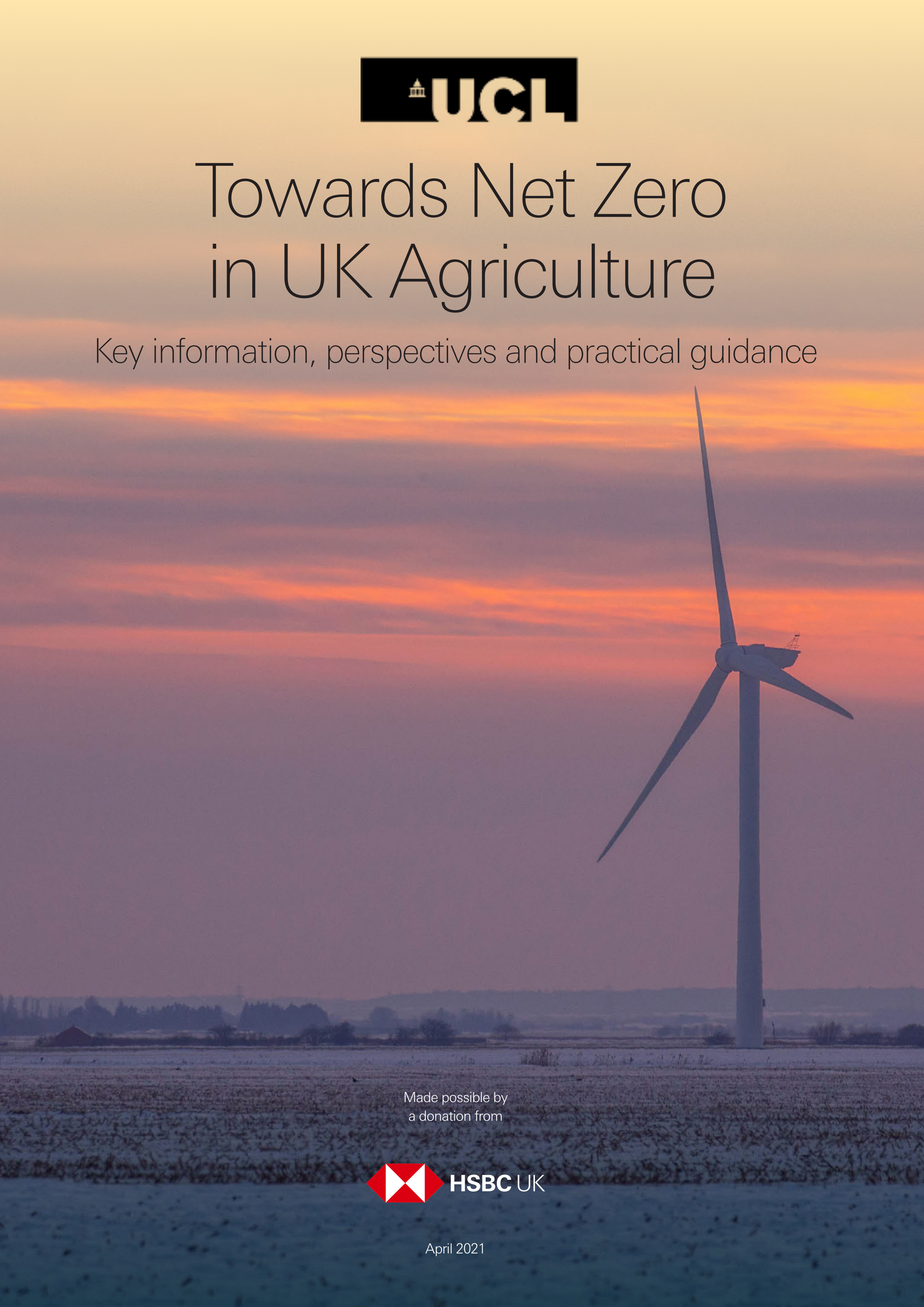

Towards Net Zero in UK Agriculture

Key information, perspectives and practical guidance

Made possible by
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Authors and acknowledgements

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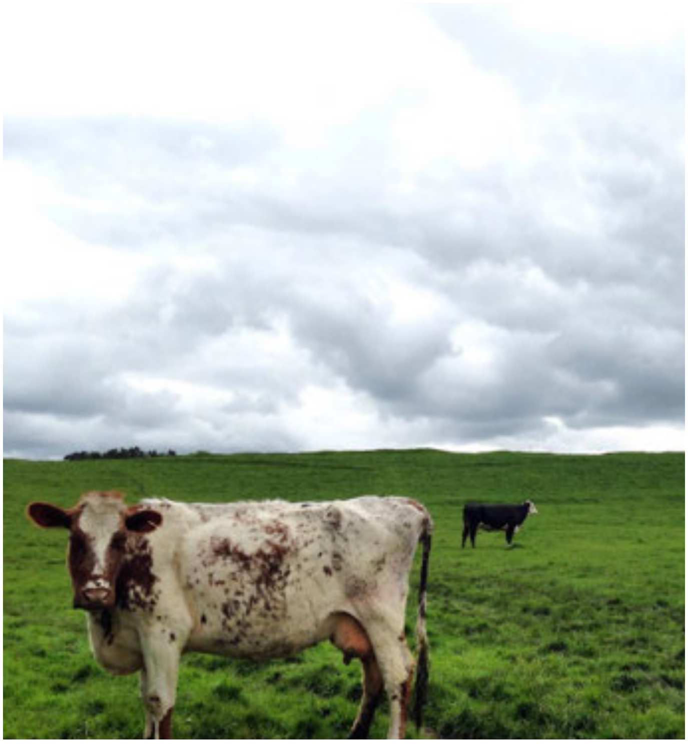

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Abbreviations

AFOLU	Agriculture, Forestry and Other Land Use
AHDB	Agriculture and Horticulture Development Board
BECCS	Bioenergy with carbon capture and storage
BEIS	Department for Business, Energy and Industrial Strategy
BPS	Basic Payments Scheme
CAP	Common Agricultural Policy
CCC	Climate Change Commission
CH_4	Methane
CO_2	Carbon dioxide
CO_2e or -eq	Carbon dioxide equivalent
COP26	26th Conference of the Parties of the United Nations Framework Convention on Climate Change
Defra	Department for Environment, Food and Rural Affairs
ELM	Environmental Land Management scheme
GHG	Greenhouse gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land use, land-use change and forestry MACC Marginal abatement cost curve
Mt	Megatons (1 million metric tons)
$MtCO_2e$	Million tonnes carbon dioxide equivalents
N	Nitrogen
NFU	National Farmers Union
N_2O	Nitrous oxide
UNFCCC	United Nations Framework Convention on Climate Change

Foreword from Professor Paul Ekins

This is one of four reports on decarbonisation to Net Zero commissioned by HSBC from the UCL Institute for Sustainable Resources (ISR). The other three focus on transport, commercial buildings and the manufacturing industry.

Farming is both a contributor to climate change, and stands to be one of the economic sectors most affected by it. As an activity, and in terms of its products, it is fundamental to human lives and societies, of an importance that is far greater than its relatively small contribution to the Gross Domestic Product (GDP) in the UK (0.5%).

> Humans can do without, and have often done without, much of the other 99.5% of economic activity that is included in GDP. No-one has ever done without food. Yet it is precisely the availability of food, and of food security, that climate change raises new questions about.

With climate change, the UK may not be able to rely on food imports from faraway places at affordable prices, as it has in the past. It is essential that it looks to the sustainability and resilience of its own agricultural sector.

Agriculture also has an important role in the mitigation of climate change. Most obviously, and in common with all other economic sectors and activities, it needs to get its own greenhouse gas emissions, some 10% of the UK total, down to as close to zero as it can by the middle of the century. But its role extends far beyond this. Agriculture is one of the very few sectors that, through the production of bioenergy with carbon capture and storage (BECCS), can generate negative emissions, as, with forestry, its crops draw down carbon dioxide from the atmosphere, while the soils it uses will need to change from being sources of carbon emissions to being sinks for them.

> Farmers have a critical role to play in both reducing their greenhouse gas emissions, and sequestering other sectors' emissions from the atmosphere.

At the same time, they are expected to produce lots of healthy, nutritious food in environmentally sustainable ways that also treat animals humanely – at a price that people can afford and which enables farmers to earn a living. It is a huge ask, and a huge task.

This report shows what needs to be done for UK agriculture to play its part in achieving Net Zero by 2050. It also shows that many farmers want to play this role, and indeed many are already doing so to the best of their ability within existing commercial constraints. But the report also makes clear that the sector as a whole will not be able to get to Net Zero, and provide wider services of carbon sequestration, as well as sustainably growing the food that consumers need and want, without wider societal and institutional support.

I hope that this report, having stressed the need for this support, will contribute to the coming important debate about how much it should be, and how it should best be delivered.

Professor Paul Ekins
UCL Institute for Sustainable Resources,
University College London

Executive Summary

In this report, based on information from the scientific literature, policy, and science- policy documents, we present the importance of reducing net agricultural emissions of greenhouse gases towards zero ('Net Zero') by a combination of changes in farm management and active sequestration measures to capture the remaining carbon. This information is enhanced by perspectives from a number of farmers from different sectors and parts of the country. Our key finding is that while a number of farmers are taking steps now, and Net Zero may be achievable through coordinated action to reduce emissions and capture carbon, there are many challenges on the road to achieve Net Zero in the UK agricultural sector by 2050. It is important that policy, resources, and support systems are developed in a strategic way through this period of uncertainty as the UK transitions away from EU policy and as the regulatory framework changes. High ambition and technological innovation are needed, along with public support and behaviour change. Farmers face a tremendous challenge of providing safe, healthy and nutritious food nationally and internationally amidst environmental, social and political changes, and there is much to be done to support them to achieve a just transition to Net Zero.

1. Net Zero and UK agriculture

- The UK has set an ambitious goal of Net Zero across all major sectors, including agriculture, by 2050.
- Agriculture was the source of 10% of total greenhouse gas (GHG) emissions in the UK in 2018, including 70% of total nitrous oxide emissions, 49% of total methane emissions, and 1.6% of total carbon dioxide emissions.
- The sources of these emissions are livestock and manure (56%), the use of farm inputs such as synthetic fertilizers (31%), and fuel and machinery (12%).
- Because of hard-to-abate GHGs like methane, achieving Net Zero in agriculture will require significant carbon capture and sequestration through soils and forests. This places agriculture at the heart of achieving Net Zero.
- There are many significant changes facing UK agriculture, including policy changes due to leaving the EU, the impacts of more extreme weather and climate change, and shifting consumer diets and preferences.
- Recognising the role of the farmer is key to Net Zero: based on a 2020 Defra survey, only 18% of farmers reported that it was "very important" to consider GHGs when making decisions relating to their land, crops and livestock.
- Understanding the practical challenges facing farmers is an important step in enabling measures and interventions to maintain their livelihoods, profitability, and productivity whilst pursuing greater environmental sustainability.

2. Measures to reduce emissions, boost productivity, and adapt to environmental changes in UK agriculture

- Based on recent scientific literature and science-policy guidance, there are four main areas where change can be implemented to achieve Net Zero. The first three of these four approaches are related to on-farm emissions.
- Firstly, improving farm productivity and efficiency through measures such as:
  - Using fertilisers more efficiently to reduce costs and nitrogen loss to the environment.
  - Improving manure management to reduce nitrogen loss to the environment.
  - A range of other improvements in livestock and arable production practices.
  - Gaining and applying greater knowledge of each farm's performance, including emissions, carbon account and efficient use of resources.
  - Reducing the carbon footprint of buildings and machinery, which can improve local air quality and reduce fuel costs.
- Secondly, by appropriate planting of trees, protecting and restoring habitats and soil, GHGs can be captured through measures, including:
  - Planting more and appropriate trees on farms on suitable land in hedgerows, forests and woodlands.
  - Conserving and restoring soil organic carbon, which improves soil fertility.
  - Improving the management of forests to make them more productive.
  - Restoring and protecting peatlands.
- Thirdly, shifting agriculture towards renewable energy and bioenergy by:
  - Generating and/or utilising renewable energy on-farm, which can bring additional income and improve self-sufficiency in energy.
  - Growing appropriate bioenergy crops, which can contribute to energy needs on the farm, increase crop diversity and income, and help prevent soil organic carbon loss.
- Lastly, there are major opportunities through developing future technology, and making societal changes toward greater sustainability.
  - Changing diets to reduce the consumption of carbon-intensive foods like ruminant meat and dairy products.
  - Shifting some land use away from agriculture for other uses.
  - Reducing food waste.
  - Several technologies in development may be able to contribute to deeper GHG emission cuts in the future. These include biochar, genetic research, and bioenergy with carbon capture and storage (BECCS).

3. Policy development and future considerations

- In the coming years, new generations of policy contributing to the goal of Net Zero in agriculture and associated land use will be put in place. Some of these policies will be aimed towards changing agricultural management and land use, while others will have a broader scope, for example setting out national decarbonisation strategies, energy policy, routes to reduce food waste, or shift to healthier diets for example. Both types of policy will influence decisions at the farm level.

- The development of most of the policies to support the Net Zero objective in agriculture will take place according to priorities established by the devolved authorities, which are responsible for agricultural and environmental policies.

- With the phaseout of Basic Payments, farmers will be looking closely at the changing menu of support. At the farm level, a new generation of support schemes is due to come into place in stages from 2021 onwards.

- Alongside the new schemes such as Environmental Land Management, there will continue to be other forms of support for land management, with the potential to help address climate priorities as well as increased market incentives to sequester carbon. It may become a requirement of future schemes to undertake a carbon audit, as is starting to occur now.

- Policy support for environmental land management can be expected to become more divergent across the four UK countries, but in each case is likely to include a combination of:
  - Annual payments for providing a stream of public goods.
  - Selective capital grant schemes for agriculture and forestry.
  - Payments geared to proven environmental results, rather than simply adherence to agreed practices.
  - Incentives for training, adopting tools such as carbon audits and planners, participation in joint projects.
  - Improved research, information and advice for farmers, more experimentation and pilot schemes, as well as an increase in the use of facilitators and consultants, aid for farm-to-farm networking and related initiatives.

- Whilst there are many unanswered questions related to policy development and support, including the extent to which new rural development policies will be introduced in succession to those available under the CAP, there is little doubt about the direction of policy, and the growing attention to the measurement and management of both GHG emissions and the removal of carbon.

4. Practical considerations towards Net Zero in UK agriculture

- The farmers from different subsectors whom we interviewed shared their insights and experiences for this report, which we summarised into ten points of guidance:
  1. Gather and organise data from farm activities; measurement is critical.
  2. See Net Zero not as the primary end goal, but as an important contribution to several key goals.
  3. Seek expert advice.
  4. Joining peer-to-peer learning groups can provide a wealth of practical experience.
  5. Focus on soil health.
  6. Be prepared to accept some risk and initial losses, learn from trial-and-error, and go out of comfort zones.
  7. Accept that measurable change takes time and effort; be consistent.
  8. Work with nature, for nature.
  9. Technology is a crucial tool towards Net Zero.
  10. Recognise that there is a growing role for farmers as leaders and innovators.

- With much uncertainty around what kind of support they will be able to access amidst policy change, farmers need to be informed of what can be reasonably expected, and their options clarified as far ahead as possible.

- The use of carbon calculators is increasing but needs to be expanded further. There are a number of carbon calculators available, from 'off-the-shelf' to more specialised life cycle assessment tools. There remain important questions about how these calculators will be used to provide evidence for carbon-based incentives in the future, and so developing standards for them will be an important step towards Net Zero.

- Retailers and others in the food chain are adopting Net Zero strategies of their own, which will result in new requirements for farmers even without policy change. The impact of this may yet to be felt on many farms but it is a further reason for assessing the position and planning action soon.

- Alignment of government strategies and timelines, technological and research efforts and a spectrum of relevant policies would help to ensure that the pathway to environmental and economic sustainability is mapped out as clearly as possible for farmers and their customers.

5. Future outlook and ways forward

- Ensuring a just transition to Net Zero – where all farmers and land managers can benefit from opportunities as well as fulfil obligations – will require the engaged participation of farmers, policymakers, practitioners, researchers, and the public.

- While future agricultural support and policy are still being developed, this is not a sufficient reason to delay ambitious actions on farm and across the sector. As demonstrated by the experiences of the farmers interviewed, progress is achievable and has other benefits than climate change mitigation. Since there may be a period of experimentation in adopting new approaches, there are advantages in starting soon.

- Net Zero is not an isolated objective to be detached from others applying in agriculture: it is one among several key milestones in the pathway to making UK agriculture sustainable and resilient to current and future environmental challenges.

1. Introduction to Net Zero and UK agriculture

1.1 The role of agriculture in Net Zero

Climate change will impact all the sectors that help sustain a healthy and productive economy and society. Responding to climate change means acting to adapt to its impacts, whilst minimising the emissions of greenhouse gases (GHGs) to prevent further climate change. The UK is in a position to be a world leader in reducing the GHG emissions that cause climate change, through its ambitious target of achieving Net Zero Emissions by 2050. As the host of the upcoming 26th Conference of the Parties of the United Nations Framework Convention on Climate Change (COP26) in Glasgow in November 2021, the UK can play a key role in driving significant change in global policy, and showcase British ambition and innovation in addressing climate change. Beyond fulfilling the commitments to the Paris Agreement to limit global warming to well below 2˚C, by pursuing Net Zero, the UK has the opportunity to transform its agriculture, business, manufacturing, and transport sectors to achieve greater environmental sustainability, thereby improving the quality of life for UK citizens and the connected global community.

Among the different sectors that contribute to climate change, agriculture plays a unique role as both a contributor of GHG emissions and also a sector that has the ability to capture carbon and thus reduce the concentration of carbon dioxide (the longest lasting GHG) in the atmosphere. Agriculture is a key source of GHG emissions, particularly emissions of methane from processes associated with livestock and their wastes, and nitrous oxide from fertilisers[1]. Globally, agricultural expansion and intensification also contribute to carbon dioxide emissions when land is cleared for cultivation through deforestation and forest degradation[2–5]. Climate change in turn will affect agriculture itself and those of nature's contributions to society that are essential to agriculture, such as pollination and natural pest control[6, 7]. Shifts in temperature and rainfall patterns due to climate change will also have impacts on crop production and the incidence of pests, weeds, and diseases that affect both crops and livestock[8]. In addition, apart from the associated GHG emissions, agricultural production has significant impacts on land and soil, water resources, terrestrial and marine ecosystems, and biodiversity[9]. The agricultural sector thus needs to be an integral part of any global or national climate strategy[10].

Whilst agriculture does contribute to GHG emissions, agricultural practices can make significant contributions to sequestering, or capturing, carbon through measures such as planting or otherwise establishing trees (afforestation), agroforestry or agroecology, and sustainable land management practices, including enhancing soil carbon stocks or planting hedgerows[11, 12]. Supporting agricultural activities through environmentally-friendly or low carbon practices (e.g. generating and utilising renewable energy, bioenergy) also provides the sector opportunities to shift away from the dependencies on the fossil fuel industry, diversify farm income, and improve farm self-sufficiency.

Support for the Net Zero target has come from the industry: the National Farmers Union (NFU) has aligned with the UK's 2050 Net Zero objectives, aiming for an even more ambitious timeframe to reach Net Zero by 2040[13]. Other developments are shaping the context for farming in the UK as well. The ongoing coronavirus pandemic has highlighted the interconnectivity between nature, food, and public health, and highlighted the need to place agriculture at the heart of transformative actions towards global and local food systems that are safe, sustainable, and resilient to climate change.

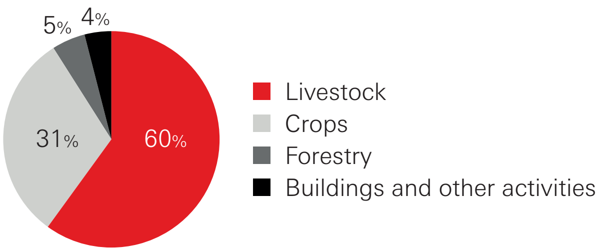
In this section, we give a brief overview of the UK agricultural sector, the history of the UK Net Zero initiative, and the sources of GHG emissions in the agricultural sector, based on recent government reports and scientific literature.

1.2 Overview of the UK agricultural sector

The agriculture sector in the UK supplies local and international consumers with a large diversity of crop and animal products. UK agriculture is characterised by a wide range of farm types and diverse activities. In terms of production value, output is split roughly equally between crops and livestock. The highest value crop is wheat (£2.4 billion in 2019); the highest value livestock products are beef (£2 billion) and milk (£4.43 billion)[14]. Production in Wales and Northern Ireland is dominated by livestock production, and milk and cattle are the highest-value products. These products are also important in Scotland, with a third of output coming from crops, including cereals such as barley and wheat. In England, major agricultural products are from horticulture (fruits and vegetables), milk and poultry, and cereals like wheat. Arable production dominates the East of the country, whilst livestock farms are found mostly in the South West. In 2019, the UK was nearly self-sufficient in beef production (86%) and was self-sufficient in lamb production (109%)[15, 16].

In 2019, there were 219,000 farm holdings in the UK[14]. These varied widely in size: around 20% of holdings were very large, with over 100 hectares of land. Large farms occupy the great majority of the land devoted to farming (76%), with numerous smaller farms using the rest of the available agricultural land. The smallest farms that use less than 20 hectares individually, farmed just 4% of the total farmed area. Large farms thus dominate farm output in terms of value, producing 55% of farm output in 2017[17]. Agriculture contributed £10.4 billion to the UK economy in 2019, which is 0.5% of the £2.21 trillion UK Gross Domestic Product (GDP) that year[14]. Overall, the agriculture sector produces 53% of the food consumed in the UK. In terms of employment, agriculture employed 426,000 people in 2018, which is 1.5% of the UK labour force, with more employed in the food and drinks sector[17]. Agriculture has a large influence over the landscape: when considered with forestry, agricultural land use accounts for 85% of the UK land area. Based on reported Defra statistics, the total area used for agriculture was 77% of the total land area of the UK. Of this agricultural land, 60% was used for livestock, 31% for crops, 5% for woodland, with the remainder for buildings and other agricultural activities in 2018 (Fig. 1.1). The total area of woodland, including on agricultural land, is 3.2 million hectares, comprising 13% of land in the UK[17].

Figure 1.1 Land for Agricultural Activities



Source: Defra, 2018. UK agricultural land by type of activity. Percentages are expressed as part of the total 19 million hectares of land used for agriculture.

1.3 History and context of Net Zero

The UK is a party to the United Nations Framework Convention on Climate Change (UNFCCC), and signed the Paris Agreement in 2016. The Paris Agreement marks the first time nearly two hundred countries agreed to keep the global temperature rise well below 2˚C and pursue efforts to limit the warming to 1.5˚C. To achieve the long-term temperature goal, the Paris Agreement commits Parties "to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century"[18]. An important feature of the Paris Agreement is allowing signatory countries to determine their own contributions and plans (called Nationally Determined Contributions, or NDCs) to reduce or capture the GHG emissions that cause climate change. The UK's efforts toward Net Zero are a fundamental component of the country's NDC.

In 2019, the UK became the first major world economy to pass laws to end its contribution to global warming by 2050[19]. Section 1 of the Climate Change Act (2008) was amended to make the target for the net UK carbon account from 'at least 80% lower than the 1990 baseline' to 'at least 100% lower by 2050'[20]. This target was changed in order to strengthen the UK commitment to limiting global temperature rise to 2˚C, following the Intergovernmental Panel on Climate Change (IPCC)[1] Special Report on 1.5˚C that warns of dangerous impacts from an additional half a degree of global warming[21, 22].

Whilst there is not yet legally-binding policy for the agricultural sector to comply with Net Zero objectives, the NFU, which represents over 55,000 UK members, has set the ambitious goal of reaching Net Zero across the whole of agriculture in England and Wales by 2040 as its contribution to achieving the UK target. The NFU aims to achieve this by promoting three main approaches: **1.** boosting productivity whilst reducing emissions, **2.** farmland carbon storage, and **3.** increasing the use of renewable energy and bioenergy; these measures are discussed in more detail in Section 2. As farms across the UK will have different capacities to make changes to the way they farm, actions to achieve Net Zero in agriculture must consider the large diversity of farm types, sizes, and range of outputs and enterprises in the sector.

1.4 Emissions from UK agriculture

1.4.1 Overview

The agriculture sector is responsible for emissions of three principal GHGs: nitrous oxide (N_2O), methane (CH_4), and carbon dioxide (CO_2). These emissions are typically measured in million tonnes of carbon dioxide equivalents ($MtCO_2e$) as a means of standardising and comparing different GHGs. This standardisation is based on the Global Warming Potential (GWP), which indicates the amount of warming caused over 100 years by a GHG (Table 1.1). Carbon dioxide is considered to have a GWP of 1, so the GWP for all other GHGs is the number of times more warming they cause compared to carbon dioxide. Methane has a GWP of 25, meaning that 1kg of methane can cause 25 times more atmospheric warming over a 100-year period compared to 1kg of carbon dioxide.

Table 1.1 Global warming potential of agricultural emissions[23].

GHG	Chemical formula	Lifetime (years)	Global Warming Potential over 100 years (GWP_100)
Carbon dioxide	CO_2	Variable, 300-1000	1
Methane	CH_4	12±3	25
Nitrous oxide	N_2O	120	298

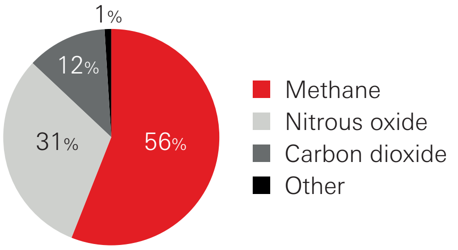
Globally, about 21–37% of total greenhouse gas (GHG) emissions are attributable to the food system. This estimate includes agriculture and land use, storage, transport, packaging, processing, retail, and consumption. Of this, 9-14% are from crop and livestock activities within the farm gate, while 5-14% from land use and land-use change including deforestation and peatland degradation, and 5–10% is from supply chain activities[24]. In 2018, emissions from the UK agriculture sector were approximately 46 $MtCO_2e$. This accounts for 10% of all UK emissions, coming after the transport, energy, business, and residential sectors. In 2018, agriculture was the source of 70% of total nitrous oxide emissions, 49% of total methane emissions, and 1.6% of total carbon dioxide emissions[25]. Despite its smaller contribution to total UK GHG emissions, agriculture was a dominant source of nitrous oxide and methane emissions compared to all other sectors.

Within the agricultural sector, methane accounted for 56% of agricultural emissions, nitrous oxide- 31%, and carbon

1 The IPCC is a UN body tasked with assessing the science related to climate change, composed of thousands of scientists from around the world who work on research and communication about climate change, its impacts, and what potential measures can reduce future risks.

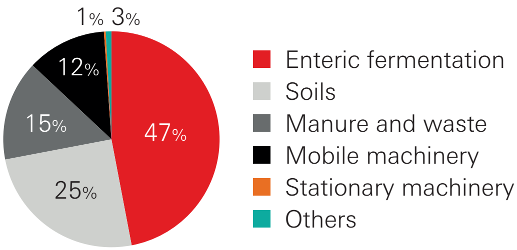
dioxide- 12% in 2017 (Figure 1.2). These come from various farm sources, including enteric fermentation from ruminant livestock (cattle and sheep), which accounted for 47% of emissions. A quarter of total agricultural emissions was from soils, which emit GHGs due to biological fixation of nitrogen by crops, ploughing in crop residues, and the cultivation of organic soils. Fifteen percent (15%) of emissions were from the management of waste and manures on agricultural land, and 9% and 1% from mobile and stationary machinery, respectively[1] (Figure 1.3).

Figure 1.2 UK Agriculture emissions by GHG



Source: Defra, 2018. Percentage of agriculture emissions in the UK, by type of greenhouse gas, based on a total of 46 $MtCO_2e$ GHG emissions for the sector.

Figure 1.3 Emissions by activity



Source: Defra, 2018. Sources of agriculture emissions in the UK, by activity.

This estimate of GHG emissions was calculated by Defra based on the number of livestock and the amount of nitrogen-based fertiliser applied to land. However, a variety of important factors that also influence emissions are not captured by the current Defra methodology, for example soil emissions, the timing of fertiliser applications, feed ratio improvements (amount of feed required to produce 1kg of dressed poultry, for example), or ongoing genetic improvements to crop varieties or livestock breeds[25]. These factors, together with other influences on livestock welfare and health affecting emissions, could result in changes to estimates of current emissions from agriculture, and efforts to better account for these should be considered a priority in agricultural research.

Additionally, emissions from UK peatlands, which are not currently included in the GHG inventory, were estimated at 23 $MtCO_2e$ in 2017[1]. Depending on the context, agriculture can be combined with certain other land uses when estimates of emissions are presented; for example, some estimates consider agriculture together with forestry and other land uses. Despite different accounting methods, it is clear that agriculture is a major contributor of nitrous oxide and methane emissions due to fertilisers and processes associated with livestock, respectively.

1.4.2 Sources and sinks of greenhouse gases

The agriculture sector contributes the largest share of methane, around 49% of the UK's total emissions of methane in 2018[25]. Unlike carbon dioxide which is a long-lived GHG, methane has a comparatively short life in the atmosphere. However, it is also a GHG that has 25 times more warming potential over 100 years than carbon dioxide[26] (Table 1.1). Methane is produced as a by-product of enteric fermentation within ruminant livestock, and from the decomposition of manure under anaerobic (without oxygen) conditions. Enteric fermentation is a digestive process whereby feed constituents are broken down by microorganisms. Both ruminant animals (e.g. cattle and sheep), and non-ruminant animals (e.g. pigs and horses) produce methane, although ruminants are by far the largest source per unit of feed intake. When manure is stored or treated as a liquid in a lagoon, pond or tank it tends to decompose anaerobically, and this produces a significant quantity of methane. In contrast, when manure is handled or deposited on pasture as a solid, it tends to decompose aerobically and little or no methane is produced. Hence the system of manure management used affects methane emission rates[1]. Food waste decomposition is another source of methane emissions[27], although this is not typically included in GHG accounts for agriculture. Peatlands also emit methane on a significant scale[28], making their management an important consideration to achieving Net Zero in the land sector.

The largest source of nitrous oxide emissions from agriculture is the application of fertiliser on cropland, both synthetic N (inorganic) fertiliser and manure (organic)[29]. Nitrous oxide is emitted by manure applied to cropland, manure deposited on grasslands by grazing animals, and manure management/storage[25]. Some natural processes release nitrous oxide, such as the deposition of agricultural nitric oxide (NOx) and ammonia (NH_3). The use of synthetic N fertilizer has played a key role in enhancing food production for the world's population, but its overuse in many parts of the world has contributed to soil, water, and air pollution[30]. Nitrous oxide emissions increase with increased N fertiliser application, more so when applied in excess[29]. Excess use can also lead to emissions from leaching and runoff from fertilisers[25]. Nitrous oxide emissions are also linked to land use change[29].

Lastly, carbon dioxide contributes a smaller percentage (1.6% in 2018) of total GHGs directly from agriculture. These relate mainly to fuel use in farm machinery. However, agriculture also drives the release of carbon dioxide through less direct, although equally significant processes. At a global level, deforestation and forest degradation driven by agriculture and land use change contribute to GHG emissions via the combustion of biomass and decomposition of the remaining plant material and soil carbon, the latter of which holds reserves of carbon twice the amount of carbon dioxide in the atmosphere[3, 12, 31, 32]. Degraded forests lose carbon due to timber and fuelwood harvesting, fires, and grazing[2].

In terms of carbon storage, soil and forests are able to store carbon, making land (including farmland) management and forestry important components of the overall effort to achieve

Net Zero. In 2017, the land use, land-use change and forestry (LULUCF) sector was a net sink, capturing nearly 10 $MtCO_2e$ in 2017 in the UK. This is equivalent to around 5% of total UK GHGs[17].

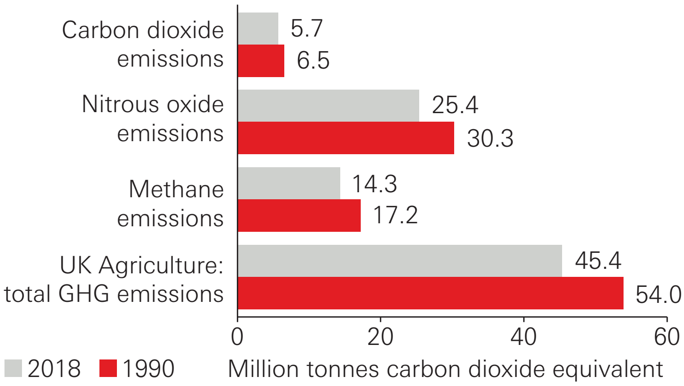
1.4.3 Other sources of GHG emissions

The global demand for food and feed that causes agricultural expansion and intensification is a major cause of deforestation in many countries, and this has impacts on the environment and on biodiversity[7, 33, 34]. Agriculture accounts for around 70% of land use change emissions, mainly through deforestation[10]. For example, much of the globally imported soybeans used in feed are grown in Brazil and Argentina, which has led to widespread deforestation and biodiversity loss[35, 36] and this contributes to the carbon footprint of livestock that are fed with this imported feed. Additionally, some of the energy used for heating agricultural buildings and for other processes related to distributing and processing food is obtained by burning fossil fuels like coal or gas, which also contributes to carbon dioxide emissions. Lastly, the production of fertilisers is also linked to high carbon dioxide emissions[30], although they are not often included in estimates of emissions from the agricultural sector. Therefore, the current estimates of GHG emissions in the UK may not capture the full picture of the whole food system's contribution to climate change.

1.4.4 Current trends in UK GHG emissions

Total GHG emissions from agriculture in the UK have declined by 16% since 1990, based on figures from 2018[14, 25] (Figure 1.4). There are many reasons put forward to explain this decline, including changes in policy, such as reduced incentives to maintain ruminant numbers under the EU Common Agricultural Policy, improvements in efficiency, national and international emission targets, as well as improved technology and productivity. However, there has only been modest progress in reducing emissions from agriculture since 2011, with emission values remaining broadly the same over the last decade. This indicates that stronger policies and action are required compared to the current voluntary approach[17].

Figure 1.4 Comparison of 2018 and 1990 GHG emissions from agriculture in the UK, in $MtCO_2e$



Source: Data from the Department for Business, Energy & Industrial Strategy[25]

1.4.5 Policy implications of current trends in emissions

Reducing agriculture emissions to near-zero will not be possible by 2050, given the inherent biological processes and chemical reactions arising from the management of crops, soils and livestock. There are many ways to reduce emissions, for example by the more efficient use of fertilisers and changes in livestock feed. However, to achieve Net Zero requires the removal of carbon from the atmosphere as well, by means of sequestration in trees and soils for example. This implies reducing the area of land under full agricultural production, which in turn would be eased by a fall in consumption of foods associated with high levels of emissions, most of which are livestock products[37]. Hence there is a need to develop parallel policies to address agricultural practice, technological development, carbon sequestration and healthy diets. There can be both synergies and trade-offs between different objectives[1, 37]. Some of the currently available and potential measures for agriculture are detailed in the following Section 2.

The agriculture sector is facing major changes in policy and forms of support. This includes new legislation related to agriculture and land management, such as the 2020 Agriculture Act. Whilst Brexit may offer an opportunity to accelerate the agricultural transition to Net Zero as the money that used to support farmers' incomes will now be used mainly to pay for 'public goods', which includes contributing to climate change mitigation[37], there is still a lot of uncertainty as to how farmers can receive support by pursuing Net Zero. More on the policy-relevant aspects of the transition of agriculture to Net Zero are found in Section 3 of this report.

1.5 Climate change impacts in the UK

Met Office long-term records show that the climate in the UK is getting warmer and wetter. The average temperature over the most recent decade (2009-2018) was on average 0.3°C warmer than the 1981-2010 average, and 0.9 °C warmer than the 1961-1990 average. All the top ten warmest years have occurred since 2002. UK winters in the most recent decade (2009- 2018), have been on average 5% wetter than 1981-2010, and 12% wetter than 1961-1990. Summers in the UK have also been wetter, by 11% and 13% respectively. UK Climate projections show an increased chance of warmer and wetter winters in the future. Summers are also projected to be hotter and drier, with an increase in the frequency and intensity of extreme events. By 2070, if climate change emissions are not reduced (high emissions scenario), this will mean temperature changes of 0.7°C to 4.2°C in winter, and 0.9°C to 5.4°C in the summer. In terms of precipitation, the UK might see changes of -1% to +35% more rain in the winter, and up to 47% less rain in the summer[38].

Taking urgent action can help reduce some of the most adverse consequences of climate change, but some of its impacts may not be averted and communities will have to cope with them. Whilst farmers are familiar with the many impacts that extreme weather can have on crops and livestock, climate change is projected to make extreme weather events such as these potentially more frequent, intense, or both[39]. Extreme precipitation leading to floods, wind damage from storms and hurricanes, and heat stress due to droughts and high temperatures already cause significant losses and damage to agriculture[40]. Climate change is anticipated to further affect crop production, due to continued increases in temperature and changing rainfall that can alter normal crop growth and development[41–43]. For example, extreme heat is known to cause decreases in wheat yields due to heat stress and grain sterility[44, 45]. Changing rainfall patterns can also affect wheat grain quality and field management decisions, such as whether to plough or not.

There are also indirect impacts of climate change on agriculture. For example, climate change is projected to affect the incidence and distribution of pests and diseases[46], and will potentially affect the occurrence of weeds and invasive species[47, 48]. Due to the climate change-induced fluctuations in food productivity and supply, there may be increased price volatility for agricultural commodities, and reduced food quality[49]. Climate change can also affect the health of farmers and their workforce due to extreme heat that may make working outdoors difficult, or risky, in terms of heat exposure[50].

There may be some benefits to agriculture from climate change, as certain areas that were previously relatively unfavourable for cultivation due to climate limitations may become more productive[43]. Additionally, increases in carbon dioxide may provide some benefits to specific crops whose growth is enhanced by the 'carbon fertilisation effect'; however, this response depends greatly on crop type and environmental conditions[51]. Thus, these benefits are expected to be short-lived as the negative impacts of climate change will significantly outweigh the benefits, especially when taking a long-term global outlook.

1.6 Working with farmers to achieve Net Zero: what's in this report?

For farmers, a central challenge is to reduce their GHG emissions whilst maintaining productivity and profitability, in addition to navigating changes in support levels and regulations. This challenge is made more complex by the need to adapt farming systems themselves to become more resilient to the impacts of climate change. There is also a need to reduce other adverse impacts of food production on the environment, including on biodiversity[12]. Indeed, achieving a just transition to Net Zero will require coordination, collaboration, and communication between farmers and different stakeholders within a variety of networks, supply chains and other relationships, some stretching beyond the UK. Making agriculture more resilient and sustainable will contribute to both environmental goals and food security. This means that farmers are key actors in achieving Net Zero.

However, there are significant barriers to achieving Net Zero in UK agriculture. In particular, there is a need to consider more deeply the needs and priorities of farmers, their attitudes towards Net Zero, and access to information and support throughout the transition and beyond. A recent Defra report[25] found that only 18% of farmers reported that it was "very important" to consider GHGs when making decisions relating to their land, crops and livestock and a further 46% thought it is "fairly important". Whilst the percentage of farmers who think that climate change is important is increasing, a remaining 30% of respondents placed either little or no importance on GHGs when making decisions. Overall, 66% of farmers were taking actions to reduce emissions, which is a 5% increase from 2019. For those farmers not undertaking any actions to reduce GHG emissions, both the lack of information (35%) and lack of clarity about what to do (39%) were cited as barriers. 42% did not believe any action was necessary, which is a decrease from 47% in 2019[25].

As indicated in the 2020 Defra survey, farmer attitudes and knowledge of Net Zero are crucial: therefore, the role of the farmer is given particular emphasis in this report. Measures that potentially could be applied to reduce GHG emissions, store carbon, and improve productivity are presented and reviewed in Section 2. Relevant policies and regulations related to farming are reviewed and discussed in Section 3. Section 4 presents practical guidance gained from the farmers interviewed, with a discussion of timelines, scenarios and costs, supplemented with a case study of an arable farm. Throughout the report, excerpts from interviews with farmers are used to highlight real examples of change. Although we focus on arable farming in the short case study, two farmers from each of the subsectors of arable, livestock and dairy, and horticulture were interviewed for this report (See Farm Profiles in Report Annex).

2. Measures to reduce emissions, boost productivity, and adapt to environmental changes in UK agriculture

2.1 Introduction

Reducing GHG emissions whilst maintaining or even improving farm productivity, supporting livelihoods, and maintaining UK competitiveness, is vital to ensuring that the UK agricultural sector makes a successful transition to Net Zero. Because of the projected impacts of climate change on agriculture, and the impacts of agricultural production on the environment, Net Zero measures need to be able to meet a wide range of economic and environmental demands in addition to consumer demand. Available approaches need to strike a balance between maintaining a strong food production sector, delivering on Net Zero goals, and preparing for, or adapting to, the impacts of climate change. Therefore, measures need to be accessible in terms of knowledge and technology, and adaptable to individual farm needs to deliver the needed emission reductions and carbon storage toward Net Zero.

In order to aid in the transition towards Net Zero by 2050, the Climate Change Committee (CCC) presented three sets of measures that will reduce agricultural GHG emissions whilst boosting or maintaining farm productivity[1]. These are the **1.** Core, **2.** Further ambition, and **3.** Speculative options. The core actions cover a variety of on-farm practices to reduce GHG emissions from soils, livestock, waste and manure management, as well as from reduced energy consumption in stationary machinery. These actions align closely with the NFU's three pillars of action to make the transition to Net Zero agriculture by 2040:

1. Productivity improvements and better resource use,
2. Farmland carbon storage in soils and vegetation, and
3. Boosting renewable energy and the bio-economy (Figure 2.1).

There are several measures toward Net Zero emissions that can also provide multiple benefits for both farm businesses and the environment. These are 'nature-based solutions', which are approaches based on the knowledge that healthy ecosystems, both natural and managed, provide a diverse range of services on which human societies depend on[2, 3]. Nature-based solutions can help deliver emission reductions while sustaining the ecosystem services that agriculture depends on, and provide benefits for biodiversity and human wellbeing. The key measures that have clear, multiple benefits for agriculture and the environment are: afforestation and forest management; restoration of peatlands; low-carbon

Figure 2.1 Summary of the core measures, further ambition, and speculative options from the Climate Change Commission to reach Net Zero in agriculture, alongside the 3-Pillar approach from the National Farmers Union[1, 6]

Core Measures			Further Ambition	Speculative Options
NFU Pillar 1: Improving farm productivity and resource use	**NFU Pillar 2: Farmland carbon storage in trees and soils**	**NFU Pillar 3: Increasing renewable energy use and generation**	**Change diets towards less carbon-intensive foods**	**More changes to diets and reductions to waste**
Improving fertiliser and resource use, livestock conditions, breeds, and welfare, manure management and farm building energy efficiency	Planting more trees in hedgerows and/or farmland, restoring and improving the management of peatland and degraded soils.	Generating renewable energy on-farm through solar panels, bioenergy from waste and crops	Shift to low carbon fuels for farm machinery Reduce food waste Freeing agricultural land for natural habitats and restoration	Using carbon capture technologies to remove GHGs Significant genetic improvements to produce low-emission breeds

farming practices; improving soil and water quality; reducing flood risks and improving the condition of semi-natural habitats[4, 5]. This section presents the main measures that can reduce emissions, capture carbon and contribute to reducing fossil fuel use. It also reviews how wider societal change can contribute to reducing emissions from agriculture and food systems by diet and supply chain changes.

2.2 Measures to reduce or capture emissions

In this report, three main sets of approaches are presented as actions toward a Net Zero agricultural sector in the UK. These are based on the CCC-recommended core actions and the NFU pillars, together with recent scientific literature. The assumptions on which CCC bases its emission reductions are found in Tables A1-A2 in the Section Annex. The measures that can reduce or capture emissions are: **1.** improving farm productivity and efficiency, **2.** planting trees, protecting and restoring habitats and soil, and **3.** shifting agriculture towards renewable energy and bioenergy. A fourth set of measures are linked to making changes to society towards greater sustainability, including dietary changes and upcoming technologies (Table 2.1).

2.2.1 Measures to improve farm productivity and efficiency

The first set of measures to reduce on farm emissions focus on improvements in productivity and better resource use. These include actions such as improving soil quality, livestock health, diets and breeding, promoting on-farm anaerobic digestion to manage waste, and improving the energy efficiency of farm vehicles and buildings. The CCC estimates that these core measures can reduce GHG emissions from the agricultural sector by 15% by 2050, based on 2017 estimates[1], and estimates of the annual abatement level achievable have been made for several individual measures per hectare (Table 2.2).

- **Emissions can be reduced by using fertilisers more efficiently.**

  The use of controlled-release fertilisers and inhibitors can increase the efficiency of nitrogen application and reduce emissions[1, 4, 6–8]. Timely weather forecasts, including seasonal forecasts, could also potentially be used to adjust the field management and fertiliser application in wet seasons[9]. Precision farming can also deliver nutrients more accurately and where they are needed in the field.

Table 2.1 Summary of presented measures that contribute toward Net Zero in agriculture.

Set of approaches to Net Zero	Actions
Improving farm productivity and efficiency	• GHG emissions can be reduced by using fertilisers more efficiently. • GHG emissions can also be reduced by improving agricultural practices. • GHG emissions can be reduced by gaining more knowledge about on-farm emissions, nutrients, and resource use. • GHG emissions can be reduced by improving the management of manure. • GHG emissions can be reduced by improving buildings and machinery, which use carbon-emitting fossil fuels as their energy source.
Planting trees, protecting and restoring habitats and soil	• GHGs can be captured by planting more trees on farms, and on suitable land in hedgerows, forests and woodlands. • GHGs can be captured and avoided by conserving existing soil organic carbon stocks and restoring carbon stocks in depleted soils. • GHGs can be captured by improving the management of forests to make them more productive. • GHGs can be captured by planting bioenergy crops such as Miscanthus. • GHGs can be captured and avoided by restoring and protecting peatlands.
Shifting agriculture towards renewable energy and bioenergy	• GHG emissions can be reduced by generating and/or utilising renewable energy on-farm, including bioenergy generated from farm waste. • GHG emissions can be reduced by growing bioenergy crops, which can contribute to energy needs on the farm, increase crop diversity and income, and help prevent soil organic carbon loss. • GHG emissions can be reduced by utilising bio- based materials for on-farm construction.
Exploring future options and changing society towards greater sustainability	• GHG emissions can be reduced by changing diets to reduce intake of carbon-intensive foods like meat and dairy. • GHG emissions can be reduced and captured by shifting land use away from crop cultivation or livestock and releasing land for other uses. • GHG emissions can be reduced by reducing food waste. • In the future, many other technologies may become available to make deeper GHG emission cuts in the agricultural sector, including biochar, genetic research, and BECCS.

Improving the efficiency of fertiliser application can help reduce water pollution with benefits for water quality, biodiversity, habitat condition and resilience to climate change[4].

- **Emissions can also be reduced by improving agricultural practices.**

  Improved farm practices can simultaneously boost productivity whilst reducing emissions. One of these measures is loosening soil compaction on cropland and pasture, which can reduce the need for cultivation and thus minimise GHG emissions. Other practices such as the increased use of organic residues, and increased use of legume crops to fix soil nitrogen can reduce excess fertiliser use and emissions[10, 11]. See Table 2.2 for other examples.

- **Emissions can be reduced by gaining more knowledge about on-farm emissions, nutrients, and resource use.**

  Several farm emission or footprint calculators allow farmers to estimate their carbon footprint, depending on various assumptions about the carbon profiles of different practices and products. These calculators differ in their ease of use, output, and user experience. Examples of these tools include the Cool Farm Tool, Agrecalc, and the Farm Carbon Toolkit. The knowledge of a farm's baseline emissions or carbon footprint and its energy or resource use can also help inform farmers about what reductions are needed, or identify priority areas requiring improvement and where they can seek additional advice. For example, accounting for nutrients in livestock manure can enable the scale of emissions from the excess use of manure to be estimated and measures to reduce it to be identified. As calculators are an important tool for accounting for farm emissions, and indeed, may become crucial for monitoring progress and accessing support, the importance of standards for calculators is discussed in Section 4.

- **Emissions can be reduced by taking measures to improve livestock feed, conditions, and welfare. Improvements in crop and livestock genetics may also reduce emissions.**

  Measures such as improving the digestibility of feed for cattle and sheep, improving animal health and fertility, and increasing the feed conversion ratio by adapting genetics can reduce methane emissions[1, 4, 6] (See Box 2.1).

  Feed additives can also reduce methane emissions from ruminant livestock[12]. A survey to determine measures that are both effective and practical in sheep farming identified six priority measures: the overall preferred measure was the use of legumes in pasture reseed mixes. Other useful measures were reducing mineral fertiliser use and replacing this with organic sources of nitrogen, including manure, pasture plants that minimise nitrogen losses, such as sugar grasses, improving ewe nutrition, increasing lamb growth rates and lambing as yearlings[13, 14].

  In the future, animal genetics research can also take on an important role towards Net Zero, by breeding livestock that emit lower methane. Some options for methane reduction from ruminants include modifications to gut microbes or the gastro-intestinal tract environment, modifying the organisms themselves, or the livestock system[15]. However, more research is needed to improve the understanding of rumen ecology, effects of nutrition management on livestock welfare, and moving from research to on-farm application[15–17].

- **Emissions can be reduced by improving the management of manure.**

  Improving the management of manure through better storage, handling and application of animal wastes on land can reduce GHG emissions[7, 10, 11]. Improved management of housed livestock manures can include measures to improve floor design, the use of air scrubbers, or the treatment of stored slurry with acid or other additives that can reduce nitrous oxide emissions[1, 18]. This will also bring benefits for the health of humans and livestock as airborne ammonia and hydrogen sulphide are extremely harmful to the health of humans and animals, especially during the manure pump-out season[18], as well as reducing water pollution from contaminated water discharge. Anaerobic digestion to convert animal manures, crops and crop by-products into

Box 2.1 Viewpoints from the farm: genetics and feed efficiency.

Featured Farm: Burling Brothers Limited, Cambridgeshire
Improved breeding and genetics are key to reduced emissions for Burling Brothers Limited, a family-run business of both arable and cattle production in Cambridgeshire. On the cattle side of their business, they specialise in working with the Stabiliser breed, which was developed in the United States by the Meat Animal Research Center. It is a composite breed made up of two native breeds and two continental breeds designed to stabilise a cross breeding programme whilst retaining maximum heterosis (hybrid vigour). Stabiliser cows have a shorter age to slaughter, in addition to the breed already being feed-efficient, which is a heritable trait. Director Dan Burling explains why this breed and its feed efficiency are key to reducing emissions:

> "Shorter age to slaughter means that they're on the planet for less time, so they're not producing their actual natural emissions. But equally, they're not eating anywhere near as much food to get there."

renewable energy can also mitigate GHG emissions, and can already be found in use on large farms[8, 10, 19, 20].

Table 2.2 Abatement rates of several measures toward Net Zero (Adapted from[21]).

The relative cost-effectiveness (in £ per ton of CO_2-eq) of these measures, represented in a Marginal Abatement Cost Curve, as well as reflections of experienced farmers on their practicality, are discussed in Section 4.

Measure	Estimate of abatement rate (tCO_2e), per hectare and per year
Using biological fixation to provide Nitrogen (N) inputs (e.g. using clover)	0.5
Reducing N fertiliser	0.5
Improving land drainage	1.0
Avoiding N excess	0.4
Fully accounting for manure and slurry N	0.4
Introducing species such as legumes	0.5
Improving management of N mineral fertiliser	0.3
Applying controlled release fertilisers	0.3
Utilising nitrification inhibitors	0.3
Improving the management of slurry and manure	0.3
Adopting farming practices and systems that are less reliant on inputs (nutrients, pesticides, etc)	0.2
Using plant varieties with improved N use efficiency	0.2
Separating slurry/manure applications from fertiliser applications by several days	0.1
Adopting reduced or no till practices	0.15
Using compost or straw based manures instead of slurry	0.1

- **Emissions can be reduced by improving buildings and machinery, which use carbon- emitting fossil fuels as their energy source.**

  Efficiency improvements to agricultural buildings through retrofitting or replacement with new, more energy-efficient buildings can decrease the energy needed to heat or cool buildings. Better performing buildings can also improve animal welfare for pigs and poultry, resulting in lower production costs[1]. This also reduces the GHG emissions from burning fossil fuel energy sources. As agricultural vehicles account for 93% of the emissions arising from machinery use in the sector, reducing these emissions close to zero requires a shift to low-carbon fuels such as low-carbon electricity (from wind, solar or nuclear power) and hydrogen. Using smaller machinery, including drones and robots, instead of large machines/vehicles where possible can also reduce fuel use.

2.2.2 Measures to capture carbon by planting trees, protecting and restoring habitats and soil

The second set of measures is focused on increasing carbon storage in soils, through planting trees or shrubs to enlarge hedgerows, increasing woodland on farms, capturing carbon through improved soil management, and restoring peatlands and wetlands, which emit GHGs when drained. This carbon storage, also known as carbon sequestration, stores atmospheric carbon dioxide in a long-term reservoir[22]. Improving the carbon capture potential of soils and vegetation could deliver GHG savings of 5 $MtCO_2e$ annually[1].

- **Carbon dioxide can be captured from the air by planting more trees on farms, and on suitable land in hedgerows, forests and woodlands.**

  The current area of hedgerows on farms in the UK is around 120,000 hectares. Creating more and larger hedgerows can deliver enhanced carbon sequestration in biomass and soils[23]. Untrimmed hedges (with a mean height of 3.5m, and width of 2.6–4.2m), can contain an above ground biomass carbon stock of 42.0 tons of carbon per hectare; managing hedges to make them wider and taller increased this stored carbon[24]. Agroforestry is the purposeful growing of crops and/or animals with trees for a variety of benefits and services[25], including carbon sequestration.

  Increasing the number of trees on farmland, while maintaining the primary use as agricultural land, could deliver a further 6 $MtCO_2e$ savings by 2050, in addition to benefits from practising agroforestry, including harvested wood for energy or construction. Increasing UK forestry cover from 13% to at least 17% by 2050 (an additional 30,000 hectares or more of broadleaf and conifer woodland each year), and improved woodland management could capture 14 $MtCO_2e$ in forests, with an additional 14 $MtCO_2e$ from harvested materials by 2050[1, 4].

  Planting hedgerows and woodlands can, in addition to reducing GHG emissions, result in many benefits for farming productivity and local infrastructure and people, including habitat creation for biodiversity, flood protection, and improved air quality, depending on tree species and location. Woodlands can also bring recreational benefits for local communities, and increased tree cover in agricultural land could improve animal welfare by providing shade for livestock on hot days[1]; this is important as the temperatures and frequency of dry, hot days are projected to increase in the UK under future climate change scenarios[26]. Increased shelter could also be provided by trees in inclement weather (See Box 2.2).

- **Net emissions can be reduced by conserving existing soil organic carbon stocks and restoring carbon stocks in depleted soils.**

When land is deforested, soils lose their source of organic carbon from leaf litter, and are more exposed to increasing temperatures. Carbon levels in these soils are then depleted when soil organic matter is decomposed by natural processes. When these soil organic carbon stocks are not replenished or conserved, this results in GHG/carbon emissions. There are numerous pathways to prevent emissions from degraded soils, including forest and grassland conservation, reforestation, cover cropping, adding trees to croplands, preventing land conversion to new agricultural land, and restoring peatland and coastal wetlands.

There are several carbon storage options that can be pursued without changes in land use. Modifying grazing intensity and adding legumes to pastures can be adopted by farms with grazing livestock. These practices are considered to have multiple co-benefits, do not require additional land area, have minimal water footprints and are readily deployable, considering that they do not require changes in land use[3, 5, 27].

On arable farms, the options include increased use of cover crops and, where conditions allow, the introduction of no-till and intermediate-level tillage, which can also help to conserve soil organic carbon stocks (See Box 2.3). This

Box 2.2 Viewpoints from the farm: shelter belting and forestry.

Featured Farm: J & AJ Smith, Kintyre, Scotland
For Scottish dairy farmer John Smith, shelter belting with trees is a measure that may prove to be important not only for improving the access of livestock to fresh grass through the year with extended grazing, which has benefits for soil organic matter and animal welfare. Tree shelter belts could also complement agricultural activities, with the added benefit of sequestering carbon. This could work well in areas that are less suitable for pasture, including hillsides. Mr Smith says,

> "[With shelterbelts], when the wind comes and the heavy rain comes, sheep and cattle would get shelter. Trees provide an enormous amount of actual heat themselves, [in addition to] warmth and shelter for livestock."

Recognising the significant challenge and issues surrounding the conversion of farmland to woodland, including in places and terrain like Scotland, is key to understanding how land can be sustainably managed toward Net Zero goals. Mr Smith says,

> "We need to get forestry complementing farming,"

Box 2.3 Viewpoints from the farm: Minimum and no-tillage arable farming

Featured farms: Wheatsheaf Farming Company and Newhouse Farm Partnership, Hampshire
In Hampshire, both Newhouse Farm manager Andy Bason and Wheatsheaf Farming Company farm manager David Miller both practice lower (or no-) tillage systems for their arable crops. They say that this system of conservation tillage has many benefits, including for cropland biodiversity and reaching climate goals. Mr Miller says,

> "Regenerative agriculture [is] looking at the environmental ways of growing things. It's a real win-win for everybody, you know, whether we talk to water companies, whether we talk to environmental groups, wildlife groups, you know, for everybody what we're doing ticks a massive number of boxes."

Mr Bason adds that the shift to conservation tillage has led to reduced fuel consumption, and better coping with wet seasons and the clay soil of their area. More on Newhouse Farm is found in Section 4 as a case study.

has benefits because lower tillage can result in higher soil organic carbon levels in the upper soil layers, which can reduce costs for nitrogen applications due to increased fertiliser efficiency for crops[28].

Organic farm practices are also known for the benefits they bring to soil organic matter and soil biology. Organic farming practices also decrease use of farm inputs and thus emissions, and to an extent can increase soil carbon sequestration[29–31].
Sheffield Organic Growers director Huw Evans says,

> "Most of the area that I cultivate through Sheffield Organic Growers is top fruit, so it's areas that are not ploughed, it's not tilled. Those areas haven't been ploughed for more than ten years, probably twelve years now. The whole of the main orchard is all permanent planting, and I'm hoping to manage it so that it's building up its levels of soil organic matter."

- **Carbon can be captured from the air (i.e. negative emissions) by improving the management of forests to make them more productive.**

This can be achieved by introducing sustainable management practices, such as enabling young and better-quality trees to thrive, which can allow for increased carbon sequestration. Improving the yields of new woodland can also increase the volume and quality of the harvested wood in addition to captured carbon. Improved varieties through genetic breeding for suitable trees can also boost productivity. Enhancing good practices and sustainable forestry measures can also increase resilience to wind, fire, pests and diseases, and to climate change[4].

- **Carbon can be captured from the air by planting bioenergy crops such as Miscanthus.**

Planting perennial energy crops like Miscanthus and short-rotation coppice (e.g. willows and poplars) on farmland can help soils capture more carbon, in addition to the potential benefits of diversifying farm crops. Once Miscanthus and other energy crops are established, there is little requirement to apply fertiliser, thus also avoiding nitrous oxide emissions[4]. Measures such as planting bioenergy crops result in saleable crops and so allow for participation in the bioeconomy where market conditions are sufficiently attractive.

- **Carbon can be captured from the air by restoring and protecting peatlands.**

Peatland and wetland restoration could potentially deliver up to 3 MtCO_2e of avoided emissions each year[1]. Restoring at least 50% of upland peat, including large areas of blanket bog, and 25% of lowland peat would reduce annual peatland emissions by 5 MtCO_2e by 2050[4]. There are important differences between upland and lowland peat: lowland peat on cropland and grassland, for example in Eastern England, accounts for only 14% of the peatland area in the UK but is responsible for 56% of peat emissions. Emissions are between 30-39 tCO_2e per hectare compared to upland emissions of around 3tCO_2e per hectare.

Restoration and management practices include seasonal re-wetting to raise the water table in the winter months when

Box 2.4 Viewpoints from the farm: Technological innovations in farming

Featured Farm: Pollybell Farm, Doncaster, South Yorkshire
Pollybell Farm is one of the UK's largest growers of organic vegetables and cereals. It is a diverse family-owned farm business that grows organic produce (carrots, parsnips, and other green vegetables), organic grains, which are used as feed for their organic livestock on over 5000 acres. Over the last few years they have built a packhouse for the vegetable produce that they grow on the farm. Their lamb business finishes ~6000 organic lambs a year. Director James Brown is at the forefront of agricultural innovation following organic principles. Mr Brown has founded Earth Rover, a new company based at the Agricultural Engineering Precision Innovation (Agri-Epi) Centre, at Harper Adams in Shropshire and also in Barcelona, where its aim is to make chemical-free fresh produce the new norm. Their pioneering ideas include an autonomous LightWeeder (patent pending) which kills weeds with light from a rechargeable battery powered by solar panels charged with on-farm renewables. They also have a trial vertical farm powered by their floating solar panels. Additionally, as they have peaty soils, they have started trials on rewetting land on an initial 50 acres, and have installed a flux tower on existing rotational farm land to monitor the GHG emissions so they have a base line for the changes they are making to land use.


Floating solar panels at Pollybell Farm. Photo from James Brown.

there are no cultivated crops and taking off unproductive trees, which can allow for degraded peat to recover. Overall, restoring peatlands also benefits air and water quality, creates habitat for biodiversity, and can protect against flood risks due to extreme weather events, which will become more frequent with climate change[4, 5, 26].

2.2.3 Measures that shift agriculture towards renewable energy and bioenergy

The last set of actions are focused on boosting the use and generation of renewable energy in farms and participating in the bio-economy through a variety of ways. Improving energy use efficiency can increase both economic and environmental sustainability by decreasing energy costs alongside decreasing GHG emissions, particularly when other sustainable practices are adopted[32].

- **GHG emissions can be reduced by generating and/or utilising renewable energy on-farm, including bioenergy generated from farm waste.**

  Previously, investments in generating energy from solar panels or wind farms were supported through the UK Government's feed-in tariffs scheme. Although this scheme has now been ended, there remain great benefits to generating renewable energy to support one's own farm activities, and reduce a farm's carbon footprint while reducing GHG emissions across the sector (See Box 2.4). Shifting from fossil fuels in UK farms to land-based renewables could deliver GHG savings of up to 3 $MtCO_2e$ every year[4]. New ways of combining solar panels with crop production are being developed and multiple land uses of this kind could have a greater role in the longer term.

- **Carbon can be captured by growing bioenergy crops, which can contribute to energy needs on the farm, increase crop diversity and income, and help prevent soil organic carbon loss.**

  Bioenergy crops can be grown to produce plant material for bioenergy. Bioenergy crops have the capacity to produce large volumes of biomass with high energy potential and contribute to increasing soil organic carbon by replenishing organic matter and reducing soil exposure. Important examples include switchgrass, poplar, and willow[33], as well as crop residues and wastes. Bioenergy can also use local biomass resources, increase local energy security, and reduce energy transmission losses. Perennial bioenergy crops are another option that may be better than annual crops in a range of conditions, for example if they can be successfully cultivated in more marginal areas of farmland, where soil fertility is low and water availability is limited, because of their higher yield potential and lower input requirements[34].

2.3 Promising future options to reduce emissions and increase capture of GHGs

Ultimately, achieving the ambitious goals of Net Zero 2050 in the UK will require the coordination of successful efforts across many different sectors and the general public. The measures outlined above, along with others not elaborated here, describe some of the steps that can be taken by farms in the immediate and short-term. However, this is a fast-changing field and significant contributions to GHG emission reductions and other environmental improvements could come from other sources, especially over a longer timescale. These include both new technologies and more structural changes within agriculture and beyond the farm gate.

These measures, called "further ambition" options by the CCC, include deeper emission cuts achieved by shifting farm machinery's power sources away from fossil fuels, reducing the share of emission-intensive foods like meat or dairy in human diets, and reducing food waste. The CCC estimates that implementing these options for agriculture, land use and forestry accompanied by action on the consumer side, would lead to emission reductions of 24 $MtCO_2e$ in 2050, or approximately half of 2018 emission estimates (46 $MtCO_2e$)[1, 4]. (See Tables A1-A2 for assumptions related to these estimates).

- **GHG emissions can be reduced by changing diets to reduce intake of carbon-intensive foods like meat and dairy.**

  Reducing consumption of the most carbon-intensive foods (beef, lamb and dairy) by at least 20% per person and reducing food waste by 20% would reduce annual on-farm emissions by 7 $MtCO_2e$ by 2050 according to the CCC[4]. A healthy diet should have an appropriate caloric intake and consist of a diversity of plant-based foods, low amounts of animal source foods, unsaturated rather than saturated fats, and small amounts of refined grains, highly processed foods, and added sugars[35]. Changing diets can have significant impacts on the resources used to produce food, including reducing the amount of agricultural land needed[4, 5], in addition to the individual and community health and nutrition gains when shifts are made towards healthier choices[35]. Changes in domestic diets are likely to have an impact on UK food production and its carbon footprint, but the relationship between consumption and production patterns is complicated by food trade flows in and out of the UK.

- **GHG emissions can be reduced and GHGs captured by shifting land use away from crop cultivation or livestock and releasing land for other uses.**

  Measures such as increasing farm productivity, resource use efficiency, or reducing livestock density can also shift land away from agriculture, making it available for other uses and ecosystems. This has great potential benefits for biodiversity and restoration when habitat can be created. Deep emissions reductions within the UK can be achieved by releasing agricultural land for other uses, even while maintaining current per capita food production[4]. In the future, because climate change is projected to negatively affect crop yields, including UK wheat[36], agriculture will also be forced to adapt to changes in productivity. This means that the way that agricultural land is used is likely to shift because of climate change, including shifts to farming intensity due to changes in water availability, for example. However, it is important to note that shifting land use or reducing livestock density is only effective if these activities are simply not shifted elsewhere ("carbon leakage"), for example through importing food via international trade.

- **GHG emissions can be reduced by reducing food waste.**

  Reducing food waste and increasing the uptake of renewable energy will help reduce emissions from the sector further. Currently, 25–30% of total food produced is lost or wasted globally[5]. A significant share of agricultural land is used for growing food that ends up being thrown away, either at the farm level, along the storage and distribution chain, or in catering and households. In the UK, an analysis of 15 fruit, vegetable and meat commodities showed waste at different stages of food processing, from grading to retail[37]. A significant proportion of this wasted food would still be edible or sellable.

  The large wastage of food equates to around 10 million tonnes of food thrown away every year in the UK, with 70% of this (14% of a UK consumer's weekly shop on food) being binned within households, associated with more than 25 Mt GHG emissions[1, 38]. This gives great scope for reducing emissions from both producer (pre-farm gate) and retail/consumer (post-farm gate) interventions.

- **In the future, many other technologies may become available to make deeper GHG emission cuts in the agricultural sector.**

  Some further options are closely related to improved animal genetics, further changes to human diets away from ruminant (beef, lamb) meat and dairy, and even higher reduction of food waste across the food supply chain. Other promising options include the use of biochar, which is treated biomass that is resistant to decomposition when mixed with soil[1]. When added to soil, it could also deliver GHG savings of up to 2.5 $MtCO_2e$ every year in the UK, or 0.7 $GtCO_2e$ globally per year[4, 39], in addition to enhancing soil quality and fertility. Compared to other carbon capture technologies such as direct air capture and enhanced weathering, which are still currently prohibitive in cost and accessibility, soil carbon sequestration and biochar have useful negative emission potential and they potentially have lower impact on land, water use, nutrients, albedo, energy requirement and cost. Biochar can be used without competing for potential agricultural or forestry land, although some land may be required to grow biomass feedstock for biochar[39]. However, its widespread application and use is still under development.

  Other future technologies include negative emission technologies, which seek to directly remove and capture carbon from the atmosphere. Bioenergy with carbon capture and storage (BECCS) is the process of producing energy from organic matter and capturing and storing the carbon produced. A recent analysis simulated that a 500MW BECCS plant in the UK would on average require 2.33 Mt of biomass to generate 2.99 $MtCO_2$ of negative emissions and 3.72 TWh of electricity[40]. Fuel sources for bioenergy generation can be crops and their residues, either directly or after conversion to fuels such as ethanol or diesel. Whilst these will still release carbon when combusted, the crops have absorbed the carbon dioxide from the air, rather than from fossil fuels[11]. In principle, therefore, and depending on how the crops are grown, bioenergy can be close to neutral in terms of carbon emissions, and net negative if the emissions from burning it are captured and stored.

  Nonetheless, the net benefits of bioenergy-based technologies need to be demonstrated, taking account of lifecycle carbon emissions and withdrawals. At present, there are still many uncertainties into how BECCS can be implemented effectively on a large scale, including around concerns that land needed for dedicated BECCS feedstocks may come into conflict with biodiversity and other land uses, and that costs are still currently prohibitive[41].

2.4 Section conclusion

A great number of measures exist with the potential to reduce the net emissions of GHGs from the agricultural sector, and a number of them have already been adopted in farms across the UK. In many cases the options can also offer several important added benefits for farms, including improving farm productivity and diversifying farm income through energy generation. Well-implemented measures should also result in environmental benefits in addition to reducing the emissions that cause climate change, including for biodiversity, soil health, and other ecosystem services that can help to protect against extreme weather, floods and climate change. However, it is also important to look at sustainability from the business perspective. Net Zero needs to be pursued in the context of commercial viability and sustainability for the industry as a whole.

As farmer Dan Burling says,

> "We still have to produce food, but there's no reason we can't produce it at Net Zero. It just needs a balance in the system and people need to talk about productivity and sustainability in the same breath as they talk about Net Zero.
>
> And sustainability [must be considered] from a business point of view as well, because if we all go out of business as a result of having to do all those measures, then all we're doing effectively is then offshoring food production."

There are several challenges also related to the uptake of these measures, including their cost. Whilst some approaches will be easily adopted, others need to be applied on a large scale, and there is the question of how to determine which are most appropriate for the large diversity of farms in the UK. Certain options need further development, and others would benefit from demonstration at a larger scale before they are promoted to the mainstream. More research is required to understand the full impact of many less-developed measures, including the potential for unintended consequences. Some options and specific technologies will be attractive because of their appeal to retailers and consumers, or because they qualify for grant schemes in addition to their technical potential.

If consumers switch to supporting diets lower in meat and dairy consumption, policy makers need to be cognisant of how these changes will impact livelihoods in the sector, and how support can be offered to these sectors to adapt to these shifts. As noted already, it is important to recognise that UK agriculture is part of a global food system. It would not be sensible for the sector to achieve Net Zero by adopting measures that reduce GHG emissions while relying on international food imports from regions producing the same products, especially if they had a greater environmental footprint. Not only would this be detrimental for UK businesses, this "carbon leakage" would contribute to GHG emissions from the added food miles of imported products, and contribute to environmental impacts in regions where food production may not meet the high standards for animal welfare and food production of the UK, and increase emissions elsewhere, in some cases by the conversion of new land to agriculture[1, 6, 42–45]. In order to be implemented well and avoid actions that could cause harm, many of these measures will require knowledge, policy and funding support. The next section will discuss the relevant policies related to the transition to Net Zero.

3. Policy development and future considerations

3.1 Introduction

To meet the national commitment to reach Net Zero by 2050, contributions will be required from all sectors and all parts of the country, although not in a uniform way nor at the same pace. In some sectors, such as electricity supply, a considerable range of policies already are in place to drive decarbonisation, whilst in others, including agriculture and land use, Net Zero policies are developing rather more gradually, with big steps still to come. In most parts of the UK, the aim is to meet Net Zero by 2050, but in Scotland, an earlier date of 2045 has been set[1]. Programmes to meet these targets are emerging, with many similarities but also some differences between the four UK countries.

In this section, policies being developed to support Net Zero are discussed: considering first the general directions of policy development, followed by a review of key national and farm-level support, focusing on the transition away from direct payments and the Common Agricultural Policy; support for woodland; and other land management. We also review the policy directions in the devolved governments and critically examine other policies in progress that may become significant in the future, on the road towards Net Zero in 2050.

3.2 Development of policy to support Net Zero

In the coming years, new generations of policy contributing to the goal of Net Zero will be put in place. One group of these policies will be aimed specifically at agriculture, forestry, peatland and other forms of land use in the countryside (Table 3.1). Another group of policies will have a broader scope, setting out national decarbonisation strategies, energy policy or routes to reduce food waste (Table 3.2). These may also include policies seeking to influence behaviours, including dietary choices in the UK, for example with possible reductions in meat and dairy consumption; this will affect future markets for food.

These Government plans are supplemented and informed by the work of influential advisory bodies, notably the Climate Change Committee (CCC). The CCC sets future carbon budgets for all parts of the UK, and draws on a variety of scenarios to propose roadmaps for different sectors of the economy including agriculture and land use.

Table 3.1. Areas of potential change in the policies related to agriculture and land use.

1. Policies directly supporting agriculture and land management	These policies will have fresh objectives now that the UK has left the EU and is pivoting towards support for the provision of environmental public goods, including climate mitigation and adaptation. In England, these policies, such as the Environmental Land Management Scheme (ELM), will flow from the new legal structure and objectives set out in the Agriculture Act[2].
2. Aid for key types of investments on farms, including equipment, buildings, water and waste management	Existing aid schemes in the four UK countries are evolving, and the trend to focus more on climate- related objectives can be expected to continue.
3. Accompanying incentives for changing land use	Incentives for activities such as tree planting or altering land management, for example by re-wetting peatland and restoring habitats, with the aim of increasing carbon sequestration and reducing emissions (See Section 2 of this report). The current range of incentives for planting trees may be reinforced in order to meet national targets. In England, the current rate of planting is below target, as recognised in the most recent review of progress in implementing the 25 Year Environment Plan[3]. A new system of “Biodiversity Offsetting” for England is being introduced within the Environment Bill, which is expected to become law in 2021[4]. The impact of commercial and residential development will be offset by habitat creation or management schemes on private land, for which land managers will be paid. Whilst not a climate-focused policy per se, accompanying benefits for carbon sequestration may arise.
4. Regulations affecting farming practice and land use	Policy changes related to the use of fertilisers may develop, as recommended by the Climate Change Committee, for example[5].
5. Advice and technical support available to farmers	Resources and support for farmers will need to change to help in adjusting to more demanding environmental objectives, including Net Zero.

Table 3.2. Areas of potential change in broader policy related to Net Zero.

1. Strategic national emission reduction plans that affect agriculture and other land uses.	Recent examples include the Government's "Ten Point Plan" on the Green Industrial Revolution[6], which takes steps beyond the 2017 blueprint for building a low carbon future in Britain, known as the "Clean Growth Strategy"[7]. Amongst other things, this includes a commitment to set up a stronger domestic carbon offset market. A stream of policies related to decarbonising the economy is expected in 2021.
2. Policies setting out plans for meeting climate and renewable energy targets in different parts of the UK, including carbon pricing policies and incentives for making investments in new technologies.	These policies will influence the scale and focus of investment in renewables and other technologies that can be deployed on farms, such as energy crops, other forms of biomass, photovoltaic arrays and anaerobic digestors. They will also affect the scale of demand for biomass of different kinds. The Department for Business, Energy and Industrial Strategy (BEIS) Bioenergy Strategy dating from 2012[9], due for renewal in 2022, is particularly relevant to the agriculture sector.
3. Changes in regulations linked to climate objectives	These policies include, for example, those related to the energy efficiency of buildings and equipment, GHG emissions from machinery, and waste disposal methods. These regulations are likely to be introduced over time and some will have impacts on farm businesses, even if they are not aimed at agriculture specifically. They can be expected to increase the supply of electric vehicles suitable for farm use for example.
4. Other policies providing funding for rural areas, enterprises and communities	These include policies such as those stemming from previous EU funds, which are due to be replaced by a new - but currently delayed - UK "Shared Prosperity Fund".
5. Policies to stimulate new markets for reducing carbon emissions	These could make carbon removal from the atmosphere, for example by tree planting or enlarging hedges, more attractive to farmers. The Woodland Carbon Guarantee Scheme, with a budget of £50 million is an example. Markets for carbon removal and the provision of other new services from land are developing, with private companies paying to offset their emissions through private tree-planting schemes for example. Further public sector schemes or rules may emerge in this area as well.

Figure 3.1 Key policies for Net Zero in UK agriculture

These groups of policies are relevant as they will help to shape the role of agriculture in contributing to Net Zero, and thus the content and rate of introduction of more targeted agricultural policies. Both sets of policies will influence the choices open to farmers in the coming decades and the support they will get. A selection of these policies applying or being developed in different parts of the UK is shown in Figure 3.1.

Of particular interest is a key report on the future of land use in the UK[5], which has attracted a lot of attention. This fed in to the CCC Sixth Carbon Budget running to 2035, which was published in December 2020[8]. This Carbon Budget proposes a 78% cut in UK emissions relative to 1990 by 2035 and a transformation of agriculture and use of farmland while retaining the same level of food production. It envisages 435,000 hectares of new mixed woodland and 260,00 hectares of energy crops on arable land by 2035. This could be achieved only with the introduction of suitable policy drivers relatively quickly.

The development of most of the policies to support the Net Zero objective in agriculture in the UK outside England will take place according to priorities established by the devolved authorities, which are responsible for agricultural and environmental policies. For example, a consultation on what will be Northern Ireland's first ever Climate Change Bill was launched in December 2020[10]. The EU framework that has had a primary role in shaping national policy in this area for several decades no longer applies. Whilst EU regulations have been carried over into domestic legislation, more departures from the policy status quo can be expected in the coming years, together with greater differences between the four administrations within the UK. The process of establishing new domestic models and levels of farm support, as well as the tailoring of established legislation to national priorities is now underway. These changes will take place alongside the expected pivot to Net Zero.

These concurrent changes make the future of policy and legislation affecting agriculture more fluid and harder to predict than usual. It is a period of transition and there are many measures under discussion or in the pipeline that have not yet emerged. Farmers and other land managers will need to be alert to developments and ready to assess how these affect their businesses and alter the opportunities open to them. They also have ideas to contribute.

3.3 Key national policies at a time of change

While there is a national target to reach Net Zero, there is no specific target for the agriculture or wider land use sector to meet in the UK at the moment. However, the private sector is active on this front. As noted previously, the NFU has voluntarily put forward a target towards Net Zero by 2040 in England and Wales. Several companies in the food chain are also adopting their own targets, which are likely to have implications for their suppliers. For example, Sainsbury's has committed to make its business and operations Net Zero by 2040 and will ask its suppliers for "their own carbon reduction commitments"[11]. Other retailers, including Tesco and Morrisons, have targets with clear implications for their agricultural supply chains.

Even without binding targets, agriculture and land use are recognised as an important sector in Government strategies for decarbonisation. For example, the current Clean Growth Strategy setting out the Government's approach to the climate challenge, published in 2017, included amongst its key policies and proposals to "design a new system of future agricultural support to focus on delivering better environmental outcomes, including addressing climate change more directly"[7].

Other areas of active policy development that will affect agriculture include bioenergy, food and trade. The NFU proposals for meeting Net Zero[12] give a very large role to bioenergy production in the set of measures envisaged including bioenergy with carbon capture and storage (BECCS). It remains to be seen how far the Government is prepared to support this kind of investment at scale. An Energy White Paper, "Powering our Net Zero future" was published in December 2020[13], confirming that BEIS is reviewing its 2012 Bioenergy Strategy. In 2021, BEIS is calling for evidence on appropriate mechanisms for supporting greenhouse gas

Box 3.1. Perspective from a farmer on the need for transformation.

James Brown, Pollybell Farm
While there is still uncertainty about how incentives and new regulations will come in, there is also the opportunity to investigate new approaches, such as how an innovative carbon tax might make the industry take the carbon challenge seriously. James Brown says:

> "Rather than having a value-added tax, every business that adds carbon [should] have to pay a tax, and you reclaim it in the same way that VAT works, as you pass it down the supply chain. Because that way you account for the negative externality that is carbon."

Box 3.2. Perspective from a farmer on animal welfare and food imports.

Dan Burling, Burling Brothers Limited
The UK has high farm animal welfare standards and a firm commitment to Net Zero. If Net Zero is pursued as a singular goal without looking at the bigger international food trade picture, there is a risk that "carbon leakage" can occur, with demand being met with imported food, not necessarily held to the same standards as UK agriculture. Dan Burling says,

> "We can go down the Net Zero route but if it means that productivity disappears off the chart, all it means is we end up having to import a load of beef from another country that will have different ways of producing and won't be trying to be Net Zero. So, all you're doing is exporting your environmental issues."

removal, including BECCS, to inform a new Biomass Strategy to be published in 2022, as recommended by the CCC.

Work is also in progress on the development of a National Food Strategy. Current detailed examination of the food system led by Henry Dimbleby, the independent lead of a review exercise, is expected to lead to a government White Paper in due course[14]. This is likely to tackle issues related to agricultural sustainability and a lower-carbon food system, as well as the health and social aspects of food consumption and production. Farmers need to be prepared for continued discussion of dietary questions and the climate footprint of ruminant meat and other foods, even if the Government does not seek to influence dietary choices more than it does today.

The UK now has an active national trade policy outside the EU and is negotiating Free Trade Agreements with a number of countries, including the USA, Australia and New Zealand, which are all significant agricultural exporters. This has raised questions about whether the UK will agree to import food produced to lower environmental standards than those applying in the UK and whether imports could cause a loss of market share for domestic producers. Some producers are concerned that if the UK adopts an ambitious approach on climate change, it may lead farmers to face unfair competition from overseas producers with lower standards. The Government has set up a Trade and Agriculture Commission to consider standards and related issues which will report in 2021, but this is unlikely to be the last word on a complex and sensitive issue.

However great the uncertainties, Net Zero clearly is permeating an increasing range of policies bearing on agriculture and food. This underlines the importance of readiness for changing markets and regulatory environments in the farming community. Farmers will be looking closely at the changing menu of support schemes to see how far they can be utilised to help meet the new challenges. In the following section, key policies related to farm-level support are presented and discussed.

3.4 Key policies related to farm-level support

At the farm level, a new generation of support schemes is due to come into place in stages from 2021 onwards. A first step in this direction is the Agriculture Act, which received Royal Assent on 11th November 2020. It sets out the powers that ministers will have to support agriculture in the future outside the CAP, and applies mainly to England. Future payments enabled by the Act should be directed at either a) support for farmers and other land managers providing "public goods", most of which are environmental, or b) strengthening agricultural, forestry or horticultural productivity. The Act is the foundation stone for specific new policies that will be set out in due course (most likely in Statutory Instruments) but it also specifies that the current system of direct payments will be phased out over a 7-year period. As defined in the Act, the concept of public goods applies to "managing land, water or livestock to mitigate or adapt to climate change". Also, within the definition of public goods is action to protect or improve soil and to provide protection from natural hazards, such as floods. Land managed for forestry and horticulture is fully in scope as a public good. This means that the focus of support will not be confined to agriculture.

3.4.1 Making the transition from direct payments

The transition from the current reliance on direct payments to public goods schemes in England will start in 2021, as mapped out in a recent policy paper from Defra entitled "The Path to Sustainable Farming: An Agricultural Transition Plan 2021 to 2024"[15].

During this period:

- Basic Payment Scheme (BPS) payments will be reduced in steps to about half their present value by 2024, and the option of a lump sum exit payment as an alternative introduced.
- Existing agri-environment schemes will continue to 2023. Farmers will be able to apply for new Countryside Stewardship Scheme agreements up to 2023 and there will be an effort to attract more farmers into the scheme in 2022/2023 as BPS payments fall.
- Following the introduction in 2021 of the Pilot for the new ELM aiming to involve around 5,500 land managers, the main scheme will be introduced in stages. The lowest tier (i.e. the least demanding for the land manager) will be known as the "Sustainable Farming Incentive", commencing in 2022. Payment rates, management requirements and other details are not yet available. The initial options for farmers to choose from are expected to cover a range of familiar forms of environmentally focused farm management, such as the care of hedgerows, integrated pest management and improved soil health. From autumn 2024 the scheme will be expanded and fully rolled out with nine expected options for farmers. These will include actions related to soil and nutrient management, tree and woodland management and livestock management.
- In 2024, the next two tiers of ELM will be introduced. "Local Nature Recovery" will address a range of primarily local issues, including natural flood management, the restoration of a range of habitats, including woodlands and wetlands, rights of way and education infrastructure. Eventually this will take over from the current Countryside Stewardship Scheme. The top tier, "Landscape Recovery" aims to deliver larger and longer-term permanent changes in land use in targeted localities, which may include a number of different land managers. The themes will include the restoration of peatlands, woodlands, coastal habitats and other ecosystems. A successful scheme embodying the right incentives could be particularly significant in moving towards the sizeable changes in land use indicated by the CCC.
- It is not divulged how the ELM payment rates will be calculated or how large they will be, which makes it difficult to assess how attractive they will be to farmers and other land managers. Many of the options involve forms of management that will contribute in broad terms to reducing

the carbon footprint of farms, but no dedicated emissions reduction option is highlighted at this stage.

- There are also new planned capital grant schemes[15]. From the autumn of 2021, a new Farming Investment Fund will be launched, within which there will be two separate spending lines, one of which will be the "Farming Equipment and Technology Fund".

3.4.2 Support for establishing and managing woodland

Policies and support related to the establishment and management of woodland are also going through a period of change. For example, there was a recent government consultation on an England Tree Strategy linked to the new £640 million Nature for Climate Fund. A number of grant schemes are in place for planting trees in different parts of the UK. One of the more novel approaches is the "Woodland Carbon Guarantee Scheme"[23] launched by the Forestry Commission and Defra in 2019. This does not provide a capital grant for planting, which potentially is available under other schemes. Instead, it gives the owner of the new woodland the chance to sell "woodland carbon units" to the Government for a fixed price determined by an auction, for a period of up to 35 years. This provides an income stream of a kind generally not available from woodland. This adds to other schemes such as the established Woodland Creation Grant (within Countryside Stewardship) and the ELM scheme Pilot on this topic. Some synchronisation or greater rationalisation of schemes seems likely.

However, there is little doubt that action is needed to accelerate the rather slow rate of progress in meeting the target of planting 30,000 ha of new woodland in England by 2025. Only 7,220 ha of woodland were planted in England between 2016 and 2020. Progress is faster in Scotland, but in all four countries there is increasing emphasis on tree planting and peatland restoration. In Northern Ireland, the least wooded part of the UK, with only around 8% of tree cover, the environment minister announced in 2020 that the annual rate of planting must increase in line with the recommendations of the CCC[24]. This will mean that the rate of planting increases from the current 200 hectares per annum to 900, creating 9000 hectares of new woodland over a decade. One of the obstacles to larger-scale tree planting in the UK has been limitations in the supplies of suitable native trees, with nurseries being affected by the current COVID-19 pandemic. This is being addressed through a new aid scheme for nurseries launched in 2020.

3.4.3 Other support for land management

Alongside the new environmentally focused schemes such as ELM and the declining direct payments, there will continue to be other forms of support for land management. One of the most important for progress towards Net Zero is the aid for investment in approved equipment, buildings and infrastructure in farm and forestry businesses. Currently Defra runs a 'Countryside Productivity Small Grants Scheme' in England[16]. This offers up to 40% of the costs of a range of approved investments, in areas including improved nutrient management, animal health and welfare, and improved resource efficiency; and has had a budget of around £60 million over three successive rounds. Its successor from autumn 2021 will be a new "Farming Equipment and Technology Fund", based on the current Scheme and offering grants towards the costs of a specified list of eligible items.

In addition, from the same date, there will be a new Farm Transformation Fund, offering grants towards the cost of larger investments in equipment, infrastructure, and technology; which might include equipment for precision agriculture and new water storage facilities on farms, for example. Additionally, there will be a dedicated "Slurry Investment Scheme" for a limited period from 2022 onwards, that will cover part of the cost of new slurry stores or covers for existing stores, against the background of the legal requirement for farms to have a storage capacity large enough to accommodate the volume arising over six months[17].

3.5 Policy directions in Wales, Scotland and Northern Ireland

The general direction of policy development in Wales is similar to developments in England, with both the BPS and the separate funding schemes for rural development due to be replaced by a new single direct support scheme for farming, the proposed "Sustainable Farming Scheme". This will also take time to be phased in as signalled in the Agriculture (Wales) White Paper in late 2020. Consultation will be followed by primary legislation to underpin the new Welsh support schemes in due course. The new scheme will reward farmers for producing "non-market" goods, including improved soils and actions to reduce global warming. It would be surprising if the important role of sheep farming in Wales was not reflected in the eventual policy design, especially given uncertainties arising from the significant dependence of the sector on exports of lambs to the EU.

Decisions on future policy in Northern Ireland have been hampered by the absence of the Assembly for a period up to January 2020 and other factors such as the pandemic, but the planning process is underway.

In Scotland, the current CAP model of agricultural support, including BPS, is being retained for longer, with only relatively small modifications up until 2024, based on a new legal foundation: The Agriculture (retained EU law and Data) (Scotland) Act. The Climate Change Plan Update of December 2020[18] updates the previous plan running to 2032 and foresees emissions falling by 75% relative to 1990 by 2030. There are considerable implications for the agriculture and land use sector. The "envelope" for agricultural emissions falls from 7MtCO_2e in 2020 to 5.3 in 2032. The rate of new woodland creation is to increase from the current 12,000 ha per annum to 18,000 ha, so that 21% of Scotland is forested by 2032. Policy to achieve these new targets is being developed in partnership with the farm sector, and farmers are playing a pivotal role in a series of groups that have been set up to analyse options and report back with proposals in 2021. These include the "Beef Suckler Climate Group", which has a leading role. Early policy proposals are expected to be focused on revisiting the current environmental conditions on agricultural support payments, and considering how they could help to drive appropriate action at farm level given the increasing urgency of the climate requirements.

It is unclear how far policy will change and whether there will be as strong a pivot to environmental public goods as in England and Wales. The political arguments for remaining more aligned to the CAP (which itself is changing) are more prominent in Scotland, especially in the governing Scottish National Party (SNP), which envisages Scotland becoming a full and independent member of the EU in the future.

There is a strong interest in the use of farm carbon audits in Scotland. Farmers and crofters can apply to the Scottish Farm Advisory Service to receive support of up to £500 to commission an experienced agricultural consultant to carry out a carbon audit. Such audits are recommended on an annual basis. For one support scheme, the Beef Efficiency Scheme, an audit is required for all those farms participating. Many farmers believe that carbon audits will be required in future, not only to access grants but also to operate as a commercial producer.

Capital grant schemes also are distinctive in Scotland. In February 2020, an "Agricultural Transformation Programme" was announced, with a £40 million budget to help farmers with actions to reduce GHG emissions and restore habitats[19]. As part of this, a pilot 'Sustainable Agriculture Capital Grant Scheme'[20] was offered for a period in autumn 2020, offering capital grants for effective farm investments in this sphere, attracting a good level of farmer interest and uptake.

3.6 Schemes and budgets in development

Targeted aid schemes aimed at both farm productivity improvement and better environmental management are likely to continue, and potentially be expanded over time, with potential for more regional or local initiatives alongside the national schemes. Current agri-environment schemes, such as

Box 3.3. Farmer perspective on what will be asked from farmers in future.

John Smith, J & AJ Smith

> "My own personal view is that everyone will have to actually have a carbon audit on the farm. So, you start as a baseline, what is the carbon audit. If you're farming, then a calculation [is] done, a nutrient budget – how you use that and how effective it is. If you are an emitter of methane or other [GHGs]… or you're not a net sequesterer, you score possibly even a budget. Going forward, you might even get a quota. That will start determining the behaviour that you need to do as targets are moved and agricultural support comes in."

Box 3.4. Perspective from a farmer on ELM scheme and small growers.

Huw Evans, Sheffield Organic Growers

Sheffield Organic Growers' director, Huw Evans, is part of an ELM scheme pilot of 40 growers (horticulturalists) to work out how the ELM scheme could best be disseminated to growers around the country. As part of this group, Mr Evans is excited at the possibility of small farms being eligible for public money by providing public goods. In his case, it would be from carbon sequestration and supporting biodiversity with his organic farmland on the outer limits of the city of Sheffield. However, there is still a lot of uncertainty.

> "I'm aware that carbon sequestration is one of the public goods that might be part of the new ELM scheme […] if we're already doing things that sequester carbon or we could change our practices to do more of it, then that might be something that we could be financially supported for in the future. Now, at the moment we don't get any financial support at all from the farming budget because we're just a little bit too small. We're just under five hectares, so we're below the threshold of any support. I asked the [organizer] and they said that Defra wouldn't be having a project like this with lots of small growers unless they thought there was going to be support for that size of farm… but nobody's sure about that."

Countryside Stewardship in England and the Environmental Farming Scheme in Northern Ireland, both partly funded through the CAP, continue for the moment, although they may be closed in some parts of the country during this period of uncertainty arising from the pandemic and budgetary concerns. In England, ELM will take over their role over a period of years. However, it is not yet clear how far the new generation of public goods support measures will rely on well-established models, such as annual area-based payments to farmers for complying with specified farm management practices. There could be a greater role for more novel approaches, such as payments related strictly to measured environmental results.

The "test and trial" schemes running in England at the moment illustrate a wide range of possibilities. In summer 2020, there were 57 of these being supported by Defra on themes such as spatial prioritisation, the role of advice and guidance, mechanisms to support collaboration and different approaches to deciding on payments. One of many observations in the progress report published in July was that "The importance of facilitation, advice and guidance is coming through strongly across all the themes, as is capacity building"[21]. This is surely a key message for policy makers to take up as they develop schemes. Opportunities to extend the scope of schemes also are emerging from these trials (See Box 3.4).

Now that the UK is outside the CAP, the level of expenditure on support for agriculture, currently around £3.5 billion annually in the UK[22], will become much less easy to forecast than it has been for decades. In the short term, there is some stability since the Government has committed to retain overall annual agricultural expenditure at the current level until the end of this Parliament in 2024. Beyond this, however, there is no guarantee of the level of support for agriculture. Given the removal of the constraints of EU budget setting within the UK and multiple pressures on public expenditure, many assume that spending on agriculture may decline. As part of the Agriculture Act, the government has committed to giving information about the expected use of its funding powers for at least the next five years ahead, starting with a 7-year multi-annual financial assistance plan from 2021. However, it is difficult to forecast exactly what this will amount to and how the scale of need for public goods and increased farm productivity will be assessed. Establishing the scale of need for helping farmers towards the Net Zero transition would be a valuable input into the process of determining future support budgets.

3.7 Discussion: looking ahead

The coming generation of agricultural policies will be much more focused on environmental outcomes, with climate mitigation measures an important element but not the sole concern. Actions which benefit not only the climate but also biodiversity, the control of flooding, reduction of water pollution and other goals will be of particular interest to policy makers. Whilst some measures will focus specifically on woodland or the restoration of habitats such as peatland, the divide between agricultural and forestry policy, fairly pronounced under the CAP, is becoming less relevant. Indeed, the need to both reduce emissions and capture carbon on a substantial scale underlines the value of a more integrated approach, considering different types of land use and vegetation in a more integrated way.

This opens new ways of thinking and the potential to combine intensive, very low input, traditional and innovative forms of management in interlocking landscapes with complementary roles. This could occur on larger units such as Pollybell Farm (See Farm Profiles in Annex) or through more co-operative initiatives bringing several different farms together. Larger scale changes in land management often will be easier to achieve on bigger farms and estates with greater resources and more options. It will be important to ensure that support

Box 3.5. Perspective from a farmer on the need to know why change is needed.

David Miller, Wheatsheaf Farming Company

"I think there's a temptation from the new Agricultural Act that they will, with our ELM schemes, they will come along and they will stipulate that people must no-till, they must grow cover crops. Elements of what we're doing will almost become compulsory for them to receive money, which I think would be totally counterproductive. Because there's a lot of people that would do it to get a payment, but, (a), they wouldn't understand what they were doing; and (b), they probably wouldn't be that interested in whether it worked or not, as long as they were getting the money in the other hand. I think inevitably, there's got to be change; by the very nature of what ELM schemes are going to try and achieve, people are going to have to change. I think it's just a danger that people will change for the sake of having that cheque put in the bank and not because of understanding what they're doing."

for smaller farms and tenanted holdings is well designed and implemented.

Farmers will need to become more efficient as the BPS is phased out. New support schemes to help the shift towards Net Zero should be put in place, but will sit alongside considerable pressure on farmers to adopt lower-carbon measures from retailers, processors, certification bodies and others in the food supply chain. Given the business case for increasing efficiency and lowering resource use on farms, it is not clear that aid from the public purse for these important but more intermediate steps will be justifiable for very long in terms of the value obtained by taxpayers. The case for concentrating public money on actions with a large environmental benefit but negligible commercial return will be strong. Governments also have an interest in expanding the role of private sector funding schemes, such as new carbon markets and catchment management schemes run by water companies, aiming for environmental gain with less public expenditure. Over time the focus of publicly funded schemes may be expected to adapt to a greater role for market-based transactions contributing to the attainment of Net Zero.

Policy support for more environmental land management can be expected to diverge more between the four UK countries, but in each case is likely to include a combination of:

- Annual payments for providing a stream of public goods.
- Selective capital grant schemes, some highly focused (including for establishing woodland, for habitat restoration and for the deployment of innovative technologies).
- Payments geared to proven environmental results, rather than simply adherence to agreed practices. Payments for building soil carbon would be an interesting prospect if it became possible to measure results sufficiently reliably.
- Incentives for training, adopting tools such as carbon audits and planners, participation in joint projects.
- As well as accompanying measures such as improved research, information and advice for famers, more experimentation and pilot schemes, there could be an increased use of facilitators and consultants, aid for farm-to-farm networking, and related initiatives.

The extent to which new rural development policies will be introduced in succession to those available under the CAP, such as aid for participative local multi-actor rural development projects under the umbrella of the EU LEADER programme, is less clear.

It would be logical to develop schemes giving greater priority to management practices that contribute to both emissions reductions and carbon capture, including soil protection and improvement. This could increase the emphasis on cover crops, changes in rotation, alterations in fertiliser selection and use, and measures that benefit both the climate and other aspects of the environment, such as improved nutrient management. However, there could be some tension between relatively prescriptive measures that insist on adherence to specified practices in order to qualify for payments and an approach that leaves management choices more to farmers. Many farmers are wary of too much stipulation and wonder whether it will lead to the best outcome.

On the other hand, there is a wide consensus that to be able to reward farmers for reducing emissions and improving sequestration, whether through policy or via market arrangements, it is necessary to be able to measure what is being achieved. Hence there needs to be a focus on improving metrics and measurement, and encouragement of farmers to take up carbon management tools or calculators, as many are already doing. Experience with these tools should help farmers to gauge their performance, their future management choices, and the kind of incentive schemes that may suit them best (See Section 4.4).

This raises questions about whether the use of specific carbon calculator tools will be encouraged through policy initiatives, and whether farmers will be offered payment for using tools, or be expected to do so at their own expense. New skills will be required to operate emerging technologies, and training allowed for. At the same time, buyers of agricultural products in the food chain are developing their own requirements for produce that is compatible with their own emission reduction pledges and they may encourage or even require the use of particular metrics and carbon calculators. Standardising metrics and methodologies and avoiding unnecessary conflicts between policy and market requirements will be important (See Section 4 for further discussion).

3.8 Section conclusion

Whilst there are many unanswered questions related to policy development and support, there is little doubt about the direction of policy related to agriculture and Net Zero. Since the scale of long-term support for agriculture in the UK through public funds is somewhat uncertain, farmers should give serious consideration to making use of those schemes that are available in the coming years if they suit the farm circumstances and plans. Delaying participation to a future date could be risky.

In assessing the value of the different incentives and support schemes on offer, farmers will have an eye on both the shorter-term transition and the longer-term implications for their land and enterprises. For example, those with poorer arable or grassland may be most interested in evaluating the extent to which they might benefit from a switch to a more extensive system or a major change in land use, depending on their own goals and the alternatives open to them. The transition towards Net Zero is likely to take place in a series of progressive steps rather than a giant leap.

4. Practical considerations towards Net Zero in UK agriculture

4.1 Introduction

In this section, we synthesise some of the practical knowledge that the farmers we interviewed have shared into ten points of guidance. While the approach on individual farms varied and reflected their specific conditions, these general guidelines emerged as common factors in enabling these farmers to make significant strides towards reducing their emissions on-farm while maintaining their productivity and profitability. These steps have helped them to prepare and adapt to the current challenges that the UK agricultural sector is facing. While a one-size-fits-all approach would not be helpful for the diverse sectors and farms in the UK, there are common measures that may aid in the transition towards Net Zero if they are adapted to individual farm needs. In this section, we also present a review of potential timelines related to the transition, associated costs and benefits, and a brief case study of an arable farm in Hampshire: Newhouse Farm Partnership.

Making the transition to Net Zero agriculture will require expert and practical knowledge, sufficient resources, including time devoted to management, stronger alignment with food markets and a wide range support for farmers and for the sector overall. In the future, what is available in terms of government funding and policy support, in England via ELM and the Agriculture Act, will become clearer. In the meantime, pursuing Net Zero can bring many benefits to farms and place them in an advantageous position to be resilient to both policy and environmental changes, and to longer-term market demands.

4.2 Ten guidelines for transitioning agriculture towards Net Zero

1. Gather and organise data from farm activities; measurement is critical.

- Measuring and setting a baseline for the relevant aspects of the farm, including its operations, main outputs, environmental impacts, and GHG emissions, is essential in determining a plan towards Net Zero. This includes gathering and organising information and data on the quantity and cost of inputs and outputs, measuring key parameters such as soil carbon and creating estimates of on-farm carbon balances with a carbon toolkit or calculator.
- Choosing a calculator that suits the needs of the farm and instils confidence in the farmer is critical, as decisions will be made on the basis of the results estimated by the calculator.
- Accounting for GHG emissions should help in identifying their largest source(s) on the farm and the appropriate measures to reduce them. In the future, having robust accounts might become essential to access external resources and support.
- Pollybell Farm Director James Brown said:

> “If you can’t measure it, you can’t manage it. And if you can manage it, you can improve it.” Many other farmers interviewed expressed the same sentiments.

2. See Net Zero not as the primary end goal, but as an important contribution to larger goals.

- Many of the measures that reduce GHG emissions also save costs and enhance productivity, so they contribute to profitability and improve longer-term sustainability, both for the business and the environment. Pursuing Net Zero is pursuing greater efficiency and long-term farm sustainability.
- For many of the farmers we interviewed, Net Zero is an achievable goal along the way towards improving their business and adapting to multiple changes in the market and society more generally. For many it is not the end goal, but rather it contributes to their own personal goals and aspirations for their farm.
- Arable farmer David Miller says,

> “It’s that combination of benefits. So, we’re helping wildlife, we’re helping the environment, we’re helping the water companies, the Clean Air Act and everything else.”

- As policy is changing fast, reducing GHG emissions is not only becoming good farming practice in environmental terms, but also may become a prerequisite for accessing future support for agricultural investment and land management, including ELM and other successors to Basic Payments. It is likely that these schemes will require proof of greater environmental responsibility and compliance.

- Retailers are already requiring more demanding environmental standards. Amongst others, this is occurring in the dairy sector, for example with Arla 360 contracts and retailers including Waitrose, Morrison's, Aldi and Sainsbury's setting out Net Zero commitments and expecting their suppliers to make a significant contribution to this. Many customers are also increasingly interested not only in sustainability more generally but in the carbon footprints of the food that they buy.

- Scottish Dairy farmer John Smith says,

> "Some of the major milk buyers have actually banned or certainly put severe restrictions on the use of soya in some of the dairy diets as part of an agenda to be greener". This is the indeed the case for retailer Marks & Spencer (M&S Food), as part of their commitment to end deforestation1.

3. Seek expert advice.

- The challenge of making the transition to Net Zero can be daunting. However, much of the knowledge and technology to make significant progress is already accessible. Personalised expert advice and group workshops (currently online due to the COVID-19 restrictions) can connect farmers to industry leaders and forward-thinkers, as well as NFU/ Agriculture and Horticulture Development Board (AHDB)/ or Farm Cluster leaders who can provide guidance and technical support.

4. Joining peer-to-peer learning groups can provide a wealth of practical experience.

- Getting 'boots dirty' and visiting fellow farmers was greatly valued by the farmers spoken to. Sharing knowledge and best practices among peers who have been successful in reducing emissions or implementing measures is invaluable. In addition, sharing information on setbacks and 'failures', which are bound to be encountered, contributes to learning in the sector, and to support the UK agricultural community through this period of change.

- In a time of COVID-19 restrictions, this aspect of socialisation and learning is missed. However, online workshops and webinars have been helpful to maintain momentum. The return of face-to-face meetings is eagerly awaited by everyone in the community.

- For many, social media (e.g. Twitter) is also a great new way to see what is being done and to stay connected or be inspired.

- David Miller says:

> "We have various groups we belong to on WhatsApp and other platforms, where we talk about a lot the things we're doing and we compare notes. I think the real way to get farmers to adopt some of these things is by experience. If somebody with a suit on comes along and tells them they've got to do something, or if they go to a farm and look at somebody who's doing it and it's working, that's chalk and cheese … farmer-to-farmer education is a massive thing compared to anything else."

5. Focus on soil health.

- Soil health is at the heart of agriculture, and the sustainable management of soil is a cross-cutting issue across most farms in the UK. Farmers interviewed in a range of sectors all emphasised soil health, not only those in arable but also producers of fruits and vegetables, livestock, and dairy specialists.

- Replenishing and maintaining soil organic matter has multiple benefits: less fertiliser use, reduced net GHG emissions by capturing carbon, and promotion of greater biodiversity. This has been wholly embraced by the organic community, but conventional farms can also adopt a range of practices to bring benefits and protect this limited natural resource. Getting started on regular soil monitoring is one of the first steps to be taken on farms that have not done this previously.

- Organic grower Huw Evans said,

> "All organic growers and farmers are interested to try to build up a level of soil organic matter, because [of] better water retention, greater accessibility of nutrients for plants."

6. Be prepared to accept some risk and initial losses, learn from trial-and-error, and go out of comfort zones.

- Some changes require being prepared to incur some initial short-term losses with a shift to less intensive practices, e.g., min-till and conservation agriculture. However, greater benefits can be enjoyed in the long-term, and initial yield losses are gained back with persistence.

- Larger changes in practice have a significant role alongside systematic improvements in efficiency. These can entail more risk and readiness to learn, to accept less predictable outcomes and sometimes to make significant investments for example in new equipment. Initial choices may need fine tuning. However, there are often some immediate benefits to be enjoyed, such as lower costs from reduced inputs and smaller machinery, less fuel use for example in conservation agriculture, or amenity benefits from new woodland.

7. Accept that measurable change takes time and effort; be consistent.

- While different measures may require different financial investment levels, an overlooked type of investment is time. It takes time to implement change, and to see the benefits of changes made to farm practices, for example from building up organic matter, and recovering costs, or indeed, influencing others in policy and industry to support change.

- Consistency is key: “You have to stick with it and not dip out after the first two years,” says Andy Bason.

8. Work with nature, for nature.

- By adopting measures that help to enrich habitats and landscapes, such as expanding hedgerows, adopting less-intensive tillage measures, and improving the management of woodland or peatland, there can be benefits for productive agriculture. These can help to diversify the farm business through tourism and education, for example. Most of the farmers we spoke to were active in some form of diversification.

- Conservation grazing for livestock, for example, in partnership with the RSPB as Dan Burling has done, brings positive benefits to nature, as well as for the livestock itself[2, 3]. Compared to other livestock, grazing with cattle can lead to a greater diversity of habitats that support important species such as wading birds[4].

- Ultimately, achieving Net Zero will benefit nature by reducing GHG emissions, resource use and intensity, and supporting biodiversity. Healthy ecosystems are essential for healthy and productive agricultural activities. Pollination, flood protection, and natural pest control are among the ecosystem services that benefit farming.

- David Miller says,

> “We are creating greater biodiversity within those cover crops […] by having a cover crop in a field we’re giving this biodiversity a habitat for an extra six, seven months a year. So, we decided to start measuring that and we’re having pitfall traps and it’s absolutely fascinating, a lot of the things that we’re finding are actually predators to a lot of the things that we have assumed are pests.”

9. Technology is a crucial tool towards Net Zero.

- Advances in crop and animal breeding and in genetics are helping to produce livestock that have a lower resource or carbon footprint, and crops that are more resistant to drought or diseases. Undoubtedly, technological innovations will help achieve Net Zero for the sector, but adoption of the most appropriate technologies will depend on farm capacity. In some cases, obtaining the necessary financial support and practical knowledge can be initially challenging.

- For example, for Dan Burling, improvements in genetics and specifically in the heritable traits of feed efficiency of the Stabiliser cows have been a great benefit for his carbon-negative status; he argues that a shift away from looking at visible traits (phenotypes) towards genotypes will modernise the industry.

10. Recognise that there is a growing role for farmers as leaders and innovators.

- Farmers play a vital role in society, in environmental management as well as in food supply. They have a record of accepting the challenges of political, environmental, and social change, and they can do so again. UK agriculture, with its high standards for welfare and the environment, has taken up the climate challenge, not least through the pledge by the NFU and can become a model for other Net Zero sectors and the world. Those who are taking the lead need support from Government, lenders and their supply chain partners.

4.3 Timescale and scenarios for meeting targets in agriculture

There are several scenarios for the route to Net Zero in the agriculture and food sectors that represent the degree to which changes are made at farm level, and by consumers, and the timelines over which change needs to occur. This reflects different assumptions about the levels of ambition being adopted for the sector, the degree to which options such as bioenergy, including BECCS, are incentivised and taken up, the range of support and capacity that is mobilised within the UK’s devolved governments, as well as the time needed for emission abatement. Here, we review several key scenarios and associated timelines relevant for the sector, focusing on the recent Climate Change Commission (CCC) Sixth Carbon Budget and the accompanying CCC Net Zero Technical Report. The assumptions here are different from those in the National Farmers’ Union (NFU) plan to reach Net Zero by 2040. The CCC follows the timeline set by the Government to reach Net Zero by 2050. The higher ambition called for by the NFU includes a much larger role for bioenergy production alongside major improvements in farm level efficiency, and less dietary change. Meeting higher ambition also requires that the government and institutional support is in place at an earlier point in time compared to what has been proposed in terms of policy action towards 2050 (Figure 4.1).

Many of the policy measures required to meet Net Zero, such as support for the commercialisation of low-carbon vehicles, and policies to support the shift towards healthier and lower-carbon diets, have a longer timeline of proposed implementation compared to what may be needed to achieve Net Zero by 2040. Indeed, achieving Net Zero in the sector by 2040 will also require research and development support (the second and last points in Figure 4.1) for crops, livestock, trees, and energy crops to be well in place before 2040. Knowledge of these timelines is important, considering the shift away from the BPS and towards ELM. A national pilot scheme for ELM is targeted in 2021 before the full rollout in 2024 (Table 4.1). The early steps of policy change outlined in Figure 4.1 do not sufficiently show how this policy timeline will match up with the changes in farming support shown in Table 4.1. Therefore, a higher level of ambition and a shorter timescale of making these key decisions—to provide important financial support and resources for Net Zero before 2050 – are needed.

The CCC in its Sixth Carbon Budget report developed five different scenarios (or pathways) reflecting various levels of ambition for both the agriculture sector and the land use, land use change and forestry (LULUCF) sector, alongside different assumptions about accompanying changes on the demand side. (Table 4.2). These pathways reflect different rates of change in the various and related components of the food and agriculture system, including: behavioural change, which includes changes to demand via dietary changes; land release, low-carbon practices, and agricultural machinery.

Among these different pathways, the “Headwinds” reflects the lowest level of change while “Tailwinds” the highest, each aligning to different rates of adoption of change in “Widespread Engagement” (high behavioural change) or “Widespread Innovation” (high technological advancement). The “Balanced Net Zero” pathway has a higher level of behavioural change by consumers compared to the lowest level of ambition (Headwinds), but the same low ambition for changes at farm level in land release, low-carbon farming and machinery. This Balanced Net Zero pathway is used to show how a limited pace of action in the agriculture sector produces only a slightly better outcome than a business-as-usual approach (See the CCC report for the full list of related assumptions), but that adopting Tailwinds and with Widespread Innovation obtains the most reduction in emissions in both the agriculture and LULUCF sectors.

Following this “Balanced Net Zero” scenario, the timelines of abatement in agriculture and LULUCF, which are closely related, are shown in Figures 4.2 and 4.3. A comparison of all the different scenarios for agriculture is shown in Figures 4.4 and 4.5. These diagrams show that it is crucial that large-scale emission reductions and carbon removal both take place in parallel in a coordinated way. Without systematic sequestration efforts, including afforestation and peatland restoration, and other actions at farm level, emission reductions from agriculture, important though they are, will be insufficient. The agriculture sector actively needs to both reduce GHG emissions and implement measures that capture carbon, either through forestry or soil in the next decade to be able to contribute its share and to realise the benefits. It is key that the right incentives and policy instruments to enable farms to make this change are in place, which requires more clarity from Government about how it plans to develop and deploy the requisite policies in the coming decades.

Farmers need to know what is expected, the options open to them, and the level of support to be expected as far ahead as possible.

Many of the changes required, including afforestation, involve strategic choices along extended timescales. Alignment of strategies, technological and research efforts, timelines, and policies can help to ensure that the pathway to environmental and economic sustainability is well-mapped out for farmers and their customers. The preliminary stages of policy adjustment are being spelled out now, setting a different frame for the support of agriculture, but not yet unveiling major new incentives for decarbonisation (See Table 4.1).

Farms already need to start thinking about how well-prepared they are to participate in the ‘public money for public goods’ approach in ELM in the run-up to 2024, and need to begin implementing changes on-farm to reduce emissions, increase forested land where possible, and increase the carbon capture of soils and hedgerows, for example. Recognising differences in capacity in the implementation of these measures across farms is also important, as some will be pioneers while others may lag behind. However, the sector as a whole needs to begin the transition in a timely manner. At the same time, dietary change in the direction of more plant-based diets will also impact the farming sector, particularly livestock and dairy products, with implications for the meat industry. Early engagement in the process towards the transition to Net Zero is needed, with advantages in heading for the high- ambition Tailwinds scenario if the right support is in place (Figs. 4.4-4.5). In any case, ‘business-as-usual’ is not an option.

Figure 4.1 Proposed timeline of key decisions on appropriate policy and investment support toward Net Zero in UK agriculture and LULUCF sectors[5].

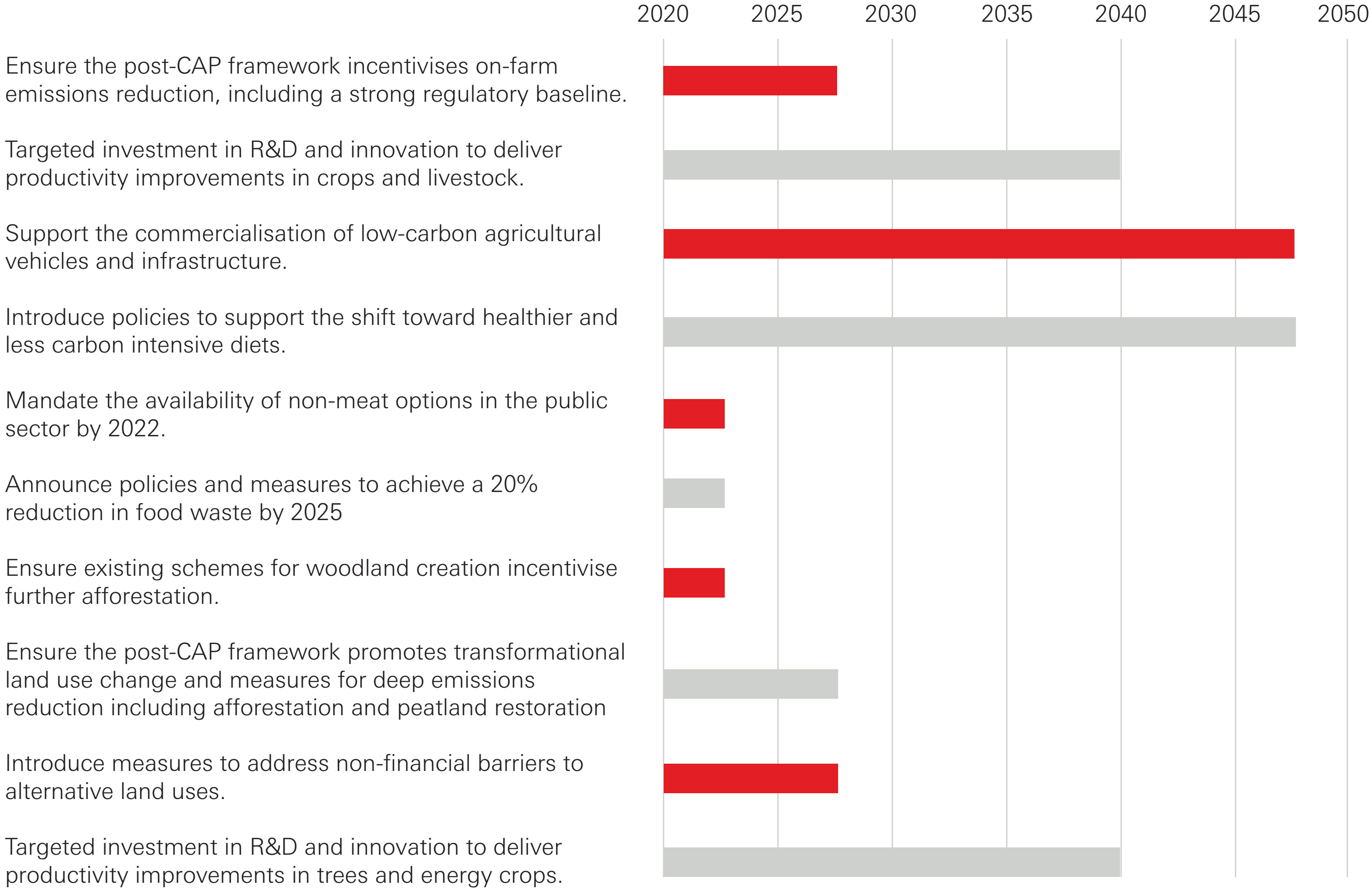


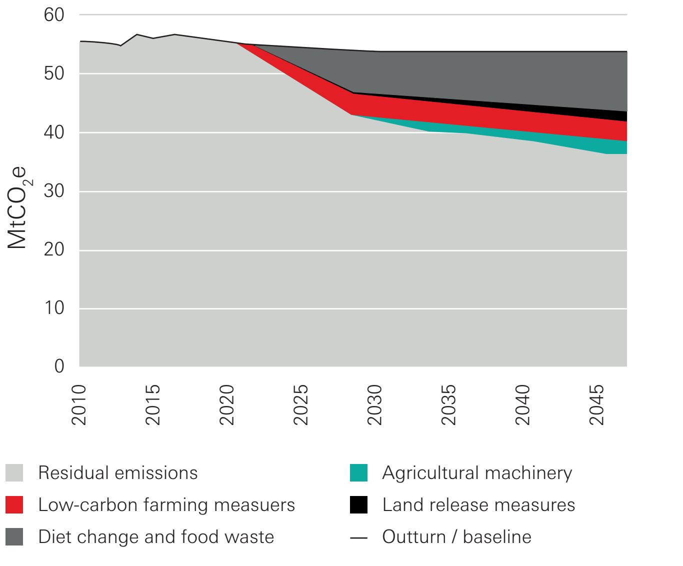
Table 4.1. Timeline of agricultural transition: Phaseout of BPS and toward ELM implementation[6].

Years	Direct Payments	Countryside Stewardship	Simplifying Basic Payments	Environmental Land Management (ELM)	Regulation and enforcement	Animal, plant health and animal welfare	Productivity	Innovation, research and development	Supply chain fairness
2021-2023	Start to phase out direct payments.	◆ Schemes will continue to be available. ◆ New schemes start in January 2021. ◆ Last year for applications to simplified Countryside Stewardship is 2023.	Further simplifications to be made for 2021 BPS.	◆ National pilot starts in 2021. ◆ First pilot module will begin late 2021.	◆ Simplifications for cross compliance start in 2021. ◆ Interim delivery model planned for 2022.	◆ Schemes for Animal Health to start from April 2022. ◆ Tree health grants launched alongside ELM in 2021.	Productivity grants available for application in 2021.	Scheme rolled out between 2021 and 2022.	◆ Introducing and enforcing statutory codes of practice from 2021 (for contracts between qualifying sellers and business purchasers). ◆ Introducing new domestic system for producer organisations from 2021.
2023-2027	◆ Reduction of payments will continue over the transition period. ◆ Percentages will increase during this time until the final payment is made or the 2027 scheme year.			ELM scheme officially launched (2024).	New regulatory model by 2024	Tree health grants to replace Countryside Stewardship by 2024.	Productivity grants continue.		

Table 4.2. Summary of key differences in the CCC Sixth Carbon Budget agriculture sector pathways[7].

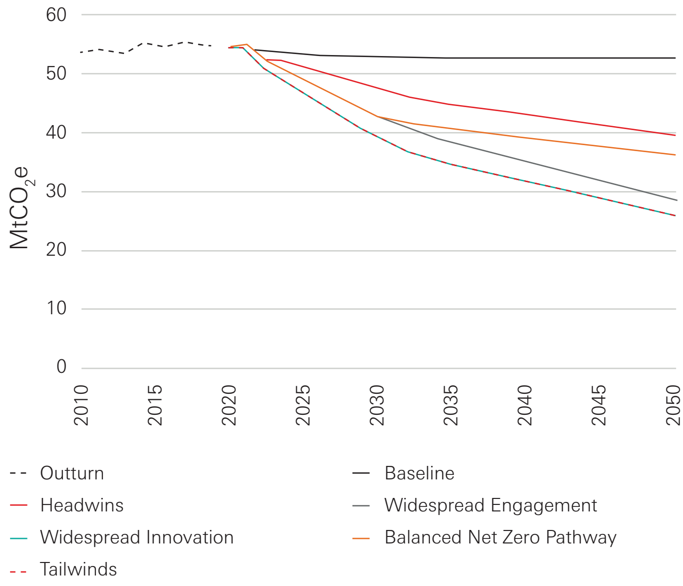
Measures / Scenarios	Balanced Net Zero	Headwinds	Widespread Engagement	Widespread Innovation	Tailwinds
Behaviour change and demand reduction	Medium level: 20% cut in meat and dairy by 2030, rising to 35% by 2050 for meat only. All replaced with plant-based; and Medium level: 50% cut in food waste by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

Figure 4.2 Sources of abatement in the UK agriculture sector, Balanced Net Zero scenario



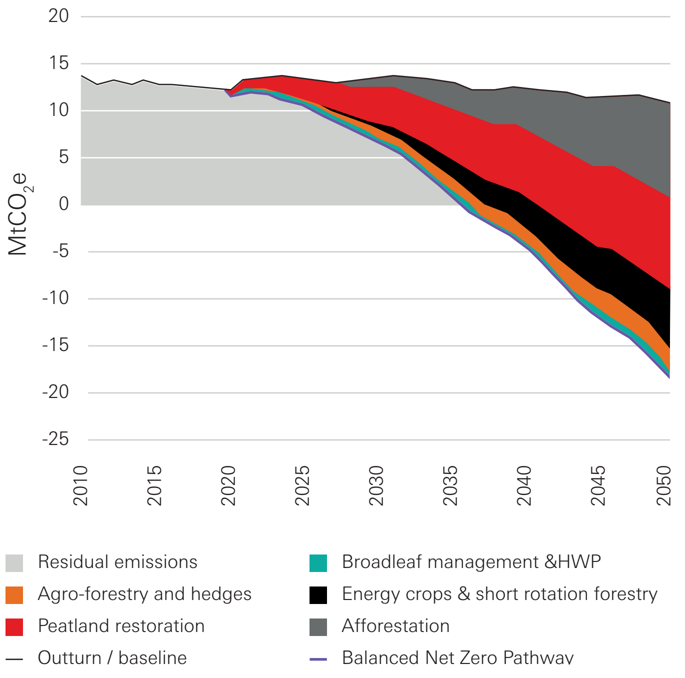
Source: BEIS (2020) Provisional UK Greenhouse gas emissions national statistics 2019; SRUC (2020); CCC analysis.

Figure 4.4 Emissions Pathways for the agriculture sector (CCC Sixth Carbon Budget)



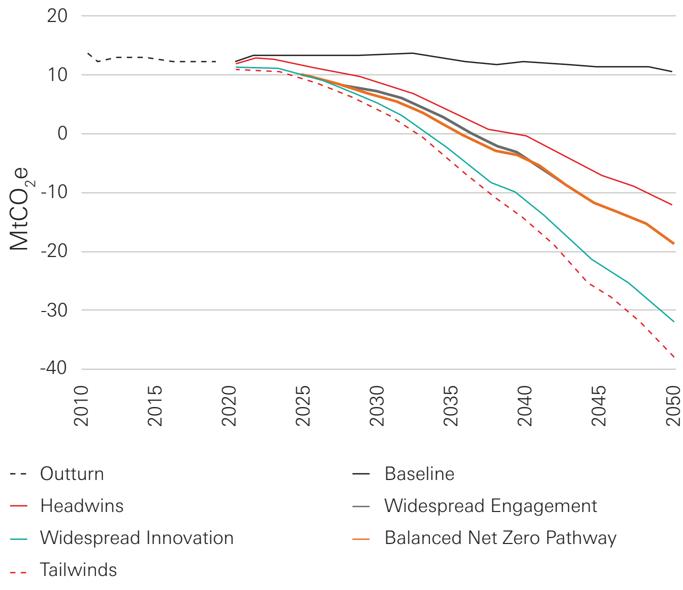
Source: BEIS (2020) Provisional UK Greenhouse gas emissions national statistics 2019; SRUC (2020); CCC analysis.

Figure 4.3 Sources of abatement in the UK LULUCF sector, Balanced Net Zero pathway



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

Figure 4.5 Emissions Pathways for the LULUCF sector (CCC Sixth Carbon Budget)



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

4.4 Standards for data and farm carbon calculators

The first of the ten guidelines presented here (section 4.2) deals with the importance of having accurate accounts of the sources of farm GHG emissions, estimates of their amount (e.g., in tons CO_2eq), sequestration activities, and estimates of how much carbon is captured by these activities (in tons CO_2eq). Within the industry, farm advisers, farmers and the supply chain agree that carbon calculators (or 'carbon audits') are an essential tool in moving to Net Zero. Cattle farmer Dan Burling says:

> "I think it's pretty much a fact that [...] what they will end up demanding is that you are measuring, [that] you are using some sort of carbon calculator."

In this regard, values need to be monitored over time in as consistent a way as possible. The value of having these figures is not only for the benefit of farms to have quantitative evidence of their carbon footprint, but also to monitor progress, costs and savings and the efficiency of measures for emission reduction or capture. Improvements and decisions can be made based on data, which can also inform the wider industry as improvements in technology continue. These accounts are also likely to be important going forward to provide evidence to obtain the benefits of support schemes, especially as they become more focused on incentivising environmental outcomes, including reduced emissions and increased sequestration. The accounting could also enable participation in schemes with climate-friendly (/low-carbon) labels on products. Moreover, if the data are robust and if adaptive measures are based on sound evidence, they should give farmers a sense of confidence that they can track whether their measures are "working", and how far they are progressing towards being carbon negative.

The choice of calculator is thus highly significant, especially in terms of its scientific credibility. While government and industry stop short of recommending an 'industry standard', there are several accessible and widely-used tools on web-based platforms, including the Cool Farm Tool and the Farm Carbon Toolkit, which have been mentioned by a number of the interviewed farmers. There are also more detailed carbon calculators which have met the high demand for data from farmers with specialised production, for example at Pollybell Farms, where they wanted more detailed life-cycle accounting tools because the off- the-shelf calculators did not meet their needs, as James Brown recounts:

> "There was a tenfold difference between the calculators that were off-the- shelf [...] When you put numbers into a calculator, what does it mean? And it's highlighted three or four calculators. Would I have gone and put my numbers into four different calculators? No, I wouldn't have done. [...] what it obviously did was it sparked an interest, which then made me want to learn more."

Dan Burling uses the Alltech's E-CO_2 carbon calculator, which differs from the other calculators in that it is aimed at livestock farmers, and is built around a Carbon Trust- accredited Environmental Assessment, which involves a farm visit for verification and support. The reports of significant differences in the estimates and accounts of various tools appear to present a strong case for setting standards for calculators, increasing the role of a single authority in validating the results and working urgently towards a higher level of consistency. For example, the widely-read Farmers Weekly recently assessed Agrecalc, Farm Carbon Toolkit, and Cool Farm Tool and identified various pros and cons for them[8]. In the scientific literature, an analysis using a model dataset for UK wheat found that the results from several farm carbon footprint tools showed large differences, mainly due to the way in which greenhouse gas emissions from fertiliser manufacture and application are accounted for. The tools designed for farm-based accounting achieved a higher 'user-friendliness' score compared to emissions calculators that had been developed for monitoring GHGs in the biofuel supply chain (but can be used up to the crop production stage). However, when applied for accounting for agriculture emissions, the bioenergy calculators performed better in the overall level of information provided, transparency, and the comprehensiveness of emission sources included in the calculations for arable crops[9].

Huw Evans says that although he obtained a "carbon negative" result for his farm with one calculator, he had to leave some options blank or make his best guesses for figures to input for his fruit and vegetable growing operation. For example, the calculator needed input on what areas are cultivated, or permanent grassland. In Sheffield Organic Growers' farmed area, they don't have dedicated grassland areas for their horticultural production, but they do have grassy areas they utilise for other things, such as compost.

This indicates that while farmers and growers know their inputs and outputs well, measuring "invisible" carbon requires trust in the tools, and the varying estimates and results from different calculators can have an impact on farmers' assessment and understanding of the Net Zero progress of their farms, as Andy Bason reflects in one of his comments:

> "I think if you look at the figures we've got here now and they look pretty good but are they actual? The figures that we know – the organic matter level, our inputs, fertilizers – these we know they're right. It's just whether the algorithm behind it is giving us the right figures, that's what I don't know."

It is key therefore that a balance be struck between usability and the level of detail and experience needed to run a carbon audit for one's farm. While having a diversity of tools- and specialised calculators for different sectors and businesses- allows tailoring to the needs of livestock or horticultural producers for example, there remain important questions about how these different tools will be used to provide evidence for carbon-based incentives in agriculture.

4.5 Costs and benefits

The cost of different measures, the relative cost-effectiveness of different options, and the means of financing them, are important considerations in the transition to Net Zero, even more so at a time of uncertainty on many fronts after Brexit and the shift away from Basic Payments. The costs of measures that can be implemented to reduce GHG emissions or increase carbon capture will vary not only according to the nature of the action required (with a great range reflecting the variety of farm types, management systems, and feasible alternatives) but also the situation of individual farms. It is logical to assess those options that are feasible and to choose those with the lowest cost, having considered associated impacts for example on output quality or marketability, or changes in biodiversity. A number of studies to evaluate the expected costs and benefits of different options in the agricultural sector have estimated the expected costs of different measures (often presented as a range) and the ratio between the cost of a measure to the amount of GHG emissions reduced or carbon captured.

A marginal abatement cost curve (MAC curve, Figure 4.6 and accompanying Table 4.3, recently updated by CCC in Table 4.4) can be useful in comparing the cost efficiency of several carbon reduction measures across the UK. It is not designed to be applied at the individual farm level, and the costs on specific farms may be rather different than those estimated in studies using aggregated data, as we confirmed when presenting the MAC curves below to our arable farmer (see case study). For more details and a full description of the methodology and assumptions related to these estimates, see the Sixth Carbon Budget Report (Agriculture), and the Scotland Rural College/Ricardo AEA report[7, 10]. MAC curves are broken into a series of blocks, which represent an individual measure that can reduce ('abate') carbon emissions (in tons CO_2e). The width of the block indicates the potential carbon emissions abatement of the measure, while the height indicates the marginal cost of the carbon emissions abatement (£/tCO_2e). In this way, the MAC curve shows measures with low cost (or cost savings, negative costs) towards the left of the graph while measures with high cost relative to emission reductions achieved are towards the right end of the MAC curve.

In principle, the most attractive measures would be those that provide high abatement potential at relatively low cost; this includes afforestation on agricultural land for example. However, there are some technologies that are costly but provide larger abatement potential: for example, the use of controlled-release fertilisers or anaerobic digesters. These are potentially worth further investigation by policymakers to establish how far it is worthwhile endeavouring to bring down costs or incentivise uptake in different ways. However, it is clear that, depending on the farm size, type, current sources of emissions, and available financial support or incentives, a suite of measures that are suitable for the farm are much more likely to be more useful than individual approaches alone.

On Newhouse Farm for example, attention to building soil carbon and increasing fuel efficiency matches well with their reasons for putting a low-tillage system in place. However, on the MAC curve these measures are towards the higher end of costs. Pollybell Farm also regarded improving the fuel efficiency of tractors and other equipment as worthwhile, although it is also not on the low-cost end of measures identified in Figure 4.6. Several measures, such as the planting of cover crops, may be desirable because of their benefits toward soil health; in reality, their actual costs may vary and be lower than shown in the MAC curve. It may be possible to establish successful cover crops with much less than the recommended seed per hectare, for example.

Some costs will vary greatly with the circumstances in each farm. The cost of establishing new woodland is much greater if new fencing is required at around £5000 per hectare for example and the scope for offsetting such costs with grants varies too. In the case of forestry, it has become easier to estimate the potential revenue from sequestration projects. The Woodland Carbon Guarantee scheme offers the prospect of more realistic returns for sequestered carbon in the view of consultants, with offers being made under the first two "rounds" of the scheme around £24 and then £19 per tonne of CO_2[11].

Figure 4.6 Marginal abatement cost curve for the UK (with interactions, CFP: Central Feasible Potential, d.r. : discount rate), using a 2030 carbon price of £78/t CO_2e[10].

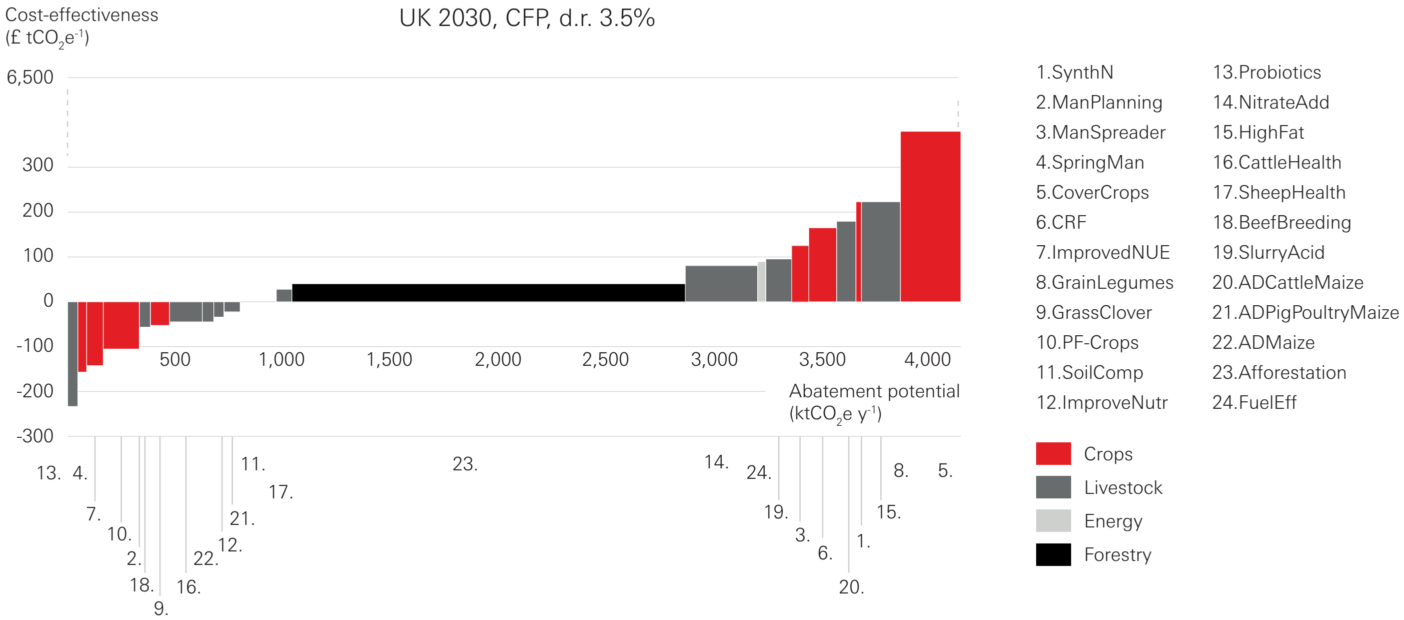


Table 4.3. Cost effectiveness of carbon mitigation measures versus their abatement potential, (with interactions, 2030, UK, Central Feasible Potential, discount rate 3.5%). The ID number refers to the bar in Figure 4.6.

Mitigation measure	ID (Fig. 4.6)	CE £ tCO_2e-1	AP $MtCO_2e$ y-1	Cumulative AP $MtCO_2e$ y-1
Probiotics as feed additive	13	-230	0.05	0.05
Shifting autumn manure application to spring	4	-155	0.03	0.08
Plant varieties with improved N-use efficiency	7	-139	0.08	0.16
Precision farming for crops	10	-108	0.17	0.33
Improving organic N planning	2	-107	0.01	0.34
Selection for balanced breeding goals in beef cattle	18	-52	0.05	0.38
Legume-grass mixtures	9	-49	0.08	0.47
Improving cattle health	16	-42	0.16	0.62
Anaerobic digestion: maize silage only	22	-41	0.06	0.69
Improving ruminant nutrition	12	-29	0.05	0.73
Anaerobic digestion: pig/poultry manure with maize silage	21	-19	0.07	0.80
Loosening compacted soils and preventing soil compaction	11	1	0.17	0.97
Improving sheep health	17	30	0.07	1.04
Afforestation on agricultural land	23	37	1.83	2.87
Nitrate as feed additive	14	82	0.33	3.20
Behavioural change in fuel efficiency of mobile machinery	24	90	0.03	3.23
Slurry acidification	19	96	0.12	3.35
Low emission manure spreading	3	126	0.07	3.44
Controlled release fertilisers	6	166	0.13	3.56
Anaerobic digestion: cattle slurry with maize silage	20	179	0.10	3.66
Improving synthetic N use	1	224	0.02	3.68
High fat diet for ruminants	15	225	0.18	3.85
Legumes in rotations	8	383	0.28	4.13
Catch and cover crops	5	6,408	0.00	4.13

Source: Adapted from Eory et al., 2015

Table 4.4. Abatement costs in agriculture and land use in 2035 (£/tCO_2e)[7].

	Measure	£/tCO_2e
Low carbon farming – crops	Cover crops	125
	Grass legumes mix	-1,040
Low carbon farming – livestock	Livestock breeding – current methods	-580
	Livestock breeding – low methane	-1,850
	Livestock breeding – genomics	-1,177
	Increased milking frequency	-850
	High sugar grasses	-415
	Precision livestock feeding	-15
	Adding nitrate to livestock diets	55
	3-NOP in livestock diets	85
	Improving sheep health	25
	Improving cattle health	-45
Waste and manure management	Cover slurry tanks	20
	Anaerobic digestion – pigs	-250
	Anaerobic digestion - cattle	-175
On-farm machinery	Stationary and mobile machinery	75
Land use measures	New conifer planting	65
	New broadleaved planting	105
	Miscanthus	180
	Short Rotation Forestry	240
	Silvoarable Agroforestry	155
	Silvopastoral Agroforestry	415
	Hedgerow Expansion	5
	Upland Peat Restoration	40
	Lowland Peat Restoration	5
	Woodland to Bog	30
	Short Rotation Coppice	-
	Broadleaf forestry management	150

4.6 Case Study: Newhouse Farm Partnership

Newhouse Farm in Hampshire is an 800ha, predominantly arable, family-owned farm. Andy Bason, the manager, has converted the arable operation to a mainly minimum-tillage system over a twenty-year period and started new enterprises, including raising a small flock of Texel sheep and harvesting wood to burn in three biomass boilers. Over the last five years, he has been monitoring the carbon footprint of the farm and using Farm Carbon Toolkit. For three years, Newhouse was an AHDB monitor farm and Mr Bason has become accustomed to recording and sharing data, as well as discussing the results.

Their data shows that the farm has become carbon negative as a result of their actions, particularly reductions in tillage and synthetic fertiliser inputs and also thanks to other savings in fuel use. There was a ~17% reduction in N fertiliser use between 2000 and 2020 with no loss of wheat yields. Fuel consumption fell by about 25%. Between 2015 and 2020, the tracker showed that soil organic matter increased by around 1%, making the farm net-carbon negative (Figure 4.7). This was better than expected, and the outcome underlined that the precision farming methods used on the farm and good management decisions do pay off.

Figure 4.7. Summary of improvements at Newhouse Farm that helped reduce carbon emissions or capture carbon.

17% reduction in Nitrogen fertiliser use: 0.71 t/ha to 0.59 t/ha (2000-2020)

1% increase in soil organic matter (2015-2020)

25% reduction in diesel consumption: 82 L/ha to 50 L/ha (2000-2020)

Soil management has been a priority during this period, with a gradual increase in the proportion of land under no till, changes to rotations, efficient use of tractor horsepower and other adjustments. The emphasis has been on fine-tuning and developing techniques that suit the heavy soils on the farm rather than adopting radical new systems. Management changes have been designed to address lower carbon alongside other goals such as lower input costs, the control of blackgrass and, recently, the demands of being a Linking Environment and Farming (LEAF) member and participant in its Resilient and Ready programme. The current minimum-tillage system has been refined over twenty years, with no major new investments required. While there was some reduction in yields initially, this was overcome and has not been a constraint in recent years. This approach is now central to the management of the farm as well as the soil. Mr Bason emphasises that the process of improvement needs to be constant, but much of it could be categorised as following good farming practice.

Thus far, the greatest investment in lowering the carbon footprint has been the time required to assemble the necessary data to feed the carbon tracker tool and the regular monitoring (six fields are subject to a regular soil sample and a full farm survey is done every five years). The initial set-up is the most demanding phase, but the support has helped too. For example, a change in the soil sampling company required different readings to be converted for a consistent result. A readiness to devote detailed attention to data collection and to apply the results is critical to the approach on this farm. So too is faith in the results from the tracker. The growth in soil carbon is not visible to the eye and, as this becomes a more important metric, potentially affecting future revenue from Defra support schemes as well, the extent of reliance on measurement and critical tools is growing. The results need to be robust and to be accepted externally. So far, they have won Mr Bason's confidence, but that cannot be taken for granted.

Mr Bason emphasises that decisions should be strongly guided by the conditions on the individual farm. For example, the question of whether to extend the area of no-tillage at Newhouse will depend on regular informed appraisals rather than a fixed plan. New projects, such as the establishment of a 10ha woodland and a possible agroforestry trial – inspired originally by a farm he visited in France – should help improve the carbon footprint, but that is not the only reason to try them. Well-chosen advice and networking with other farmers can be valuable even to someone with Mr Bason's experience.

> "There's not many meetings that I go to that I don't jot something down in my notebook,"

he says. On this farm, getting the right advice, support for survey work and data management as well as good back up for ELM schemes when they come, (rather than tick box forms), might be more attractive than help to buy new equipment which is less of an immediate priority. The Net Zero target requires significant future increases in soil carbon, but Bason is confident that recent achievements can be taken further.

4.7 Section conclusion

The practical advice offered here, reflecting the experience of a group of engaged farmers from different sub-sectors of agriculture, indicates that there is a group making good progress towards Net Zero across diverse farm types and sizes in the UK. However, as the review of costs, timelines and recent policy documents shows, there needs to be coordinated effort not only on the industry side, but also, importantly, from government and financial institutions – boosted by support and knowledge from fellow farmers, agricultural extension services, and academe – to support a just transition to Net Zero and to reach the high-level of ambition needed to transform the UK agricultural industry.

5. Future outlook and ways forward

In this report, we outlined some key information, shared perspectives from farmers, and offered insights into some of the practical challenges facing the UK agriculture sector in the road towards Net Zero. While there are considerable challenges, there are certainly many opportunities to improve both the carbon footprint and the overall sustainability of UK agriculture in the coming decade. Amidst this time of uncertainty and change – indeed, in the midst of the COVID-19 pandemic – giving greater importance to food systems is critical to ensure food security for the UK, protect the environment, and secure a form of livelihood that many depend on.

While future agricultural support and policy are still in development, this is not a sufficient reason to delay ambitious actions on farms, and in the wider food system and supply chain. As demonstrated by the experiences of the farmers interviewed, progress in reducing emissions by taking steps to become more efficient, monitoring change, and pushing for innovation is taking place on many farms, and new ideas are emerging. Net Zero is not an isolated objective to be detached from others applying to agriculture; it is one amongst other key milestones in the pathway to making UK agriculture sustainable, and resilient to current and future environmental challenges.

Farmers have an immense responsibility to provide safe, healthy, and nutritious food to families across the UK, while maintaining a high standard and reputation on the world market. This task should be supported by well-planned government and institutional support and sufficient resources to ensure the environmental and economic sustainability of farming. This includes an important role for effective agricultural extension services, research and academic bodies, and industry bodies like the NFU and AHDB. Aside from this, the importance of peer support must be stressed; it may be a determining factor in what inspires farmers to make change.

Amongst the farmers interviewed, there is a shared optimism that Net Zero can be achieved with the right knowledge and support. This optimism is needed not only to achieve Net Zero by 2050, but to proactively transform the sector and play a pivotal role in a sustainable and resilient food system for many decades to come.

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7. Report Annex

7.1 Tables

Table A1. Assumptions for agriculture sector reductions from the Climate Change Committee[1].

Assumption type	Description of adopted assumptions with key details
Baseline emissions to 2050	Based on Energy and Emissions Projections (EEP) by BEIS (published Jan 2018) and still based on the pre-Smart Inventory methodology. Year 2017 rebased to match out-turn emissions from 2019 GHG inventory, which is based on the Smart Inventory. Thereafter, apply the EEP trajectory to get the Business-as-usual (BAU) scenario for 2050.
Emissions from energy use by 2050 (stationary machinery)	Under Core, savings for energy efficiency was as per the 5th carbon budget (CB) analysis. Under Further Ambition, consistent with the non-residential sector more generally, fully decarbonise by switching residual natural gas to electricity (85% efficiency factor applied for TWh from gas to electricity).
Emissions from energy use by 2050 (mobile machinery)	No savings under Core scenario. Under Further Ambition scenario, consistent with off-road vehicles in industry more generally, 90% of emissions is decarbonised by switching to electric, hydrogen and use of robotics. 10% of BAU emissions from continued use of gas soil (diesel) remain by 2050. Use of biofuel is zero by 2050.
Non-CO_2 savings under Core scenario	The calculations are based on the following assumptions as follows: **1.** Keep 5th CB measures that fall within the GHG Action Plan and Clean Growth Strategy, and are resource-efficient options with low regrets. This means excluding three measures for the reasons given: crops with enhanced nitrogen use efficiency (imply developing new crop varieties); Triticale, which is a hybrid wheat; and slurry acidification, which has zero uptake at present. These three measures are moved into the Further Ambition scenario. **2.** Adopt a lower level of uptake for the Core measures (45% uptake rather than 85% used for the 5th CB). Lower uptake reflects the lack of policy in place to reduce emissions. **3.** Switching from 85% to 45% uptake would involve reducing abatement for crops by 20% and for livestock measures by 25% (based on conversation with SRUC). **4.** Retain the baseline abatement savings unchanged as this does not change with uptake. **5.** For nitrate additives and costs use the revised values calculated by the 2019 Scottish Rural College consultancy project. **6.** For the Devolved Administrations (DAs), calculate the savings based on their share of emissions for each of the main sources of agriculture emissions (soils, enteric, waste & manure management, machinery use)
Non-CO_2 savings under Further Ambition scenario	Calculations based on the higher uptake of the Core scenario measures and additional measures from 2019 SRUC project. The calculations are based on the following assumptions as follows: **1.** Scenario is based on the land area and livestock numbers under a multi- functional land use (MFLU) scenario from the CCC's 2018 Land Use report. This means agricultural land area and cattle and sheep numbers are less than under the BAU thus non-CO_2 emissions are less than the BAU. Thus, the emissions savings potential from the measures are reduced. **2.** Apply 75% uptake of Maximum Technical Potential (MTP) to Core measures and the three 5th CB measures excluded under Core (crops with enhanced nitrogen use efficiency, Triticale and slurry acidification). **3.** Add in cost-effective abatement from additional measures identified by 2019 Scottish Rural College work (75% uptake of MTP) **4.** For the devolved administrations, calculate the savings based on their share of emissions for each of the main sources of agricultural emissions (soils, enteric, waste & manure management, machinery use)
Behaviour change	For diet change and food waste reduction adopt the 'medium' level of ambition from the Land Use report: 20% reduction in beef, lamb and dairy by 2050; and 20% food waste reduction by 2025.

Table A2. Assumptions for land, land-use change and forestry sector reductions from the Climate Change Committee[1].

Assumption type	Description with key details
Baseline emissions to 2050	Based on the UK Centre for Ecology and Hydrology (CEH) business-as-usual projection developed for the CCC Land Use report, which includes all sources of peatland emissions. For forestry and settlements, the CEH emissions for 2017 were rebased to match the outturn emissions for that year based on the 2019 GHG inventory.
Emissions savings	Based on the Multi-Functional Land Use (MFLU) scenario from the Land use report, with the exception of forest management in which the CCC adopt a high level of ambition.
Peatland	Emissions based on the CEH work for the BEIS wetland supplement published April 2019. Unlike the CCC Land Use report, we use the higher peat number of 23 $MtCO_2e$ (rather than 18.5 $MtCO_2e$). As yet, no decision made as to what number will be used in the GHG inventory in future. Further Ambition: increase in peatland restoration from 25% of peat area to 55% (25% of lowland and 50% of upland restored)
Forestry (tree planting, yield improvement and management)	Tree-planting: Core apply the stated ambition of England and DAs (20,000ha/year 2020-2025 and 27,000ha/year >2025). Further Ambition scenario, 30,000ha/year. Yield improvement: FA scenario 10% increase in yield class for conifers and broadleafs. Forest management: 80% of broadleafs sustainably managed.
Hedges and agro-forestry	Core: agro-forestry 5th carbon budget estimate, based on 2% of agricultural land. Further Ambition scenario: agro-forestry on 10% of agricultural land; and hedges increased in length by 40%.
Energy crops	Further Ambition scenario only: Miscanthus, short-rotation forestry and short- rotation coppice planted on 0.7m ha of agricultural land by 2050.
Behaviour change	Agricultural land area released by diet change and the other measures based on the ‘medium’ level of ambition from the Land Use report.

7.2 Farmer and Farm Profiles

7.2.1 Andy Bason, Newhouse Farm Partnership, Hampshire

NEWHOUSE FARM

Photo from Andy Bason, Newhouse Farm Partnership.

Newhouse Farm comprises 800 hectares (2084 acres) of arable land, as well as some livestock in Hampshire. For cropping, they mainly farm wheat, barley, oilseed rape, beans, and peas on 600 hectares of their available farmland. They also have a small pheasant shoot. They have three biomass boilers on the farm, which are fed from timber grown, harvested and processed on the farm. The farm is owned by Ian and Victoria Cammack and run by farm manager Andy Bason, who grew up on the farm, along with two other staff. Newhouse Farm was previously an AHDB monitor farm and are now part of LEAF's Resilient and Ready programme. Newhouse Farm used to be a very intensive conventional arable farm, as they were ploughing and using a lot of input and energy into establishing the crops. Now however, they have gone the complete opposite way and are practising minimum/no-tillage.

This dramatic shift was spurred by a desire to work better and more efficiently with the land – Hampshire soil types are normally chalky and flinty, and the farm has some large areas of clay soil, which can be difficult to work with in both wet and dry weather. Adopting measures towards restoring soil organic matter and preventing compaction have helped reduce fuel use, as well as the use of traditional fertiliser inputs, while maintaining yield. Less intensive tillage has also been better for coping with wetter seasons. In addition, because of the increase in organic matter, they sequester carbon and have estimated a negative carbon balance; this will be augmented by plans to expand their woodland and agroforestry. These measures place them in a good position toward Net Zero and environmental incentives.

Their participation in monitoring initiatives (AHDB, LEAF) has led them to have the benefit of the data and evidence of the benefits from their shift away from intensive agriculture. Compared to 2015, recent soil tests in 2019 showed an increase in organic matter levels by 1%; a fuel reduction of 82 L/ha to 50 L/ha; and a reduction in fertilizer application from 0.71 t/ha to 0.59 t/ha. The saved time from doing min/no-till means that they are able to establish crops in a better window, and this has offset the initial yield reduction from the shift. Mr Bason is pleased with their successful transition from something very intensive, to something time- and fuel-efficient. He is keen on connecting with other farmers as well as communicating the importance of farming and the environment to the public, which he believes is the best way forward for learning in this period of environmental and political change. Having received support from fellow farmers, and organisations like AHDB and LEAF, he is looking forward to pushing for further changes and improvements at Newhouse Farm.

7.2.2 James Brown, Pollybell Farm, South Yorkshire

James Brown brings his pioneering business-oriented and innovative spirit to the award-winning Pollybell Farm, a diverse family-owned farm business in Doncaster, South Yorkshire that grows organic produce (carrots, parsnips, and other green vegetables), organic grains, which are used as feed for their organic livestock on over 5000 acres. Pollybell Farm is one of the UK's largest growers of organic vegetables and cereals. Over the last few years they have built a packhouse for the vegetable produce that they grow on the farm. Their lamb business finishes ~6000 organic lambs a year. They have a full holistic, sustainable organic rotation ('The Pollybell Way') that enables them to supply multiple markets.

The scale and scope of their farming enterprise, which also generates renewable energy (solar, including floating panels, and wind turbines), and their level of investment and innovation has made Pollybell Farm highly productive and successful. Some of their forward-thinking pursuits include a high level of technology adoption, including automation on field. Much of their success in reducing emissions and increasing sustainability also has to do with their ambition to continuously improve their productivity, for example with their highly trained staff, and efficient use of farm vehicles and equipment. Simple yet effective changes such as training drivers, and moving their tractor shed to reduce the number of movements has led to reductions in energy use and increases in efficiency that aid towards Net Zero.

Photos from James Brown, Pollybell Farm.

Snapshots from Pollybell Farm

Unique to Pollybell Farm is that they practise organic farming on drained peatland. Peatlands can be a significant source of emissions unless they are restored through measures such as re-wetting of the land. As carbon in the peat oxidises, the land drops, and this has posed unique challenges to the management of water on farm. Pollybell has a thirty million gallon, winter peak-flow, reservoir which improves the farm's capture and reuse of peak flows of water which would otherwise be wasted, and which also takes pressure off local water supplies. As biodiversity and habitat are of utmost importance to the values of Pollybell Farm, Mr Brown has ambitious plans to restore some of the peatland, which means adopting innovations such as hydro- or aeroponics to continue his large-scale vegetable production, and further diversifying his farm to expand its potential for conservation.

One of the challenges that Pollybell Farm has encountered is that their ideas to further the level of innovation and technology on the farm have not yet been met with an equal level of ambition and support at the level of government and finance. However, it is radical ideas from pioneers like Mr Brown who can push the envelope to lead UK agriculture into the future.

7.2.3 Dan Burling, Burling Brothers Limited, Cambridgeshire

Burling Brothers Limited is a family-run business and manages both arable and cattle (Stabiliser cows) production in Cambridgeshire. On the arable side, they have around 1,200 acres of mainly milling wheat, and are also growing oilseed rape, beans, rye for feed, beans, barley, and forage maize. They also use cover crops and direct drilling which can bring benefits to soil health and emission reduction due to lower energy inputs, respectively. Dan Burling is in charge of the cattle side of their farm, managing around 600 head of cattle which are allowed to rough graze (conservation grazing) on Royal Society for the Protection of Birds (RSPB) land, which can bring great benefits to biodiversity.

The Stabiliser breed was developed in the United States by the Meat Animal Research Center. It is composite breed made up of two native breeds and two continental breeds. The idea behind its breeding was to stabilise a cross breeding programme whilst retaining maximum heterosis (hybrid vigour). This breed programme allows for predictable and repeatable results. With high levels of performance and genetic recording, economic and environmental traits can be quickly identified and selected for through the use of a balanced multiple trait selection tool which creates individual estimated breeding values and profit scores for individual animals. Stabiliser cows have a shorter age to slaughter, which means that they consume less feed and produce less emissions, in addition to the breed already being feed-efficient (a heritable trait). Data collection and usage is very important in using the Stabiliser breed, and this allows Mr Burling to use his skills and knowledge in data and soil science to make evidence-based decisions; their efforts have led them to be carbon negative. The choice to graze their cows on land that isn't suitable for arable production is a conscious one, in order to not waste land that could be used for food production and instead bring benefits to the habitat and wildlife by allowing livestock to access fibre that they can naturally digest as ruminants. They also use surplus produce otherwise destined for farm waste to feed their livestock. Through this, Mr Burling believes they are 'turning sunshine into steak'.

Photo from Dan Burling

Going into the future, Mr Burling believes that greater adoption of the breed, as well as modernising the livestock industry to place greater importance on genetics and genotypes, rather than traditional reliance on visible traits (phenotype). He emphasises that focusing on genetic improvements is accessible, in terms of technology, knowledge, and cost. He believes it is important to maintain a strong UK livestock industry, make it more efficient, improve animal welfare, improve its environmental sustainability, and by doing so with data and evidence to support it, Net Zero will be just one of the many goals achieved.

7.2.4 Huw Evans, Sheffield Organic Growers, Sheffield

Sheffield Organic Growers is a peri-urban farm composed of a cluster of four independent organic growers one mile beyond the edge of the city of Sheffield, South Yorkshire. Together, the four growers grow a range of vegetables, fruit and herbs on approximately five hectares of land. They grow fruits (e.g. apples and pears), and vegetables (e.g. salad vegetables, squash). They are certified by either the Soil Association or the Bio- dynamic Association. They use polytunnels, which allow for growing of a wider range of vegetables, and can increase their value. They sell through independent grocers and directly to customers via veg bag schemes.

The model of growing fruits and vegetables locally and close to the city can reduce the emissions of food transport. Mr Evans believes that "thinking globally but acting locally" is important in addressing issues such as climate change and achieving Net Zero. Soil health, biodiversity and organic matter (via sequestration through their permacultures) and increasing the knowledge of seasonal food production are of key importance to Sheffield Organic Growers. As an organic grower, his aspirations are to make sure that farm practices bring benefits to the soil and to the wider environment, alongside running a successful business. Organic growing reduces the associated emissions from the production of synthetic fertilisers and pesticides. The main sources of GHGs are from the fuel-related emissions from the delivery of inputs (compost) and from the transport of produce off the farm.

Their model of cooperation between the four different growers brings many benefits, from pooled knowledge, shared access to resources and machinery as well as shared responsibilities. Some of the challenges they encounter are related to pests and wildlife, practising farming on sloping sites, as well as the many regulations and schemes they had to become familiar with as new entrants into farming. Access to water resources is also important as they are off-grid and need to request to drill boreholes, especially as they are considering expansion. As part of a pilot for the ELM scheme, Mr Evans is excited about the possibility of support for small growers, who are typically ineligible for Basic Payments because of farm size. His vision for Sheffield Organic Growers is to continue producing good quality organic fruits and vegetables that their customers can enjoy, that people become aware of their model and its principles, and appreciate the health, beauty and permanence of organic farming.

7.2.5 David Miller, Wheatsheaf Farming Company, Hampshire

David Miller is the award-winning farm manager of Wheatsheaf Farming Company, which has around 700 hectares of land in Hampshire. Wheatsheaf was formed in 2002 for three landowners and four farm business partners, where Mr Miller is the only full-time employee. They have a rotation of winter oilseed rape, winter barley, winter wheat, winter beans, spring linseed and spring barley. After hitting a yield plateau despite spending more money on chemical inputs, they took it back to the basics to understand the way they were farming and realised how depleted soil organic matter levels were. With an interest in pursuing higher productivity while regenerating and restoring soil biology, Mr Miller has led the way in implementing a no-till system at the farm, which has led to significant savings in fuel use, farm inputs, and has also improved the biodiversity of the farmland. They also use cover crops in a bespoke cover crop mixture, which has helped reduce their costs.

Focusing on regenerating and building up organic matter has helped their farm reduce its greatest sources of emissions from farm inputs and fuel use; adopting no-till systems sequesters carbon and builds up organic matter in the soil. When talking about productivity, Mr Miller emphasises that looking solely at yields is not the only measure of success: their shift has led them to spend a lot less money on diesel, and their fixed costs on machinery and labour are also much lower – they have become a much more efficient system. Their innovation and desire to keep pursuing greater gains in efficiency across their crops means that they have sought advice from an independent agronomist to break away from traditional systems that rely heavily on chemical and synthetic inputs.

Photos from David Miller and Wheatsheaf Farming Company

Mr Miller emphasises that pursuing regenerative or conservation agriculture results in incremental gains, and that pursuing these measures can be challenging for farmers who may be used to an idealised image of what arable farming should look like. However, he says that the best way forward is for farmers to work and learn together to see that implementing these changes can improve farms and farming overall towards multiple goals, not just Net Zero. Since making the plunge to no-till systems nearly a decade ago, Mr Miller now sees the multiple benefits from it: helping wildlife, the environment, water companies, the Clean Air Act. With ELMS and changes to agriculture in the UK, he thinks it's important that farmers see the reasoning behind making these changes toward sustainability. At the end of the day, farming is a business: farmers need to take the steps to retain profitability and productivity while pursuing Net Zero and resilience to other changes to farming

7.2.6 John Smith, J & AJ Smith, Kintyre, Scotland

Photo from John Smith.

John Smith and his wife Ruth run a herd of pedigree Holsteins (around 350 heads), rearing replacements and some dairy beef on a predominantly grass-based system on the Kintyre peninsula. Mr Smith was the former Milk Committee chair of NFU Scotland and is part of the Farming1.5 group in Scotland, which seeks to promote sustainable farming in line with the challenges of climate change. Farming1.5 recently produced a report on a transformation pathway for Scottish agriculture in line with environmental objectives, including Net Zero. As such, he is uniquely attuned to the challenges faced by the dairy sector in line with Net Zero, including those related to agricultural support.

He foresees that into the future, there will be criteria that dairy producers will need to comply with, and if they do not meet with this, they won't be able to access financial support, which is an incredibly valuable part of the agricultural industry; indeed, it's what helps to keep food on the table of consumers. There is already some retailer pressure for milk suppliers to conform to higher environmental standards. He emphasises that without agricultural support, food prices would be higher. This importance of support is why he thinks there will be great participation in schemes to award support to farms that shift towards higher sustainability; however, it is important that farmers know the reasons why the shift is needed, and what can be done to match the needs of the individual farms.

In the case of his dairy farm, methane emissions from the livestock are the greatest source of emissions. One of the measures he has taken on farm is extended grazing. This measure allows for livestock to access fresh grass throughout longer periods of the year. This means that manure is deposited to the field, to help grass continue to grow, and that builds up the fertility of the soil and the land. The constant cycling of organic matter and grass growth means that this helps to build up and sequester carbon, in addition to the welfare benefits of livestock having access to fresh grass. This can also reduce the costs of production compared to traditional winter feeding, and the construction of tree windbreaks to shelter livestock can also sequester additional carbon. Mr Smith did not pursue out-of-season grazing primarily to address climate change initially, but it has provided improvements to farm efficiency, and finding value in hillsides that are quite challenging to farm, or have low productivity as forage for livestock instead. In this, he acknowledges the important role that Scotland can have as a powerhouse and leader in sequestration and agroforestry.