CLIMATE CHANGE
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Status, potentials and challenges

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Abstract: Mitigating agricultural greenhouse gas emissions in the UK

This report describes the current state of agriculture in the UK with regard to the greenhouse gas (GHG) emissions it produces and the climate and other socio-economic policies that it faces. We identify options that could reduce agricultural emissions and estimate the mitigation potential of those options. Finally, we identify barriers to adopting these mitigation strategies and some possible solutions to overcoming those barriers.

Kurzbeschreibung: Länderbericht Großbritannien

Dieser Bericht beschreibt den aktuellen Stand der Landwirtschaft in Großbritannien im Hinblick auf die von ihr verursachten Treibhausgasemissionen sowie den aktuellen sozioökonomischen und klimapolitischen Rahmen für den landwirtschaftlichen Sektor. Wir identifizieren Optionen für Maßnahmen, die die landwirtschaftlichen Emissionen reduzieren könnten, und diskutieren das Minderungspotenzial dieser Optionen. Abschließend werden Hindernisse für die Umsetzung dieser Minderungsoptionen und einige mögliche Lösungen zur Überwindung dieser Hindernisse aufgezeigt.

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List of abbreviations

AFOLU	Agriculture, forestry and other land use
BEIS	Business, Energy and Industrial Strategy
BPS	Basic Payment Scheme
CAP	Common Agricultural Policy
CAT	Climate Action Tracker
CCC	Committee on Climate Change
CO_2	Carbon dioxide
COP	Conference of the Parties
Defra	Department for Environment, Food and Rural Affairs
ELM	Environmental Land Management
EU	European Union
FBI	Farm Business Income
GBP	Great British Pound
GDP	Gross Domestic Product
GHG	Greenhouse gas
Ha	Hectare
HMT	Her Majesty's Treasury
IPCC	Intergovernmental Panel on Climate Change
LFASS	Less Favoured Area Support Scheme
LULUCF	Land use, Land-Use Change and Forestry

MRV	Measurement, Reporting and Verification
MtCO2e	Mega tonnes of CO_2 equivalents
N_2O	Nitrous oxide (laughing gas)
NAP	National Adaptation Programme
NDC	Nationally Determined Contributions (in Paris Agreement)
NUE	Nitrogen Use Efficiency
SFI	Sustainable Farming Initiative
TIFF	Total Income from Farming
UNFCCC	United Nations Framework Convention on Climate Change

Summary

The aim of this report is to identify possible emission mitigation options in the agricultural sector of the UK, the barriers towards implementing those options and provide some recommendations on how to overcome those barriers. The report begins with a description of the current state of agriculture in the UK with regard to the GHG emissions it produces, and the climate and socio-economic policies that shape the sector. We then identify three key options that could reduce agricultural emissions and discuss the mitigation potential of a wider range of measures that has been identified by the UK Climate Change Committee (CCC). Finally, we identify barriers that act at the farm, national, international and consumer levels along with possible steps to overcoming those barriers.

Agriculture shapes the UK's landscape since arable land constitutes 71% of total land area in the UK, of which 35% is dedicated cropland and 65% to pasture and range land. Agriculture in the UK is generally highly intensive and industrialised. In 2021, agriculture contributed approx. 0.5% to the national economy (GDP). Overall, the UK imported about 46% of the food it consumed in 2020.

According to national data, agriculture made up 11% of total GHG emissions in 2020, equalling 41 Mega tonnes of CO_2 equivalents ($MtCO_2e$). The largest sources of emissions are enteric fermentation (45%), reflecting the critical role of livestock production in the UK's agricultural economy, manure management (14%) and on-farm energy use (11%). Total emissions from agriculture have decreased by 17% since 1990. Since 2008, agricultural emissions remained at almost constant levels though. Methane emissions from agriculture have decreased by approx. 13% since 1990, mainly due to decreasing livestock numbers, particularly in cattle. However, methane emissions have remained largely at the same level since 2009. More than 2/3 of the UK's nitrous oxide (N_2O) emissions are generated in the agricultural sector. They mainly result from the application of nitrogen fertiliser, manure (applied and excreted) and leaching/run-off. Since 1990, N_2O emissions have decreased by approx. 20%, reflecting a decrease in fertiliser usage over this time period.

Up to 2021, agricultural policy and support was dominated by a system of direct payments. The largest scheme is the Basic Payment Scheme (BPS), under which payments in 2020 amounted to Great British Pound (GBP) 2.8 billion. The scheme will end after 2024 to be replaced by delinked payments through a number of funding schemes, include the Environmental Land Management (ELM) schemes. The new policies and funding schemes, which have been implemented and initiated since the UK's decision to leave the European Union (EU), replace the common agricultural policy (CAP) and mark a significant shift to prioritising environmental and climate concerns in agricultural practices.

Three mitigation options were identified for detailed analysis based on the contribution of different emission sources, the potential for socio-economic and environmental co-benefits, the country-specific context of the agricultural sector, and the general feasibility for implementation.

For the UK, we selected the following three mitigation measures:

- Improving fertiliser/nutrient management,
- Enhancing the use of plants with improved nitrogen use efficiency, including cover crops, and
- Increasing animal health.

These on-farm mitigation measures form part of a broader set of mitigation options, including the increase of carbon sinks and demand side measures, which have been identified for the UK. These include

- low-carbon farming practices to reduce emissions from soils (e.g. grass leys and cover crops), livestock (e.g. diets and breeding) and waste and manure management (e.g. anaerobic digestion),
- decarbonising fossil fuel use in agriculture through electrification, biofuels, hydrogen and hybrid vehicles,
- and measures to release land from agriculture through dietary changes, reduction of food waste, productivity improvements and moving horticulture indoors.

In the 'balanced pathway,' these measures could reduce emissions in the agricultural sector by up to 14 $MtCO_2e$ by 2035. It is noteworthy that measures to release land from agriculture through reducing meat and dairy consumption involves the highest mitigation contribution (7 $MtCO_2e$ by 2035) of the package of measures included in the UK's scenarios towards net zero. Additionally, the rewetting of peatlands bears significant mitigation potentials in the land use sector in the UK.

There are critical barriers that hinder the implementation of measures to achieve the outlined mitigation potentials and impair other activities to reduce greenhouse gas emissions in the agricultural sector. For the selected mitigation measures, we identified technical, economical, and policy/legal barriers. More generally, uncertainty among farmers about the right measures, a lack of willingness to act, lacking knowledge, high investment costs, tenure structures and cultural and social habits act as barriers at farm level. At the policy level, the restructuring of available incentives to replace the CAP is a step in the right direction, but progress on agreeing on the details of the new incentive schemes is slow. Additionally, specific targets or a comprehensive land use strategy are still lacking. Also, no target or vision is available on the transformation on the broader food system, even though consumers show willingness to change dietary patterns. Funding for research and innovation in the agricultural sector is lacking as well.

To accelerate the uptake and implementation of the measures described in this report, it is key to 1) enhance the national climate mitigation framework in agriculture and align other environmental and food security objectives with mitigation objectives, 2) improve the regulatory framework on existing laws and policies by setting out the details on future agricultural subsidies and incentives, and 3) implement sectoral policies to comprehensively address the areas where most mitigation is possible. These mitigation policies and incentives should also foster co-benefits between adaptation and mitigation in the agricultural sector. More specifically, the UK could develop demand-side measures to reduce dietary choices and food waste, extend the environmental protection area, promote research on sustainable agricultural practices and on the impacts of agroecological farm practices on yields, land use and wider environmental outcomes and enhance training for farmers to support the uptake of agroecological practices.

Zusammenfassung

Ziel dieses Berichts ist es, mögliche Optionen zur Emissionsminderung im Agrarsektor Großbritanniens zu identifizieren, die Hindernisse bei der Umsetzung dieser Optionen aufzuzeigen und Empfehlungen zur Überwindung dieser Hindernisse zu geben. Der Bericht beginnt mit einer Beschreibung des aktuellen Stands der Landwirtschaft in Großbritannien im Hinblick auf die produzierten Treibhausgasemissionen und die klima- und sozioökonomische Politik. Anschließend werden drei wichtige Optionen zur Verringerung der landwirtschaftlichen Emissionen aufgezeigt und ihr Minderungspotenzial abgeschätzt. Abschließend werden Hindernisse auf betrieblicher, nationaler, internationaler und Verbraucherebene sowie mögliche Schritte zur Überwindung dieser Hindernisse aufgezeigt.

Die Landwirtschaft prägt die Landschaft des Vereinigten Königreichs, denn 71 % der Gesamtfläche des Landes sind Ackerland, davon 35 % Ackerland und 65 % Weideland und Weideflächen. Die Landwirtschaft im Vereinigten Königreich ist insgesamt sehr intensiv und hochindustrialisiert. Im Jahr 2021 trug die Landwirtschaft etwa 0,5 % zur Volkswirtschaft (BIP) bei. Insgesamt importierte das Vereinigte Königreich im Jahr 2020 etwa 46 % der verbrauchten Lebensmittel.

Nach nationalen Angaben machte die Landwirtschaft im Jahr 2020 11 % der gesamten THG-Emissionen aus (41 $MtCO_2e$). Die größten Emissionsquellen sind die enterische Fermentation (45 %), was die entscheidende Rolle der Viehzucht in der britischen Agrarwirtschaft widerspiegelt, der Umgang mit Gülle (14 %) sowie der Energieverbrauch (11 %). Die Gesamtemissionen aus der Landwirtschaft sind seit 1990 um 17 % zurückgegangen. Seit 2008 sind die landwirtschaftlichen Emissionen jedoch nahezu konstant geblieben. Die Methanemissionen aus der Landwirtschaft sind seit 1990 um etwa 13 % zurückgegangen, was vor allem auf den Rückgang des Viehbestands, insbesondere bei Rindern, zurückzuführen ist. Seit 2009 sind die Methanemissionen jedoch weitgehend auf demselben Niveau geblieben. Mehr als 2/3 der N_2O-Emissionen des Vereinigten Königreichs werden in der Landwirtschaft erzeugt. Sie resultieren hauptsächlich aus der Ausbringung von Stickstoffdünger, Dung (ausgebracht und ausgeschieden) und Auswaschung. Seit 1990 sind die N_2O-Emissionen um etwa 20 % zurückgegangen, was auf einen Rückgang des Düngereinsatzes in diesem Zeitraum zurückzuführen ist.

Bis 2021 wurde die Agrarpolitik und -förderung durch ein System von Direktzahlungen dominiert. Die wichtigste Regelung ist das Basic Payment Scheme (BPS), in dessen Rahmen sich die Zahlungen im Jahr 2020 auf 2,8 Mrd. GBP beliefen. Die Regelung läuft nach 2024 aus und wird durch eine Reihe von neuen Finanzierungsinstrumenten ersetzt, zu denen auch das ELM-Schema (Environmental Land Management) gehört. Die neuen Maßnahmen und Finanzierungsinstrumente, die seit der Entscheidung des Vereinigten Königreichs, die EU zu verlassen, umgesetzt und initiiert wurden, ersetzen die GAP und markieren einen bedeutenden Wandel hin zu einer Priorisierung von Umwelt- und Klimabelangen in der landwirtschaftlichen Praxis.

Für eine detaillierte Analyse wurden drei Minderungsoptionen auf der Grundlage des Beitrags der verschiedenen Emissionsquellen, des Potenzials für sozioökonomische und ökologische Nebeneffekte, des länderspezifischen Kontexts des Agrarsektors und der allgemeinen Durchführbarkeit ermittelt.

Für das Vereinigte Königreich haben wir die folgenden drei Minderungsmaßnahmen ausgewählt:

- Verbesserung des Düngemittel-/Nährstoffmanagements

- Verstärkter Einsatz von Pflanzen mit verbesserter Stickstoffnutzungseffizienz, einschließlich Deckfrüchten
- Verbesserung der Tiergesundheit.

Diese Minderungsmaßnahmen in landwirtschaftlichen Betrieben sind Teil eines breiteren Spektrums von Minderungsoptionen, einschließlich der Vergrößerung von Kohlenstoffsenken und nachfrageseitigen Maßnahmen, die für das Vereinigte Königreich ermittelt wurden. Dazu gehören

- kohlenstoffarme landwirtschaftliche Praktiken zur Verringerung der Emissionen aus Böden (z. B. Grasnarbe und Deckfrüchte), Viehzucht (z. B. Fütterung und Zucht) und Abfall- und Dungmanagement (z. B. anaerobe Vergärung),
- Dekarbonisierung des Einsatzes fossiler Brennstoffe in der Landwirtschaft durch Elektrifizierung, Biokraftstoffe, Wasserstoff und Hybridfahrzeuge,
- sowie Maßnahmen zur Freisetzung von Flächen aus der Landwirtschaft durch Ernährungsumstellung, Verringerung von Lebensmittelabfällen, Produktivitätssteigerungen und Gemüseanbau in Innenräumen.

Basierend auf dem "Balanced Pathway" im sechsten Kohlenstoffbudgets (Sixth Carbon Budget), das das Climate Change Committee des Vereinigten Königreichs entwickelt hat, könnten diese Maßnahmen die Emissionen im Agrarsektor bis 2035 um bis zu 14 MtCO_2e reduzieren. Dabei muss berücksichtigt werden, dass Maßnahmen zur Reduzierung des Fleisch- und Milchkonsums, die wiederum zur Freisetzung von Flächen aus der Landwirtschaft führen, den höchsten Beitrag (7 MtCO_2e bis 2035) des Maßnahmenpakets in den Szenarien des Vereinigten Königreichs auf dem Weg zur Klimaneutralität leisten. Außerdem birgt die Wiedervernässung von Torfgebieten ein erhebliches Minderungspotenzial im Landnutzungssektor des Vereinigten Königreichs.

Es gibt kritische Barrieren, die die Umsetzung von Maßnahmen zur Erreichung der skizzierten Minderungspotenziale behindern und andere Aktivitäten zur Reduzierung von Treibhausgasemissionen im Agrarsektor beeinträchtigen. Für die ausgewählten Minderungsmaßnahmen haben wir technische, wirtschaftliche und politische/rechtliche Hindernisse identifiziert. Generell wirken auf betrieblicher Ebene die Unsicherheit der Landwirte über die richtigen Maßnahmen, mangelnde Handlungsbereitschaft, fehlendes Wissen, hohe Investitionskosten, Besitzstrukturen sowie kulturelle und soziale Gewohnheiten als Barrieren. Auf politischer Ebene ist die Umstrukturierung der verfügbaren Anreize, die an die Stelle der GAP treten sollen, ein Schritt in die richtige Richtung, aber die Einigung über die Einzelheiten der neuen Anreizsysteme kommt nur langsam voran. Außerdem fehlen noch immer spezifische Ziele oder eine umfassende Landnutzungsstrategie. Auch gibt es keine Zielvorgaben oder Visionen für die Umgestaltung des Lebensmittelsystems im weiteren Sinne, obwohl die Verbraucherinnen und Verbraucher sich bereit gezeigt haben, ihre Ernährungsgewohnheiten zu ändern. Auch die Finanzierung von Forschung und Innovation im Agrarsektor ist unzureichend.

Um die Übernahme und Umsetzung der in diesem Bericht beschriebenen Maßnahmen zu beschleunigen, ist es von entscheidender Bedeutung, 1) den nationalen Gesetzesrahmen für den Klimaschutz in der Landwirtschaft zu verbessern und andere Umwelt- und Ernährungssicherheitsziele mit den Klimaschutzzielen in Einklang zu bringen, 2) den bestehenden Regelungsrahmen an Gesetzen und Politiken zu verbessern, indem die Details für künftige Agrarsubventionen und -anreize festgelegt werden, und 3) sektorale Politiken umzusetzen, die die Emissionen aus der Landwirtschaft mindern. Diese Minderungsmaßnahmen und -anreize sollten auch Wechselwirkungen zwischen Anpassung und Minderung im

Agrarsektor fördern. Konkret könnte das Vereinigte Königreich nachfrageseitige Maßnahmen zur Verringerung von Ernährungsgewohnheiten und Lebensmittelabfällen entwickeln, den Umweltschutzbereich ausweiten, die Forschung zu nachhaltigen landwirtschaftlichen Praktiken und zu den Auswirkungen agrarökologischer landwirtschaftlicher Praktiken auf Erträge, Landnutzung und allgemeine Umweltauswirkungen fördern und die Ausbildung von Landwirtinnen und -wirten verbessern, um die Einführung agrarökologischer Praktiken zu unterstützen.

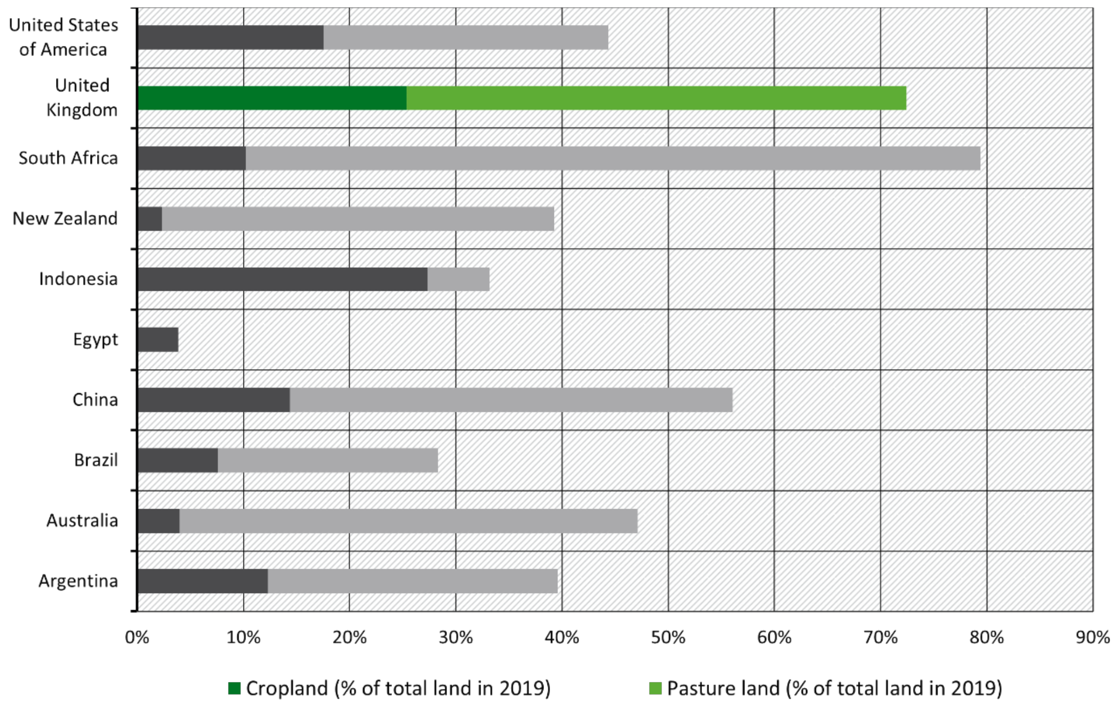
1 General characteristics of the agricultural sector and policy landscape

1.1 Characteristics of the agriculture sector in the UK

Arable land constitutes 71% of total land area in the UK (17.2 million hectares), of which 35% is dedicated cropland and 65% to pasture and range land (UK Government 2021b; 2022c). Compared to the other 9 countries considered in our analysis, this is the second largest share of arable land of total land area of all 10 countries considered in our analysis (see Figure 1). Recent trends indicate a slight overall decrease in cropland as well as pastureland. The cropland area decreased by approx. 4% between 2011 and 2021 to 4.48 million hectares in 2021 with slight fluctuations during this period (UK Government 2021b; 2016).

Of total utilised agricultural land, approx. 72% are used as grassland and 26% used for crops. Land use for both utilisations have remained relatively stable since 1990. In the South West of England, the agricultural focus is on dairy farming while climatic conditions in the East make this region suitable for cropping (UK Government 2021b). In Wales, Scotland and the north-west of England, large areas are designated as "Less Favoured Areas" that produce a lower agriculture yield due to their hillier geography. On these areas, the focus is on sheep and dairy farming as arable farming is not economically viable in all places (UK Government 2021c; Richtie et al. 2019).

Figure 1: Agricultural land as a share of total country area (2019)

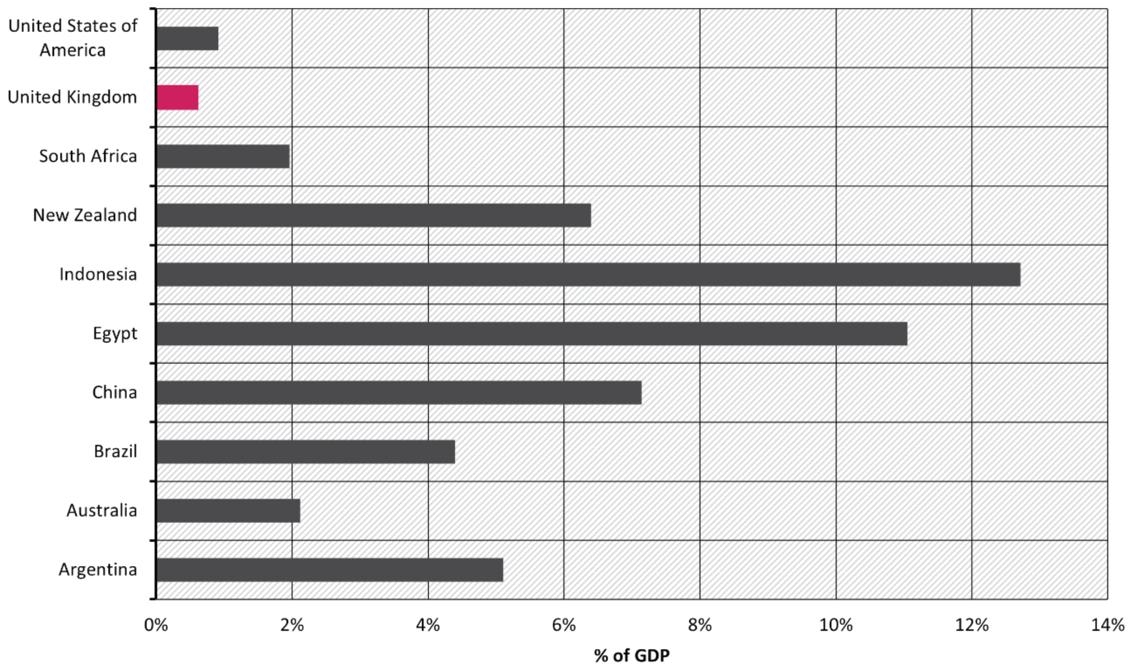


Source: FAO (2022a) for all countries. Data includes "Cropland" and "Land under permanent meadows and pastures"

Agriculture in the UK is generally highly intensive and industrialised. In 2021, agriculture contributed about 0.5% to the national economy (GDP) (compared to a global average of 3.5%), marking an increase of 8.9% compared to 2020 (UK Government 2022c; OECD 2021a).

The Total Income from Farming (TIFF; total income from agriculture as a whole)[1], driven by commodity prices, exchange rates and levels of production, is estimated at GBP 6.0 billion in 2021, marking the third highest TIFF since 2000 (in real terms) and an increase of 14% from 2020. This was driven by increases in total livestock and total crop outputs. Taking into account the larger agri-food sector (including retailing, wholesaling, manufacturing and non-residential catering), the contribution to national Gross Value Added was 6.0% in 2020, of which agriculture itself makes the smallest contribution of 8% (UK Government 2021b; 2022c).

Figure 2: Agriculture, fisheries, and forestry's contribution to GDP (2019)



Source: World Bank (2022) data for all countries except New Zealand due to lack of data. Value for New Zealand was taken from OECD (2021a)

The agricultural land use remains stable with around 72% grassland and 25% used for crops over the last 30 years. Cereal crops account for 53% of the croppable area in the UK as of 2021 (UK Government 2022c). Compared to 2019, total cereal production of wheat, barley, oats and minor cereals (rye, triticale and mixed grain) decreased by 29% to 19 million tonnes. This decrease was due to the decrease of arable area used for production and lower yields. The total amount of harvested cereal production in the UK covered 88% of total supply for use in the UK for 2020. Further important crops are oilseeds (7% of total croppable area) and potatoes (2% of total croppable area) (UK Government 2021b).

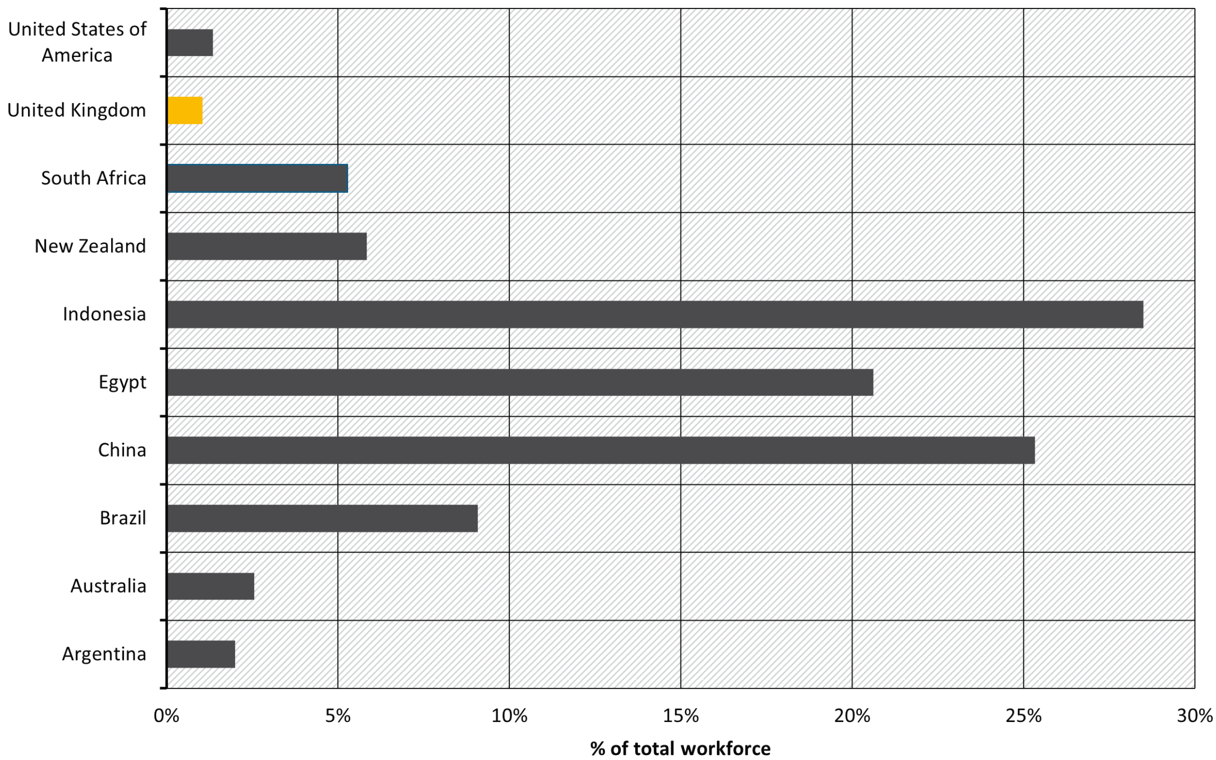
Overall, the UK imported about 46% of the food it consumed in 2020 (UK Government 2022c, p. 171). The majority of UK exports and imports of agricultural commodities are made to/from the Eurozone. The main trading partners are all close geographical neighbours, except of the United States (Irish Republic, Netherlands, France, Germany). Fresh fruit and vegetables are the main imported product. The value of food, feed and drink imports (GBP 45.9 billion) was more than twice as high as the value of exports (GBP 20.2 billion) in 2021 (UK Government 2022c, 149-155). Compared to the EU Member States, the UK was the largest producer of sheep and goat meat in 2020 and the third largest producer of milk, beef and veal (UK Government 2021b).

[1] Representing business profits and remuneration for work done by owners and other unpaid workers.

1.2 Socio-economic dimensions

Agriculture's share of employment is low in the UK; it amounts to 1.44% in 2020 (lowest share across the 10 countries analysed, see Figure 3) and encompasses an agricultural workforce of 467,000 people (decrease by 9,000 since 2019). The agricultural workforce is ageing; in 2016, approx. 36% of all holders were over 65 years of age (UK Government 2022c). The compensation of employees only comprises 10% of total inputs and costs paid out by farmers in 2021 (ibid, p. 45). The larger agri-food sector (including retailing, wholesaling, manufacturing and non-residential catering) employed 4 million people in 2021, which accounts for 13% of all employees (ibid, p. 166).

Figure 3: Agriculture employment as a share of the total workforce (2019)



Source: World Bank (2021) data for all countries except Argentina due to data discrepancy. Value for Argentina was taken from ILO (2021)

In 2021, there were 216,000 agricultural holdings in the UK (compared to 218,000 holdings in 2016). In global comparison, farms are rather large in the UK. The average UK farm size was 81 ha in 2021; the 41,000 holdings greater than 100 ha[2] (19%) own about three quarters of the total area, thus reflecting a significant share of large-scale production systems. Nevertheless, almost half of all farms were less than 20 ha in size (UK Government 2022c).

The average Farm Business Income (FBI; breakdown of average income by farm type) for England amounted to GBP 46,500 (at current prices), which comprises an increase from GBP 39,000 in 2019/2020. For over 28% of farms in England, the FBI was greater than GBP 50,000 while 16% of farms did not make a positive FBI in 2020/2021 (UK Government 2022c, p. 28).

[2] Including non-croppable areas.

Crops and livestock contribute roughly equally to the UK agriculture's production value. Wheat is the highest value crop and beef the highest value livestock product (UCL 2021, p. 8).

Subsidies make up about 9.9% of the total value of all outputs and subsidies in 2021 (UK Government 2022c, p. 41). After Brexit, agricultural support payments previously made under the EU's Common Agricultural Policy (CAP) are replaced by payments from the British government. Coupled payments that are linked to production amount to GBP 47 million in 2021 less levies (UK Government 2022c, p. 120; see also section 1.4).

A report by the Environment Agency found in 2019 that intensive agriculture has led to a depletion of organic carbon stocks of arable soils by 40-60% in the UK. Additionally, 4 million hectares of soil are at risk of compaction in England and Wales, which has negative effects on soil fertility and water resources, and over 2 million hectares of soil are threatened by erosion (UK Environment Agency 2019).

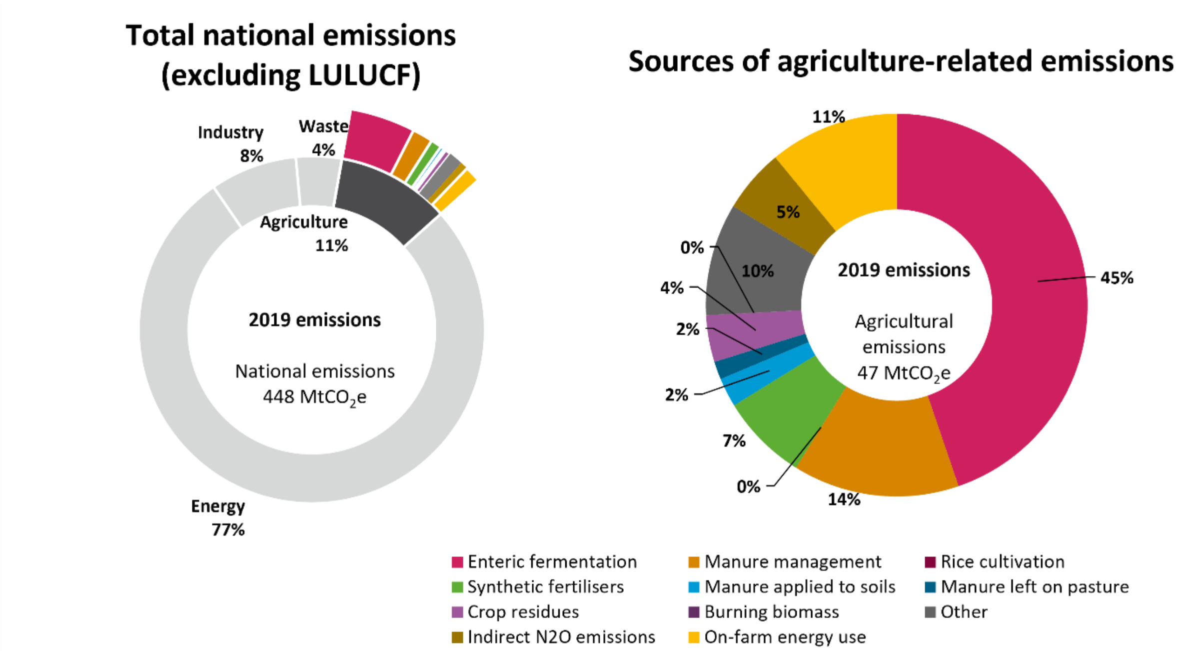
Pollutants from agriculture including nutrients (phosphorus and nitrates), chemicals including pesticides, faecal bacteria and pathogens, soil sediment as well as microplastics negatively impacts water quality (UK Environment Agency 2021). Water pollution from agriculture and rural land use is associated with 28% of surface water bodies failing to meet the standards of 'high' or 'good' according to the Water Framework Directive in 2020 (UK Government 2022c, p. 134).

Less than 1% of the total water extracted in England was attributed to agriculture for irrigation purposes in 2017 (UK Government 2022c). Nevertheless, nearly 15% of surface water bodies and 27% of groundwater bodies in England are affected by over extraction (UK Environment Agency 2022).

1.3 Greenhouse gas emissions from agriculture, forestry and other land use (AFOLU) and the main drivers

Agriculture made up 11% of total GHG emissions in 2019 (UK Government 2022g) and 2020 (UK Government 2022c, p. 124), equalling 42 $MtCO_2e$ in 2019 and 41 $MtCO_2e$ in 2020 (UK Government 2022g, excluding on-farm energy use). The largest sources of emissions are enteric fermentation (45%), manure management (14%) and on-farm energy use (11%) (see Figure 4).

Figure 4: The UK's GHG emissions profile, 2019



Source: UK Government (2022g)[3]

Agricultural activities are the major contributor to both methane emissions as well as nitrous oxide emissions in the UK. In 2020, methane emissions from livestock accounted for 61.3% of agricultural emissions, 35.8% were N_2O emissions mainly from soils and 2.9% CO_2 emissions mainly from the use of fossil fuels. In terms of activities, enteric fermentation from the digestion processes of ruminant livestock is responsible for more than half of total emissions, reflecting the critical role of livestock production in the UK's agricultural economy. Agriculture accounted for 69% of total NO_2 emissions (14.5 $MtCO_2e$), 48% of total CH_4 emissions and 2% of total CO_2 emissions of the UK in 2020 (UK Government 2022c).

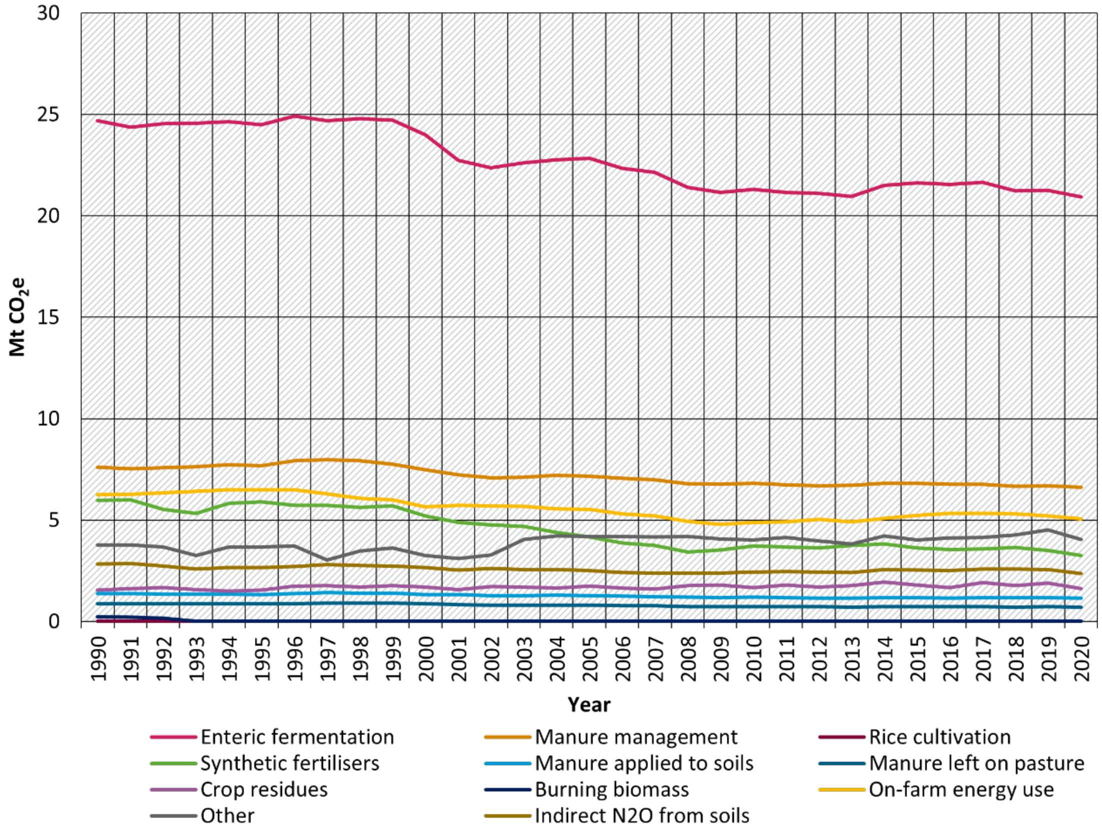
Total emissions from agriculture have decreased by 17% since 1990 (UK Government 2022g). Since 2008, agricultural emissions remained at almost constant levels though (UK Government 2021d). Methane emissions from agriculture have decreased by about 13% since 1990, mainly due to decreasing livestock numbers, particularly in cattle. However, methane emissions have remained largely at the same level since 2009 (UK Government 2022c, p. 136). The emissions intensity of beef (approx. 13 kg CO_2e/kg meat in 2020), pork and dairy products has declined over the last 20 years, but increased for sheep meat (approx. 16 kg CO_2e/kg meat in 2020) (CCC 2022b, p. 291). Changes in farming practices due to EU environmental legislation to address non-GHG pollutants (e.g. Nitrates Directive) have also contributed to the overall decrease in emissions since 1990 (CCC 2020c, p. 204).

More than 2/3 of the UK's N_2O emissions are generated in the agricultural sector. They mainly result from the application of nitrogen fertiliser, manure (applied and excreted) and leaching/run-off. Since 1990, N_2O emissions have decreased by about 20%, reflecting a decrease in fertiliser usage over this time period. Ammonia emissions from soils and livestock have

[3] While on-farm energy use is generally reported under energy sector emissions for national data, we include it as an agriculture-related emissions source in this study because of its role in agricultural production (fuel use in harvesters, stable heating, grain drying etc.) and its relevance in several countries in terms of magnitude and mitigation potential. We refer to 2019 instead of 2020 data, which was the latest data available at the time of writing, due to COVID-related economic dynamics that affected national emissions in 2020.

decreased by about 22% since 1990 as well, but increased since 2013 again due to a rise in ammonia emissions from soils (UK Government 2022c, 135-136).

Figure 5: Agriculture-related emissions in the UK (1990-2020)

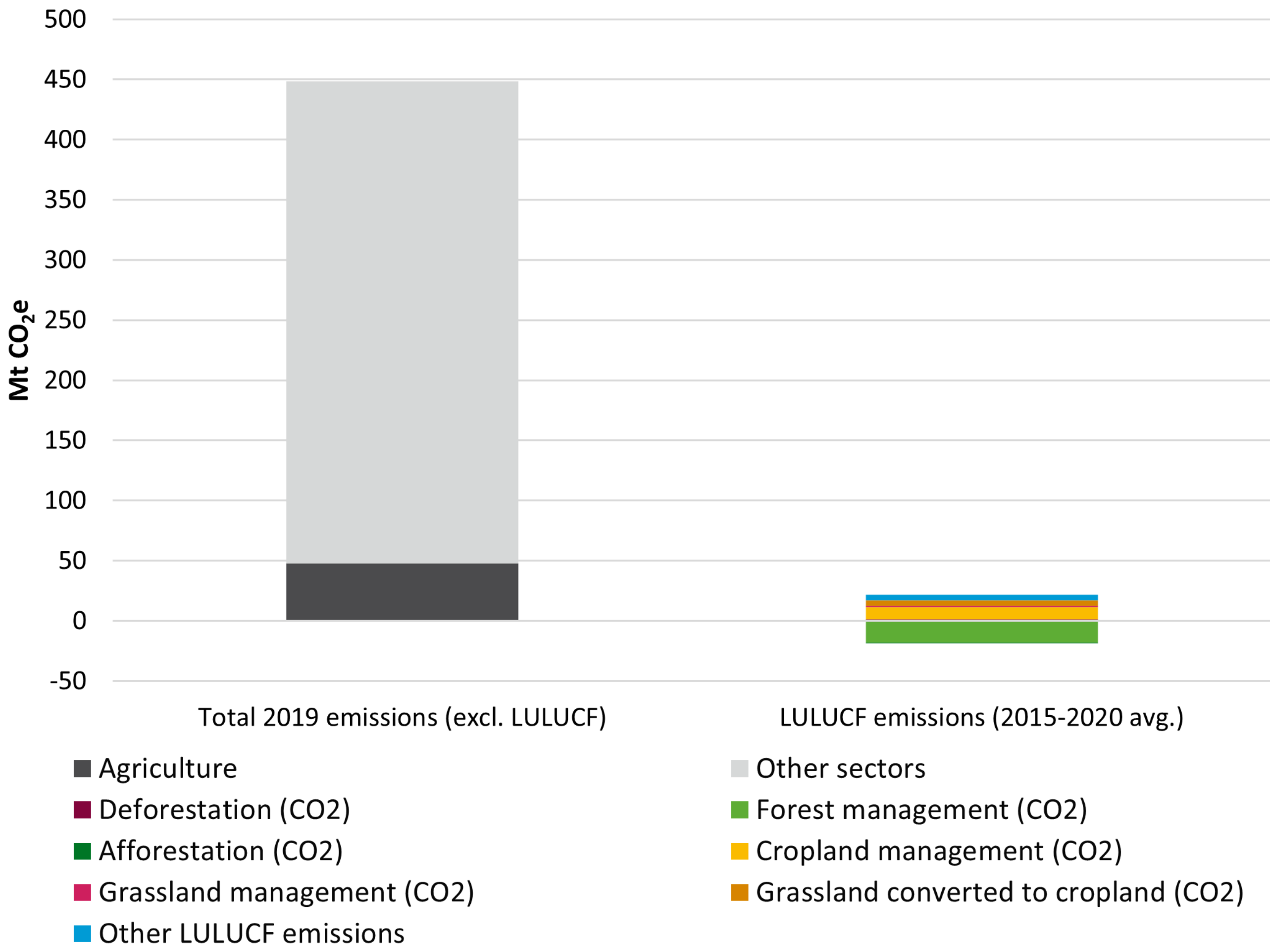


Source: UK Government (2022g)

Total net Land Use, Land-Use Change and Forestry (LULUCF) emissions amounted to 4 $MtCO_2e$ in 2020, comprising a forest sink of about 17 $MtCO_2e$, savings in harvested wood products of 2 $MtCO_2$ and emissions of approx. 23 $MtCO_2e$ from grassland management, cropland management and other LULUCF emissions (UK Government 2022g). Total net LULUCF emissions have decreased by 70% since 1990, but remained at similar levels since 2008. While the UK's forests form the largest sink of the country, in recent years, tree planting has decreased compared to previous years and the ageing of existing woodlands have diminished sequestration rates by forestry. In Scotland, afforestation rates have exceeded those of the rest of the UK combined in most years since 1990. In the last three years, more than 13,000 hectares of forest per year were afforested in the UK. However, this still falls short of the government's commitment to reach 30,000 hectares/year in 2025 (CCC 2022b, 292ff.).

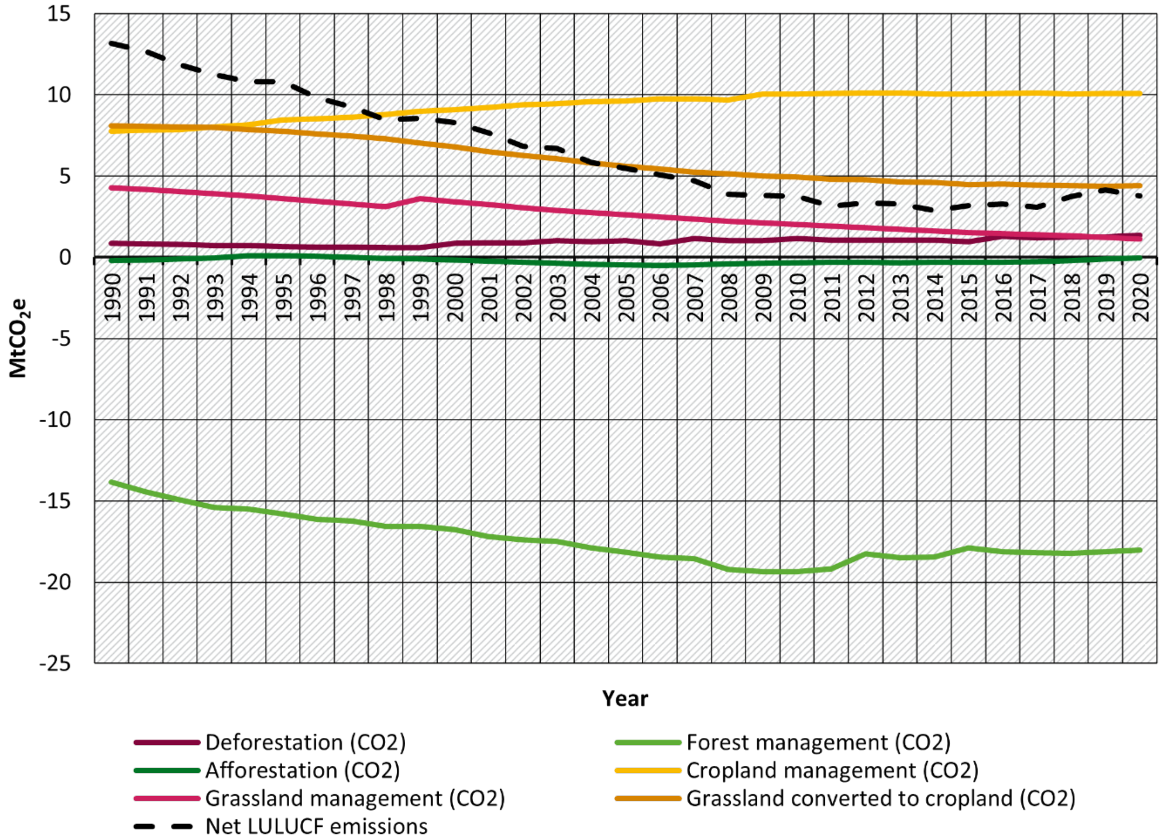
Peatlands make up the largest share of emissions from the land use sector due to drainage and use as croplands and grasslands as well as conversion to cropland and settlement. Only a small share of peatlands is used as cropland or intensively used grassland, however. Emissions from peatlands have decreased by 15% since 1990. Progress towards targets to restore 35,000 ha of peatlands in England by 2025 and 20,000 ha/year from 2021 are currently being missed (CCC 2022b, 292ff.).

Figure 6: The UK's land use, land use change and forestry (LULUCF) emissions (average over the period 2015-2020) relative to total national emissions in 2019 (excl. LULUCF)



Source: UK Government (2022g). The category "other LULUCF emissions" includes CO_2 emissions from wetlands, emissions from settlements, emissions from other land, and harvested wood products, as well as all non-CO_2 LULUCF emissions, referring to CH_4 and N_2O emissions primarily from organic soils, nitrogen mineralisation/immobilisation, and biomass burning

Figure 7: LULUCF emissions in the UK (1990-2020)



Source: UK Government (2022g). This graph does not include a category for "other LULUCF emissions," consisting of CO_2 emissions from wetlands, emissions from settlements, emissions from other land, and harvested wood products, as well as all non-CO_2 LULUCF emissions, referring to CH_4 and N_2O emissions primarily from organic soils, nitrogen mineralisation/immobilisation, and biomass burning

1.4 Government structures and agricultural policy framework

There are three Departments in the UK Government that are involved in climate policy making including the Department for Business, Energy and Industrial Strategy (BEIS), working on energy topics and promoting international action on climate change, the Department for Environment, Food and Rural Affairs (Defra) which is responsible for issues related to agriculture and Her Majesty's Treasury (HMT), the economic and finance ministry. Ministers from all four UK nations also meet every two months at the Inter-Ministerial Group for Net Zero, Energy and Climate Change to discuss climate-related topics (UK Government 2022a).

The Committee on Climate Change (CCC) is an independent statutory body established as part of the Climate Change Act in 2008. It advises the government on emissions targets and reports to Parliament on progress made in reducing GHG emissions. The Committee also conducts independent analysis on climate-related topics. It is an executive non-departmental public body, funded by the Department for Business, Energy and Industrial Strategy.[4]

The UK submitted its first **Nationally Determined Contributions** (NDC) in December 2020 in which it commits to reducing economy-wide GHG emissions by at least 68 % by 2030 compared

[4] See https://www.theccc.org.uk/ and https://www.gov.uk/government/organisations/committee-on-climate-change.

to 1990 levels (UK Government 2020).[5] The UK submitted a revised 2030 NDC in 2022 without enhancing the overall ambition of the target though.[6] To achieve the UK's NDC, additional measures will be necessary (Climate Action Tracker 2022).

The UK's NDC covers all sectors and gases required under the Paris Agreement, also including the LULUCF sector.[7] The UK's NDC is one of the few targets globally which is rated as almost sufficient by the Climate Action Tracker (CAT), indicating that a country's climate policies and commitments are not fully aligned with the 1.5°C temperature limit but moderate improvements could change this. However, the UK's commitments are not assessed to represent a fair share of the global effort to mitigate climate change. Particularly in relation to agriculture, the CAT sees policy gaps in the UK (Climate Action Tracker 2022).

At national level, a **net zero target** has been included in the legally binding **Climate Change Act** through a revision in 2019.[8] The Climate Change Act sets **carbon budgets** for the UK Government which cap emissions over successive five-year periods. For 2018-2022, the UK set the target to reduce emissions by 37% compared to 1990 levels, from 2023-2027, emissions are to be reduced by 52%, from 2028-2032 by 57% and from 2033-2035 by 78% (sixth carbon budget). While up to 2022 the targets were achieved, according to the Climate Change Committee further action is required to meet the fourth carbon budget set for 2023-2027 and subsequent budgets (CCC 2022a).

The **Clean Growth Strategy**[9] published in 2017 details the UK's current policies and measures through the 2020s and beyond. In 2021, a **Net Zero Strategy** was published which describes the intended pathway for reducing emissions until the end of the Sixth Carbon Budget period in 2037 with a view towards achieving Net Zero in 2050. According to the Climate Change Committee's 2022 progress report, the Net Zero Strategy "sets a clear and credible range for emission reductions in each sector of the economy and highlights choices on how the emissions targets can be achieved" (CCC 2022b, p. 22). The pathway set in the Net Zero Strategy would slightly overachieve the targets set for the UK's Sixth Carbon Budget if it were fully implemented (ibid).

The Sixth Carbon Budget report of the UK's Climate Change Committee (2020d) outlines different scenarios for the path towards achieving the country's net zero target. The "**Balanced Net Zero Pathway**" forms the basis for the recommendations by the Committee and the UK's NDC. This scenario "makes moderate assumptions on behavioural change and innovation and takes actions in the coming decade to develop multiple options for later roll out" (CCC 2020d, p. 24). For the agricultural sector, the scenario identifies priority areas for reducing emissions (see section 2).

Most recently, the government published a report entitled "**Mission Zero: Independent Review of Net Zero**" in the light of the Russian invasion of Ukraine and other global developments. The

[5] Prior to Brexit, its commitments had been included in the EU's NDC.

[6] The revised target includes additional information on the definition of the target and sets out how the UK will achieve its 2030 NDC and how it will assess progress towards meeting the NDC (Climate Action Tracker 2022).

[7] For Scotland, Wales and Northern Ireland, separate emissions reduction targets are defined. Progress towards these targets contributes to the achievement of UK-wide targets. Also, specific policy frameworks and climate strategies apply to these territories (UK government, 2020). Northern Ireland also set a Net Zero GHG emissions target by 2050. Methane emissions are to be reduced by 54% by 2050 only though, so that emission reductions in the agricultural sector will need to be achieved through a substantial increase of low-carbon farming practices and productivity (CCC 2022b, 305f).

[8] Climate Change Act 2008, see https://www.legislation.gov.uk/ukpga/2008/27/contents.

[9] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/700496/clean-growth-strategy-correction-april-2018.pdf

aim of the report is to better describe the impacts of different approaches to reach net zero on the UK society and economy. Among other things, it makes recommendations for short-term action by 2025, including the publication of a comprehensive land use framework by mid-2023 (UK Government 2022f).

Notably, the National Farmers Union (NFU) of the UK announced in 2020 that they aspire to achieve net zero agricultural emissions from UK agriculture by 2040 through efficiency improvements, increased carbon storage and bioenergy production (NFU 2020).

The key legislation in the agricultural sector is the **UK Agriculture Act 2020**.[10] It regulates financial assistance to farmers after Brexit and sets further rules for interventions and agricultural product standards.

Up to 2021, agricultural policy and support was dominated by a system of direct payments. The largest scheme is the **Basic Payment Scheme (BPS)**, under which payments in 2020 amounted to GBP 2.8 billion (UK Government 2021b). The scheme will end after 2024 to be replaced by delinked payments.[11] Funding is also provided through **agri-environment schemes** (GBP 368 million in 2020), aiming to support more sustainable agricultural practices. Under the **Less Favoured Area Support Scheme** (LFASS), GBP 30 million were provided in 2020 (UK Government 2021b).

In Scotland, farmers receive coupled payments through the **Suckler Beef Scheme and the Scottish Upland Sheep Scheme**, which is a form of financial support linked to production (UK Government 2021b).

The **Agriculture Transition Plan** (Path to Sustainable Farming) (2020) outlines policy instruments to replace the EU's Common Agricultural Policy (CAP) by national funding mechanisms for famers and landowners for 2021 to 2024.[12] The major policy reforms which have been implemented and initiated since the UK's decision to leave the EU were to replace the CAP and move away from the system of Direct Payments until 2027 include the following:

- In England, the new **Environmental Land Management (ELM) schemes** were established. These funding schemes aim to steer financial support to agriculture from land-based subsidies as paid under the CAP to "public money for public goods". The ELM includes the **Sustainable Farming Initiative (SFI)** which provides funding to farmers for implementing sustainable agricultural practices (CCC 2022b, p. 304). A **Local Nature Recovery scheme** as a second component of the ELM schemes will continue the **Countryside Stewardship scheme** to support local actions to integrate nature into food production (DEFRA 2023b). The ELM also includes funding for habitat restoration activities at larger scale from 2022 onwards (CCC 2022b, p. 308) through a **Landscape Recovery scheme** (DEFRA 2022b).

- Since 2021, the **Farming Investment Fund** provides grants to farmers in England for adopting sustainable agricultural practices (CCC 2022b, p. 304). It supports farmers in buying equipment, technology and infrastructure needed to implement sustainable farming practices. The scheme will be competitive and funds will be provided to farms that score high on defined criteria.

[10] See https://www.legislation.gov.uk/ukpga/2020/21/contents/enacted.

[11] See https://www.gov.uk/guidance/delinked-payments-replacing-the-basic-payment-scheme.

[12] See https://www.gov.uk/government/publications/agricultural-transition-plan-2021-to-2024.

- **Payments for animal health and welfare** in the form of capital grants and potentially results-based payments.
- **Scheme to support new entrants to the sector** that want to build up new land-based businesses.
- **Slurry Investment Scheme**, supporting new environmentally-friendly slurry stores and equipment by grants (DEFRA 2020).
- **Farming in Protected Landscape programme** was launched in June 2021 which supports farmers in England based in National Parks or other protected areas to improve the natural environment and public access on their land (UK Government 2022c).

Further support will be made available for research and innovation, farm resilience during transition and training of farmers (DEFRA 2020). All four UK nations will implement these new policies through their own national laws. The new policies and funding schemes mark a significant shift to prioritising environmental and climate concerns in agricultural practices. The share of direct payments in total support to farms will decrease from 2/3 in 2021 to 1/3 in 2025. The Basic Payments Scheme will be fully phased out by 2028 (UK Parliament 2022). It remains to be seen how they will be implemented and whether they will enable the UK to reduce emissions from agriculture and contribute to achievement of the UK's climate targets (Carbon Brief 2023).

Additionally, the government's **25 Year Environment Plan** includes targets to reverse soil degradation and restore soil fertility by 2030.[13] The **Environmental Improvement Plan 2023** is the first revision that is envisaged to take place every five years and outlines concrete steps to deliver the targets laid out in the 25 year plan.[14] It fills a gap by connecting the UK's environment and biodiversity actions with the climate targets set at national and international level (Carbon Brief 2023). Farmers' and environmental organisations have broadly endorsed the new approach. Yet, farmers and land managers have expressed concerns whether they will suffer from a loss of support in transitioning from direct payments to the new schemes. They also called for further details to be developed rapidly (UK Parliament 2022).

Despite the variety of policies and support schemes in place, according to the Climate Change Committee's 2022 Progress Report, important policy gaps remain and progress in the agricultural sector has repeatedly failed to meet the indicators required for setting it on a pathway compatible with the net-zero target (CCC 2022b).

1.5 Current developments and trends

The productivity of UK agriculture has generally been increasing over the last 20 years, marking increased efficiency in the sector (UK Government 2022c). Land use has seen little change in the last thirty years with specific crops varying annually due to weather or economic impacts. Likewise, yields have been relatively stable over the last decades. Also, trade of agricultural products has followed similar patterns over the past years (DEFRA 2021), with some exceptions resulting from the Covid pandemic (see section 1.5.2). Production of beef and lamb has

[13] See https://www.gov.uk/government/publications/25-year-environment-plan.

[14] See https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1133077/environmental-improvement-plan-2023.pdf.

remained rather stable over the past ten years while the production of pork and poultry saw increases over this period (DEFRA 2021).

The area that is organically farmed comprises 2.9% of the total farmed area on agricultural holdings in the UK in 2020 (507,000 hectares). Permanent pasture makes up more than half (61%) of the organic area, followed by temporary pasture (20%) and cereals (9.2%). Cereals, vegetables and other arable crops are the main crop types that are grown organically. Organically reared cattle accounted for 3.1% of the total UK herd in 2020; for poultry, sheep and pigs the share was even lower (UK Government 2022c, pp. 140–147). The share of organically farmed land was highest in 2008, but has been rising again since 2018. In line with the general trend in agricultural management, a decreasing number of farmers is managing larger areas of organically cultivated land (UK Government 2022c).

1.5.1 Diets and food waste

Meat consumption per capita has declined by approx. 20% since 2009 to approximately 600g/person per week in 2019.[15] Between 2009 and 2019, the share of people that communicated a shift from dairy products to plant-based alternatives increased from 7% to 13% (CCC 2022b, 300). However, total meat production has increased by approx. 17% within the last ten years (mainly due to increases in pork and poultry) and amounted to 4.1 million tonnes in 2021 (UK Government 2022c, p. 97). The increasing demand is mainly driven by population growth, however. For customers in the UK as a high income country, environmental and health issues play a more significant role in food demands (DEFRA 2021).

It is estimated that total per capita food waste has decreased by approx. 20% between 2007 and 2018, which can partly be attributed to the effects of consumer campaigns, better labelling and storage guidance and more widespread food waste collections from councils (DEFRA 2021, p. 128).

1.5.2 Recent developments in national context

In 2021/2022 Russia's war against Ukraine coupled with other global developments led to higher prices for key agricultural products like cereals, meat and milk. On average, the price for all agricultural outputs as a result of tight global supplies already increased by 10% from 2020 to 2021. Together with increased yields due to favourable weather conditions, these developments increase the value of agricultural outputs. At the same time, farmers had to afford higher costs for feed and fertilisers as well as energy supply. Nevertheless, average incomes on general cropping farms in England are expected to rise by 70% and for cereal farms by 51% in 2021/2022 (UK Government 2022c).

As a consequence of Brexit, the UK had to replace funding for farmers from the EU's CAP by payments from the British government. This situation was used as an opportunity to re-design the system for agricultural payments to better account for climate and environmental concerns. The UK government called out a transition period between 2021 and 2027, to help especially the farmers who had to manage without the direct payments of the European Union from 2021, and to make agriculture more sustainable (see section 1.4). Plans to replace the CAP payment system are currently at different stages of implementation in the devolved nations. In Scotland, an update to the Climate Change Plan has been published in 2021, but detailed strategies on how to achieve emission reductions yet remain to be developed. In Wales, the sustainable land

[15] This translates to 31.2 kg per capita meat consumption per year which is low in European comparison. For example, per capita meat consumption in Germany in 2022 was estimated to exceed 60 kg per capita in 2022; in Poland, Italy and France, meat consumption was estimated between 55 and 60 kg per capita in 2022 (Statista 2023).

management scheme will be continued until the end of 2023 before being replaced by a Sustainable Farming Scheme. Northern Ireland's agricultural policy beyond 2022 is set to include subsidy support in the form of a Farm Sustainability Payment, payments to incentivise low-carbon practices, measures to increase efficiency of beef and measures for the protection and restoration of nature (CCC 2022b, 305f).

Imports and exports of food and feed from and into the UK remained relatively stable over the last three years. As of 2021, Brexit has not strongly affected the trading relationships (DEFRA 2021). After leaving the EU, the UK entered into trade agreements with the EU and multiple other countries such as Japan, Switzerland, Norway and Iceland (but not China). Due to the Covid-19 pandemic the overall export of food, feed and drink decreased in 2020 and 2021, deviating from a general upwards trend since 2004 (UK Government 2022c).

After the turmoil in the British government with multiple changes of Prime Ministers in 2021/2022, it remains to be seen which path the country will take on climate action in the agricultural sector. For King Charles III, the fight against climate change is a major concern. The Conservative Party puts environmental concerns less high on the agenda. The new Prime Minister, Rishi Sunak, might bring climate action back into focus after Liz Truss had expressed scepticism about the ambition required for meeting the UK's 2050 climate targets. His economic position at the right of the Conservative Party is focused more on business contributions to the energy transition than on necessary regulatory interventions to increase taxes on polluting activities and support low-carbon infrastructure projects in order to meet the UK's long-term climate targets, however (Nugent 2022).

1.6 Vulnerability and adaptation

More frequent extreme temperatures and changes to rainfall patterns will negatively affect agricultural production in the UK. For some crops, changing climatic conditions might have positive effects. However, overall global warming will increase risks for agricultural production. The heatwave in the summer of 2018 reduced yields for a number of key crops in the UK, including wheat, carrots and potatoes. In the East of the UK, where most croplands are located (see section 1.1), changed precipitation patterns can pose severe risks of soil erosion which will, in turn, negatively affect yields. Furthermore, increased temperature and changed humidity can promote pests, diseases and heat stress (DEFRA 2021). For example, the migration of diseases with climate change can have negative impacts on livestock, like spread of bluetongue disease among sheep in northern Europe (Dorset Council 2021).

The CCC has identified eight priority risk areas and the UK government outlined approaches to address these risks in its risk assessment published in 2022, including reducing pollution and protecting habitats, increasing soil-friendly farming practices, new breeding and water management technologies and diversifying supply chains (DEFRA 2022c).

The UK Climate Change Act of 2008 obliges the government to undertake a climate change risk assessment every five years. Furthermore, a National Adaptation Programme (NAP) must be prepared every five years and set out the government's objectives, proposals and policies for responding to the risks identified. The Climate Change Committee reviews progress made by the UK government in adapting to climate change every two years. Additionally, the UK reports on adaptation in its National Communications to the UNFCCC and has submitted one of the first Adaptation Communications under the Paris Agreement in 2020 (DEFRA 2022c).

2 Key areas with high mitigation potential

2.1 Introduction

In this section, we prioritise three mitigation options for a closer analysis and quantification of their mitigation potential, in the country-specific context. To prioritise measures, we first examined the emissions contribution of each subsector (see section 1.3). As shown in Figure 4 above, enteric fermentation from livestock is the largest source of emissions, making up 45% of agriculture-related emissions. The second largest source is manure management (14% of agriculture-related emissions), both linked to the UK's livestock production. We combine this knowledge with the potential for socio-economic benefits, based on the description of the sector in Section 1, and the general feasibility for implementation (Siemons et al. 2023).

2.1.1 Selection of priority mitigation actions

The largest source of agricultural emissions come from enteric fermentation from livestock (see section 1.3). Since 2015, the marginal abatement cost curves developed for the UK's agricultural sector which inform the sectoral carbon budgets set by the UK Climate Change Committee (see section 1.4), explicitly refer to livestock health as a mitigation option (MacLeod and Moran 2017). Additionally, approx. a quarter of agricultural emissions relate to N_2O emissions from soils (CCC 2020d) while fertiliser application rates are high in the UK. Measures to increase productivity are key in reducing the demand for land in order to maintain the same levels of food and fibre production (CCC 2022b). Against this background, we selected the following mitigation actions to describe and estimate their mitigation potential in the country for the purpose of this paper:

- Improving fertiliser/nutrient management,
- Enhancing the use of plants with improved nitrogen use efficiency, including cover crops, and
- Increasing animal health.

Improved fertiliser/nutrient management can reduce nitrogen loss and resulting N_2O emissions. **Enhancing the use of cover crops** can increase the amount of carbon stored in soils and reduce nutrient losses. Such crops thereby reduce N_2O emissions and enhance carbon removals while also contributing to soil health. Measures to **improve reproductive health in livestock** can decrease the rate of disease and output loss, reducing emission intensity from milk and meat production.

2.1.2 Overall mitigation potential

The three selected measures are described in further detail below. The mitigation potentials available from the literature for these measures vary, but are generally estimated to be in the order of 0.4 to 1.4 $MtCO_2e$ annually. Combined, they could contribute emission reductions between 1.4 and 2.5 $MtCO_2e$ annually (2.5-5% of total emissions from the agricultural sector as indicated in the Sixth Carbon Budget Report (CCC 2020d)). There might be overlaps between their mitigation potentials, particularly for improved fertiliser management and increasing the use of plants with improved nitrogen use efficiency (NUE). The three measures comprise options for on-farm GHG mitigation which can be delivered through multiple different measures that contribute smaller amounts of GHG mitigation.

Their comparatively low mitigation potential shows that a broader set of mitigation measures is required in order to reach the target indicated for the agricultural sector in the Sixth Carbon Budget Report, particularly including demand-side measures that reduce the consumption of animal products and can thus lead to a reduction in animal numbers, as well as increasing of carbon sinks. This section presents overall mitigation potentials in the agricultural sector available from publications of the UK government.

The "Balanced Net Zero Pathway" set out in the Sixth Carbon Budget report of the UK's Climate Change Committee (2020d) identifies priority areas for reducing emissions in the agriculture and LULUCF sector which are listed below. Implementing key measures in the agriculture and land sectors could reduce *net emissions from both sectors combined* to 40 $MtCO_2e$ by 2035 and 16 $MtCO_2e$ by 2050 (compared to 67 Mt CO_2 e in 2018). *Residual emissions* in the agricultural sector in this scenario could fall to 39 $MtCO_2e$ by 2035 and 35 $MtCO_2e$ by 2050 compared to 54.6 $MtCO_2e$ in 2018 for "agriculture" as defined in the Sixth Carbon Budget, thus marking a decrease by 29% between 2018 and 2035 (CCC 2020d, p. 163-165).[16] Key measures identified by the UK CCC for the agricultural sector include

- Low-carbon farming practices to reduce emissions from soils (e.g. grass leys and cover crops), livestock (e.g. diets and breeding) and waste and manure management (e.g. anaerobic digestion), potentially contributing 4 $MtCO_2e$ emission reductions by 2035;
- Decarbonising fossil fuel use in agriculture through electrification, biofuels, hydrogen and hybrid vehicles, potentially leading to emission reductions of 2 $MtCO_2e$ in 2035;
- Measures to release land from agriculture through dietary changes (potentially contributing annual abatement of 7 $MtCO_2e$ by 2035), reduction of food waste (reducing emissions by close to 1 $MtCO_2e$ in 2035), productivity improvements (improving crop yields through improved agronomic practices and increase stocking rates for livestock, reducing emissions by 1 $MtCO_2e$ in 2035) and moving horticulture indoors. Due to potential overlaps, these measures together could deliver emission reductions of 8 $MtCO_2e$ by 2035 (CCC 2020d, p. 164-165).

In the 'balanced pathway', these measures could result in emission reductions of up to 14 $MtCO_2e$ by 2035 (Figure 8). It is noteworthy that reducing meat and dairy consumption involves the highest mitigation contribution of the package of measures included in the UK's scenarios towards net zero. Assuming more widespread engagement and uptake as well as additional innovation in technology (including crop breeding, lab-grown meat, feed additives) could deliver emission reductions in these areas of up to 19 $MtCO_2e$ by 2035 though (CCC 2020d, p. 166-167) (Figure 9). In these more ambitious scenarios, the assumptions related to reduced demand for meat and dairy products are based on more drastic behavioural changes.

Additionally, the balanced pathway foresees key measures in the land use sector including afforestation, rewetting of peatland, planting perennial energy crops alongside short rotation forestry (potentially combined with CCS technologies) and other land measures including agroforestry on farmland, extending the hedgerows and improving woodland and hedge management. According to the assumptions of the 'balanced pathway,' the measures outlined

[16] The amount of emissions of the agricultural and land use sector given in the Sixth Budget Report deviate from the information provided by the UK in its GHG inventory which could be due to different definitions of the scope of the sectors. We refer to the figures given in the Sixth Budget Report here in order to present the order of magnitude of the emission reductions which the UK proposes in the "Balanced Net Zero Pathway".

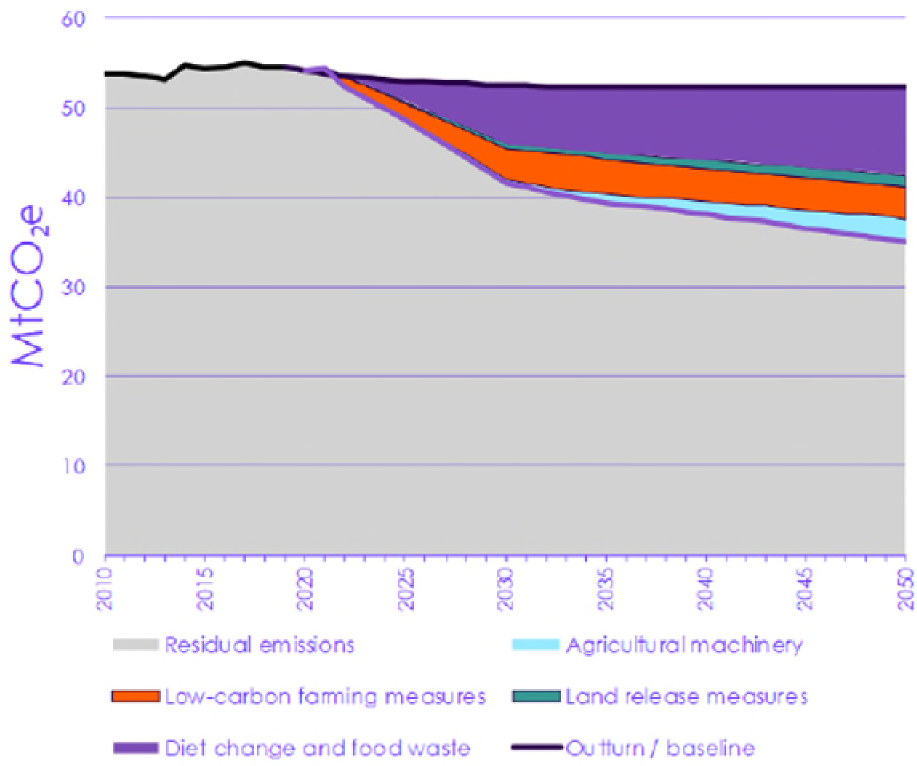
above for the agricultural sector would release sufficient land from agriculture in order to implement these land use measures (CCC 2020d, 170ff.).

Particularly, rewetting of peatlands bears significant mitigation potentials in the land use sector in the UK since peatlands make up the largest share of emissions from the land use sector (see section 1.3). UK peatlands store huge amounts of carbon estimated at more than 3 billion tonnes; which is more than the carbon stored in forests in the UK, Germany and France together. Approx. 12% of the UK land area are peatlands (around 3.0 million hectares). Only 22% of these lands are in a condition that is close to their natural state or rewetted. Semi-natural peatlands make up approx. 41% of the UK peatlands area. Lowland peat that has been drained for agricultural purposes accounts for 7% of peatland area. Total emissions from peatlands are estimated at 23.1 $MtCO_2e$/year. The drained cropland area accounts for approx. 32% of total emissions from peatlands (7.6 $MtCO_2e$/year, despite their low share in terms of ha), while semi-natural peatlands make up around 15% of total peatland emissions (around 3.4 $MtCO_2e$/year). Natural or rewetted peatlands in the UK act as a sink with about 1.8 $MtCO_2e$/year (UK Office for National Statistics 2019).[17]

The UK Committee on Climate Change has suggested restoring 55% of peatlands by 2050. Resulting avoided emissions are considerable; they are estimated between 12 $MtCO_2e$/year (without rewetting of agricultural lands) and 16 to 19 $MtCO_2e$/year (including cropland in the area that is to be rewetted). Seasonal management of the water level on croplands could avoid 1.5 $MtCO_2e$/year in 2050. The economic value of total climate change benefits resulting from restoration are estimated to exceed the costs of restoration by far (GBP 109 billion compared to GBP 21 billion over the next 100 years) (UK Office for National Statistics 2019).

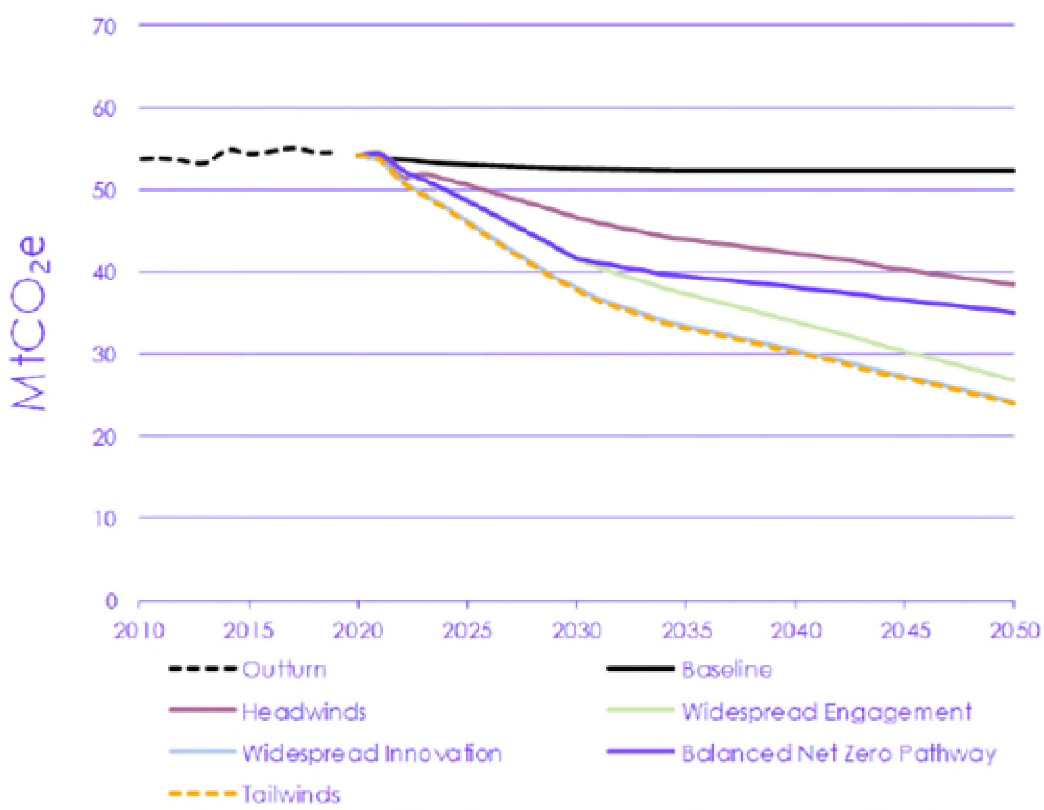
[17] Grassland makes up 8% of the total peat area and is responsible for 6.3 $MtCO_2e$/year; woodland makes up 16% of the total peat area and makes up 4.6 $MtCO_2e$/year and area on which peat is extracted makes up 6% of the total peat area in the UK and accounts for 1.2 $MtCO_2e$/year (UK Office for National Statistics 2019).

Figure 8: Sources of abatement in the Balanced Net Zero Pathway for the agriculture sector



Source: CCC 2020d, p. 167

Figure 9: Emissions pathways for the agricultural sector



Source: CCC 2020d, p. 166

2.2 Prioritised mitigation options

2.2.1 Improved fertiliser/nutrient management

Measure	While the use of synthetic nitrogen fertiliser has played and continues to play an important role in supplying food for the world's population, its overuse has negative effects on soils, water and air pollution by N_2O, ammonia and NO emissions. Globally, about 50% of applied nitrogen is not absorbed by crops (WRI 2019). Measures to reduce fertiliser use include precision application of fertilisers depending on productivity of fields, and controlled-release fertiliser systems (WRI 2019). Particularly, it is important to ensure that the timing of nitrogen application fits to crop needs in order to avoid that nitrogen is lost (Robertson and Vitousek 2009). Additionally, emissions from fertiliser use could be reduced by optimising the use of manure as fertiliser, so that it would partially replace synthetic fertiliser. This mitigation option reduces N_2O emissions associated with the overuse of synthetic fertilisers as well as costs.
Status	Currently, fertiliser application rates are still high in the UK (see section 1.3). Approx. 78% of farms spread manure or slurry including almost all dairy farms; while 85% spread fertiliser. At close to half of those farms that spread slurry or manure, the spreader is never calibrated according to a survey from 2022 (UK Government 2022e). In 2020, 121 kg nitrogen were applied per ha on croplands, falling below the average of 140-150 kg/ha between 1990 and 2019 (UK Government 2022c, p. 130). This figure exceeds the average for 21 EU Member

States (Einarsson et al. 2021).[18] On grasslands, 53 kg per ha nitrogen were applied, continuing the downward trend since 1990 that is mainly due to a reduction in total cattle numbers and improvements in manure use efficiency (UK Government 2022c, p. 130). More than 60% of farmers say that they are pursuing efforts to improve their nitrogen fertiliser application accuracy (while not all farms are applying synthetic nitrogen fertiliser, e.g. organic farms or some grazing livestock farms) (UK Government 2022b). While for 78% of farm areas in England in Wales, nutrient management plans exist (where applicable), an estimated 5% never use this plan (SRUC 2020, p. 18).

In 2021, approx. 65% of farms applied organic manure on at least one field of their farm; with cattle manure making up the largest share (UK Government 2022d). Farm holdings with livestock commonly apply slurry or manure to their fields. However, 43% of farmers indicated that they never calibrate their manure or slurry spreaders which can easily lead over-application (UK Government 2022e). Under the newly established Sustainable Farming Initiative (see section 1.4), a nutrient management standard was launched in 2022 under which farmers can receive funding for better nutrient management on their farms (DEFRA 2023a).

Against this background, reducing the use of synthetic fertiliser use as a result of more precise and more deliberate timing of application is listed as one of a list of measures to reduce on-farm emissions in the UK (UCL 2021). Additionally, it is among the three most common actions taken to reduce GHG emissions on farms already, according to a survey among farmers (UK Government 2022e).

Potential

Among on-farm mitigation methods, better nutrient management is listed as a key mitigation option in the UK's 2021agri-climate report. According to this report, implementing good nutrient management[19] could bring emission down by close to 1 $MtCO_2e$ annually (maximum technical potential) in England. Implementation of better nutrient management has started already with 0.4 $MtCO_2e$ achieved emission reductions in February 2021 (UK Government 2021a). A study by UCL indicates an annual economic mitigation potential by 2030 of 0.4 $MtCO_2e$ for improved organic N planning, controlled release fertilisers, improving synthetic N use, precision farming, low manure spreading and shifting autumn manure application to spring (UCL 2021, p. 40). The difference between the different estimates available in the literature may be due to different assumptions and methodologies used for calculating the given mitigation potentials. Furthermore, there might be overlap between different specific activities related to improved fertiliser management that the studies handle in different ways.

Co-benefits

Reducing nitrogen surplus has various positive co-benefits for ecosystems and biodiversity.[20] Fertiliser use can negatively affect water quality through nutrient enrichment (eutrophication) resulting excessive growth of macrophytes and

[18] Excluding CY, EE, LT, LV, MT, SI.

[19] This would imply using a fertiliser recommendation system, integrating fertiliser and manure nutrient supply, not applying manufactured fertiliser to high-risk areas, fertiliser spreader calibration, using manufactured fertiliser placement technologies and avoiding spreading manufactured fertiliser to fields at high-risk times (UK Government 2021a).

[20] According to a recent report under the Geneva Air Convention of the United Nations Economic Commission for Europe (CCE), a number of ecosystem types are more sensitive to nitrogen surplus than suggested by previously assumed values for critical loads for harmful nitrogen inputs (Aazem 2022).

algae which can diminish dissolved oxygen levels. Resulting ammonia emissions also contribute to the acidification of soils (UK Government 2022c, 134ff). Reducing fertiliser use can therefore contribute to soil health and protecting biodiversity by avoiding changes in soil pH, and toxicity of soils (Bobbink et al. 2010). Additionally, negative water effects like freshwater acidification and groundwater contamination can be mitigated if fertiliser use is reduced (Vries et al. 2013). Moreover, saving costs for fertiliser provides socio-economic benefits to farmers.

Barriers

Technical barriers: Soil and climate conditions imply uncertainty and heterogeneity for required levels of nitrogen and leaching effects (OECD 2021b).

Economical barriers: To avoid a loss of income from yield decreases, farmers may tend to over-apply fertiliser as a protective measure. Furthermore, the costs of preparing and updating a nutrient management plan might be an economic barrier for farmers to take action to improve their fertiliser use (SRUC 2020, p. 18).

Policy/legal barriers: Financial support that is tied to output might act as a barrier to reducing synthetic fertiliser use (Stuart et al. 2013). The EU's CAP and the UK's Basic Payment Scheme were organised this way in the past. Additionally, nitrogen surplus is currently not priced or legally limited in the UK, except for Nitrates Vulnerable Zones that cover all of Northern Ireland, some parts of Wales, 14% of Scotland and 55% of England (CCC 2020a; WWF-UK 2022).

2.2.2 Increasing use of plants with improved nitrogen use efficiency

Measure

The use of plants with improved NUE can reduce nutrient losses, including nitrate that would otherwise be converted to N_2O. Additionally, they contribute to mitigating agricultural emissions by increasing carbon stored in soils (Paustian et al. 2016). Thereby, they indirectly reduce emissions from managed soils, including emissions resulting from the use of fertilisers. Moreover, such plants improve the nutritional characteristics of fodder. This mitigation option includes using cover crops on agricultural soils, including clover on grassland systems, and increasing the use of legumes in crop rotation.[21]

NUE values vary greatly by country, individual farm, and crop type. While fruits and vegetables have a low average NUE of 14%, the global average is 42% (Zhang et al. 2015).

Status

NUE has improved in the past decades (SRUC 2020, p. 14). However, the nitrogen balance for the UK was a surplus of 92 kg/ha on managed agricultural land in 2020, marking an increase of 7% compared to 2019 due to lower levels of production in 2020 and resulting lower offtake. Compared to 2000, the surplus rate decreased by 17% due to reduced application of synthetic fertilisers and reduced manure production as a result of lower livestock numbers, although this has been partially offset by lower nitrogen offtake over the same period (UK Government 2022c, pp. 132–134). In many European countries, the nitrogen balances show significantly lower surpluses (Eurostat 2022).

[21] See also factsheet on improved crop rotation, available at www.umweltbundesamt.de/publikationen/Role-of-soils-in-climate-change-mitigation.

This measure is already implemented by numerous farmers in the UK: 73% of livestock holdings used a clover mix on part and 19% on all of their temporary grassland. About one fourth of farmers indicated they had increased their use of legumes in crop rotations on croplands (UK Government 2022e). Under the newly established Sustainable Farming Initiative (see section 1.4), a nutrient management standard was launched in 2022 under which farmers can receive funding for better nutrient management on their farms, including the use of legumes in crop rotations and on grassland (DEFRA 2023a).

Potential

Using plants with improved nitrogen use efficiency and using clover in place of nitrogen fertiliser has a GHG reduction potential of approx. 0.7 $MtCO_2e$ (maximum technical potential) in England. Implementation of this measure had already delivered 0.1 $MtCO_2e$ emission reductions in February 2021 (UK Government 2021a). For the UK, a study prepared for the CCC identifies an economic mitigation potential of approx. 0.7 $MtCO_2e$ annually by 2035 for using grass legumes mixes on grasslands and cover crops (SRUC 2020, p. 33). For increasing plant varieties with improved N-use efficiency, legume-grass mixes and using legumes in rotations, an annual economic mitigation potential by 2030 of 0.4 $MtCO_2e$ is indicated for the UK in a study by UCL (2021, p. 40). While the estimated mitigation potential varies between different literature sources, it has a similar order of magnitude, amounting to between 0.4 and 0.7 $MtCO_2e$. The difference between the different estimates available in the literature may be due to different assumptions and methodologies used for calculating the given mitigation potentials. Furthermore, there might be overlap between different specific activities related to using plants with improved NUE that the studies handle in different ways.

Co-benefits

Besides reducing GHG emissions from the reduced use of synthetic fertiliser and increasing carbon sequestration, increasing the carbon stored in soils has multiple environmental and social co-benefits. Particularly, it improves soil health and fertility with positive effects on biodiversity. It can also improve water quality, make soils more resilient to climate change impacts and counteract land degradation (Paustian et al. 2016; Sietz et al. 2021; L. K. Tiemann et al. 2015). Compared to monocultural systems, improved crop rotations can also increase crop yields (Jalli et al. 2021).[22]

Barriers

Technical barriers: Soil and climate conditions imply uncertainty and heterogeneity for required levels of nitrogen and leaching effects (OECD 2021b).

Economical barriers: 54% of farm holdings in the UK had a nutrient management plan in 2022 and 36% of farmers keep track of soil organic matter in their soils. More than half of all farms regularly calculate the whole farm nutrient balance for nitrogen, phosphorus or potassium. As barriers preventing farmers from keeping track of soil organic matter they expressed that monitoring is not important enough to test for, that it is difficult to interpret the results, high costs and other reasons (UK Government 2022e). This resonates with general concerns about the uncertainty related to monitoring and assessing soil organic carbon stocks (Paustian et al. 2016).

[22] See also factsheet on improved crop rotation, available at www.umweltbundesamt.de/publikationen/Role-of-soils-in-climate-change-mitigation.

Policy/legal barriers: Financial support that is tied to output like the UK's Basic Payment Scheme might act as a barrier towards prioritising agricultural practices that reduce emissions and sequester carbon.

2.2.3 Increasing animal health

Measure

Strategies that are only focused on increasing productivity of livestock can lead to reducing its carbon footprint but may come at the cost of animal welfare. Improving animal health therefore aims to reduce emissions while at the same time improving animal welfare (Llonch et al. 2017). Animal health conditions are related to infectious diseases as well as non-infectious causes like the environment, genetics and malnutrition (FAO 2022b). Cattle diseases lead to increased mortality, depressed milk production, increased waste from discarded treatment milk and reduced reproductive performance (Statham et al. 2020). In general, the emissions intensity of ruminant meat and milk production is affected by maternal fertility rates, mortality rates, milk yield, growth rates and feed conversion ratios. All of these parameters are influenced by the health status, so that improving the health status of animals can be assumed to reduce the associated emission intensity (Skuce et al. 2016; FAO 2022b). A study from the Netherlands estimates, for example, that emissions resulting from certain diseases of dairy cows, including foot lesions, clinical mastitis and subclinical ketosis, amount to about 0.4 $MtCO_2e$ per year in the country (Mostert 2018). FAO studies also showed considerable mitigation potentials for measures to improve animal health for different regions of the world (FAO 2022b).

Options for improving animal health include supplementing animal feed to improve nutritional management and reproductive status, accelerate growth and weight-gain and correct dietary imbalances. Additionally, preventive control measures (including changing housing and management to reduce stress and exposure to pathogens, vaccinations, improved screening and biosecurity, disease vector control), control measures relating to fertility and milk yield as well as curative treatments, such as antiparasitics and antibiotics, can contribute to reducing the emissions intensity of livestock. By preventing disease and improving the performance of livestock, such measures help to reaching finishing weights earlier and achieving higher feed conversion rates (Skuce et al. 2016; Statham et al. 2020; UK Government 2022e).

Status

UK livestock systems are particularly vulnerable to endemic disease impacts because they are largely pasture-based (SRUC 2020, p. 28). Livestock contribute about half of the overall production value of agricultural outputs (UCL 2021, p. 8), underlining the economic importance of livestock production for the agricultural sector.[23]

The UK government launched an Animal Health and Welfare Pathway in 2022 which aims to support farmers in enhancing animal health, improve biosecurity, tackling anti-microbial resistance and reduce GHG emissions. Funding for reviewing animal health practices will be made available through the new

[23] In 2021, total livestock output was GBP 16,285 million, marking an increase of GBP 1,034 million or 6.8% from 2020. This increase results from higher prices (except for pigmeat), particularly for milk and beef (UK Government 2022c, p. 39). Meat production accounts for a total value of GBP 9,137 million in 2021 with cattle and poultry contributing a third and pigs and sheep contributing 16% and 17% respectively (UK Government 2022c, p. 98). In 2021, total meat production decreased for the first time since 2012, falling by 0.8% compared to 2020. The total value of meat increased by 5.9%, however (UK Government 2022c, p. 97).

Sustainable Farming Initiative (see section 1.4). Grants will be provided for capital investments and further results-based payments will be made available for demonstrating high outcomes relating to animal health and welfare from 2025 onwards. Additionally, the government plans market interventions including product labelling to increase the transparency and demand for high welfare products. Also, regulatory standards for animal welfare shall be increased (DEFRA 2022a).

In 2022, 73% of livestock farms in the UK had a Farm Health Plan in place and 83% of these farmers indicated that they were using the plans routinely or in taking decisions on disease management (UK Government 2022e).

Potential

While measures to improve animal health have the potential to reduce the emissions intensity of livestock, they can lead to an absolute increase in emissions in absolute terms unless the herd size is kept constant or reduced.

The British Department for Environment Food and Rural Affairs (DEFRA) commissioned a study on the impact of controlling 10 selected endemic cattle diseases and conditions on cattle productivity, agricultural performance and GHG emissions that was published in 2015. In their scenario assuming a higher level of uptake, a number of cost-effective cattle health mitigation measures can reduce GHG emissions by 6% or 1.4 $MtCO_2e$ annually compared to the assumed baseline scenario and assuming a high level of uptake (as a result of reduced emissions intensity and reduced animal numbers). Interlinkages between these measures are not considered in the study. This calculation is based on the assumption of holding production output constant. As a result of the measures to improve animal health, total cattle numbers would be reduced under this assumption in response to disease treatments and productivity gains. This in turn could entail the release of land from agricultural production and thus have indirect positive land use implications. According to the study, 7-11% of the UK's grassland area could become available for alternative use, such as woodland, if production levels are not increased (ADAS UK Ltd 2015). There is a risk, however, that farmers respond to improved animal health and productivity by expanding livestock numbers. This could partially offset the reduction of emissions intensity (ADAS UK Ltd 2015).

A more recent study carried out for the CCC identifies an economic mitigation potential of approx. 0.6 $MtCO_2e$ annually by 2035 through better health planning for cattle and sheep (not taking into account measures related to animal feeding) (SRUC 2020, p. 33). For this study, it is not clear whether reduced animal numbers as a consequence of improving animal health is accounted for. The difference between the different estimates available in the literature may be due to different assumptions and methodologies used for calculating the given mitigation potentials. It must also be noted that there might be overlap between different specific activities related to improved animal health that the studies handle in different ways.

Co-benefits

Besides reducing GHG emissions, measures to improve cattle health most importantly improve animal welfare. Additionally, they are profitable in their own right in case of the UK, providing substantial economic benefits to farmers (Statham et al. 2020). If livestock numbers are reduced as a response to increased health and productivity, this can have indirect positive environmental effects. By releasing land from agricultural use that is not used for livestock any more, this land could be turned into a protected area or managed in other ways that allow for greater sequestration levels of carbon (ADAS UK Ltd 2015).

Good animal health additionally is the basis for other mitigation options to be effective, including e.g. feed additives. Also, it lowers risks associated with spreading exotic diseases as a result of trade (FAO 2022b).

Barriers

Technical barriers: A general challenge related to improving animal health is the lack of standardised measurement and monitoring of its status (FAO 2022b). As a result, improving animal health might not be visible in countries' GHG inventories and therefore not appear as an attractive mitigation option to promote to governments (MacLeod and Moran 2017).

Economical barriers: Farmers may lack the financial resources needed to access the technology and labour needed to improve their health monitoring. Farmers also cite uncertainty with yield benefits as a primary barrier to adopting health interventions (FAO 2022b).

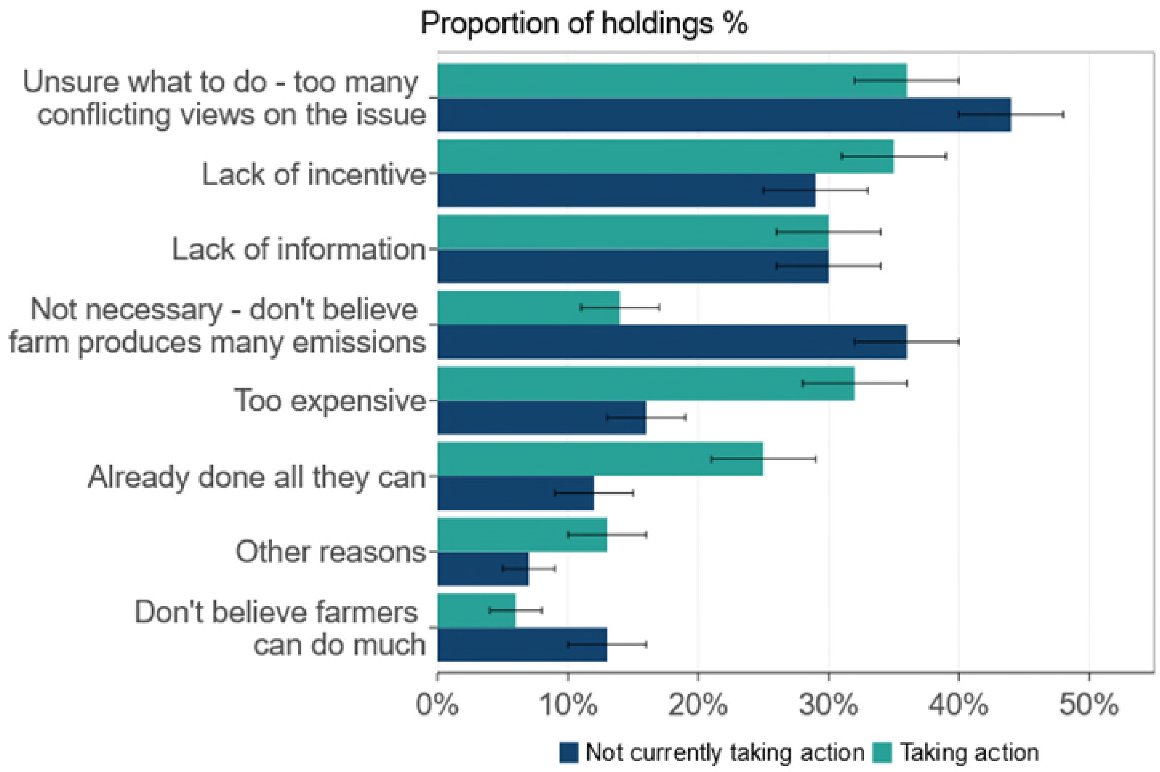
3 Barriers to implementing mitigation potential

In this section, we look into the main barriers identified for the UK, in the context of the prioritised mitigation options, building on the findings of a report on general barriers prepared under this research project (Siemons et al. 2023) and the country-specific circumstances described in Section 1 of this report. The analysis of barriers below follows the clustering proposed in Siemons et al. (2023), according to the relevant governance level for taking action, while taking into account the classification from the Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change and Land (Smith et al.) within each of the governance levels.

3.1 Farm level

A survey on greenhouse gas mitigation practices among farmers (UK Government 2022e) revealed several key barriers for the uptake of GHG mitigation measures even though these could bring economic benefits to the farmers. The most important reasons for not taking climate action relate to being unsure about the right measures to take, lack of incentives, lack of information and high costs. Additionally, 36% of farmers not taking action so far showed a lack of willingness, expressing the view that mitigation action is not necessary (Figure 10) (UK Government 2022e).

Figure 10: Factors preventing action to reduce GHG emissions



Source: UK Government 2022e

The most common motivation for taking mitigation action is that such action is considered good business practice for farmers (expressed by 84% of farm holdings). Additionally, concern for the environment is a key reason for implementing sustainable practices (63% of holdings) (UK Government 2022e).

Uncertainty about the impacts of sustainable farming practices on emissions presents a further technological barrier towards uptake of such practices (CCC 2022b, p. 310). Additionally, lacking knowledge, experience or skills prevent UK farmers from adopting climate-friendly farming measures. High investment costs and uncertainty about the economic viability of new options are further barriers to changing agricultural practices (CCC 2018, 63f.). However, in a survey among farmers, only 28% said there were not enough incentives to reduce emissions and 18% considered mitigation measures too expensive. Of those farmers already taking action, 26% considered mitigation measures too expensive to implement them (UK Government 2021a).

Moreover, 28% of farms in England, 24% in Scotland and 22% of farms in Wales are tenanted to farmers, limiting farmers' possibility to steer long term land management (CCC 2020b, p. 152). For changing livestock management, certain farming systems, like uphill grassland, may be socially and culturally important and thus difficult to change (CCC 2018, 63f.). Climate impacts and anthropogenic pressure on natural ecosystems also put limits on the potential of soils to sequester carbon (CCC 2022b, p. 320).

3.2 National level

The UK has been active in developing new policy instruments to steer a sustainable transformation of the agricultural sector and organise the transition away from the EU CAP. While this is an important opportunity to reset the agricultural policy framework and can be seen as a step to create laws, incentives and increase funding for sustainable farming practices that were lacking under the previous funding approach, progress to develop alternative policy instruments is slow. The introduction of the ELM schemes in England has experienced delays which provoked uncertainty among farmers. In Scotland, Wales and Northern Ireland, details on policy incentives to replace the CAP subsidy system have not yet been defined. The voluntary nature of existing schemes has also limited the uptake of sustainable agricultural practices. Furthermore, a comprehensive land use strategy remains absent (CCC 2022b).

As a further legal barrier, the UK Government Food Strategy lacks clear targets or a vision for a sustainable transformation of the broader food system. Neither this strategy nor the Net Zero Strategy sets a pathway for achieving dietary changes to reduce livestock emissions. Only Wales is developing policy measures for addressing the demand side (CCC 2022b, 83ff.). This is despite the fact that consumers seem willing to adopt diets that are less carbon-intensive. Furthermore, policy incentives on food waste are still lacking (ibid, p. 309).[24] Also, government support to enhance farmers' skills and knowledge is lacking (ibid, p. 312).

Overall, the government's vision for the agricultural sector tends to rely on innovation and technological approaches to reduce emissions from agricultural activities and increase productivity. The Climate Change Committee comes to the conclusion that these plans are very optimistic, lack detail and lack strategies for also tackling the demand side (CCC 2022b, p. 320). Additionally, funding for research and innovation in the agricultural sector is evaluated as insufficient by the CCC (CCC 2018).

3.3 International level

The UK's high dependence on imports could imply that domestic products that were produced in an environmentally-friendly way are not competitive to imported products. Additionally, while there is considerable guidance from the scientific community for achieving healthy and sustainable diets globally, there are no clear targets defined on a country or regional level, and

[24] Only the Net Zero strategy by the Welsh Government proposes a long-term strategy to promote such dietary changes (CCC 2022b, p. 309).

there is no international pressure to help support a shift to more sustainable global food systems.

3.4 Consumer level

Even though consumers generally seem to be willing to adopt less carbon-intensive diets in the UK (see section 3.2), barriers related to personal habits, cultural traditions and social norms can counteract efforts to reduce meat and dairy consumption (WRI 2016). Moreover, a study from 2015 found that awareness of the consequences of red meat consumption on climate change was still low in the UK (Chatham House 2015). Additionally, eating habits and expectations related to the shape and appearance of food can act as a barrier towards reducing food waste (WWF 2021). We have not identified any specific barriers on the consumer level that would complicate the three prioritised mitigation options described in section 2 though.

4 Recommendations

In a world compatible with the Paris Agreement, the agricultural sector will need to meet the growing food demand of people and animals, while contributing to other equally relevant climate and development objectives and adapt to a changing climate. In the UK as a highly industrialised country, emissions in the agriculture and land use sector must decrease significantly in order to reach the country's mitigation targets. This is to be achieved by adopting low-carbon farming practices, increasing the productivity of the agricultural sector, reducing meat and dairy consumption and food waste while at the same time restoring peatlands and increasing sequestration by sustainable forestry and land use (CCC 2022b). This paper identified and quantified three mitigation actions in the UK's agricultural sector that would improve productivity and provide environmental and economic co-benefits:

To maximise emission reductions in the agricultural sector, the United Kingdom would need to take a multi-faceted approach. According to the UK CCC, the three areas for mitigating emissions in the agricultural sector include low-carbon farming practices, decarbonising fossil fuel use in agriculture, and measures to release land from agricultural production (section 2.1.2). Among the low-carbon farming practices, the improvement of fertiliser/nutrient management, enhancing the use of plants with increased NUE including cover crops and increasing animal health are among the key measures to reduce GHG emissions. Different estimates for their mitigation potential reveal uncertainties in the quantification of the impact of these measures though and potential overlaps with other measures (section 2.2). The largest mitigation impact according to national sources could be achieved through measures to release land from agriculture through dietary changes which would lead to a reduction in the number of livestock in the UK (section 2.1.2).

However, the successful implementation of agricultural mitigation measures is hampered by numerous barriers on the farm-, national-, international-, and consumer-level. For the selected mitigation measures presented in more detail in this report, we identified technical, economical and policy/legal barriers. These include uncertainties around determining the right balance of nitrogen in soils and leaching effects for measures related to nutrient management. Furthermore, concerns about economic losses, uncertainty related to monitoring and assessing soil organic carbon stocks as well as the costs of better nutrient management planning act as barriers to changing practices. Finally, the incentives for better nitrogen management have been insufficient under the Basic Payment Scheme. A lack of standardised measurement and monitoring counteracts efforts to improve animal health. Lack of financial resources for health monitoring as well as uncertainty related to the economic benefits also obstruct mitigation action (section 2.2).

More generally, uncertainty among farmers about the right measures, a lack of willingness to act, lacking knowledge, high investment costs, tenure structures, and cultural and social habits act as barriers at farm level. At the policy level, the restructuring of available incentives to replace the CAP is a step in the right direction, but progress with regard to agreeing on the details of the new incentive schemes is slow. Additionally, specific targets or a comprehensive land use strategy are still lacking. Also, no target or vision is available on the transformation of the broader food system, even though consumers show willingness to change dietary patterns. Funding for research and innovation in the agricultural sector is lacking as well (section 3).

To accelerate the uptake and implementation of the measures described in this report, it is key to enhance the national mitigation framework in the agricultural sector and reconcile agricultural goals and mitigation options, while protecting the sector from environmental and economic risks. Some concrete options are outlined in the following paragraphs:

1. *Enhance the national climate mitigation framework in agriculture and align other environmental and food security objectives with mitigation objectives*

In the UK, the national climate mitigation framework already sets targets for the agricultural sector. However, no dedicated Net Zero delivery plan or strategy is in place for the agriculture and land use sector yet. Given the overlap with other key goals, it is essential to develop strategies for agriculture and land management that align food security, climate, biodiversity and other environmental objectives (CCC 2022b, p. 304). Also, all policy and procurement decisions should be in line with the net zero target (ibid, p. 558). The land use framework announced for 2023 in the government's Food Strategy should be designed in that way (ibid, p. 316). A focus should be put on soil health in all agricultural policy to deliver mitigation outcomes as well as other environmental benefits (UCL 2021).

2. *Improve regulatory framework on existing laws and policies*

In recent years, the regulatory framework for mitigating emissions from agriculture and land use has been developed and strengthened following Brexit and reforms to the Common Agricultural Policy (CAP). However, the development of agricultural subsidies and land management schemes still remain to be completed and developed more precisely for longer time horizons. The reform of the CAP provides a unique opportunity to readjust and coordinate policies and targets on agriculture, mitigation, food security and wider environmental goals. The remaining details for policies and support schemes for longer time frames to replace CAP mechanisms should be developed as soon as possible. Specifically, incentives to increase uptake of sustainable agricultural practices should be enhanced, including management incentives under the ELM scheme and grants for investments in capital and infrastructure should be provided (CCC 2022b).

3. *Further ideas for strengthening mitigation in prioritised areas*

Building on existing policy structures and initiatives, the UK government can foster mitigation in the agricultural sector. More specifically, the implementation of mitigation in the agricultural sector could be fostered by the following options (see CCC 2022b; UCL 2021; FAO 2022b; CCC 2020b):

- **Develop demand-side measures to reduce dietary choices and food waste** to complement innovation and technological approaches. A Government Food Strategy was released in 2022, but lacks clear targets and measures to reduce meat and dairy consumption and food waste. Without changes to dietary patterns, mainly in developed countries, a sustainable and just 1.5°C pathway is not feasible. With the planetary health diet,[25] a dietary recommendation is available that can feed a growing world population while respecting planetary impact limits and being compatible with climate goals. Discussing alternative narratives next to the current agricultural expansion plans could help understand the implications of a shift to largely plant-based diets and potentially avoid disruptions in the sector in the medium to long term.
- **Promote research and development on sustainable agricultural practices,** including measures addressing innovation, productivity, and the demand side, as well as impacts on yields, land use and wider environmental outcomes.
- **Implement enabling measures to address non-financial barriers:**

[25] https://eatforum.org/eat-lancet-commission/the-planetary-health-diet-and-you/

  - **Enhance training for farmers to support the uptake of agroecological practices** and managing the transition of the workforce to meet the demands of a sustainable agriculture and land use sector should be enhanced.
  - **Provide support to tenant farmers** to set the right contractual incentives for sustainable long-term management of their rented land.

- **Develop robust Measurement, Reporting and Verification (MRV) frameworks for the new support schemes** in order to be able to evaluate their impacts.
- **Extend the Nitrate Vulnerable Zones** in which the application of synthetic fertiliser is limited to the whole UK.
- **Consider developing minimum environmental standards for agricultural imports.**
- Further develop **policies to address supply chains** to also ban commodities associated with legal deforestation and the destruction of other ecosystems than forests.

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