 25-year Environment Plan. Biomass production for energy or products (e.g. in the construction sector) has the potential to offer meaningful emissions reduction but wider environmental risks need to be carefully managed. Releasing agricultural land for non-food uses whilst increasing food production is possible if new technologies and farming methods are applied to land to raise agricultural productivity.
- **There are three key barriers to transitioning to different patterns of land use and management**. These are inertia in moving away from the status quo; mismatched financial incentives and other non-financial barriers, and a lack of information and support for land managers and consumers. New environmental land management policy should support a move towards alternative land uses and reward land-owners for public goods that deliver climate mitigation and adaptation objectives where wider environmental benefits are also achieved. Information and support are needed to help land managers to anticipate and respond to changing climatic conditions.

4.1 Synergies and managing potential trade-offs between climate change mitigation, adaptation and wider sustainability

The analysis of mitigation and adaptation scenarios in this report have highlighted three particular areas of synergy.

These are:

- Some land-use change can confer net benefits across climate change mitigation, adaptation and wider environmental goals.
- Successful mitigation and adaptation requires early, anticipatory action to maximise the net benefits.
- An integrated, strategic approach is needed now to enable the transformational changes required.

Each of these areas is expanded on below, drawing on the analysis presented in chapters 2 and 3 of this report.

Benefits and trade-offs of different land use measures

Some of the measures analysed in this report have clear, multiple benefits across climate change mitigation, adaptation and the government's wider environmental goals.

- The measures assessed in this report need to be considered as part of a suite of options that are required to meet the broader environmental goals that the government has outlined in its 25-year Environment Plan.[105] The desire to mitigate and adapt to climate change cannot be separated easily from meeting these wider objectives, as illustrated in Table 4.1. Particular measures with clear, multiple co-benefits include:
  - **Restoration of peatlands.** Restoration of some upland, lowland and afforested peat soils could reduce net GHG emissions by 24 - 42% (saving 4 -11 $MtCO_2e$) by 2050. Restoration including peat that is predominantly used for grouse shooting is also needed to enable peat-forming sphagnum species to be in good condition for peat ecosystem function. This restoration is essential in order to allow upland peat habitats to withstand an inevitable shift to hotter, drier conditions over the rest of this century. Restoration of damaged upland peat in the Moor House and Upper Teesdale adaptation scenario was shown to increase net present values by £240million over the next 80 years.
  - **Increased woodland and hedgerow planting.** New carefully planned tree planting (with the right trees in the right places), including on-farm, and hedgerow planting increases carbon sequestration to between 15 - 28 $MtCO_2e$ in the UK mitigation scenarios. In the Somerset adaptation case study, a 10% increase in woodland and hedgerows contributes to an increase in net present value of £650million over the next 80 years.
  - **Catchment sensitive farming. Practices that optimise the efficient** use of nitrogen on both cropland and grassland can reduce N_2O emissions on agricultural soils. If farms are located near water courses, these measures can also help reduce diffuse water pollution with consequent benefits on water quality and aquatic biodiversity, improving habitat condition and thus the level of resilience to climate change.

Table 4.1. The synergies provided by the measures outlined in this report for climate change mitigation, adaptation and wider environment goals outlined in the government's 25 Year Environment Plan

Measure	Mitigation benefits?	Adaptation benefits?	Contributes to 25YEP goals?
Peatland restoration	✓	✓	✓
Afforestation	✓	✓	✓
Increased hedgerows and other boundary features	✓	✓	✓

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[105] HM Government (2018) *A Green future: our 25 year plan to improve the environment*

Table 4.1. The synergies provided by the measures outlined in this report for climate change mitigation, adaptation and wider environment goals outlined in the government's 25 Year Environment Plan

Measure	Mitigation benefits?	Adaptation benefits?	Contributes to 25YEP goals?
Catchment sensitive farming	✓	✓	✓
Coastal managed realignment		✓	✓
Increased biomass production	✓		

Notes: Ticks are given where we consider that measure to form a *key part* of meeting the goals set out in the column headings. Managed realignment of coastal areas, for example, is not considered a key measure for climate change mitigation, though new habitat formation under realignment could lead to increased carbon sequestration under certain circumstances.

Maintaining current food production per capita (a net increase with population growth) is achievable alongside freeing up agricultural land for non-food uses.

- All of the potential mitigation pathways assessed in this report can be achieved by releasing between 25 - 30% of agricultural land to other uses that benefit climate change mitigation and adaptation. At the same time, the analysis suggests that net agricultural output[106] could still increase, through productivity improvements (e.g. crop breeding, and adopting best practice in agronomy). In the adaptation scenarios, conversion of arable land to different crops, agro-forestry and woodland changes net present values from -£20million to +£70million over the next 80 years, in the case of the Petteril.
- Increased use of biomass for bioenergy has the potential to be an important component of long-term greenhouse gas emissions reduction targets, but wider sustainability considerations must be managed successfully.
- The production of biomass feedstocks can have some negative impacts on environmental sustainability issues if risks are not managed as part of a wider biomass strategy. Some of the examples considered in the accompanying report on Biomass[107] include potential negative impacts on biodiversity, soil health, water quality and impacts on invasive species. However the report also notes that biomass production can deliver a number of co-benefits. For example, the planting of a perennial energy crop such as miscanthus, and woody biomass such as short rotation coppice and short rotation forestry can lead to increased biodiversity if planted on arable land. The Committee's Biomass report looks at these sustainability issues in detail, considers factors that are likely to lead to best practice, and recommends stronger governance to ensure the co-benefits are maximised and trade-offs minimised in future UK biomass production.

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[106] Assuming constant real prices

[107] CCC (2018) *Biomass in a low-carbon economy*

The need for early action

Early, anticipatory action to change land use and land management will greatly increase the benefits accrued from both a climate change mitigation and adaptation perspective.

- Chapter 2 shows that for some measures, the time period (often decadal) to reduce and sequester emissions through afforestation and peatland restoration mean that early action is required. For example, while peatland restoration will reduce emissions losses in the first instance, a longer period of time (that extends beyond 2050 in our analysis) is required before it turns from a net source into a net sink. For those measures that are contingent on the use of innovation and technology to increase yields for example, consideration has to be given to the time it may take between R&D and commercial deployment to ensure the benefits can contribute in a timely manner.
- Chapter 3 has analysed the difference in costs and benefits from taking action to change land use before a climate threshold is reached, compared to after. Anticipatory action was shown to improve total net present value by between £2,500 and £8,400 per hectare across the four case studies analysed. In addition to reducing economic benefits, reactive action has the potential to lead to irreversible damage. For example, in the case of Moor House and Upper Teesdale, delaying peatland restoration until after warming and drying has occurred post-2050 will mean it is too late for the sphagnum species to adapt to the changes, and the peatland will be lost. This was highlighted as a key risk to soil health in the UK Climate Change Risk Assessment (2017).

The need for an integrated, strategic approach

The way land is used and managed will need to change fundamentally over the rest of this century, in order to meet long-term climate change mitigation and adaptation goals.

- The analysis for this report suggests that significant changes to land use are needed now and over the next 80 years to move the sector towards achieving net zero greenhouse gas emissions, while protecting natural capital that the land currently represents and which will otherwise degrade as the climate changes. Such changes will not be possible using piecemeal or short-term policy at the national level. At the national scale, the mitigation scenarios in particular require substantial changes in land use by 2050:
  - A reduction of grasslands[108] of just over a third (equivalent to 4.5 million hectares), which includes some lowland and upland peatland.
  - An increase in the area of new woodland of up to 1.5 million hectares (which increases UK woodland area from 13% to around 19%) under the high ambition scenario, and up to 0.9 million hectares for agro-forestry and hedgerows.
  - A significant increase in the land used for bioenergy crops (including short rotation forestry) of up to 1.2 million hectares compared to the current 10,000 hectares (England only) for miscanthus and short-rotation coppice.

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[108] Includes permanent and temporary grassland and rough grazing

At the local scale, changes in land use are also assessed as being beneficial from an adaptation perspective to retain ecosystem services under certain conditions:

- Restoration of 100% (13,000ha) of upland peatlands to their natural blanket bog state, through grip blocking, revegetation, fire prevention, and ceasing the practices of managed cutting for grouse shooting (Moor House and Upper Teesdale).
- Conversion of 5% (14,000ha) of arable land to semi-improved grassland and saltmarsh (Norfolk and Suffolk Broads).
- Diversification of 20% (780ha) of arable farmland into different crops (sunflowers, grain maize, soya, fruits and vines) and agroforestry, and a further 7% (680ha) conversion of pastoral land into wet woodland and semi-natural grassland (Petteril).
- 20% (26,400ha) reduction in pastoral grassland, converted to lower intensity grassland and peatland. A further 10% (1,000ha) increase in woodland, converted from arable land (Somerset Levels).

4.2 Identifying and removing barriers to transformational land use

Changes on this scale will require a coordinated, national approach. There are several key barriers that will prevent the scale of action that is required to meet long-term climate change mitigation and adaptation goals:

- **Missing and incomplete markets for public goods.** At present, the private and social costs and benefits related to land use can differ widely, leading to sub-optimal land management strategies from a social perspective. For example, there has been a large-scale effort through government programmes to increase the value land owners place on preserving the carbon locked up in peat soils, in order to incentivise peatland restoration over and above activities such as maintaining heather cover and burning to support grouse shooting. Between 2007 and 2013, £27 million was paid out to land owners who had taken up moorland restoration under the Higher Level Stewardship scheme. Water companies invested £45 million between 2005 and 2015 in programmes to work with landowners to improve peatland condition as a way of improving water quality.[109] However, so far these restoration efforts remain insufficient to incentivise the degree of restoration that is needed in the face of climate change. The condition of upland peat SSSIs in England is continuing to decline, from 19% in favourable condition in 2003 to 10% in 2016.[110]
- **Information failure.** Analysis undertaken for the adaptation scenarios found that local experts were much more conservative in assessing the scale of change to land use that might be needed in response to climate change impacts compared to national experts, when looking at changes in climate suggested by the current UK climate projections, UKCP09. The general belief amongst local experts was that land management would evolve autonomously in response to the changes in local climate (for example through growing different crops, building contingencies to increase water storage on farms) removing the need for more radical land-use change. This view was not shared by national experts who viewed the risks from climate change as being potentially much more severe. It was clear from these interactions that the range of potential impacts on land under likely climate scenarios set out in the UK Climate Change Risk Assessment was not generally appreciated at

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[109] CCC (2013) *Managing the land in a changing climate*

[110] CCC (2017) *Progress in preparing for climate change: 2017 Report to Parliament*

the local level.[111] To date these sorts of sources of evidence have not been directed towards individuals, and there is a gap in information provision and awareness raising, which the Adaptation Committee has made previous recommendations on.[112]

- **Financial and non-financial barriers to converting agricultural land to alternative uses.**
  - **Financial.** These include a range of barriers such as the loss of an annual income that is derived from the sale of agricultural products. This may occur if switching to other uses where income is delayed for a few years (e.g. two to three years before the first harvest of energy crops, but much longer if planting trees). In recent years it may also reflect the loss of the CAP Basic Payment, which is only payable for land that is deemed to be in agricultural (i.e. food) production. The latter has, in England at least, been one of the main factors in deterring farmers from integrating more trees onto their land. The move towards post-CAP public payment for public goods could go a long way to removing this barrier. Many of these measures may also have higher establishment costs, which can be seen as a risk. An example is the planting of energy crops, in particular the cost of the rhizome, which is the planting medium for miscanthus.[113]
  - **Non-financial.** Using agricultural land for alternative uses requires land owners and managers to have the knowledge and training on what and how to plant and undertake on-going management. There may be less scope to change land use if farmers are tenants, due to clauses in the contract that may prohibit such a change. Where farmers could make the change, there is likely to be a general reluctance on their part to undertake a large investment if the benefits are unlikely to be realised within the period of their tenancy. Around 30-40% of farms are estimated to be tenanted, and the average tenancy is only 3.7 years.[114] On lowland peat, seasonal management of the water table may be constrained by the need to keep the land permanently drained for continued flood management, while better understanding of the hydrology of the surrounding area is required to ensure that practices undertaken by one farmer do not impact a neighbouring farmer.
- **Innovation:** Further investment in innovation and technology will be crucial for delivering a range of options that can:
  - Increase agricultural productivity sustainably, which is crucial to allow for the release of land out of agricultural use. This includes the use of breeding to boost crops yields beyond what is possible through the adoption of best practice in agronomy, while also developing crop varieties that are better able to withstand the impacts of a changing climate.
  - Reduce on-farm non-CO_2 emissions through the development of low-carbon fertilisers, and the use genetic selection of livestock for inherently low enteric emissions.
  - Reduce production costs to deliver at scale a range of novel protein sources that are produced without the requirement for land (e.g. synthetic meat and dairy products).

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[111] JBA (2018) for the CCC: *Exploring the economics of land-use change for increasing the resilience to climate change in England*

[112] CCC (2017) *Progress in preparing for climate change: 2017 report to Parliament*

[113] *CEH and CCC (2018) Workshop on Steps to scaling up UK sustainable bioenergy supply*

[114] ADAS (2017) for the CCC. *Research to provide updated indicators of climate change risk and adaptation action in England.* A report commissioned by the Adaptation Committee

- **Behavioural change:** A move to healthier diets consistent with official guidelines would represent a significant shift from the average UK diet, and imply a level of interest going well beyond current trends in more plant-based diets. Reducing food waste would require concerted effort across the supply chain, in particular amongst consumers who account for most of the waste deemed to be edible.

Potential areas for improvement in addressing climate objectives include the better use of policy levers such as the successor to the EU Common Agricultural Policy (CAP).

- The government's post-CAP reform policy plans could significantly contribute to delivering against many of the changes needed to support climate change mitigation and adaptation goals, as well as other key outcomes set out in the 25-Year Environment Plan.
- Replacing the CAP with a system of support that more effectively balances the need to produce food and meet climate change objectives, with the need to maintain and enhance natural capital for the benefit of future generations will be a challenge to policymakers. Improved outcomes from land use policy could include greater storage of carbon in soils and forests, greater extent, condition and connectivity of habitats, and more effective flood risk management at the catchment scale. The Agriculture Bill should explicitly state these measures as being beneficial for both climate change mitigation and adaptation.
- Decision makers face the challenge of reconciling conflicting public attitudes on issues such as diet change; and also reconciling differences between the preferences of individuals and communities with societal needs. Post-CAP land use policy may need to take advantage of a broad range of mechanisms for managing and influencing land use, such as incentives, the market, regulation, and formal decision-making processes.[115] Such a transition needs a coordinated approach across national and local government, and the private sector.

EU-exit presents a mix of increased uncertainty and a potential unique opportunity for land-use change.

- The decision to leave the European Union creates significant uncertainty, but there is the potential to design more effective domestic land use and agriculture policies that contribute to both emissions reduction and climate change adaptation. The transposition of EU environmental law into domestic legislation will need to at least sustain current levels of protection and enforcement.
- New environmental land management policies should ensure that measures that provide clear, multiple co-benefits for adaptation, mitigation and wider environmental goals are supported first and foremost: afforestation and forestry management; restoration of peatlands; low-carbon farming practices; improving soil and water quality; improving hazard regulation and improving the condition of semi-natural habitats.

Building on this report and the Biomass report, we will consider the barriers in more detail and how these could be addressed via policy in our agriculture and land use report next year.

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[115] Government Office for Science (2010) *Land use futures; making the most of land in the 21st century*

4.3 Recommendations for action

1. New land use policy should promote transformational land uses and reward land-owners for public goods that deliver climate mitigation and adaptation objectives. New policies should also reflect better the value of the goods and services that land provides. The key measures that have clear, multiple benefits are: afforestation and forestry management; restoration of peatlands; low-carbon farming practices; improving soil and water quality; reducing flood risks and improving the condition of semi-natural habitats. These measures should be rewarded if they go beyond a minimum standard that land-owners should already be delivering.

2. Support should be provided to help land managers transition to alternative land uses. This includes help with skills, training and information to implement new uses of land, and support with high up-front costs and long-term pay-backs of investing in alternative uses. It should also include action to address barriers to the take-up of innovative farming practices, which will drive productivity improvements. A structured approach to incorporating the potential impacts from a changing climate into long-term planning is essential for land managers to adapt successfully to climate change. The government should provide support and information through the National Adaptation Programme or the new Environmental Land Management System, to allow this planning to take place.

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