Developing WWF's preferred pathway to aligning UK agriculture and land use with net zero

Report

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Executive Summary

The WWF had at the time of writing an interim target to reduce GHG emissions in the UK agriculture sector by at least 24% by 2030 (13 $MtCO_2e$) on 2020 levels and by 50% by 2050 (27 $MtCO_2e$). To help evaluate this, recent reports and literature were gathered to review possible land-based mitigation practices, agroecological measures, and dietary shifts which may allow for a pathway for this goal to be reached or surpassed. Based on the categories of farming practices, livestock management, agroforestry, afforestation, and peatland restoration the means and ranges of mitigation potential from these categories were estimated for the UK. The Committee of Climate Change's (CCC) 6th carbon budget 'Widespread Engagement Scenario' - which includes a dietary shift - was used as a baseline scenario or used as reference.

Considering only on-farm practices, the introduction of agroecological or regenerative farming practices can play a more significant role in reducing GHG emissions than envisaged by the CCC. Although each of the studies considered uses a slightly different mix of practices, and some consider the impact of dietary shifts, the figures for GHG abatement to 2030 and 2050 exceed the CCC's estimates of 3.66 and 2.54 $MtCO_2e\ yr^{-1}$. One of the reasons for this is that the CCCs decision to exclude certain practices underestimates the potential of agroecological farming. Here, there seem to be modest improvements that can be made on croplands (e.g., by introducing low/no-till, incorporating residues back into the soil) and major improvements in UK grasslands through growing legumes, better fertilisation management, and improving grazing practices. Taking an average value from all the considered studies, we estimated a potential for an overall reduction of 5.6 MtCO2e yr^{-1} to 2030/2035, and 8.2 Mt CO2e yr^{-1} to 2050 by introducing agroecological measures in livestock, croplands, and introducing agroforestry practices.

Regarding dietary shifts, there is scope for more ambition compared to the CCC Widespread Engagement Scenario. Current protein consumption levels in the UK are higher than recommended. The CCC approach of cutting all livestock by 50% and maintaining current protein levels through crops already gives a margin to reduce GHG emissions and free up land. However, if protein sources were to be reduced to healthier levels, the reduction would be higher.

For the UK, in total, there is the potential to reduce agricultural GHG emissions by 5.6 $MtCO_2e\ yr^{-1}$ through agroecological solutions, and between 6.9 – 17.26 $MtCO_2e\ yr^{-1}$ for a possible dietary shift (depending on the level of meat reduction ranging from 20 to 50% and the relating lower production). If afforestation and peatland restoration are considered they add around 7.5 $MtCO_2e\ yr^{-1}$ and 3.1 $MtCO_2e\ yr^{-1}$, respectively, to the mitigation potential. The total of these solutions sums up to around 23.1 $MtCO_2e\ yr^{-1}$ for a 20% reduction in livestock production for 2030. If BECCS and blue carbon were also included, this potential could be significantly higher.

The aim of the 24% reduction of emissions from agricultural sector from 2020 by 2030 (13 $MtCO_2e\ yr^{-1}$) compared to 2020 levels could therefore be achieved with agroecological

measures (including crop and livestock management, agroforestry) and a 30% reduction in livestock production enabled by a dietary shift.

The goal of a 50% reduction in emissions from the agricultural sector by 2050 (27 $MtCO_2e\ yr^{-1}$) would need to consider further measures. Agroecology measures and a dietary shift up to 50% of less meat and milk would result in an annual reduction of ~25.5 $MtCO_2e\ yr^{-1}$. Considering a reduction in protein to healthy levels would gain an additional margin as the same amounts would not need to be produced in crops (e.g. a 50% less meat and milk production without producing the same amount of protein from crops would result in 23.7 $MtCO_2e\ yr^{-1}$, Table 8).

Country-specific pathways should consider the production and use of land areas to date. England is dominated by croplands and permanent grassland, whereas the other nations have a lower proportion of cropland areas. Northern Ireland and Wales have mainly permanent grassland. Scotland is geographically dominated by rough grazing and permanent grasslands. This suggests pathways in England should be concentrated on crop management and agroforestry. Agroecological practices regarding improved livestock management is important for all nations and should be considered in equal measure.

Dietary shift and the corresponding reduction in livestock production, needs to be considered carefully. This report gives only indication in reduction of GHG emissions and the possible freed land. Country-specific economic considerations should be taken into account, as well as social aspects for country-specific pathways.

Contents

Introduction

To achieve the UK's legal obligation to reach 'net zero' by 2050, substantial reductions in agricultural emissions are required. As of 2018, agricultural emissions in the UK were 54.6 $MtCO_2e\ yr^{-1}$ (CCC 2020a), which accounted for 10% of all the UK's greenhouse gas (GHG) emissions, although this varies considerably by nation (Scotland and Wales 16%, Northern Ireland 27%) (Northern Ireland Assembly 2021). Given the natural biological processes that underpin agriculture production, GHG emissions produced in agriculture cannot be fully eliminated but there are several areas in which emissions can be reduced to help towards the overall UK goal of net zero. Furthermore, current agricultural lands can also function as a vital carbon sink through using agroecological practices and agroforestry. Additionally land, spared by changing agricultural practices and dietary shift, can be freed up for afforestation and habitat restoration. In this report, we consider the CCC's plan for net zero in agricultural and land use, in particular its 'widespread engagement scenario', and explore whether further agroecological (see box 1) measures can be taken to reach net zero more quickly.

Box 1: What is agroecology?

The term 'agroecology' was first used in the 1930s (Wezel *et al.* 2009), although the methods it espouses are derived from traditional agricultural practices (Hecht, 2018). It can refer to a scientific discipline, a set of agricultural practices, or even a social or political movement (Wezel *et al*. 2009). At its core, agroecology is 'the application of ecological concepts and principles to farming' (Soil Association, n.d.)

The key agroecological practices which can contribute to agricultural C sequestration are:

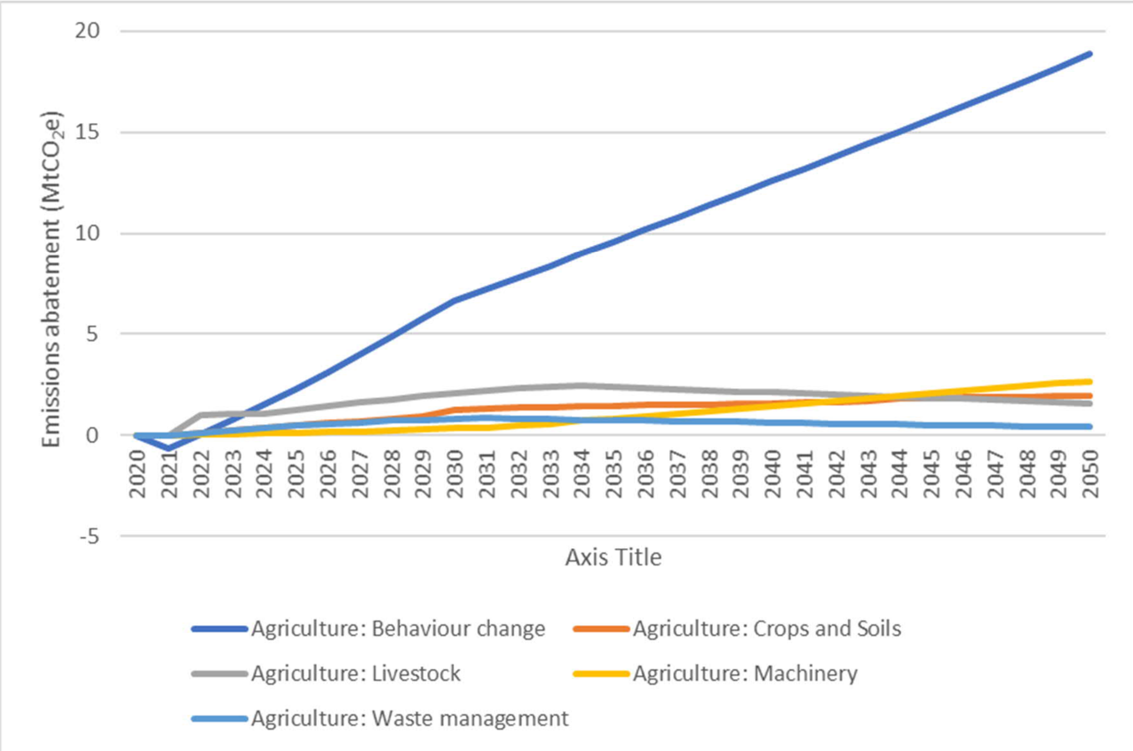
- No till/reduced till
- Cover cropping
- Diverse crop rotations with increased perennials
- Grassed waterways
- Buffer strips
- Agroforestry
- Integrated livestock management

(Paustian *et al.* 2020)

CCC Widespread Engagement Scenario

The CCC's 6th Carbon budget (CCC 2020a) outlines four pathways to net zero for the UK. The primary 'Balanced Net Zero Pathway' is, as the name suggests, an attempt to develop a roadmap that includes a mix of different supply and demand-side measures to reduce and sequester GHG emissions. There are also three 'explanatory' scenarios: 1. 'Headwinds', which relies on carbon capture and storage (CCS) and the use of hydrogen, 2. 'Widespread Innovation', which relies on future technological innovations such as Direct Air Carbon Capture and Storage and 'cultured' or in-vitro meat production, and 3. 'Widespread Engagement', which entails greater behaviour change in the public, including a 50% reduction in all meat and dairy, and a concomitant increase in plant-based foods by 2050. As per Figure 1, much of the emissions reduction in the Widespread Engagement Scenario comes through behaviour change, both in the farm (e.g., by planting cover crops) and in wider society though shifts in dietary patterns. It is shifts in diet that make up the majority of the emissions reductions. The on-farm measures are divided into 'behaviour change' (including dietary shift), of which there is expected to be a 60-80% uptake, and 'innovative', which is projected to have an uptake of 50-75% in the Widespread Engagement Scenario (CCC 2020b). Table 1 lists the on-farm measures for reducing emissions.

Alongside on-farm measures, the Widespread Engagement Scenario also includes afforestation rates of 50,000 ha per annum by 2030, and 70,000 ha per annum between 2035 and 2050. Trees are grown on 10% of cropland area, and 15% of current grasslands will include tree planting in a silvopastoral system. The area of restored peatland increases from its current level of 25% to 58% by 2035 and 79% by 2050 of peatland. This involves the full restoration of all upland peat by 2045, with 25% of lowland grassland rewetted by 2035, and 75% of this area rewetted or sustainably managed by 2050. Finally, energy crops (e.g. miscanthus, short rotation coppice) will increase to 4047 ha (10,000 acres) by 2035 (CCC 2020b). Figure 2 displays the impact in terms of GHG emission abatement of these measures.

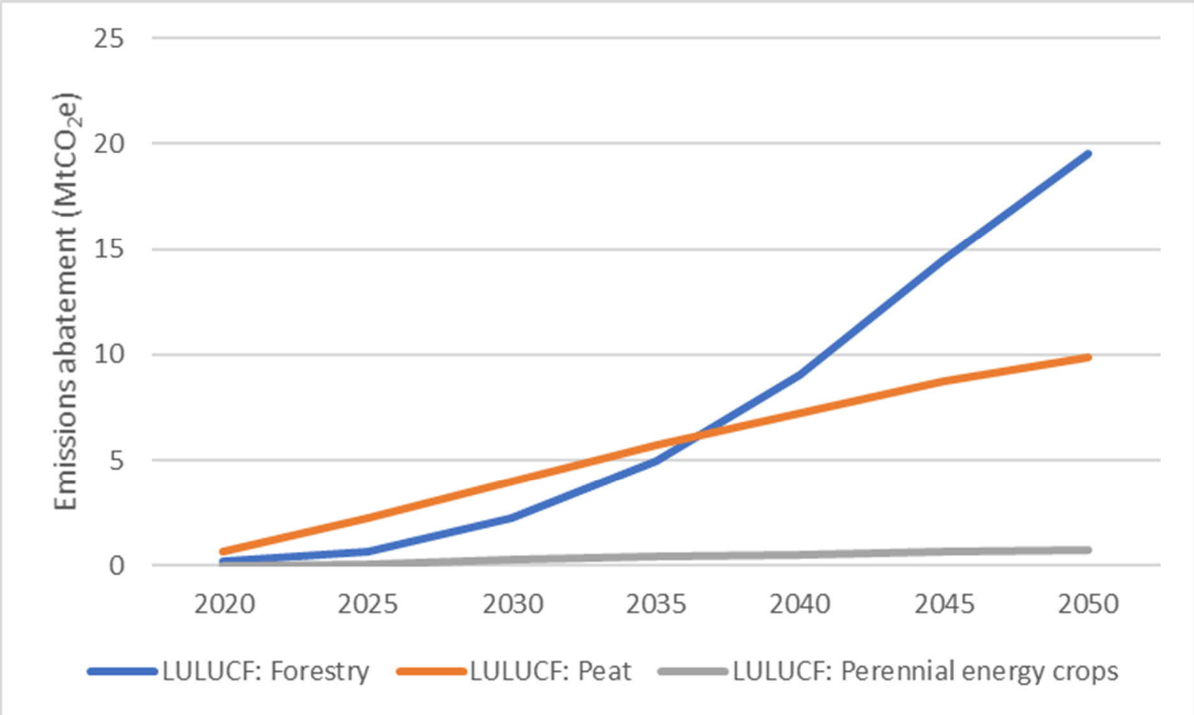


	$MtCO_2e$ Abatement per annum	
Subsector	**2030**	**2050**
Behaviour change	7	19
Crops and soils	1	2
Livestock	2	2
Machinery	0	3
Waste Management	1	0

Figure 1: Agricultural emissions avoided in CCC ‘widespread engagement scenario’. The avoided emissions include the changes due to dietary shifts. Source: CCC Sixth Carbon Budget Dataset

Table 1: On-farm low-carbon farming practices as used in the CCC's 6th Carbon Budget

Behaviour Change	Innovative
Planting cover crops	3NOP additives
Livestock health measures	GM cattle
Livestock high starch diets	Livestock breeding
Grass Leys	Nitrate feed additives
High sugar grasses	Covering slurry
Increased milking frequency	Precision feeding
Grass and legume mixes	Anaerobic digestors



	$MtCO_2e$ abatement per annum	
Subsector	**2030**	**2050**
LULUCF: Forestry	2	20
LULUCF: Peat	4	10
LULUCF: Perennial energy crops	0	1

Figure 2: Land use emissions abatement in CCC 'widespread engagement scenario'. Source: CCC Sixth Carbon Budget Dataset

The 18 measures considered for reducing agricultural emissions were created from a long list of 31 drawn up by SRUC (SRUC 2020). In the 'Widespread Engagement Scenario', these 18 measures[1] (see Box 2), have been calculated as having the potential to abate **3.66** and **2.54** $MtCO_2e\ yr^{-1}$ annually by 2030 and 2050, respectively (Figure 5).

[1] The CCC used 18 measures, we describe 15 as e.g. although anaerobic digestion is split between pigs and cattle in the CCC report, the principle is the same

Box 2: SRUC's proposed measures for non CO_2 abatement.

Grass Leys: Incorporating grass leys into 4-year arable crop rotations. This sequesters C and increases yield, but incurs a financial loss

GM Cattle: Not included in the widespread engagement scenario.

Cattle breeding low methane: GHG emissions can be reduced by selectively breeding animals that need less feed, produce higher yields, and are less likely to be non-productive. This means that GHG per litre/kg of finished product will be lower.

Cover crops: These are non-cash crops that are either part of a rotation or frown alongside other crops. Depending on the type of crop, these can maintain SOC, prevent erosion, decrease N leaching, and increase productivity.

3NOP: 3-nitrooxypropanol (3NOP) is an additive that reduces enteric methane emissions when added to ruminant feed.

Ruminant nitrate feed additive: Adding nitrates into ruminant feed reduces the volume of CH_4 produced.

Health planning for cattle and sheep: Improving the health status of livestock, through preventative measures such as improving housing conditions and curative measures such as antibiotics, can reduce disease and thus increase yield. This will lead to lower GHG emissions per litre/kg of product.

Covering slurry: There are various methods for covering slurry to reduce ammonia and methane emissions, in the SRUC model the use of impermeable flexible plastic covers was found to be the most efficient.

High starch diet for dairy cows: This reduces methane emissions by increasing the digestible energy content of the feed.

Precision feeding: Using technological solutions such as regular weighing of animals, more precise diets can be formulated and thus the total amount of feed used reduced. Most applicable to housed animals such as pigs, dairy cows, or chickens, this can reduce direct emissions and the emissions from feed production.

Anaerobic digestors: Using anaerobic digestors reduces GHG and ammonia emissions and produces biogas and digestate which can be used as fertiliser (although its use can be problematic). The use of anaerobic digestors also requires high levels of up-front expenditure as well as technical and business skills.

High sugar grasses: Incorporating high sugar grasses into pasture-based systems can potentially increase N-use efficiency in ruminants, which can reduce N_2O emissions.

Increased milking frequency: This increases milk yield and reduces N excretion, meaning less direct emissions and less GHGs per litre of milk.

Grass and legume mix: Sowing mixes of grass and legumes in temporary and permanent grasslands can help fix N in the soil, thus reducing the need for synthetic N fertilisers.

Source: SRUC (2020)

Going further: UK mitigation potential to 2030 and 2050

An analysis of mitigation estimates from recent published reports (NFU2019, Environment Agency 2021, RAE/RS 2018, CEH 2020, CCC 2020, FFFC Farming for change, CCC 6th Carbon Budget) for the UK, and specifically UK agriculture, gives an overview of the general mitigation potential of the sector. Based on the data presented in these reports, the ranges of the mitigation potential and averages are presented for different categories (peatland restoration, afforestation, livestock management, farm management, agroforestry) in Figure 3 to Figure 5. The mitigation potential summarizes the reduction of GHG emissions and the C sequestration in the soil and changes in the above ground biomass in carbon dioxide equivalent (CO_2e). The numbers reflect a wide range as the pathways differ in the different reports. However, the wide range for peatlands and afforestation reflect the different approaches and the commitment to the land areas used for peatland regeneration and afforestation (Figure 3). The mitigation potential for the actual agricultural managements (livestock, crop management, agroforestry) does not show such a wide range from the different studies (Figure 4).

Under the same agricultural production and with no change in diets from today (2018/2019 baseline differs a bit for the reports), the UK mitigation potential in agriculture and land use could be on average 16.1 $MtCO_2e\ yr^{-1}$ till 2030 and up to 29 $MtCO_2e\ yr^{-1}$ in 2050 (Figure 5, Table 2). Reaching those carbon mitigation potentials in most reports (NFU2019, Environment Agency 2021, RAE/RS 2018, CEH 2020, CCC 2020, FFFC Farming for change, CCC 6th Carbon Budget) includes a large increase in afforestation over the next 30 years and large areas of restored peatlands (Table 2, Figure 3, Figure 5, Appendix A: Table A 1). Agroecological measures in crop and livestock management and agroforestry can reach ~1.7, 2.4 and 1.5 $MtCO_2e\ yr^{-1}$, respectively in 2030 and 1.7, 1.6 and 4.9 $MtCO_2e\ yr^{-1}$, respectively in 2050 (Figure 4, Figure 5, Table 2). On average these could sum up to a mitigation potential of 5.5 $MtCO_2e\ yr^{-1}$ in 2030 and 8.2 $MtCO_2e\ yr^{-1}$ in 2050, which is considerably more than the figures in the CCC's 'widespread engagement scenario' (3.66 $MtCO_2e\ yr^{-1}$ in 2030 and 2.54 $MtCO_2e\ yr^{-1}$ in 2050).

There are several relevant agricultural practices which are omitted from the CCC analysis: these are summarised in Box 3, and one particularly striking omission is that they did not consider practices which have the potential to sequester carbon in agricultural soil. Smith, Haszeldine, and Smith (2016) estimate that changing agricultural practices in 8.5 Mha (i.e. roughly 73% of currently utilised agricultural land) of UK land has the potential to sequester between 0.255 and 8.5 $MtCO_2e\ yr^{-1}$. Current levels of C sequestration in agricultural soils are estimated to be 0.17 $MtCO_2e\ yr^{-1}$ (CEH 2019), so there is potential for significant improvement.

Box 3: On-farm agroecological practices not considered in CCC report

Regenerative agricultural practices (e.g. reduced tillage, integration of crop residues back into soil, cover or catch crops, intercropping, improved or longer crop rotations, addition of manure or other organic matter) 0.5 - 1 $tCO_2e\ ha^{-1}\ yr^{-1}$ (Environment Agency 2021)

Improved grazing (e.g. rotational, lower stocking rates) 0.28 $tCO_2e\ ha^{-1}\ yr^{-1}$ (Environment Agency 2021)

Carbon sequestration in agricultural soil: On croplands these include **crop management** (improved varieties and rotations, cover crops, perennial cropping systems, use of agricultural biotechnology), **nutrient management** (optimising fertiliser types and application rates and timings, and including precision application), **reduced tillage and residue retention**, and **improved water management** inc. drainage of waterlogged soils. On grasslands, measures include **vegetation management** (improved grass varieties, deep rooting grasses, increased productivity, and nutrient management), **animal management** (stocking densities, grazing management, improved feed production), and **fire management**. Estimate that emissions abatement can be 10 MtCO2e per annum, based on soil carbon sequestration practices being implemented on 4.5 Mha of land: 75% of arable land, and pastureland not set aside as 'available'. (RAE/RS 2018)

Carbon sequestration in agricultural soil 5 $MtCO_2e\ yr^{-1}$ (NFU 2019)

While the CCC considers some of the agroecological practices summarised in box 1 (e.g. cover cropping, some livestock practices, agroforestry), the evidence above suggest that there is far greater scope for C sequestration than currently considered, with the caveats that soil will eventually reach a saturation point for C, some areas are more suitable for C sequestration, and some areas currently under agricultural use would be better suited for return to a natural state (e.g., peatlands) (Environment Agency 2021). Additionally, the permanence of the carbon storage in the soil relies on maintaining the management change in future to avoid any release of the stored carbon back to the atmosphere.

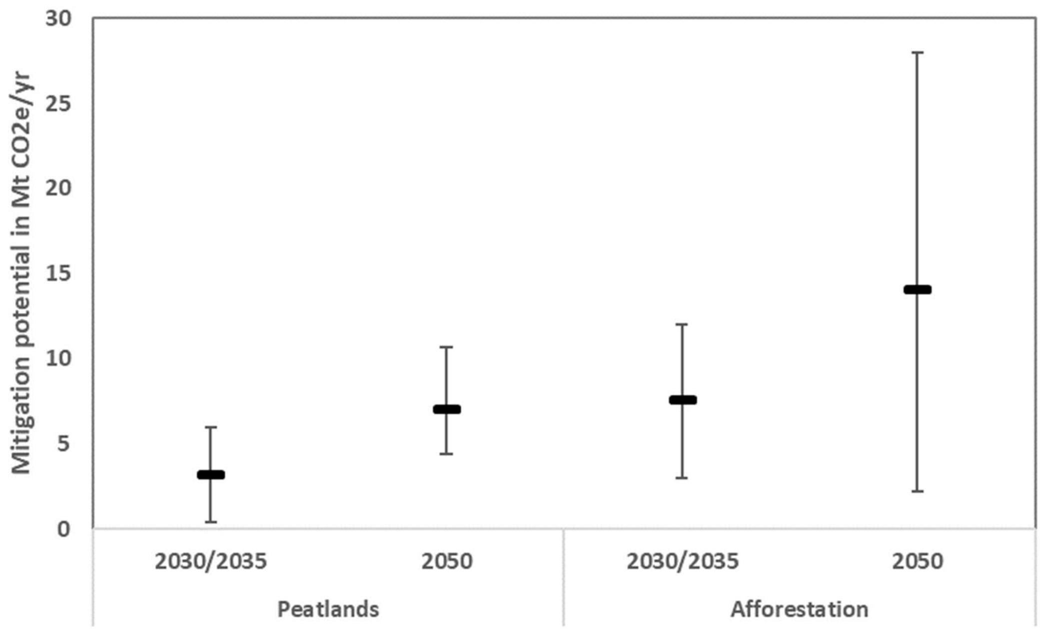


Figure 3: Mitigation potential for peatland restoration and afforestation in the UK for 2030/3035 and 2050 (NFU2019, Environment Agency 2021, RAE/RS 2018, CEH 2020, CCC 2020, FFFC Farming for change, CCC 6th Carbon Budget)

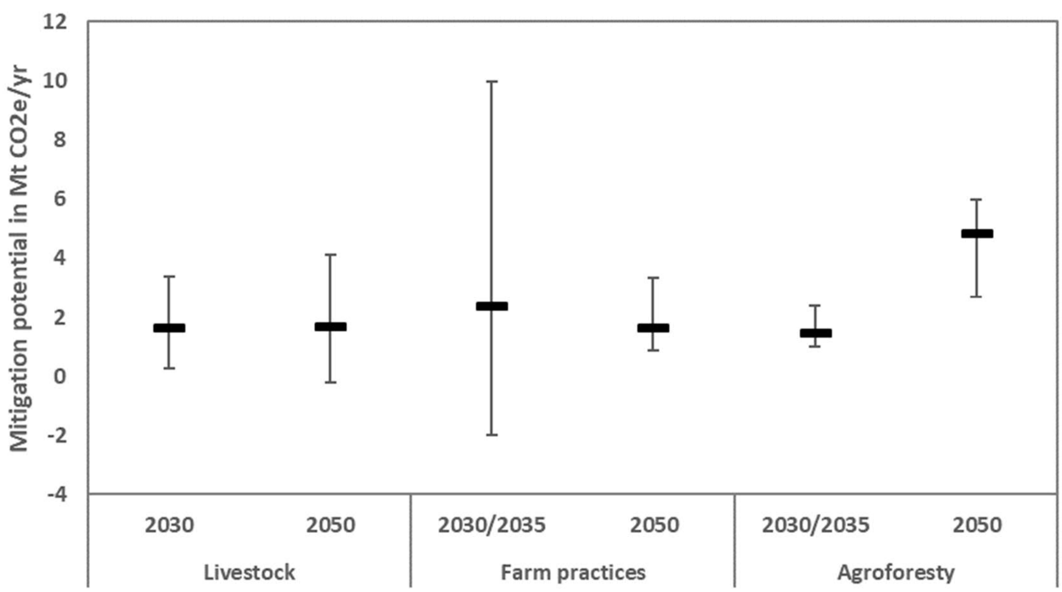


Figure 4: Mitigation potential for livestock crop managements in the UK for 2030/2035 and 2050 based on several reports and studies (NFU2019, Environment Agency 2021, RAE/RS 2018, CEH 2020, CCC 2020, FFFC Farming for change, CCC 6th Carbon Budget), see Box 4 for specification

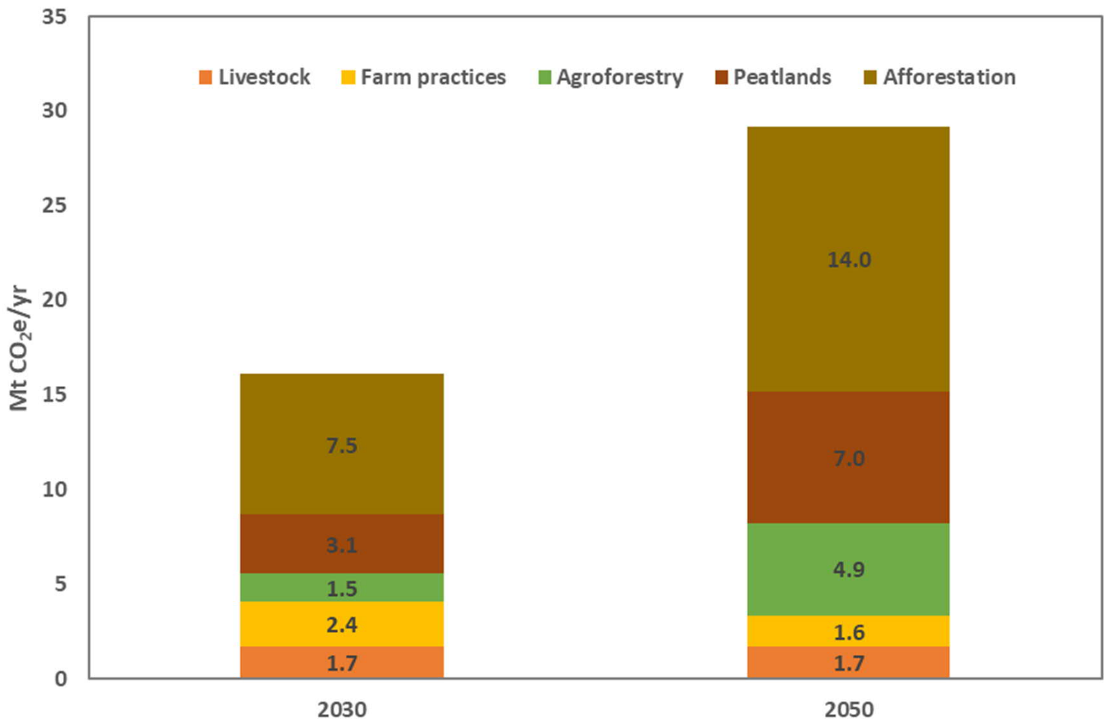


Figure 5: UK mitigation potential from different practices, averaged mitigation potential from several reports and studies (NFU2019, Environment Agency 2021, RAE/RS 2018, CEH 2020, CCC 2020, FFFC Farming for change, CCC 6th Carbon Budget)

Table 2: Mitigation potential for different practices from several reports and studies for UK (NFU2019, Environment Agency 2021, RAE/RS 2018, CEH 2020, CCC 2020, FFFC Farming for change, CCC 6th Carbon Budget)

	Livestock		**Farm practices**		**Agroforestry**	
$MtCO_2e/yr$	2030	2050	2030/2035	2050	2030/2035	2050
average	1.7	1.7	2.4	1.6	1.5	4.9
min	0.3	-0.2	-2.0	0.9	1.0	2.7
max	3.4	4.1	10.0	3.4	2.4	6.0
	Peatlands		**Afforestation**		**CCC 6CB report, agroecological solutions**	
	2030/2035	2050	2030/2035	2050	2030	2050
average	3.1	7.0	7.5	14.0	3.7	2.5
min	0.4	4.4	3.0	2.2		
max	6.0	10.7	12.0	28.0		

Box 4: Practices included in the management categories (not all these practices are used in all reports to reach the given mitigation potential). Some of these practices (e.g. moving to low carbon fuels for machinery and buildings) would not fall under the definition of 'agroecology':

Livestock: anaerobic digestion and manure management improves in livestock housing, manure storage and manure application, improved manure management, reduced N leaching from manure application, manure is treated by anaerobic digestion, additional technologies, e.g. slurry acidification

Farm practices: move to low carbon fuels for buildings and machinery, loosen compacted soils, precision farming (variable rate fertilizer application, controlled traffic farming), increased use of organic residues (e.g. digestives), better accounting for nutrients in livestock manures, increased use of legume crops, improvement in N use efficiency, adoption of genetically modified (GM) crops with improved disease control, Organic fertiliser, inorganic fertiliser

Agroforestry: silvopastoral or silvoarable systems

Peatlands: peatland restoration

Afforestation: planting conifers and broadleaf

Beyond agroecology: further measures for reducing emissions and sequestering C

Biochar, BECCS and C sequestration

Addition of biochar (a C rich material formed by pyrolysis of organic material) as an organic amendment can increase Soil Organic Carbon (SOC) and influence soil quality (Lehmann and Joseph 2009). Biochar has been used for centuries to improve soil quality and increase crop productivity. In recent years, it has become more prominent in its role as a GGR option and more research shows the impacts that biochar can have on SOC, agricultural production and other environmental aspects (Smith 2016). The global mitigation potential of biochar is estimated as 0.5 – 2 $GtCO_2e\ yr^{-1}$.

Bioenergy with carbon capture and storage (BECCS) is a new technology, although each part of the technology has been proven at demonstration and commercial scale. BECCS entails burning CO_2-absorbing biomass, capturing the emissions and storing them in long-term underground reservoirs. BECCS is based on the concept that biomass feedstocks can be burned for energy with lower carbon emissions than the fossil fuels replaced, since the CO_2 released on burning would has been recently fixed from the atmosphere during biomass growth. However, if the CO_2 is captured and stored (effectively removing it from the active carbon cycle (Smith *et al.* 2013, Smith *et al.* 2014) e.g. in geological formations) negative emissions, or greenhouse gas removal, can be achieved. The whole BECCS chain needs to be considered, including any indirect land use change induced, any “carbon debt” from growing the bioenergy feedstock, geological storage potential and relevant CCS components, where its feasibility is considered. The global mitigation potential is estimated to be 0.5 – 5 $GtCO_2e\ yr^{-1}$, and could be higher in the latter half of this century.

Calculations of the impacts of BECCS must take land use changes into account, whether these are direct (e.g. conversion of grassland or forest to energy crops) or indirect (e.g. conversion of forest or grasslands to agriculture to compensate for the planting of energy crops on existing agricultural lands). As a result of all of these factors, the ‘carbon payback period’, that is, the duration of the carbon debt incurred as a result of harvesting, and land-use change if it occurs, may vary from decades to centuries for trees. While, for fast-growing energy crops, and for forest or agricultural wastes and residues the payback periods are much shorter, assuming carbon stores and sequestration potential have not been lost through land use conversions. In addition, if energy crops are planted on lands with high carbon stock it can take decades to over a century to compensate for the carbon losses from the initial land-use change. Conversely, establishing energy crops on marginal lands can result in much faster carbon neutrality and much deeper CO_2 removals over time. Another uncertainty is the energy balance of BECCS. Calculations of the overall energy balance suggest that BECCS projects may deliver relatively little net energy, far less than the IAMs project. A recent study concluded that energy output was strongly case-specific, with the energy return on investment varying between 0.5 (i.e., more energy was consumed than produced) to 5.7 (roughly comparable to solar PV) (Fajardy and MacDowell 2018). The implementation of BECCS technology has impacts on the environment in which it will be implemented. As such implementation strategy should view the socioecological system as a whole. Stoy *et al.* (2018) provide a framework showing the implementation of BECCS considering biodiversity, social systems, and the water – energy- food nexus.

Assuming land availability for sustainable bioenergy production of approximately 1.4 Mha across the UK, ETI (2016) reported that BECCS in the UK can mitigate between 20 and 70 $MtCO_2$/year, with the potential to store up to 1 $GtCO_2$ offshore by 2050. The Committee on Climate Change (2018a, b) suggested that by 2050 BECCS could deliver between 20 and 65 $MtCO_2e\ yr^{-1}$ in the UK (equivalent to up to around 15% of current UK CO_2e emissions). This range, however, would depend on the amount of sustainable biomass available. Given that by 2050 up to 65% of the power generated in the UK is expected to be local (FES, 2018), Albanito et al. (2019) suggested that two main pathways could allow the penetration of BECCS in the UK energy system: (a) integrating with existing large-scale centralized power stations, and (b) through the development of distributed (i.e., local) power generation systems. In this context, assuming the use of only marginal (i.e., sustainable) agricultural land, in the UK the potential agricultural land available for bioenergy crops production would range from 0.39 to 0.5 Mha in a centralized and distributed BECCS systems. This means that the conversion of low-grade agricultural land could achieve only 36% and 46% of the CCC - BECCS target of 50 $MtCO_2e$

yr^{-1} by 2050 from the centralized and distributed energy scenarios, respectively. If we consider the centralized energy scenario, the above target gap can be closed by converting 0.59 Mha of additional agricultural land of grade 3 across GB, or by importing approximately 8 MtDM yr^{-1} of solid biomass from forest systems. In the distributed energy scenarios, this gap could be filled by converting 0.49 Mha of agricultural land of grade 3, or by importing 6.6 MtDM yr^{-1} of solid biomass from forest systems.

Increasing the SOC stocks, with the aim to reduce the overall GHG emissions, is one of the strategies that can be applied at large scale (Ciais *et al*. 2013). One policy initiative to encourage soil carbon sequestration is the "4 per 1000" initiative proposed under the UN Framework Convention on Climate Change (UNFCCC) with the aim to globally increase the soil C concentration in agricultural soils by 0.4% each year. This could potentially produce a global C sink of 10.2 $GtCO_2e$ yr^{-1} in the topsoil depth (Soussana *et al*. 2019), though the feasible economic potential is likely to be lower at 1.5 – 2.6 $GtCO_2e$ yr^{-1} (Smith 2016).

Blue Carbon

Blue Carbon refers to the potential for carbon sequestration by marine and coastal ecosystems, and can include mangrove, tidal marsh, seagrass, and potentially pelagic ecosystems (Lovelock and Duarte 2019). In these ecosystems, C is sequestered in the sediment, living biomass both above and below ground, and non-living biomass such as dead wood. The C can be stored for decades in biomass, and millennia in sediment. The potential for blue carbon sequestration is proportionally higher than terrestrial C sequestration, although there is less overall area in which to realise this (McCleod *et al*. 2011). Alongside the carbon sequestration possibilities, restoration and protection of these environments also carries ecological and economic benefits such as providing natural barriers to limit storm damage and coastal erosion (Lovelock and Duarte 2019).

In the UK, saltmarshes, mudflats, and sands are currently estimated (i.e., through natural processes) to sequester between 10.5 and 60.1 $MtCO_2e$ yr^{-1} , and newly created saltmarshes can sequester C at the rate of over 1 tonne ha^{-1} yr^{-1}(Marine Conservation Society and Rewilding Britain, 2021). Given the vast areas of coastal waters, and the plethora of benefits including C sequestration, the protection and restoration of coastal ecosystems should be a priority in the government's plans to reach net zero. Blue Carbon is not currently included in the UK GHG inventory, and was not considered in the CCC's sixth carbon budget. It has been suggested that there is the potential for up to 17.49 $MtCO_2e$ to 2030, and 39.7 $MtCO_2e$ mitigated compared to BAU by recovering saltmarshes, seagrasses, and kelp and seaweed (Sky Ocean Rescue and WWF 2019).

Country specific mitigation potential

The CCC report also includes pathways for each nation of the UK. Based on current land use and areas the CCC report models the mitigation practices for each nation (Figure 6, Appendix B: Figure B 1 to Figure B 5) accordingly for arable and grasslands. The annual mitigation potential for 2030 and 2050 are given for all practises combined in Figure 6 and for all used practices in Appendix B (Figure B 1 to Figure B 5).

In England the highest mitigation potential is allocated to arable land and management. In Scotland, Wales, and Northern Ireland the highest mitigation potential comes from grassland management. It is noticed that the mitigation potential from this managements in total will be higher in 2030 than in 2050. This is mainly a result of the ongoing change through mitigation practices and the freed land resulting from the dietary shift – with less arable land or pastures the mitigation practices have over all a lower mitigation potential. However, the total emissions from agriculture will be lower as less meat is produced at the same time (currently not shown in the graphs – only the land areas which will change, see Figure 7, Figure 8 and Figure 9).

These mitigation figures are unsurprising given the overall area, proportion of current cropland, and the area potentially suitable for cropland in each nation. Although not clear, it is assumed that the CCC widespread engagement scenario proportions the overall reduction in livestock numbers (discussed further below) between each of the nations, evenly. Given the reliance of Wales, NI, and Scotland on the livestock sector, as well as the areas of land in Scotland that are not suitable for growing crops, this approach may be neither equitable nor rational.

Publications focussing on changing agricultural practices as a part of the UKs overall Net Zero ambitions are difficult to find, but one of the most useful sources is Lampkin, Smith, and Padel's (2019) report for the WWF on Scotland's agriculture and its potential contribution to Net Zero. They conclude that an overall reduction of 2.9 $MtCO_2e$ yr^{-1} compared to 2017 emissions is achievable in Scotland, which is significantly higher than the total potential in the CCC 6CB Widespread Engagement Scenario. Most of the options that contribute to this decrease would fall under the definition of agroecological farming (e.g., cover crops, improved grazing management, and agroforestry), with practices leading to a reduction in N fertiliser use showing particular promise as they are easy to implement (if not cost-neutral) and can reduce emissions while having no impact on yield. The authors did not consider dietary shift but note that the introduction of organic farming would have significant yield penalties, which would have implications for diets. This is similar to Smith *et al*. (2019), who found that the introduction of organic farming in England and Wales would bring reduced GHG emissions, but that the accompanying decrease in yield would lead to the risk of offshoring these emissions. Using figures from the Environment Agency (2021) report, we can roughly estimate the impact that these practices can have overall in the nations of the UK (Table 3). This would involve no land use change (i.e., no conversion of agricultural land to forest or peatland), and would not rely on any dietary shift, although as above the switch to agroecological practices will likely incur a yield penalty. The agronomic changes required would include the use of cover crops and improving crop rotations, reduced tillage, and better retention and use of crop residues. On grasslands, the practices would include sowing legumes, the use of organic and inorganic fertilizers to stimulate growth, and improved grazing measures such as lower stocking rates, rotational, and seasonal grazing (Environment Agency 2021).

Table 3: Potential for GHG abatement on different agricultural land uses. Sources: Scottish Agricultural Census 2018; DEFRA farming stats 2020; Statswales.gov 2017; Agricultural Census in Northern Ireland 2020; Environment Agency 2021

	Arable Land in ha (Crops and fallow only) Kha	Reduction potential annually (0.5-1 $tCO_2e\ ha^{-1}\ yr^{-1}$)	Grassland (ha) (Rough/common grazing + grassland over 5 years) Kha	Reduction potential annually (0.2 – 4 $tCO_2e\ ha^{-1}\ yr^{-1}$)	Total annual reduction potential
England	3876	1.94 – 3.88 Mt	4103	0.82 – 16.4 Mt	2.76 – 20.28 Mt
Scotland	574	0.287 – 0.57 Mt	4930	0.99 – 19.7 Mt	1.277 – 20.27 Mt
Wales	90	0.045 – 0.9 Mt	3573	0.71 – 14.3 Mt	0.755 – 15.2 Mt
Northern Ireland	46	0.023 – 0.46 Mt	816	0.16 – 3.3 Mt	0.183 – 3.76

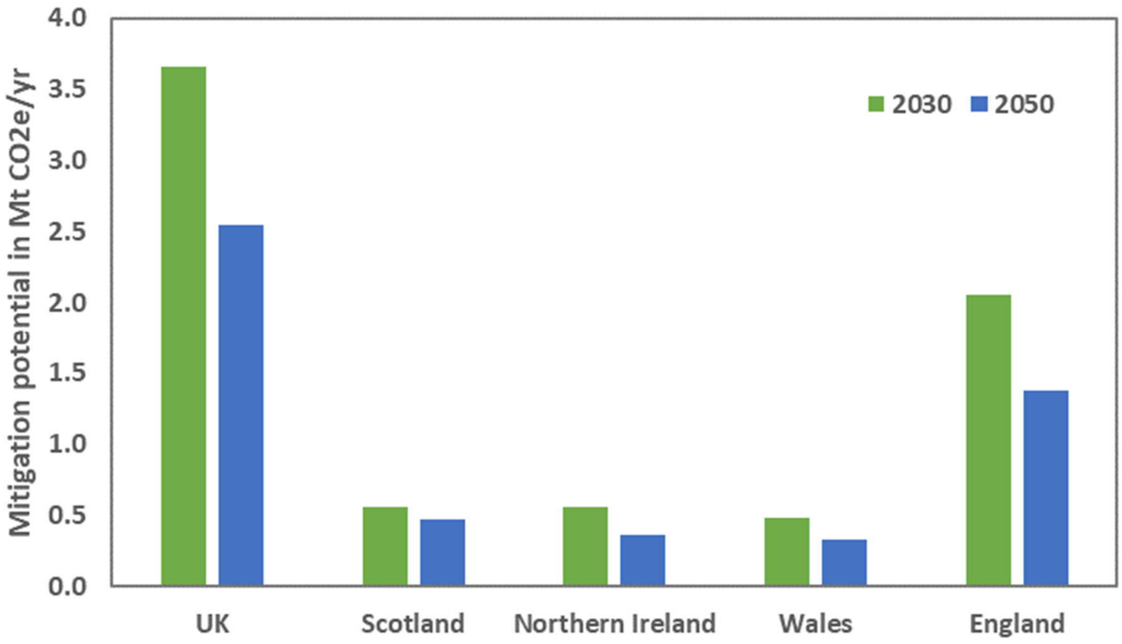


Figure 6: Mitigation potential of agroecological practices for UK, Scotland, Northern Ireland, Wales and England in 2030 and 2050 based on the widespread engagement in the CCC 6CB report

Table 4: Mitigation potential of different agroecological practices for UK, Scotland, Northern Ireland, Wales and England (practices with high potential are bold for the single countries)

Mitigation potential in $MtCO_2e\ yr^{-1}$	UK		Scotland		Northern Ireland		Wales		England	
Practices	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
GrassLegumesMix	0.552	0.317	**0.130**	**0.125**	**0.099**	**0.055**	**0.119**	**0.079**	0.204	0.058
BreedingCurrent	0.048	0.071	0.004	0.007	0.008	0.011	0.012	0.009	0.024	0.044
BreedingGenomics	0.144	0.206	0.013	0.019	0.023	0.033	0.012	0.027	0.095	0.127
IncreaseMilkFreq	0.078	0.025	0.007	0.002	0.012	0.004	0.010	0.003	0.048	0.016
HighSugarGrasses	0.062	0.021	0.005	0.003	0.010	0.003	0.008	0.003	0.039	0.013
ADPigs	0.249	0.138	0.012	0.007	0.021	0.012	0.002	0.001	0.214	0.119
ADCattle	0.416	0.194	0.038	0.018	0.067	0.031	0.055	0.026	0.256	0.120
HealthCattle	0.558	0.282	0.087	0.045	0.088	0.044	0.065	0.033	**0.317**	**0.160**
PrecisionFeeding	0.028	0.008	0.003	0.001	0.004	0.001	0.004	0.001	0.017	0.005
HighStarchDiet	0.010	0.003	0.001	0.000	0.002	0.000	0.001	0.000	0.006	0.002
CoverSlurryImperm	0.139	0.077	0.018	0.010	0.060	0.034	0.010	0.006	0.051	0.028
HealthSheep	0.283	0.165	0.064	0.037	0.019	0.011	0.072	0.042	0.128	0.075
NitrateAdd	0.275	0.194	0.035	0.025	0.040	0.028	0.034	0.025	0.166	0.116
3NOP	0.597	0.522	**0.103**	**0.089**	**0.103**	**0.089**	0.067	0.059	**0.324**	**0.285**
Cover crop	0.218	0.167	0.041	0.031	0.004	-0.004	0.008	0.007	0.166	0.133
Breeding low methane	0.002	0.066	0.000	0.011	0.000	0.011	0.000	0.007	0.001	0.038
GMCattle									0.000	0.000
GrassLeys		0.087		0.039		-0.002		0.008	0.000	0.042
Total	**3.657**	**2.544**	**0.561**	**0.469**	**0.559**	**0.359**	**0.481**	**0.336**	**2.056**	**1.38**

Land area and land area change

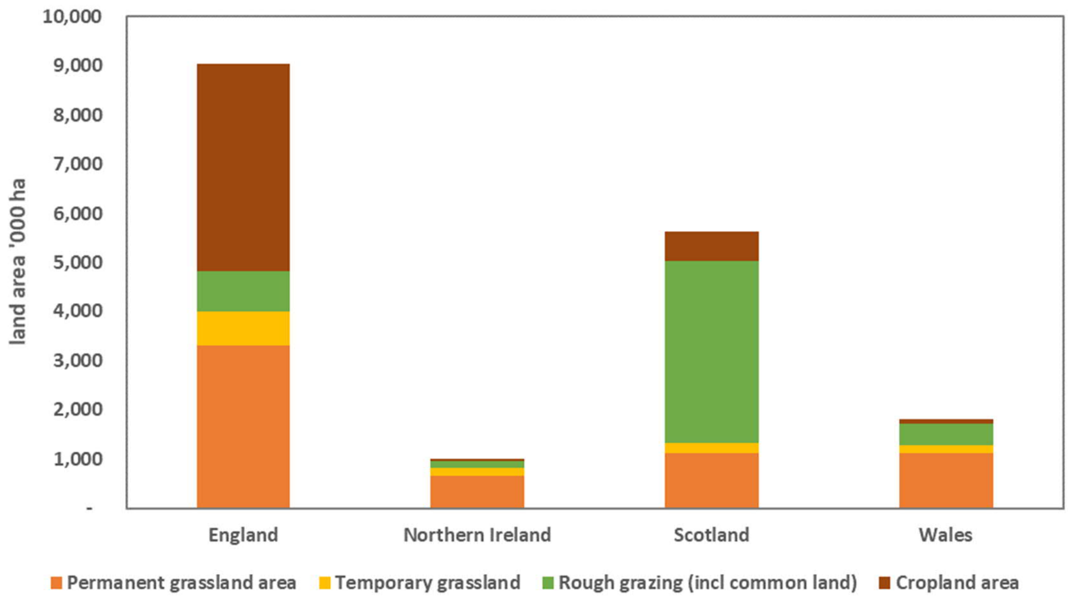


Figure 7: Land use in 2019

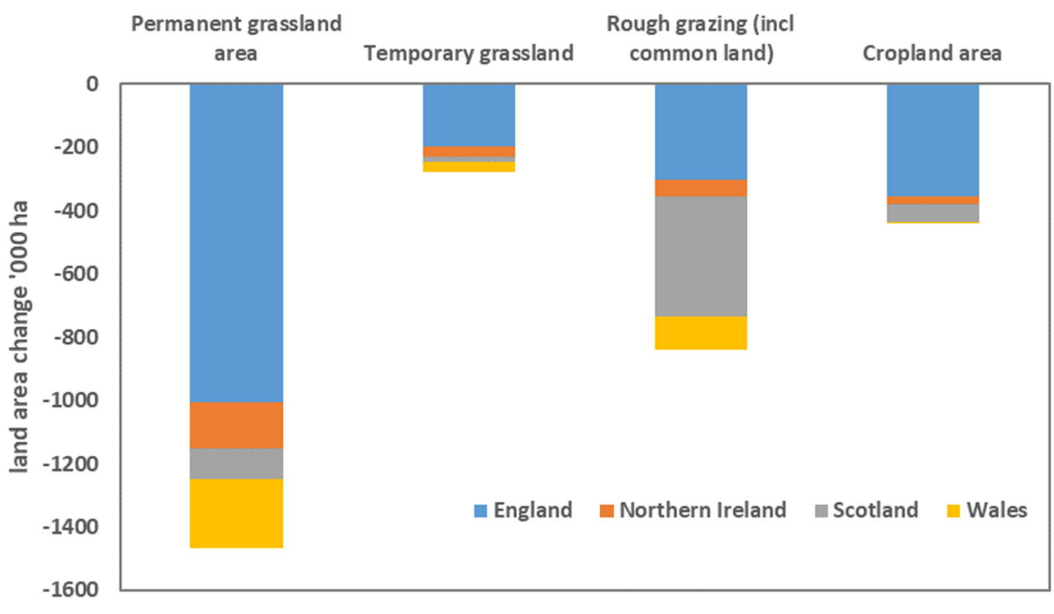


Figure 8: land use change as expected in the CCC 6CB widespread engagement in 2030

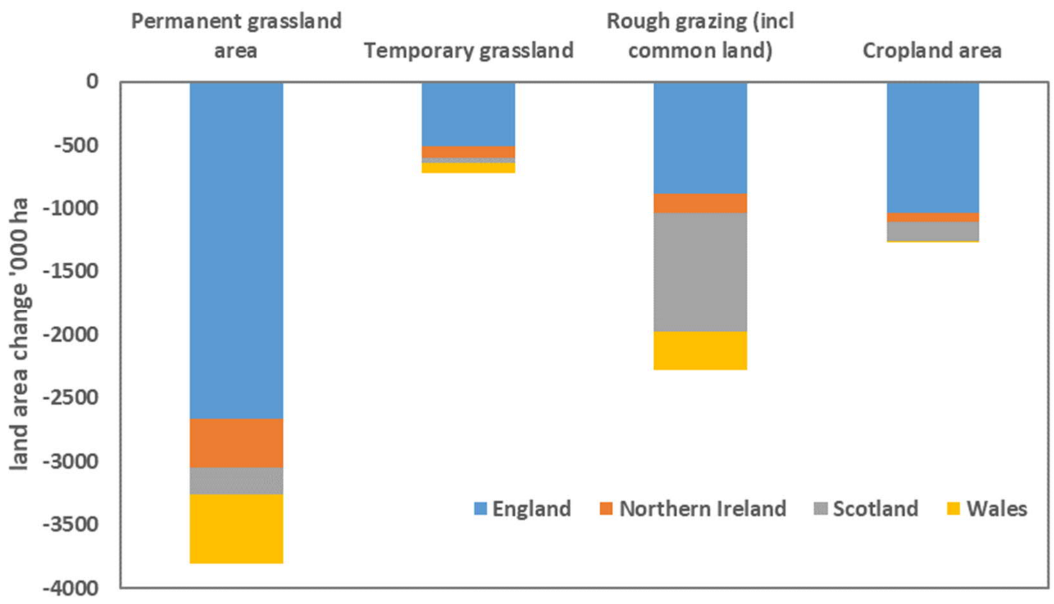


Figure 9: land use change as expected under the CCC 6CB widespread engagement in 2050

Dietary shift

Alongside supply-side changes to UK food production, if net zero is to be achieved there needs to be a considerable shift in diets, particularly a reduction in animal-based proteins. There are two main pillars to such a shift: the speed at which it occurs, and what replaces animal-based proteins in the diet. The CCC widespread engagement scenario considered a decrease in meat and dairy of 20% by 2030, and 50% by 2050. Although the exact numbers are a little difficult to unpick, this should equate to ~5-6 $MtCO_2e\ yr^{-1}$ by 2030 and ~17-18 $MtCO_2e\ yr^{-1}$ by 2050. This falls short of the WWF ambition of a 27 $MtCO_2e$ reduction annually by 2050. To maintain current protein levels of 75g per person per day, this is offset by an increase in legume and cereal production. The methodology used to calculate this reduction involved reducing the head of all UK livestock by 20/50%, calculating the ratio of plant-based proteins needed to substitute for meat-based proteins, and then projecting the area required for crops to grow these. This frees up significant areas of land for other uses (Figure 10).

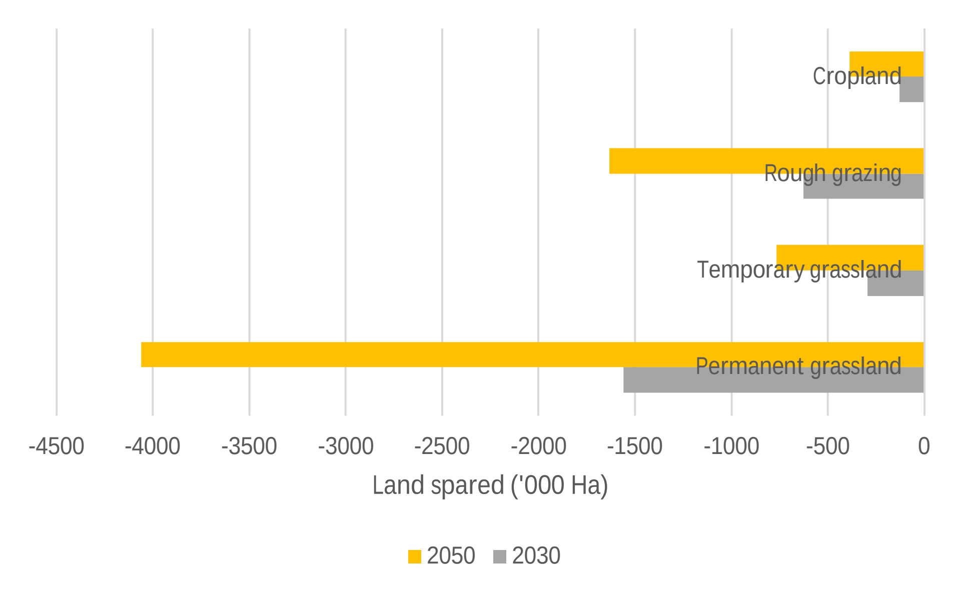


Figure 10: Land spared by dietary shift in CCC 'Widespread engagement scenario'. Source: CCC Dataset

An alternative scenario has been proposed by the Food, Farming and Countryside Commission (FFCC) wherein pork and chicken consumption are drastically reduced, dairy consumption decreases, beef sees a relatively smaller reduction and lamb consumption remains constant. This results in an overall reduction in animal protein consumption to 35g per person per day (FFCC 2021). Given the GHG emissions per kg of food of beef and lamb (see Table 5), this may seem counterintuitive. However, the question is complex as, for example, chicken may have lower emissions per kg of meat, but their mass consumption leads to significant environmental problems (Eating Better Alliance 2020) and the space needed for their feed is a primary driver of overseas deforestation (WWF 2021). Furthermore, cattle can play a vital role in agroecological farming by supplying nutrients to the soil through their manure, which can reduce the need for synthetic fertilisers. The FFCC claim that this agroecological approach will free up 1.2 Mha of land for other uses, as well as nearly doubling the amount of fallow land (to 603,400ha) for creation of environmental infrastructure such as meadows or ponds. The overall drop in GHG emissions equates to 20.7 MtCO_2e yr^{-1} by 2050. Although higher than the CCCs proposal, this is again some way short of WWFs target of 27 MtCO_2e.

Table 5: GHG emissions from food items, based on data from Clune et al. 2017. Protein data from FNDC, 2021, GHG intensity from WRI, 2014.

	kg CO2e/kg	**Protein (g/100g)**	**GHG intensity (t CO_2e/t edible protein)**
beef	28.77	Mince, stewed: 21.8	337.2

		Slice: 25.3 Burger, 62-85% beef, grilled: 18.3	
pork	5.82	Sausages, chilled, grilled: 14.5 Loin chops, roasted, lean and fat: 36.2	57.6
chicken	4.12	Roast chicken (meat only): 27.3 Chicken breast grilled with skin (meat only): 29.8	42.3
egg	3.4	Chicken, boiled: 14.1 Chicken, fried without fat: 16	
Dairy		Milk, whole: 3.4 Yoghurt, whole milk, plain: 5.7 Tea, semi skimmed milk: 0.5	
root vegetables	0.25	Carrots, frozen, boiled: 0.4 Parsnip, roasted: 2.4	
cereals	1.02	Bran, wheat: 14.8 Couscous, plain, cooked: 7.2 Porridge oats: 10.9	
legumes	0.78	Peas, frozen, boiled: 5.5 Haricot beans, canned, reheated: 7.1	
Scallops		Steamed: 23.2	11.1
Salmon		Farmed, baked: 25.2 Cold smoked: 22.8	9.8

However, given the fact that current protein levels (75g per person per day) are higher than government dietary recommendations (50g per day[2]) there is scope for an overall reduction in protein consumption that will benefit both human health and the environment. As of 2017, UK protein supply per person per day was 46g of plant protein, 30g of meat, 3.48g of eggs, 18.39g of dairy, and 5.24g per day of fish and seafood[3] (Our World in Data, 2021). Another potential source of protein – particularly in the UK – is the use of aquaculture. Protein derived from aquaculture tends to have lower emissions (particularly products such as bivalve molluscs which can also improve water quality) and require no land. The farming and harvesting of shellfish in UK waters can help sequester carbon and allow the restoration of other areas (i.e., those currently used for scallop dredging (Marine Conservation Society and Rewilding Britain, 2021). Furthermore, as it is a relatively new industry there is large scope for further improvements in GHG emissions (MacLeod *et al.* 2020, WRI 2014)

Accelerated transition

A report by the Green Alliance (2019b) analysed the impact of faster dietary shift to 2030. It is based on the CCC (2018) 'high ambition' targets in their 'high biomass/natural peatland' scenario which envisages 20.6% meat and dairy reduction by 2030 and 50% by 2050, against a backdrop of tree and bioenergy crop planting and peatland restoration on freed up land. The Green Alliance found that by accelerating the reduction in meat consumption, emissions reductions could be significantly increased (Figure 11), allowing for 'net zero' to be reached by 2040. It is suggested that the optimum scenario would involve a reduction in meat and dairy of 30% by 2030, with dietary protein obtained from poultry, plant-based proteins, and novel protein sources (Green Alliance 2019a). Extrapolating these figures to 50% by 2030 would give a figure of 12.89 $MtCO_2e\ yr^{-1}$ by 2030, which is significantly higher than in the 20% reduction by 2030 pathway suggested by the CCC.

[2] 50g per person per day is an average figure, with differences arising from age, gender, lifestyle etc.
[3] The total protein supply figure for 2017, 103g, is markedly higher than the 75g consumed, highlighting the levels of food waste in the UK.

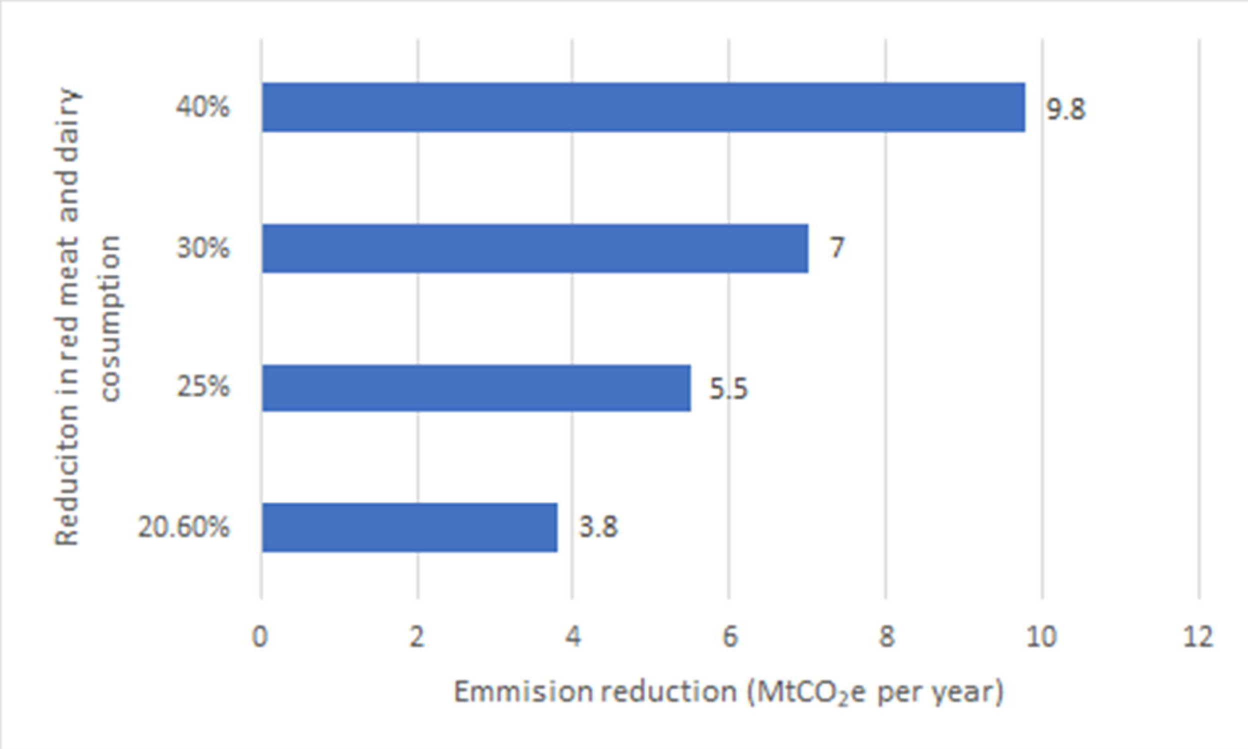


Figure 11: Impact of faster dietary shift to 2030 on UK emissions. Source: Green Alliance 2019b

Based on FAOSTAT data of meat production and export in the UK, the production in UK for the UK market could be calculated for 2019 (see Table 6: FAOSTAT data of production and export of meat products for UK, amount of meat produced in UK for UK marked, total GHG emissions produced by productionTable 6). Based on this estimates the total amount of GHG emissions for meat production produced in the UK was calculated with a total of 26 MtCO_2e for beef, 6.96 Mt CO_2e for chicken, 5.59 MtCO_2e for pig meat and 8.18 MtCO_2e for sheep meat. Considering a dietary shift of 20%, 30%, 40% and 50% of reduction in these meats and assuming a reduction in production accordingly will reduce GHG emissions by a wide margin. Based on total consumptions of meat in the UK (see Table 7), the reduction in GHG emissions will be even higher considering production not only in UK but also from imports. The same amounts of reduction in meat consumption could free land and pastures with highest potential in Scotland and Wales – the two countries with highest livestock production UK (see Figure 12).

If a stable protein consumption is assumed by replacing meat and milk protein with protein from cereals and legumes (example see Table 8) the reduction in GHG emissions are still huge as the agricultural production of crops is much lower as for livestock (Table 5). The production of 1 kg beef would give 200 g protein and produce 28 kgCO_2e. To provide the same amount of protein, 2 kg of cereals need to be produced that would result in ~2 kgCO_2e of GHG emissions. At the national scale, a 20% reduction of beef, pork, chicken and milk would result in 9.5 $MtCO_2e$ less GHG emissions. To produce the equal of protein from cereals and legumes, 2.57 $MtCO_2e$ would be emitted from crop production. This would result in an overall mitigation potential of 6.9 $MtCO_2e$.

Overall, a shift in diets by reducing meat consumption and encourage a more plant based diet will reduce GHG emissions and free land areas (which could be used for other mitigation options like afforestation) – the impact would already be as large as the agroecological options (~ 5 $MtCO_2e$) for a 20% meat reduced diet in 2030.

Table 6: FAOSTAT data of production and export of meat products for UK, amount of meat produced in UK for UK marked, total GHG emissions produced by production

FAOSTAT data for 2019	UK production	UK EXPORT	average weight per head	meat per head	meat	total meat exported	meat produced for UK	GHG	GHG	GHG mitigation potential (in Mt CO2e) by reducing meat consumption by			
Meat	**tonnes**	**head**	**Kg**	**%**	**kg**	**tonnes**	**tonnes**	**kg CO_2 kg^{-1}**	**$MtCO_2e$**	20%	30%	40%	50%
Meat, cattle	914,000	14373	650	60%	390	5605.47	908394.53	28.77	**26.13**	5.23	7.84	10.45	13.07
Meat, chicken	1,723,000	22816000	2	75%	1.5	34224	1688776	4.12	**6.96**	1.39	2.09	2.78	3.48
Meat, pig	960,000	1759	80	60%	48	84.432	959915.568	5.82	**5.59**	1.12	1.68	2.23	2.79
Meat, sheep	307,000	260990	80	66%	52.8	13780.272	293219.728	27.91	**8.18**	1.64	2.46	3.27	4.09

Table 7: GHG emissions based on meat consumption in UK and mitigation potential based on a reduction of consumption

consumption in UK in 2017	**consumption***		**GHG**	**GHG**	**GHG mitigation potential (in Mt CO_2e) by reducing meat consumption by**			
	tonnes	**kg**	**kg CO_2e**	**Mt CO_2e**	**20%**	**30%**	**40%**	**50%**
pig meat	1,709,000	1,709,000,000	9,946,380,000	9.9	1.99	2.98	3.98	4.97
beef and veal	1,204,000	1,204,000,000	34,639,080,000	34.6	6.93	10.39	13.86	17.32
lamb	300,000	300,000,000	8,373,000,000	8.4	1.67	2.51	3.35	4.19

* source: https://www.statista.com/statistics/642948/red-meat-consumption-volume-united-kingdom-uk/

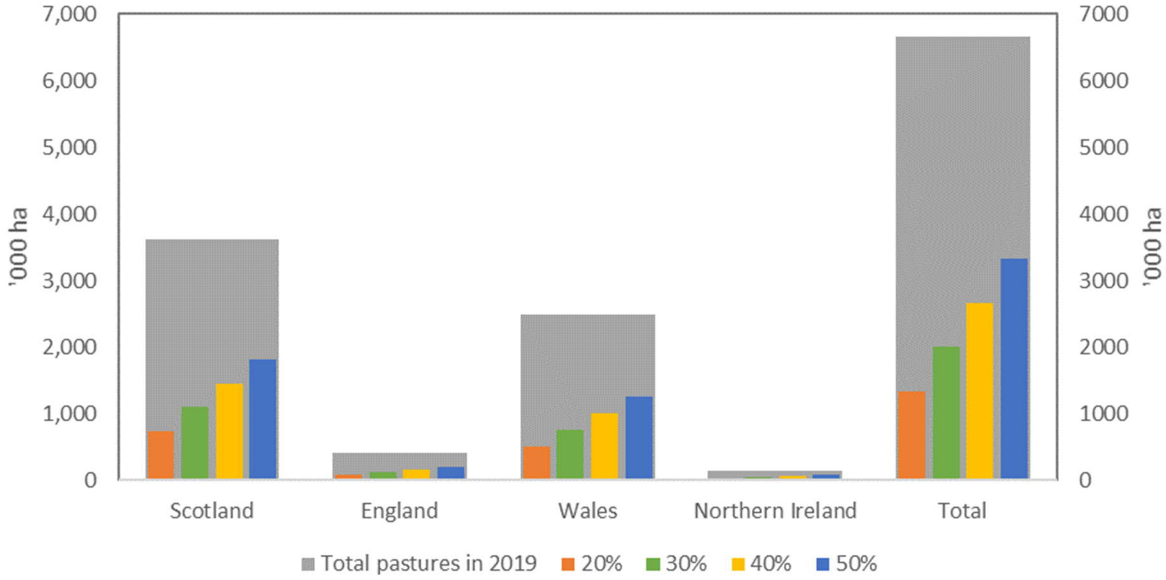


Figure 12: Land area used as pastures in UK, Scotland, England, Wales and Northern Ireland (grey) and the possible land areas that could be freed from pastures if livestock production is reduced by 20%, 30%, 40% or 50%

Table 8: Example of overall reduced GHG emissions by a reduction in meat and milk consumption at constant protein input (meat protein is replaced by cereal and legume protein)

				GHG mitigation potential (in Mt CO_2e) by reducing meat consumption by			
	protein (g/100g)	protein (g/kg)	kg CO_2e/kg	20%	30%	40%	50%
beef	20	200	28.77	5.2	7.8	10.5	13.1
pork	25	250	5.82	1.1	1.7	2.2	2.8
chicken	28	280	4.12	1.4	2.1	2.8	3.5
milk	3.5	35	1.43	1.7	2.6	3.5	4.3
GHG mitigation reduction from meat reduction				**9.5**	**14.2**	**18.9**	**23.7**
cereals	10	100	1.02	1.13	1.69	2.26	2.82
legumes	6	60	0.78	1.44	2.16	2.88	3.60
GHG emissions to produce additional protein				**2.57**	**3.85**	**5.14**	**6.42**
Overall GHG mitigation potential				**6.90**	**10.36**	**13.81**	**17.26**

Box 5: Limitations and Considerations of this study

- There are other aspects concerning diets that are not considered in the study, e.g. balanced nutrition
- Scope 3 emissions (i.e., those arising from feed and fertiliser production and overseas deforestation) have not been considered
- We have not considered food waste
- The study does not consider the impact from imports only UK based production
- If livestock production would be reduced in the UK, available manure as organic amendment for crop production could be limited
- Measures based on carbon sequestration, like afforestation or agricultural management of reduced till and cover crops, have large mitigation potential in the 20-30 years after implementation (what works well for goals in 2030 and 2050) but once a new carbon equilibrium is reached in the soil or tree is grown, it is not as a mitigation option available anymore (Lal 2018, Smith 2016b).

Developing a Preferred Pathway to Net Zero

Overview of practices and mitigation potential

With the caveat that this report involved collating published literature and reports, and only presents a simple calculation of the impact of dietary shift, it appears clear that there is significant potential to go above and beyond the plan set out in the CCCs Widespread Engagement Scenario for mitigation GHGs. The WWFs ambition of 24% reduction in direct GHG emissions from agriculture by 2030, a reduction of 13.1 $MtCO_2e$ yr^{-1}, looks feasible and could even be surpassed.

Considering only on-farm practices, the introduction of agroecological or regenerative farming practices can play a more significant role in reducing GHG emissions than envisaged by the CCC. Although each of the studies we consider uses a slightly different mix of practices, and some consider the impact of dietary shift also, the figures for GHG abatement to 2030 and 2050 exceed the CCC's estimates of 3.66 and 2.54 $MtCO_2e$. One of the reasons for this, we believe, is that the CCC's decision to exclude certain practices underestimates the potential of agroecological farming. Here, there seem to be modest improvements that can be made on croplands (e.g. by introducing low/no-till, incorporating residues back into the soil), but major improvements can be made in UK grasslands through growing legumes, better fertilisation management, and improving grazing practices. Taking an average value from all the studies we considered, we suggest there is potential for an overall reduction of 5.6 $MtCO_2e$ yr^{-1} to 2030/2035, and 8.2 $MtCO_2e$ yr^{-1} to 2050 by introducing agroecological measures in livestock, croplands, and introducing agroforestry practices. As some of the reports we compared considered a dietary shift (see Appendix A), these numbers would be slightly reduced to account for any reduction in animal proteins, but the overall mitigation potential would be higher when GHG emissions produced from agriculture are compared to today.

The CCC Widespread Engagement pathway includes 50,000 ha of trees planted per annum by 2030, and 70,000 ha per annum between 2035 and 2050 that results in 2 $MtCO_2e$ yr^{-1} and 20 $MtCO_2e$, respectively. Restoration of 58% of peatland by 2035 and 79% by 2050 gives values of 4 $MtCO_2e$ yr^{-1} and 10 $MtCO_2e$ yr^{-1}, respectively. Other reports include afforestation and restoration of peatlands as well as two options to sequestrate carbon and reduce therefore the overall emissions – both options give high mitigation potential till 2050.

Dietary shift

Regarding dietary shift, there is scope for more ambition compared to the CCC Widespread Engagement Scenario. Current protein consumption levels in the UK are higher than recommended, and consumption of animal proteins are much higher. The CCC approach of cutting all livestock by 50%, and maintaining current protein levels through crops gives already a wide margin to reduce GHG emissions and free up land. However, if protein sources and namely animal protein would be reduced to healthier levels the reduction would be higher. Given the role that livestock can play in agroecological systems, the offshore impact of chicken feed production, and the importance of livestock in Scotland, Wales, and Northern Ireland, a more nuanced approach is called for.

Looking at the production of livestock in the UK and the consumption, an overview was presented on how the annual GHG emissions could be reduced if there would be a dietary shift of 20%, 30%, 40% or 50% reduced livestock production/consumption and how much land could be freed (Table 6 to Table 8).

A useful starting point in developing a pathway is the FFCC (2021) report, as it espouses an agroecological pathway for farming alongside freeing up land for afforestation and rewilding. While their vision for dietary shift – with more emphasis placed on reducing poultry, pork, and dairy products – offers an interesting counterpoint to the received wisdom that beef consumption and production should be most heavily reduced, we feel that there is scope for further ambitions for reduction in beef above and beyond what the FFCC suggest.

For the UK, in total, these figures have the potential to reduce the UKs agricultural GHG emissions by 5.6 $MtCO_2e$ yr^{-1}, for agroecological solutions and between 6.9 – 17.26 $MtCO_2e$ yr^{-1} for a possible dietary shift (see Table 9: Total emissions reduction potential in 2030). If afforestation and peatland restoration is considered it will add around 7.5 $MtCO_2e\ yr^{-1}$ and 3.1 $MtCO_2e\ yr^{-1}$, respectively, of mitigation potential. The total of these solutions sums up to around 23.1 $MtCO_2e\ yr^{-1}$ for a 20% reduction in livestock production for 2030. If figures for BECCS and blue carbon were also included, this value could be significantly higher.

The aim of the 24% reduction of emissions from agricultural sector from 2020 by 2030 (13 $MtCO_2e$) on 2020 levels could be therefore achieved with agroecological measures (including crop and livestock management, agroforestry) and a reduction in livestock production caused by a dietary shift by around 30%.

The aim of the 50% reduction of emissions from agricultural sector from 2020 by 2050 (27 $MtCO_2e$) would need to consider further measures. Agroecological measures and a dietary shift up to 50% of less meat and milk would result in an annual reduction of ~25.5 $MtCO_2e$. Considering a reduction in protein to healthy levels would gain an additional margin as the same amounts would not need to be produced in crops (e.g., a 50% less meat and milk production without producing the same amount of protein from crops would result in 23.7 $MtCO_2e\ yr^{-1}$, Table 8).

Table 9: Total emissions reduction potential in 2030 and 2050

	Agroecology	**Affores-tation**	**Peatland restoration**	**Dietary shift**	**Total Agroecol + Dietary shift**	**Totals**
	Emissions avoided ($MtCO_2e\ yr^{-1}$)					
2030	5.6 (-0.7 – 15.9)	7.5 (3 - 12)	3.1 (0.4 - 6)	6.9 – 17.26*	12.5**	23.1**
2050	8.2 (3.4 – 13.5)	14 (2.2 – 28)	7 (4.4 – 10.7)	6.9 – 17.26*	25.46***	46.46***

* The mitigation potential based on a dietary shift is based on a 20%-50% reduction in meat and milk and the therefore reduced production in beef, pork, chicken and milk. These assumptions are based on total consumption in the UK and include possible imported meats.
** considering a dietary shift of 20% less meat and milk till 2030
***Considering a dietary shift of 50% less meat and milk till 2050

Country specific pathways

Country specific pathways should consider the production and use of land areas to date. England is dominated by cropland area and permanent grassland. Whereas the other nations have a lower proportion of cropland areas. Northern Ireland and Wales have mainly permanent grassland areas. Scotland is geographically dominated by rough grazing and permanent grasslands.

This suggests pathways in England to be concentrated on crop management and agroforestry. Agroecological practices regarding improved livestock management is important for all nations and should be considered in equal measure.

Dietary shift and the corresponding reduced livestock production need to be considered carefully. This report gives only an indication in reduction of GHG emissions and the possible freed land. Country-specific economic considerations should be taken into account, as well as social aspects. For example: Reducing the livestock production by 50% would have the largest impact in Scotland (for mitigation and freeing up land), but as livestock is the main output of agricultural production in Scotland, it could be recommended to reduce the livestock production further than 50% in England to allow a higher livestock production in Scotland to ensure equal agricultural productivity in all nations – but this should be considered under social and political considerations and not on the mitigation potential alone.

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Appendix A

Table A 1: Assumptions in agricultural GHG emissions reduction plans

Source	Afforestation assumptions	Peatland assumptions	Dietary shift assumptions	Other assumptions	Baseline
NFU 2019	N/A	N/A	N/A	11.5 $MtCO_2e$/year from ‘boosting productivity and reducing emissions. 9 $MtCO_2e$/year from ‘Farmland Carbon Storage’ (inc. agroforestry (0.7Mt) + peatland and wetland restoration (3Mt). 26 $MtCO_2e$/year from BECCS etc.	2017 Baseline
RS/RAE 2018	Increase of 1.2Mha on current forest cover of 3.2Mha (15 $MtCO_2e$ pa)	Restoration of 0.8Mha freshwater wetland, 0.04Mha (2 $MtCO_2e$ pa) marshland and 2.7Mha peatland (1MtCo2e pa direct reduction, plus future sink, per 1Mha).	N/A	Soil carbon sequestration of 10 $MtCO_2e$ pa)	BAU
FFCC 2021	Up to 1.2Mha potentially available for afforestation (12.8 $MtCO_2e$ pa). 1.4Mha on utilised ag land (i.e., 10% of total) used for silvopasture and	N/A	Halving of animal-based proteins by 2050: 40% reduction in milk, 37% reduction in beef, 17% reduction in sheep, 70% in pork, 52% reduction in	Eliminating synthetic fertiliser use.	Afforestation: 2010 levels.

	silvoarable agroforestry (2.2 $MtCO_2e$ pa)		poultry, 57% reduction in eggs.		
CEH 2020	The Low Ambition/BAU measures assume that current rates of planting and felling (based on the average rate for 2014-2016, see Table 12 in section 3.2) are continued. It assumes that there is no change from current management, where 100% of conifer forests are assumed to be managed, but only 20% of broadleaved forests. It assumes that the conifer forests will continue to produce the current mix of harvested wood products (paper, panel board and sawn wood, with some fuel) and that all broadleaved harvested wood products will be used for fuel. The Medium Ambition measures	The Low Ambition measures are based on the Wetland Supplement Central scenario (Evans et al., forthcoming), which only includes peatland restoration for which there is current policies and funding in place. Industrial peat extraction sites are restored at planned dates where known (England only) or remain at 2014 levels. Only Scotland has policies/funding in place for peatland restoration (Scottish Government 2018): the target areas are 50 kha of upland peatlands and forest restored by 2020 and 250 kha restored by 2030 (representing 40% of the currently degraded peatland area). No restoration of peatland is	N/A	Increased livestock grazing intensity but livestock numbers kept constant with BAU. Improved N use efficiency, crop breeding and manure management. Move towards indoor horticulture. Hedgerows and agroforestry increased.	BAU (Production and per capita output maintained). Afforestation based on 2016 levels

	increase afforestation to the 5th Carbon Budget maximum levels, with 31 kha planted annually across the UK to 2100.. New planting avoids deep peat and areas of landscape sensitivity. Although some planting may occur on cropland and intensive grassland, this will be limited to small areas of shelter belt, and most commercial planting is likely to be mainly on extensive grassland used for rough grazing and improved pasture. Broadleaf woodland which is currently unmanaged is brought back into production, with 67% actively managed by 2030 for biomass fuel and timber. Thinnings from both conifer and broadleaf forest are assumed to be	assumed in other administrations of the UK. The Medium ambition measures are based on the Wetland Supplement Low Emission scenario (Evans et al., forthcoming), where policy aspirations4 for peatland restoration in each administration of the UK are projected forward beyond 2021. This assumes that by 2050 and across all administrations: restoration of 25% of the area of degraded intensively managed lowland peat which are currently cropland or improved grassland to semi-natural habitat; restoration of 50% of the area of degraded upland peat which is currently heather moorland, extensive grassland or modified bog; restoration of 25% of forest (conifer) on peat with less			

	used for fuel. Production of long-lived harvested wood products (sawn board) for construction increases. Overall yields increase linearly to 10% above current levels by 2050 as a result of improved management, planting the right species in the right location, and climate change (CO2 fertilisation effect). The High Ambition measures increase afforestation beyond the 5th Carbon Budget maximum levels to rates exceeding those in the 1970s, when there was also rapid forest expansion (50 kha annually across the UK to 2100. New planting avoids deep peat, but landscape sensitivity is not a barrier. Commercial afforestation occurs on improved grassland and	than Yield Class 8; cessation of all peat extraction with 100% restoration to semi natural habitats by 2050. The High ambition measures are based on the Wetland Supplement Stretch scenario (Evans et al., forthcoming), which exceeds current policy aspirations for peatland restoration. This assumes that by 2050 and across all administrations: · restoration of 50% of the area of degraded intensively managed lowland peat which are currently cropland or improved grassland to semi-natural habitat; · restoration of 75 % of the area of degraded upland peat which is currently heather moorland, extensive grassland or modified bog; · restoration of 50 % of forest on peat with less than Yield Class 8; · cessation of all peat extraction with 100% restoration to semi natural habitats by 2030. In addition, under the High ambition there is more abatement of			

	cropland as well as extensive grassland used for rough grazing capable of supporting trees. Most broadleaf woodland which is currently unmanaged is brought back into production, with 80% actively managed by 2030 for biomass fuel and timber. The areas of forest producing constructional timber increases beyond the Medium ambition levels. Overall yields increase linearly to 20% above current levels by 2050 as a result of improved management, planting the right species in the right location, breeding and climate change.	emissions from intensively managed lowland peats by raising the water table on a seasonal or permanent basis on the remaining areas used for crop production or improved grassland (i.e. unrestored intensively managed lowland peatlands). This is intended to represent the abatement of emissions by halving the water table depth (and thus halving emissions) while still maintaining some agricultural production.			

Appendix B: UK nations GHG abatement potential

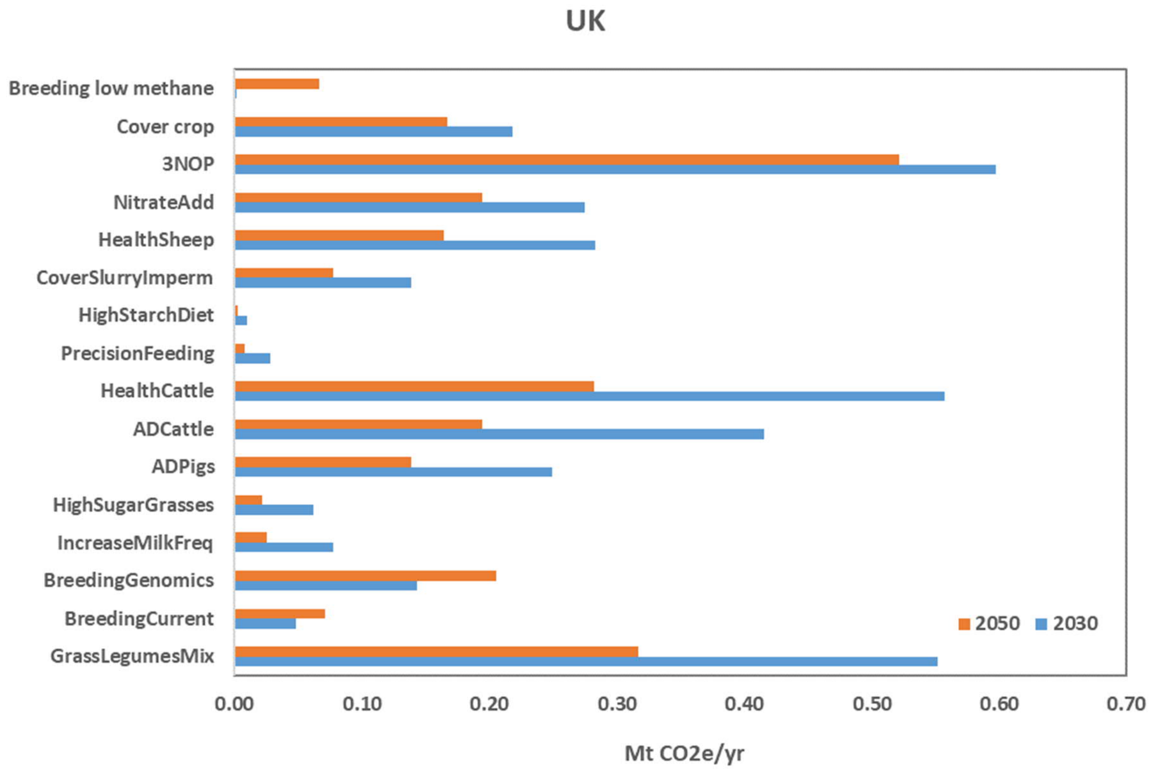

Figure B 1: Mitigation potential for several agroecological practices in the UK in 2030 and 2050 based on the CCC 6CB report, widespread engagement

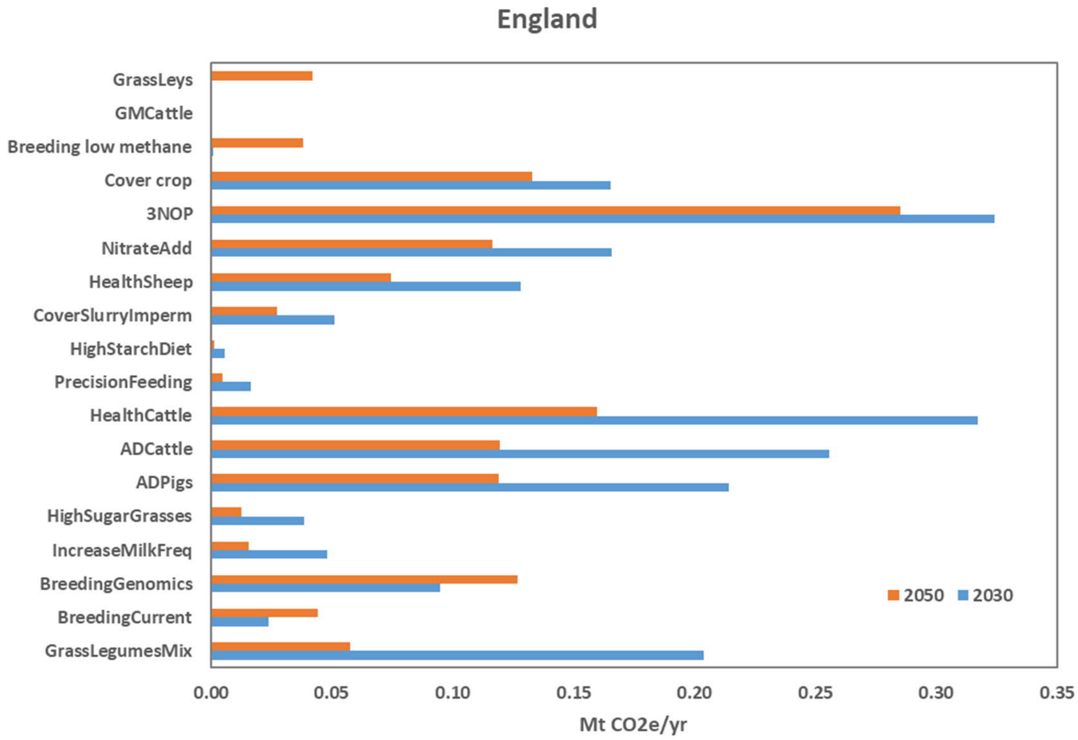

Figure B 2: Mitigation potential for several agroecological practices in England in 2030 and 2050 based on the CCC 6CB report, widespread engagement

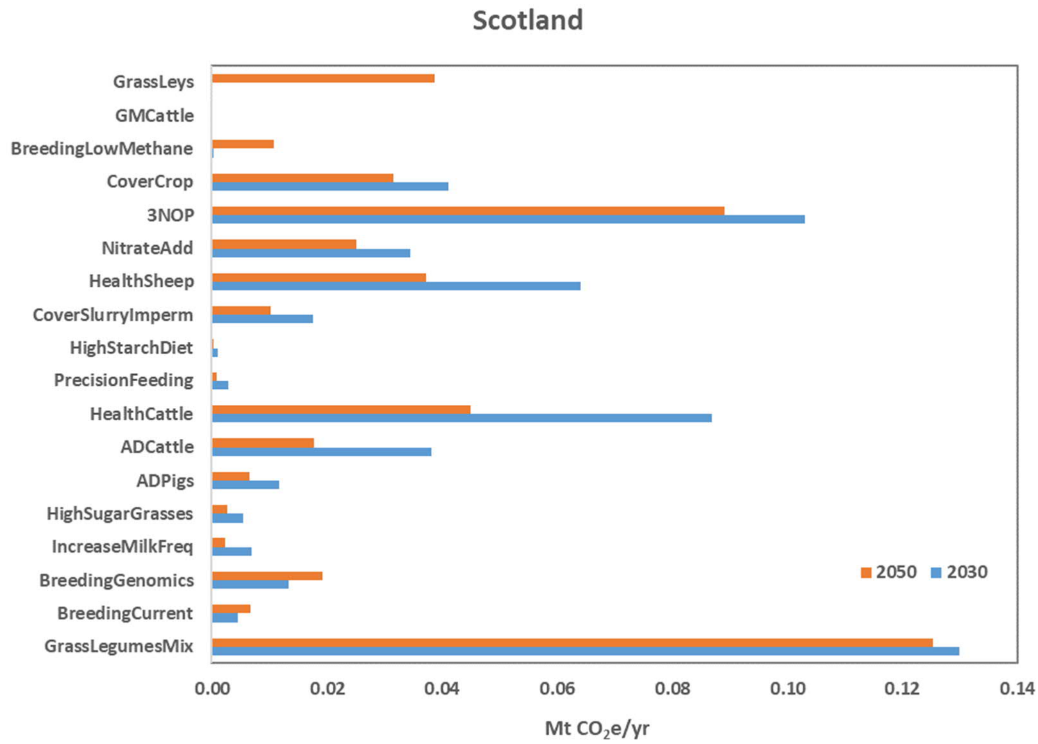

Figure B 3: Mitigation potential for several agroecological practices in Scotland in 2030 and 2050 based on the CCC 6CB report, widespread engagement

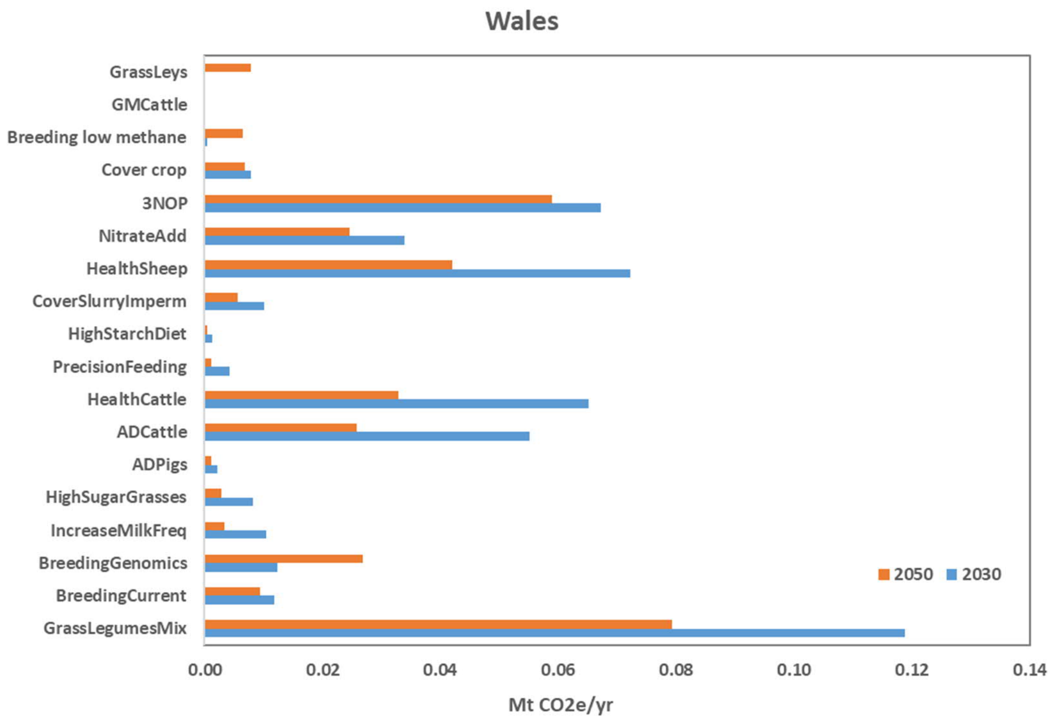

Figure B 4: Mitigation potential for several agroecological practices in Wales in 2030 and 2050 based on the CCC 6CB report, widespread engagement

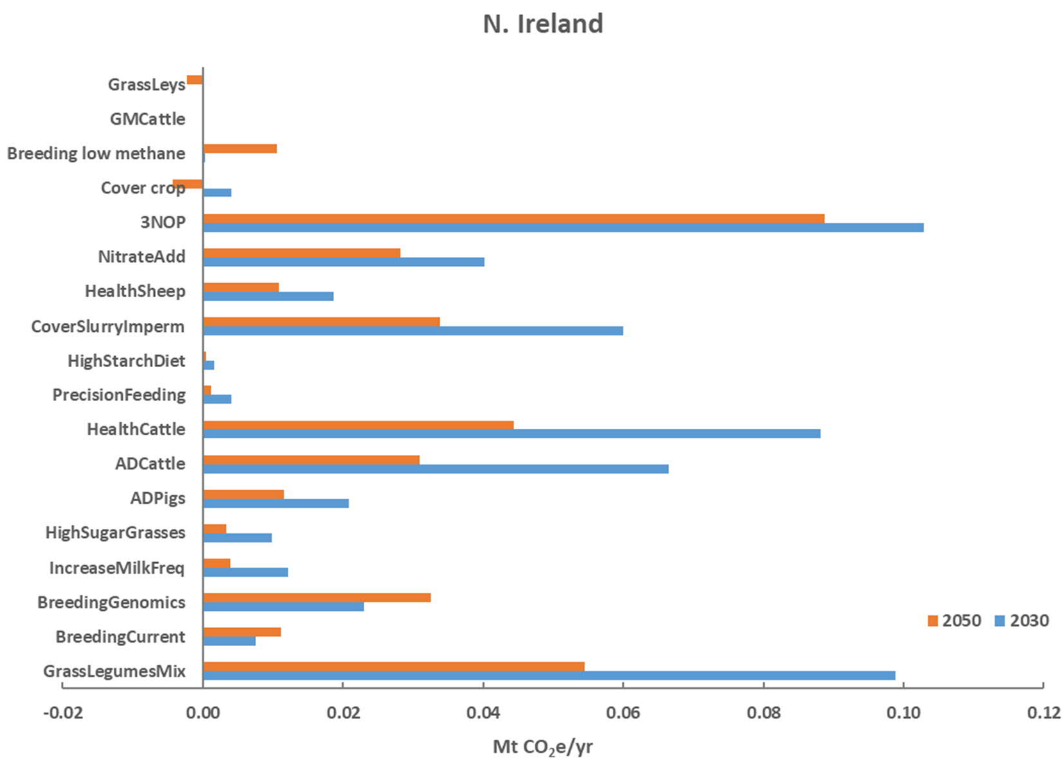

Figure B 5: Mitigation potential for several agroecological practices in Northern Ireland in 2030 and 2050 based on the CCC 6CB report, widespread engagement