Chapter 7

Chapter 7: Reducing emissions from agriculture and land use, land-use change and forestry

Introduction

In this chapter we consider options for reducing emissions arising from agriculture and land use, land-use change and forestry activity.

The UK inventory estimates that agriculture emissions in 2008 amounted to around 48 $MtCO_2e$ or 8% of total UK greenhouse gas emissions. Emissions have fallen from 61 $MtCO_2e$ in 1990, mainly due to reduced activity as a result of reform of the EU Common Agricultural Policy. The Government is aiming to reduce agriculture emissions by around 3 $MtCO_2e$ in England over the next ten years (a similar level of ambition in the devolved administrations would deliver an additional 1.5 $MtCO_2e$). Without further abatement beyond this ambition, agricultural emissions would account for a high share of allowed emissions in 2050 (e.g. around 28%). This would be unsustainable given emissions from other difficult to reduce sectors (e.g. aviation, shipping, and industry). Therefore it will be important to continue to reduce the emissions intensity of agricultural production in the 2020s.

On a net basis, the land use, land-use change and forestry (LULUCF) sector absorbed 2 $MtCO_2$ in 2008. Going forward, LULUCF is forecast to revert to a net emitter of emissions due to a decline in the historical forest planting rate.

In this chapter we consider options for reducing emissions through the 2020s from agriculture and LULUCF including:

- Options for agriculture to reduce emissions from soils, livestock and manures through the uptake of best practices and new technologies.
- More radical supply-side options (e.g. introduction of biotechnological options such as GM, changes to agricultural systems).
- Scope for reducing CO_2 emissions from energy use on farms (e.g. from farm vehicles).
- Opportunities for reducing emissions through reducing food waste and rebalancing diets.
- Role of afforestation in reducing net LULUCF emissions.

Our aim is to identify promising options for further consideration and to develop scenarios for agriculture and LULUCF emissions reductions through the 2020s. We build these into economy-wide scenarios which underpin our advice on the level of the fourth carbon budget (see Chapter 3).

The key messages in this chapter relating to agriculture are that:

- The scale of the opportunities to reduce agriculture emissions is more uncertain than in other sectors of the economy. Even the precise scale of emissions is uncertain, due to incomplete understanding of both the science and of the current mix of farming practices.

Moreover the extent to which specific technically feasible abatement opportunities can in fact be achieved and reflected in the UK's greenhouse gas inventory is complicated by the difficulties of monitoring either changes in farming practices or changes in actual resulting emissions. Further analysis is required to reduce uncertainties and to identify policy levers which can increase certainty of implementation.

- Analysis suggests that there is a technically feasible abatement opportunity of 4-14 $MtCO_2$ by 2030, through the uptake of best practices and technologies to reduce N_2O emissions arising from soils and CH_4 emissions arising from livestock and manures.
- In addition there is scope for abatement through reducing energy use on farms (e.g. through use of low-emissions engines and alternative fuels and technologies).
- Given the difficulties of ensuring attainment of technically feasible abatement, we have assumed that 5 $MtCO_2e$ of this reduction can be achieved in the Medium Abatement scenario (in addition to the 4.5 $MtCO_2e$ assumed for the UK between now and 2020). This will deliver a 12% reduction by 2030 relative to 2020 levels, and a reduction of 18% relative to today's levels.
- This assumed pace of reduction is significantly lower than in other sectors of the economy, and if further reductions could not be achieved by 2050, agriculture would then account for 40 $MtCO_2e$ out of the total 160 $MtCO_2e$ target. Combined with emissions in other difficult to reduce sectors (industry direct emissions, aviation and shipping) this level of agricultural emissions would make the 2050 target extremely difficult and perhaps impossible to attain.
- In addition, the vast majority of measures that we assume under the Medium Abatement scenario are available at negative cost (i.e. can save money for farmers). All the measures are less than our projected economy-wide carbon price and should therefore form part of a least-cost emissions path for the overall economy.
- It is therefore essential that work continues to identify further reduction opportunities beyond those which we have assumed for the fourth budget. To achieve these further reductions might require:
  - The development of stronger policy levers to ensure the attainment of technically feasible and uncontroversial abatement opportunities (e.g. reduced use of nitrogen fertiliser via better application techniques) while at the same time mitigating any competitiveness risks.
  - Novel technologies, including potentially controversial ones, such as the use of GM technology.
  - Changes in consumer behaviour, such as via reductions in food waste, or via a changed mix of diets, with reduced consumption of carbon-intensive foods.
  - Our assessment of emissions reduction from diet rebalancing raises broader questions about production- versus consumption-based emissions accounting approaches, which we believe it would be useful for the Committee to investigate in detail, both as regards agriculture and more generally.

The key messages relating to LULUCF are that:

- Available land use and land-use change options, mainly increasing the number of trees, could absorb up to 3 $MtCO_2$ in 2030. This would require initiation of forest planting programmes today to deliver estimated abatement potential.
- For LULUCF, we use a range of abatement of 1-3 $MtCO_2e$ in our economy-wide scenarios.

We set out the analysis that underpins these messages in seven sections

1. Agriculture emissions in the period to 2020
2. Options for reducing emissions from agriculture through best practices and technology
3. Opportunities for reducing emissions from agriculture through reduced food waste and changed diets
4. The role of land use, land-use change and forestry (LULUCF)
5. Policies to support agriculture and LULUCF emissions reduction
6. Scenarios for agriculture and LULUCF emissions to 2030
7. Implications for the first three budget periods

1. Agriculture emissions in the period to 2020

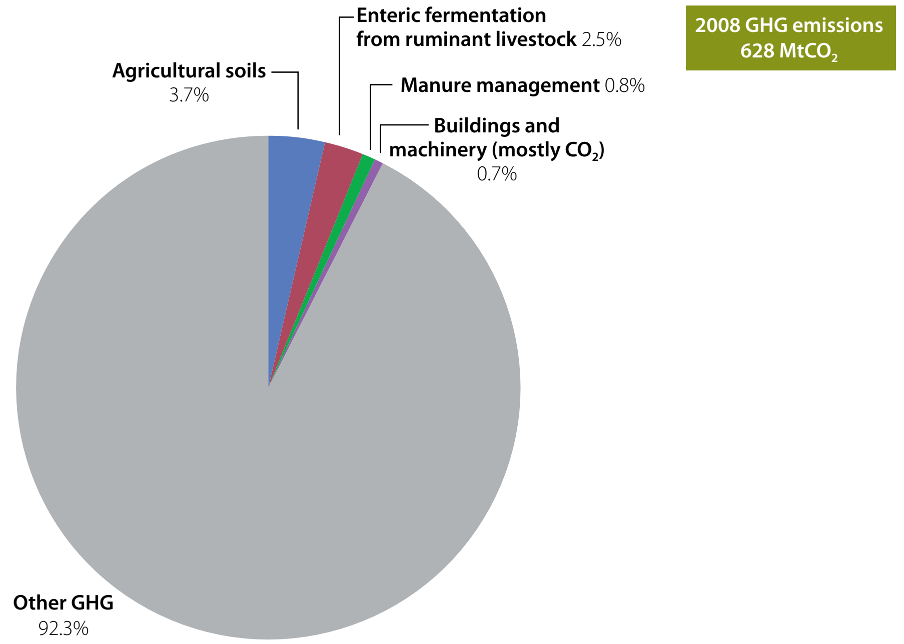
Current agriculture emissions

The UK agriculture inventory estimates current agricultural emissions to be around 48 $MtCO_2e$ or 8% of total greenhouse emissions (Figure 7.1).[1]

- These mainly comprise nitrous oxide (N_2O) emissions from the use of fertiliser on soils (54%) and methane (CH_4) emissions from enteric fermentation, a process related to digestive systems of cattle and sheep (38%) (Figure 7.2).
- Estimated emissions fell by 21% between 1990 and 2008 (Figures 7.3 and 7.4) – mainly reflecting changes in agricultural activity:
  - Livestock numbers fell as a result of Common Agricultural Policy (CAP) reform, which decoupled subsidies from production.
  - The quantity of fertiliser applied to agricultural lands fell, particularly on pasture land, reflecting lower stocking densities.
  - There is some evidence of improved efficiencies in livestock production and nitrogen use efficiency, neither of which may be wholly captured in the UK GHG inventory.
- In 2008, N_2O and CH_4 emissions from agriculture accounted for 47% of all non-CO_2 emissions (Figure 7.5).

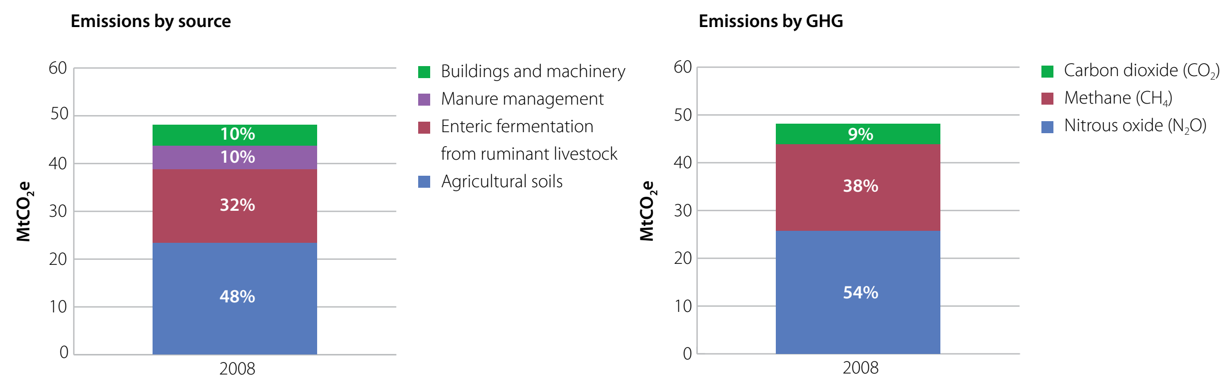
1 This figure includes crown dependencies which are not covered by the UK Climate Change Act.

Figure 7.1: GHG emissions from agriculture in the context of total UK emissions (2008)



Source: NAEI (2010).

Figure 7.2: Agriculture emissions (2008)



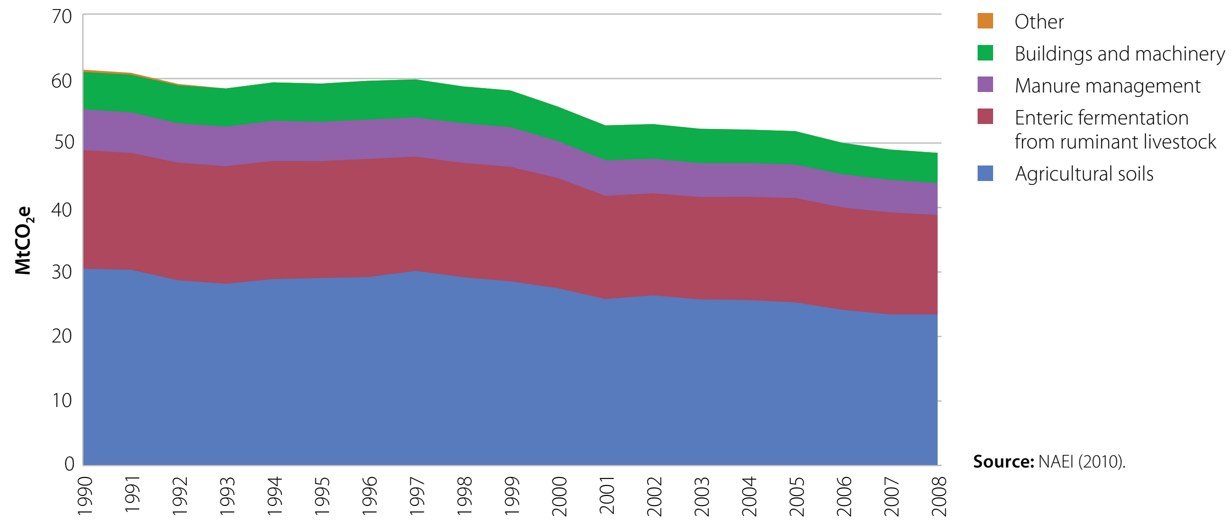
Source: NAEI (2010).

- Agriculture is also responsible for CO_2 emissions arising from the use of machinery (e.g. tractors) and consumption of fuel in farm buildings. Agricultural CO_2 emissions accounted for 0.8% of UK CO_2 emissions in 2008.

Estimates of agricultural emissions include significant uncertainties:

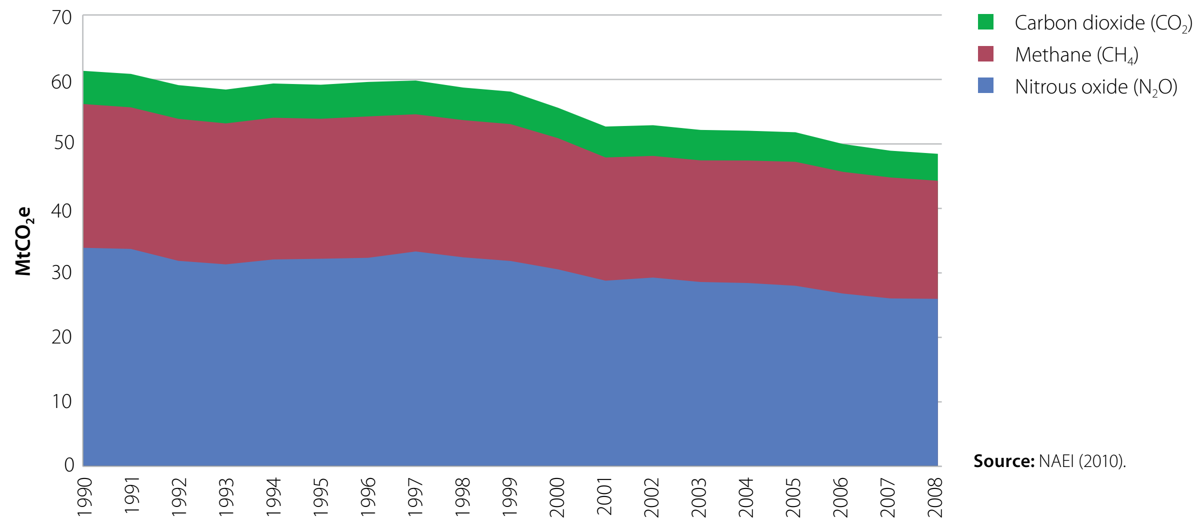
- In the UK inventory agriculture emissions estimates are calculated by multiplying a measure of activity by an 'emissions factor' (the amount of emissions associated with that activity).

Figure 7.3: Agriculture emissions by source (1990-2008)



Source: NAEI (2010).

Figure 7.4: Agriculture emissions by GHG (1990-2008)

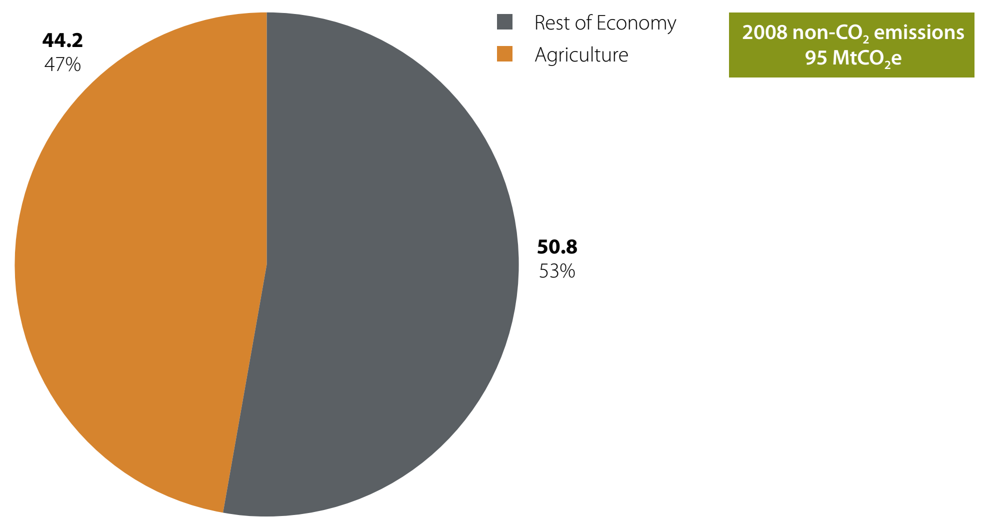


Source: NAEI (2010).

- Uncertainty about past and current agricultural activity is unlikely to be higher than in other sectors. However, uncertainty in emissions factors is likely to be much larger than compared to other sectors. Emissions factors represent generic world or regional averages, but these may not be appropriate for UK conditions as emissions are heavily influenced by variable elements such as climate and soil quality as well as farming practices.[2]
- If the uncertainties in emissions estimates are taken into account, agriculture could account for between 2% to 13% of all UK emissions.

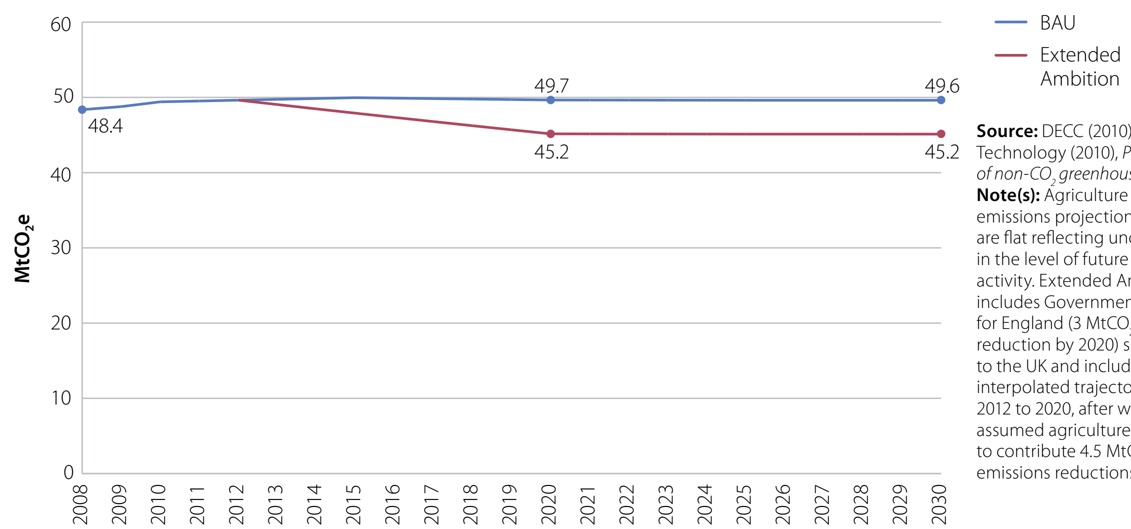
2 The UK inventory for agriculture is at present calculated using default IPCC emissions factors in the absence of better country-specific emissions factors. The Government has committed to investing in the agriculture evidence base to better understand and measure emissions from biological systems and develop a more accurate inventory that can reflect mitigation activities.

Figure 7.5: Agriculture share of non-CO_2 emissions (2008)



Source: DECC (2010).

Figure 7.6: Agriculture emissions reference projections (2008, 2020, and 2030)



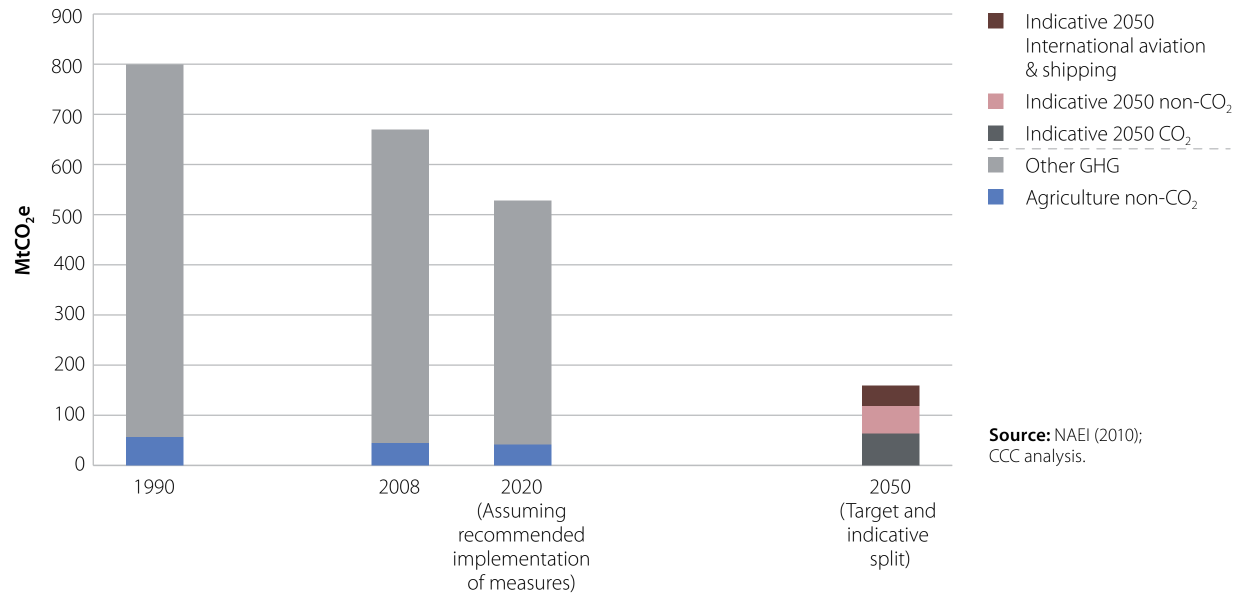
Source: DECC (2010); AEA Technology (2010), *Projections of non-CO_2 greenhouse gases.*
Note(s): Agriculture BAU emissions projections to 2030 are flat reflecting uncertainties in the level of future agricultural activity. Extended Ambition includes Government ambition for England (3 $MtCO_2e$ reduction by 2020) scaled to the UK and includes an interpolated trajectory from 2012 to 2020, after which it is assumed agriculture continues to contribute 4.5 $MtCO_2e$ in emissions reductions to 2030.

Projected emissions in 2020

Agriculture emissions are projected by the Government to be at 50 $MtCO_2e$ in 2020 under 'business as usual activity' (BAU). This figure reflects forecasts for livestock and crop production and is slightly higher than the current emissions level of 48 $MtCO_2e$ (Figure 7.6). Analysis in our 2010 Progress Report to Parliament suggested that there is scope for 5-12 $MtCO_2e$ reduction in UK agriculture emissions by 2020 (a 27-39% reduction from 1990 levels). This is through a range of cost-effective soils, livestock, and manure management measures (<£40/tCO_2e), of which the majority are available at negative cost (i.e. they would save money for farmers).

The previous Government committed, in its Low Carbon Transition Plan (LCTP), to reduce emissions from agriculture in England by 3 $MtCO_2e$ in 2020. We scale this up to 4.5 $MtCO_2e$

Figure 7.7: Agriculture sector emissions in the context of UK greenhouse gas emissions (1990-2020, 2050)



Source: NAEI (2010); CCC analysis.

at the UK level on the basis of analysis conducted by the Scottish Agricultural College. This is around 40% of the maximum technical potential we identified in our 2010 Progress Report to Parliament. An industry action plan, developed by the Climate Change Task Force (a joint collaboration between agriculture industry groups) identified measures to deliver the LCTP emissions reduction, and proposed an approach to delivery based on provision of information, advice and voluntary action.

Given the high levels of uncertainty over future emissions, both as regards business as usual emissions and the emissions impact of abatement measures, we recommend that the focus of policy effort should be on implementing measures and on developing a more robust evidence base to better identify current farming practice and resolve uncertainties over abatement potential. In this chapter, as in other sectoral chapters, we start by defining an emissions entry point in 2020, from which we develop emissions scenarios through the 2020s. In line with the previous Government's LCTP ambition, we assume that UK agriculture emissions are reduced by 4.5 $MtCO_2e$ in 2020. Therefore we assume that emissions fall from the Government's business as usual projection level of 50 $MtCO_2e$ in 2020 to 45 $MtCO_2e$ (i.e. around 10% of UK emissions allowed under the intended budget of 450 $MtCO_2e$ in 2020 – Figure 7.7). With no further change, agriculture emissions would account for 28% of total allowed emissions under the 2050 target (160 $MtCO_2e$) in the Climate Change Act.

Reference emissions projection to 2030

Our agriculture reference projections to 2030 are again based on the Government's business as usual projections net of abatement targeted in the period to 2020:

- Government projections assume that baseline agricultural emissions will increase slightly going forward, from the current level of 48 to just under 50 $MtCO_2e$ in 2025, reflecting forecasts for livestock and crop production.

- Netting out 4.5 $MtCO_2e$ from the BAU projections to 2025 gives agriculture emissions of 45 $MtCO_2e$ (of which 41 $MtCO_2e$ are non-CO_2 emissions).
- In the absence of formal projections to 2030, we assume flat emissions between 2025 and 2030 (Figure 7.6).

We now consider scope for emissions reduction from this reference case in the period to 2030, and set out scenarios based on different assumptions about abatement in Section 6.

2. Options for reducing emissions from agriculture through best practices and technology

We divide our analysis of scope for on-farm agriculture emissions reduction into non-CO_2 and CO_2 abatement, and now consider each category in turn.

(i) Measures to reduce on farm non-CO_2 emissions

Currently identified scope for emissions reductions from soils and livestock measures

Analysis by the Scottish Agricultural College (SAC)[3] has guided our assessment of abatement potential. The SAC analysis considers a range of measures to reduce emissions from soils and livestock including:

- more efficient use of nitrogen fertilisers,
- breeding livestock for improved genetics, fertility and productivity,
- improvements in livestock feed efficiency and use of dietary additives,
- improved manure management and anaerobic digestion.

The analysis found a range of 8.6 to 18.9 $MtCO_2e$ of abatement potential from the above measures at a cost of less than £70/tCO_2e (i.e. our projected carbon price for 2030, see Chapter 2), by the end of the third budget (2022) (Figure 7.8):

- The range reflects uncertainties relating to the baseline against which the measures are applied; the technical effectiveness of abatement measures; and whether some measures would be permitted under future regulatory regimes (Box 7.1).
- Of the maximum 18.9 $MtCO_2e$:
  - 14.3 $MtCO_2e$ is available at negative cost and therefore represents an opportunity for farmers to increase their competitiveness whilst reducing the emissions intensity of production
  - 14.5 $MtCO_2e$ is available at a cost of less than £40/tCO_2e
  - All of the abatement potential is available at a cost less than our 2030 projected carbon price of £70/tCO_2e (see Chapter 2 for our carbon price projections).

3 Scottish Agricultural College et al. (2010), *Review and update of UK marginal abatement cost curves for agriculture.*

Figure 7.8a: Agriculture MACC maximum technical potential, pessimistic case (2022)

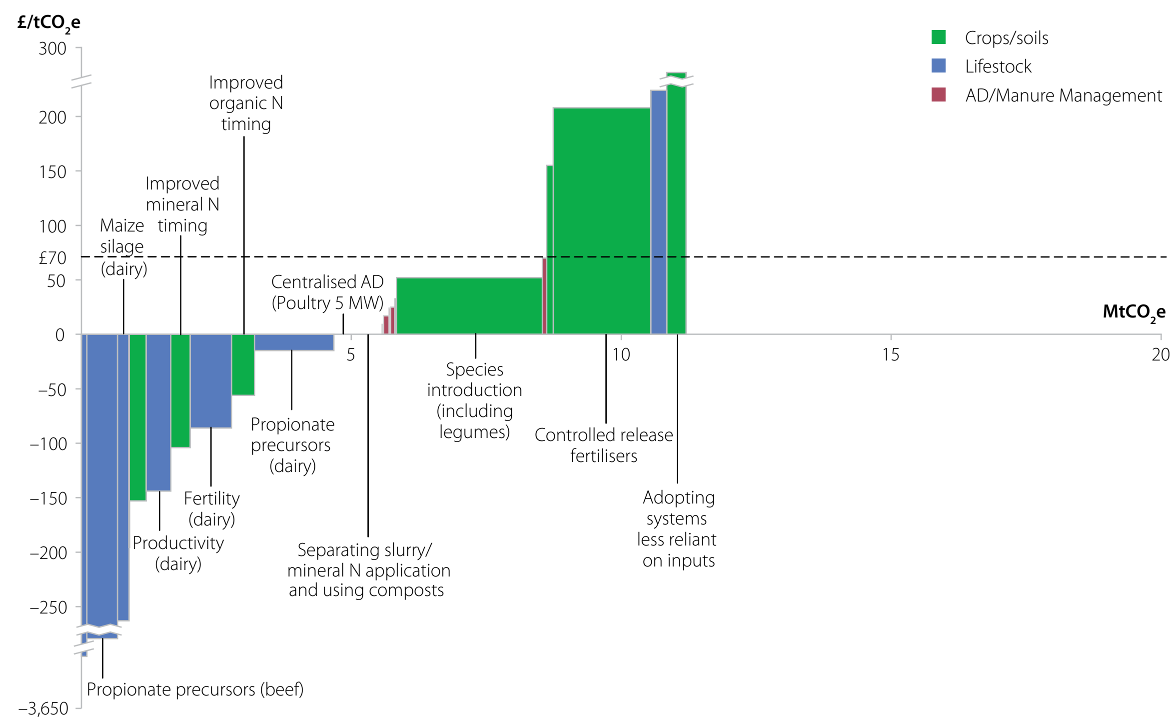
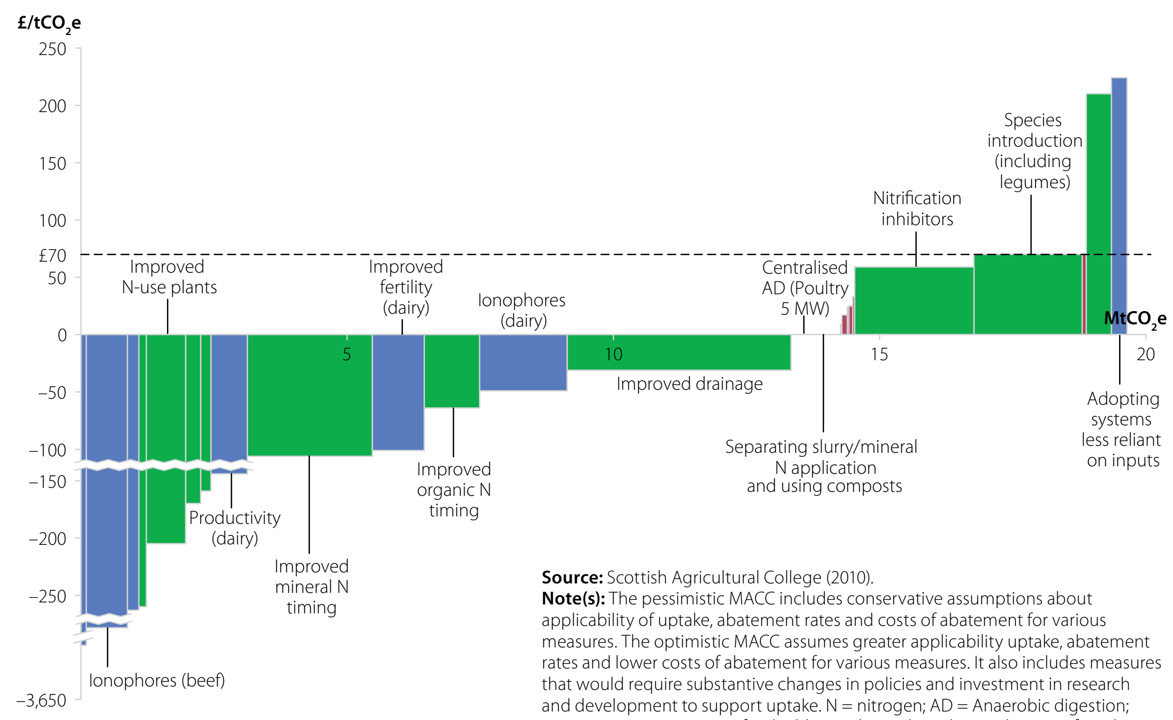


Figure 7.8b: Agriculture MACC maximum technical potential, optimistic case (2022)



Source: Scottish Agricultural College (2010).
Note(s): The pessimistic MACC includes conservative assumptions about applicability of uptake, abatement rates and costs of abatement for various measures. The optimistic MACC assumes greater applicability uptake, abatement rates and lower costs of abatement for various measures. It also includes measures that would require substantive changes in policies and investment in research and development to support uptake. N = nitrogen; AD = Anaerobic digestion; propionate precursors are feed additives that reduce the production of methane in ruminants; ionophores are feed additives that can improve the performance of cattle and are at present banned in the EU. More details and a full measure list is available in the technical annex on the CCC website.

Therefore the analysis suggests scope for additional technical abatement of 4-14 $MtCO_2e$ through the 2020s over and above the 4.5 $MtCO_2e$ reduction that is assumed in the LCTP (scaled to the UK).

Box 7.1: Uncertainties in the Agriculture MACCs

The SAC MACC analysis identifies technical potential ranging from 8.6-18.9 $MtCO_2e$ by 2022. The range indicates a pessimistic and optimistic set of assumptions, which reflect a number of uncertainties. These include:

- Baseline uncertainty as to the present state of farming practice. For example, the extent to which farmers are already implementing measures or the amount of additional land to which a measure can be applied.
- Technical uncertainty or the ability of measures to deliver identified potential given current evidence and/or timelines required to test and deploy options. For example, nitrification inhibitors, which slow the rate of conversion of fertiliser ammonium to nitrate, need to be adequately tested under UK conditions to establish their efficacy.
- Regulatory uncertainty. For example, the use of ionophores in livestock (which inhibit the production of methane from enteric fermentation) is at present illegal within the EU.

We assume that the technical potential identified in the MACCs is inclusive of abatement targeted in the LCTP, or 3 $MtCO_2e$ within England by 2020 which scales to 4.5 $MtCO_2e$ at the UK level. The residual abatement is calculated by netting off 4.5 $MtCO_2e$, resulting in 4 to 14 $MtCO_2e$ in additional abatement available by 2022 (which is also available throughout the 2020s).

The ability to unlock additional technical potential depends upon resolving the uncertainties described above. For some measures, such as anaerobic digestion and nutrient management practices, there is greater confidence in their ability to deliver emissions reductions. Other measures require further testing under a variety of UK conditions. Still others require resolution of other issues (e.g. trade-offs between other objectives of farming including animal welfare and biodiversity). The level of confidence in MACC measures given remaining uncertainty is summarised below.

Table B7.1 Confidence in MACC measures given remaining uncertainty

Category	Measure(s)	Confidence	2022 Abatement Potential ($MtCO_2e$)	
			Pessimistic	Optimistic
Nutrient management	Improved timing of fertiliser application, avoiding excess application, etc.	Medium	1.2	4.2
Soil management	Drainage	Low	0.0	4.2
	Reduced tillage	Low	0.3	0.3
Nitrification inhibitors		Low	0.0	2.2
Using more nitrogen-efficient plants	Improved nitrogen-use plants	Medium	0.0	0.7
	Species introduction	Medium	2.7	2.0
Livestock breeding	Improved genetics in beef/dairy; improved fertility in dairy	High	1.3	1.8
Livestock feeding	Propionate precursors for beef/dairy	Medium	2.0	0.0
	Ionophores for beef/dairy	Low	0.0	2.4
	Use of maize silage for dairy	Medium	0.2	0.2
Anaerobic digestion	Pigs and poultry farm units	High	0.6	0.6
Manure management	Covering lagoons & slurry tanks	Medium	0.2	0.2
		Total	**8.6**	**18.9**

Source: Scottish Agricultural College (2010), *Review and update of UK marginal abatement cost curves for agriculture*, Table E.6.

Additional measures identified in the Scottish Agricultural College analysis

The SAC analysis considered a broader set of options to reduce emissions from crops and soils activity, and from livestock than those appearing in the final MACCs. It prioritised MACC mitigation measures based on relative costs, abatement potential, technical feasibility and acceptability to industry.

SAC acknowledged, however, that costs for other measures that were screened from the MACCs could decrease and that new options will become available over time as result of targeted research and technological development. These additional measures could include:

- Wider measures to improve soil management (e.g. residue management and waste management to improve soil structure and sequester carbon).
- Improved cattle health through reductions in endemic disease.
- Alternative dietary energy sources for ruminants (e.g. increasing high starch concentrates) to reduce the production of methane in ruminants or to improve animal yields.
- Other scales and types of anaerobic digestion systems that may become cost-effective, depending on incentives and future market prices.
- Increased use of nitrogen efficient crop varieties, including the potential use of genetically modified (GM) organisms (Box 7.2).
- Adopting alternative production systems e.g. mixed farming (Box 7.3).

Thus a range of management and technological options (including unanticipated technologies) could provide additional abatement. This would require research effort and funding, and be subject to regulatory barriers, public acceptability and trade-offs between low-carbon and other objectives (e.g. animal welfare) being addressed.

Box 7.2: The potential for biotechnology in agriculture mitigation

The MACC analysis considers various biotechnological options for reducing emissions from agriculture, including introducing crops which use nitrogen more efficiently, thus reducing the amount of fertiliser required and associated N_2O emissions. In the longer term, additional biotechnological options for mitigating agriculture emissions may also involve use of genetic modification (GM) technology to improve nitrogen use efficiency and confer nitrogen fixing capabilities to cereal crops.

There is potential to improve nitrogen use efficiency in plants by traditional breeding and GM methods. In breeding programmes, desired traits are introduced by crossing plants from related varieties or species and selecting individuals with the desired characteristic. These can then be developed into new varieties. Traditional breeding programmes can have long lead-times due to constraints in developing and selecting new varieties. For instance it can take ten years or more to develop crops with the desired characteristics. Biotechnological approaches such as marker-assisted breeding and selection can be used to significantly speed up this process and are likely to be used increasingly in plant breeding programmes.

GM-based approaches to improving nitrogen use efficiency would involve the introduction of novel genes, either from the same species or from another species, into a plant. While to date there has been little success in engineering improved nitrogen use efficiency, it has been argued that GM approaches may deliver faster results than conventional breeding programmes.

Box 7.2: The potential for biotechnology in agriculture mitigation

A longer-term option to reducing fertiliser use in agriculture is developing crops (e.g. cereals) that can convert nitrogen gas, abundant in the atmosphere, into a usable form. This 'nitrogen fixing' capability is already present in legume crops (e.g. clover and beans). These crops have nodules on their roots that contain bacteria, which carry out the fixing process. Legume crops are used in some farming systems to provide nitrogen through crop rotation. Enabling other crop plants to fix nitrogen may require the use of GM technology. In last year's *Reaping the Benefits* report, the Royal Society notes that if engineering of nitrogen fixation in non-legume crops is possible, it is a long-term development (over 10 -15 years away) and would require significant investment in research and development.

The use of GM has been controversial in the EU and to date there has been limited commercial cultivation of GM crops in the region. Future use would require resolution of consumer acceptability issues, both around understanding the science of GM as well as safety concerns.

It is also noted that GM crop development has predominantly been driven by the private sector, while public funding for agricultural research and development has declined over the past 20 years. Going forward, and as we identified in our July 2010 report *Building a low-carbon economy: the UK's innovation challenge*, innovation within agriculture should be a priority given the early stage of development of key agri-biotechnologies and the potential importance of these options for meeting carbon budgets and for addressing other issues (e.g. feeding a growing global population).

The Royal Society has called for an inclusive approach to considering new technologies in food production systems where no techniques or technologies should be ruled out before the risks and benefits are assessed. We similarly recommend that the Government consider the full set of agri-biotechnological options, including both traditional and GM approaches, in developing longer-term approaches to reducing emissions from agriculture.

Source: Royal Society (2009), *Reaping the benefits – Science and the sustainable intensification of global agriculture*; J. Piesse and C. Thirtle (2010), *Agricultural R&D, technology and productivity*, Phil. Trans. R. Soc; B. Collard and D. Mackill (2008), *Marker assisted selection: an approach for precision plant breeding in the twenty-first century*, Phil. Trans. R. Soc; Pathak et al (2008), *Molecular physiology of plant nitrogen use efficiency and biotechnological options for its enhancement*, Current Science.

Box 7.3: The role of changed agricultural systems in mitigation

While most agricultural systems will inevitably lead to net emissions of greenhouse gases, farming systems are characterised by different mixes of inputs and practices, with differing implications for GHG emissions. Key farming systems relevant to UK production include:

- Conventional farming, which tends to be more intensive and is characterised by mechanisation and the use of synthetic inputs such as chemical fertilisers and pesticides.
- Precision farming, which involves use of spatially explicit information on soils (e.g. via GPS, sensors, and information management tools) to target inputs of nutrients and optimise nutrient supply, thereby minimising potential losses.
- Mixed farming, which combines arable and livestock production and can be effective at closing the nutrient cycle (e.g. animal wastes can be returned more easily to arable fields as fertiliser).
- Organic farming, which avoids use of synthetic fertilisers or pesticides, relying instead on organic fertilisers and crop rotation to promote soil fertility.
- Agro-forestry, which combine arable and/or livestock production with trees, relying on interactions between both to offer environmental benefits, including carbon sequestration.

In considering the relative emissions impacts of farming systems, it is important to note the following:

- There exist as many differences in farming practices within the same system as there exist across systems. Thus under any given farming system there is likely to be great variation in emissions.
- Specific management practices are not discrete and can be adopted across farming systems.
- Changing farming systems often hinges on factors such as land quality and location.

Box 7.3: The role of changed agricultural systems in mitigation

- Calculating the emissions intensity of a given farming system depends on the method employed:
  - Emissions arising from organic systems may be smaller on a per-hectare basis, due to reduced fertiliser inputs and extensive grazing methods, but emissions arising from conventional farms may be smaller when calculated on a per unit of product basis, as conventional yields are typically higher than organic yields.
  - Mixed farming systems may close the nutrient cycle, saving in upstream fertiliser and transport emissions, which are not currently captured in the agriculture MACCs.
  - Organic and agro-forestry systems can play an important role in absorbing and sequestering soil carbon, which would not be captured within the UK agriculture inventory.

If the goal is to maximise production on available land, intensive production may be beneficial from a GHG perspective, but may be associated with other environmental and animal welfare trade-offs. Given global land constraints and concerns around enhancing food security for a growing population, there is an increasing call for the sustainable intensification of global food production systems, defined as achieving higher yields from the same area of land without severely impacting the environment. This underscores the need, in developing policies to reduce emissions from agriculture, to examine trade-offs and interactions between delivering emissions reduction and other objectives of the farming sector (including productivity, animal welfare, biodiversity, air and water quality, etc.).

(ii) Measures to reduce on-farm CO_2 emissions

Farms currently emit around 4 $MtCO_2$ (i.e. in addition to 44 Mt of other GHGs) due to mobile machinery and stationary combustion:

- Emissions from mobile machinery (e.g. arising from diesel use in tractors, combine harvesters, mowers, sprayers and balers) are currently around 3.6 $MtCO_2$, with scope for reduction through use of efficient engine technology and alternative vehicle fuels.
- Emissions from stationary combustion (e.g. of natural gas for space heating in farm buildings) are currently around 0.5 $MtCO_2$, with scope for reduction through use of high-efficiency and biomass boilers.

AEA analysis currently commissioned by Defra suggests that there is cost-effective opportunity to reduce on-farm CO_2 emissions associated with mobile machinery and stationary combustion by 2030. Given the earlier stage of analysis we do not reflect this opportunity in our scenarios for agriculture emissions (see Section 6 below) and economy-wide emissions scenarios (see Chapter 3) but will revisit this abatement potential at a later stage.

3. Opportunities for reducing emissions through reduced food waste and changed diets

Our analysis to date has focused on changing farming practices and using new technologies as they relate to crops, soils and livestock to reduce emissions from agriculture. We now consider potential opportunities offered through changes in consumer behaviour as they impact agriculture production emissions.

Reducing food waste

Our analysis of scope for reducing non-CO_2 emissions from waste (Chapter 3, Box 3.8) includes emissions reduction from diverting food waste from landfill. However, diverting food waste does not avoid emissions associated with production and distribution of food, and therefore additional emissions reductions are available where waste can be reduced.

Currently around 16 million tonnes[4] of total UK food and drink is wasted:

- 8.3 million tonnes are wasted by households
- 3.6 million tonnes are wasted in the retail sector and the supply chain
- 4 million tonnes are wasted elsewhere, such as in schools, the hospitality sector, and agriculture; although these waste stream estimates require further analysis
- Of the 8.3 million tonnes wasted by households, 5.3 million tonnes or around 15% of total food and drink purchased is waste that could be avoided through the introduction of good practices
- Total emissions associated with this avoidable food waste (5.3 Mt) are estimated to be 20 $MtCO_2e$ on a consumption basis[5], with UK agriculture emissions from soils and livestock accounting for around 6.5 $MtCO_2e$ (32%) of this
- The associated annual cost is of the order £12 billion in total, equivalent to around £480 per household.

Analysis by WRAP suggests that up to half of avoidable household food and drink waste (or 2.7 Mt) could be prevented through simple measures including information-provision and engagement with retailers, brands, local authorities and householders to encourage reduced food waste. If this level of reduction in food waste were to be achieved the corresponding emissions reduction could be up to 10 $MtCO_2e$ on a consumption basis:

- 3.2 $MtCO_2e$ could result from savings in agricultural production, although it is difficult to estimate the likely impact of food waste reduction measures on agricultural emissions. For example, better planning, storage, and packaging may reduce household purchase of food, but it is not clear whether this would result in a corresponding reduction in agricultural production (e.g. the food and drink sector could export more products).
- 1.2 $MtCO_2e$ could result from avoided landfill emissions due to not purchasing food that would otherwise be wasted and end up in landfill. This is additional to waste abatement potential in Chapter 3 which does not include diversion of household food waste from landfill.

Notwithstanding challenges in changing behaviour to addressing this opportunity, it is available at negative cost (i.e. saves households money) and social research evidence suggests people are keen to reduce waste.[6] Therefore policy effort in this area is worthwhile.

4 WRAP (2010), *Waste arisings in the supply of food and drink to households in the UK; updated following personal communication with WRAP.*
5 WRAP (2009), *Household Food and Drink Waste in the UK*; This figure includes contributions from the relevant elements of the food and drink sector including agriculture, manufacture, packaging, distribution, retail, transport to the home, storage and preparation in the home and waste treatment and disposal (net of emissions associated with exports).
6 Owen, L., Seeman, H., and Prince, S (2007), *Public Understanding of Sustainable Consumption of Food*: A report to the Department for Environment, Food and Rural Affairs; WRAP (2010), Results of Courtauld Commitment Phase I.

Reducing emissions through changed diets

Varying carbon intensity of different foods

In our 2008 Report we presented evidence, based on life-cycle analysis of GHG emissions arising from food products, which showed the relatively higher carbon intensity of red meat products. This reflects the inefficiency of sheep and cows at processing food, and emissions arising from their digestive processes (Figure 7.9):

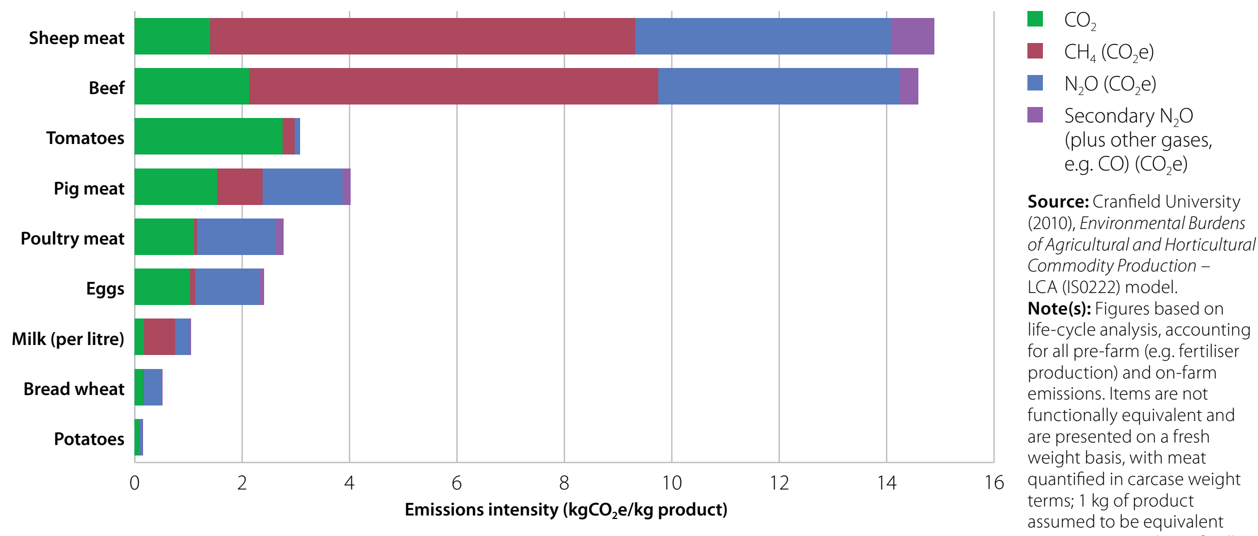
- Cows require 15.6 kg and sheep require 27.7 kg of feed (concentrates, grass, and barley), to produce 1 kg of meat. This may be compared to pigs and chicken, which require 4.2 kg and 3.1 kg respectively for each kg of meat.[7]
- Cows and sheep are ruminant animals, feeding on grass and digesting this through a process called enteric fermentation, giving rise to significant methane emissions.

In effect, cows and sheep require relatively high amounts of grass and feed, producing large amounts of methane, which has a much higher Global Warming Potential than CO_2 (around 25 times).

We suggested in the 2008 report that rebalancing diets towards less emissions-intensive foods could therefore reduce emissions. We recommended that this should be considered to meet the 2050 target, subject to a number of issues around land-use impacts, nutritional content of diet, and emissions accounting being addressed:

- Ruminants convert grass (which cannot be digested by other animals) into food (e.g. meat and dairy) and use grassland that in some cases cannot be used for other purposes (e.g.

Figure 7.9: Estimated GHG emission intensities of different food products



Source: Cranfield University (2010), *Environmental Burdens of Agricultural and Horticultural Commodity Production – LCA (IS0222) model.*
Note(s): Figures based on life-cycle analysis, accounting for all pre-farm (e.g. fertiliser production) and on-farm emissions. Items are not functionally equivalent and are presented on a fresh weight basis, with meat quantified in carcase weight terms; 1 kg of product assumed to be equivalent to 16.7 eggs or 1 litre of milk.

7 Cranfield life-cycle assessment (LCA) model (2010); Estimates are averages across several possible breeding and finishing systems in the UK; Cranfield University (2010), *The effect of changes in UK food consumption patterns on land requirements and greenhouse gas emissions*, Table 11.

for arable crop production and/or forestry). Therefore changing diets requires increased production of substitute commodities (e.g. crops for human consumption) and as a result could lead to land-use change and related emissions (e.g. release of soil carbon) both domestically and abroad.

- Food products have different nutritional characteristics and cannot be treated as direct substitutes. Therefore any change in diet would have to deliver adequate nutritional content.
- Food products (and feed inputs) are both imported and exported, so any change in UK food consumption may not impact UK food production and emissions. This is an issue given the accounting framework under the Climate Change Act, which is based on production rather than consumption emissions. It raises the possibility that changed diet would not contribute to meeting carbon budgets, notwithstanding any global benefits that this would give rise to. It reflects a broader issue around production-versus consumption-based accounting approaches to emissions, to which the Committee will give future consideration.

New analysis of emissions impacts of changed consumption

We commissioned Cranfield University to assess scope for emissions reduction through consumption change, including impacts on land-use change and emissions, by addressing three key questions:

- Can UK land support a reduction in the consumption of meat/dairy products and an increased production of substitute goods?
- What are the net GHG emissions and land-use impacts of this change (including soil carbon releases/sequestration, feed production impacts, and N_2O and CH_4 emissions)?
- If the UK cannot wholly support consumption change, what are the international implications GHG emissions (land-use and GHG impacts)?

The analysis uses three illustrative scenarios with different degrees of consumption change away from red and white meat and dairy products[8]:

- **Scenario 1:** A 50% reduction in livestock product supply balanced by increases in plant commodities
- **Scenario 2:** A shift from red (e.g. beef and sheepmeat) to white (pigs and poultry meat), with no overall reduction in livestock consumption
- **Scenario 3:** A 50% reduction in white meat supply balanced by increases in plant commodities

Each scenario would provide comparable levels of energy, protein and fat supply as current average UK consumption patterns (Table 7.1). In general there are likely to be health benefits from reducing excessive animal protein intake (Box 7.4) although further work is required to determine the health impacts of low-carbon diets for other groups of nutrients.

8 The Cranfield study refers to red meat as ruminant (beef and sheep) and white meat as monogastric (pig and poultry) whilst acknowledging pigmeat is not strictly defined as white meat in nutritional terms.

Table 7.1: UK average macronutrient levels as affected by consumption change scenarios

Scenario	Energy Supply (kcal/day)			Protein supply (g/day)	Fat supply (g/day)
	Livestock products	Non-livestock products	Total		
Baseline: Average UK consumption patterns (2004)	957	2334	3291	103	128
Scenario 1: 50% reduction in animal products	482	2843	3325	89	111
Scenario 2: Switch from ruminant (beef/sheep) to monogastric (pigs/poultry) products	956	2334	3290	105	120
Scenario 3: 50% reduction in monogastrics products (pigs/poultry)	843	2471	3314	97	125

Source: Cranfield University (2010), *The effect of changes in UK food consumption patterns on land requirements and greenhouse gas emissions.*
Notes: The consumption scenarios relate to the flows of food commodities entering the food system (e.g. production plus imports net of exports). The macronutrient levels are derived using integrated FAOSTAT data sets for the energy, protein and fat content of various food commodities supplied in the UK.

Box 7.4: Nutritional and public health impacts of consumption change

The consumption change scenarios analysed in the Cranfield study involve significant changes to average UK food consumption patterns that may appear unlikely or extreme today. However there are likely to be nutritional and public health benefits from reduced consumption of livestock products.

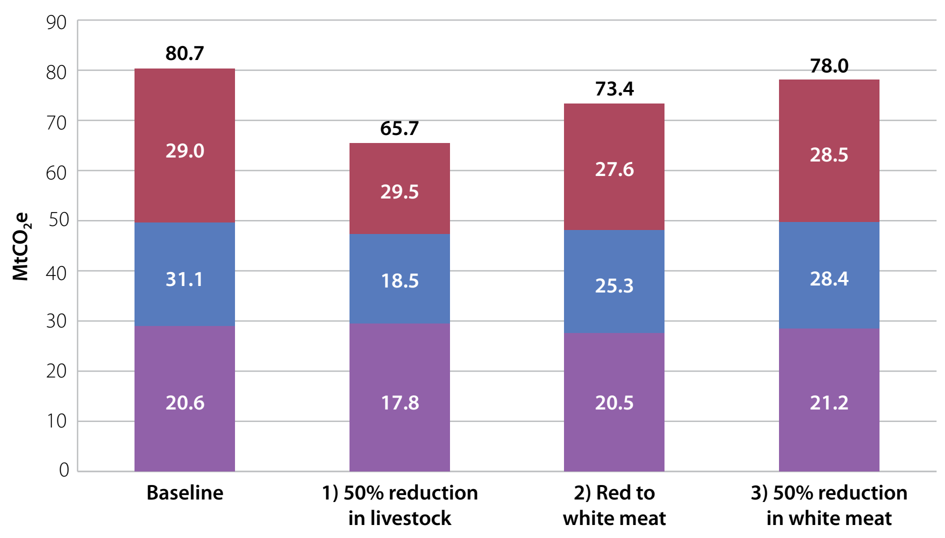
The Food Standards Agency's 'eatwell plate' depicts the types and proportions of foods recommended for a healthy and well-balanced diet. Meat, grouped with fish, beans and other alternatives, and dairy, is part of the recommended balanced diet (although it is recommended that individuals eat moderate amounts, choose lower fat versions, and use smaller quantities of meat in dishes). While there have been positive changes in UK diets over the last 15 years, reflecting a general move towards healthier consumption patterns, UK consumers are, on average, not consuming diets in line with dietary targets and guidelines:

- UK households consume animal protein in excess of what is recommended by reference nutrient intake levels, with animal protein comprising a larger share of intake. The UK Scientific Advisory Committee on Nutrition has recommended that individual consumption of red and processed meat should not rise and that high consumers should consider a reduction with the aim of reducing the risk of colorectal cancer.
- Average per capita fruit and vegetable consumption, while increasing, remains below the recommended level of five portions per day.
- Intake of saturated fat, of which excessive consumption is linked with cardio-vascular and coronary heart disease, exceeds recommendations in all age groups (foods high in saturated fat are often more processed, and thus may also have greater life-cycle emissions associated with refrigeration, heating and reheating, etc.).

Notwithstanding concerns about vulnerable people (e.g. children, elderly and lower socioeconomic groups), the above suggests that there are potential health, in addition to GHG emissions, benefits of dietary change away from livestock products and processed foods, which could be brought about by diets moving more in line with healthy eating guidelines. Further analysis of the nutritional impacts of low-carbon diets, particularly in consideration of impacts to micronutrients (e.g. iron) is required.

Source: Scientific Advisory Committee on Nutrition (2008), *The Nutritional Wellbeing of the British Population*; J. Kearney (2010), *Food consumption trends and drivers*, Phil. Trans. R. Soc.

Figure 7.10: Agriculture GHG emissions associated with current UK consumption patterns and consumption change scenarios



Source: Cranfield (2010), *The effect of changes in UK food consumption patterns on land requirements and greenhouse gas emissions.*
Note(s): Includes on-farm production emissions and upstream emissions associated with fertiliser production. Pre- and on-farm UK emissions have been separated.

The Cranfield analysis shows that all scenarios result in direct emission reductions, with more significant reductions in scenarios with reduced red meat and dairy consumption (Figure 7.10).

- **Scenario 1:** Direct emissions associated with UK agricultural production would fall by 13 $MtCO_2e$ within the UK, or by 40% from estimated current levels[9]; emissions arising abroad related to supporting UK consumption patterns would increase slightly by 2%.
- **Scenario 2:** UK emissions would fall by 6 $MtCO_2e$, or by 19%; emissions abroad would fall by 5%.
- **Scenario 3**: UK emissions would fall by 3 $MtCO_2e$, or by 9%; emissions abroad would fall by 2%.

Therefore on the basis of direct emissions impact, diet change has a potentially useful contribution to make to meeting carbon budgets. However, it is also necessary to account for land-use impacts before asserting that this is unambiguously the case.

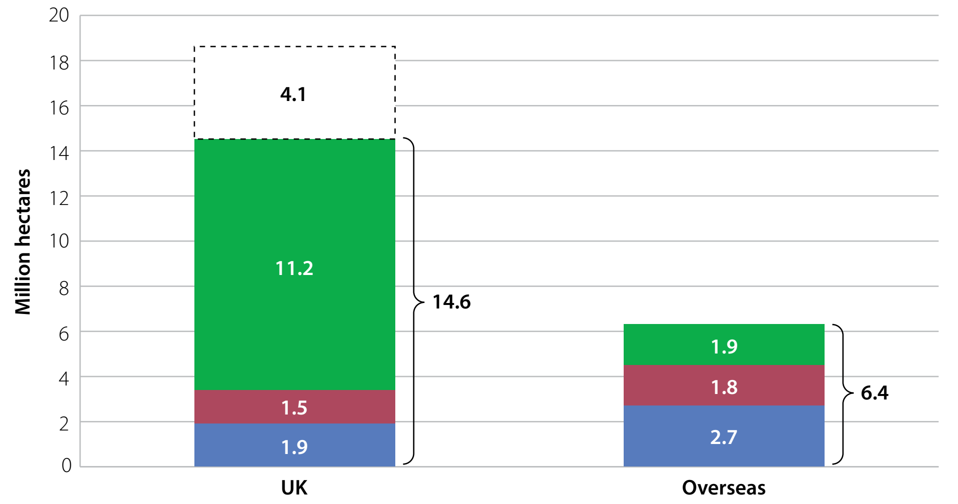
Land-use impacts

The study calculates that currently around 21 million hectares of land (14.6 million hectares within the UK and 6.4 million hectares overseas) are required to support current UK food consumption patterns, with the bulk of this land accounted for by livestock production (Figure 7.11):

- Grassland accounts for around 60% of total land used to support UK food consumption, with the vast majority of this (around 85%) in the UK. Approximately 40% of total grassland within the UK was determined to have some arable potential (i.e. suitable for purposes other than grazing).

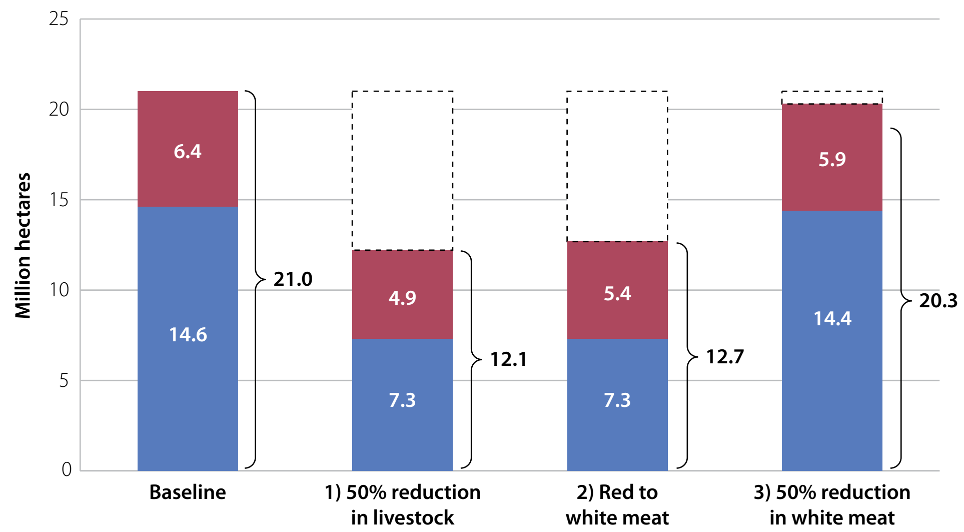
9 Cranfield's LCA model includes both upstream emissions associated with fertiliser production as well as on-farm emissions. Both emissions sources are presented in Figure 7.10.

Figure 7.11: Domestic and overseas agricultural land used to support current UK consumption patterns



Source: Cranfield (2010), *The effect of changes in UK food consumption patterns on land requirements and greenhouse gas emissions*; Defra (2010), *Agriculture in the United Kingdom*.
Note(s): Cranfield analysis found that 21 million ha of agricultural land (14.6 million within the UK and 6.4 million abroad) currently support UK diets.

Figure 7.12: Agricultural land requirements under consumption change scenarios



Source: Cranfield (2010), *The effect of changes in UK food consumption patterns on land requirements and greenhouse gas emissions.*

- Arable land used to grow feed for livestock accounts for around 16% of total land, with roughly equal amounts in the UK and overseas.
- Around 22% of total land is used for growing crops for human consumption, with the majority of this (around 60%) overseas.

In considering land-use impacts, it is important to recognise that sheep and cows are inefficient processors of food compared to chickens and pigs. Therefore reduced consumption of red meat and substitution for more white meat (and crops for consumption by humans) is likely to free up land. This is borne out in the Cranfield analysis, which suggests that diet change could free up to around 40% of land used (both domestically and overseas) to support current UK food consumption (Figure 7.12):

- **Scenario 1:** UK land requirements fall by 50% and overseas land requirements by 24%
- **Scenario 2:** UK land requirements fall by 50% and overseas land requirements by 15%[10]
- **Scenario 3:** UK land requirements do not change but overseas land requirements fall by 8%

The potential emissions impact of *changing* land use within UK farming to support changed diets (e.g. release of soil carbon from converting land) depends on how freed-up land is used. For example, depending on its quality, land released from growth of crops for animals can be used to grow crops for humans with limited emissions impact.

The emissions impact of *converting* land released from the scenarios again depends on how this land is used. Scenario 1, for example, estimates that 7.3 million hectares could be freed up within the UK of which 0.3 million hectares is arable land and 2.4 million hectares is grassland with some arable potential. Freed-up land could be used for:

- **Extensification of livestock production:** Released grassland could be used more extensively for beef, sheep, and dairy production by using clover to fix nitrogen rather than synthetic fertilisers. Extensification could result in an additional saving of up to 1.7 $MtCO_2e$ through fertiliser reductions.[11] Under this management option, some of the positive aspects of livestock could be maintained (e.g. use of crop residues and food waste as feed, use of lowest quality land, and reduced stocking densities continuing to provide ecosystem services at desired levels).
- **Increasing food production:** All potentially tillable land could remain cultivated or be converted to arable land to increase food production for export, which may be required given increasing global population. Similarly all grassland could continue in animal production for export. Agriculture production emissions would increase as would land-use change emissions associated with conversion of freed-up land to arable land.
- **Bioenergy production:** Released arable land could be used for increasing the growth of feedstock for bioenergy.
- **Forestry:** Agriculture land could be converted to forestry, managed for sequestering carbon or for substituting fossil fuel use in other sectors (e.g. biomass and building materials).
- **Other purposes**, such as house-building.

Some of these purposes potentially generate wider environmental and biodiversity benefits as well as economic benefits. Other purposes (e.g. house-building) could, depending upon the specific nature of the land, impose additional environmental costs. In reality, land use allocation and decisions are determined by numerous factors, including economic forces,

10 Pig and poultry production depends on feed crops, which compete directly with land used to grow crops for human consumption. While under this scenario the overall release of arable quality grassland exceeds the increased land required to grow feed crops for pigs/poultry, it is important to note that UK demand for overseas land to grow feed crops would increase relative to baseline levels.

11 Emissions savings associated with upstream fertiliser production and on-farm N_2O emissions.

regulatory regimes and by the location and underlying characteristics and qualities of the land in question.

The recent Foresight Land Use Futures Project[12] finds that current UK policies do not take into account the ecosystem services provided by land and suggests a set of interventions to address this. While not explicitly considering the potential role and consequences of dietary change on land use, the report concludes that policies are needed to make better use of the land across the UK for climate change mitigation and for supporting the transition to a low-carbon economy (as well as managing the impacts of changing climate, Box 7.5).

Summary of emissions impacts through changed consumption

The Cranfield analysis shows that there is clear scope for emissions reduction due to changed consumption, and net of any emissions due to land-use change. For example, under Scenario 1, UK and overseas emissions associated with agricultural production to support UK consumption could be reduced by around 20% (and agricultural land used to support UK consumption could be reduced by 40%. This is in contrast to our previous cautious approach, where we suggested that emissions reduction from consumption change may be limited due to impacts of land-use change.

We do not explicitly reflect the potentially significant opportunity for direct and land-use related abatement from diet change into our agriculture emissions scenarios (Section 6 below). However we recommend that the Government should consider encouraging a less emissions intensive diet alongside other motivators (i.e. nutrition benefits). We consider policies to encourage dietary change in Section 5.

Box 7.5: Impacts of climate change on UK agriculture

The impact of climate change on UK agriculture is likely to be mixed. There will be increased yields of some crops and the possibility to grow new crops, however there will be risks from new pests and diseases, water shortages and reduced soil quality.

Some of these impacts may be apparent by the 2020s; however the natural variability of UK climate from year to year may be just as important as the long-term warming trend from greenhouse gas emissions over this timescale. For example, UKCP09 projections suggest that by the 2020s, summer mean temperature could increase between 0.5°C and 2.5°C and summer precipitation could change between -25% and +10%, while recent climate has shown annual variations of a similar magnitude. Beyond the 2020s, however, we are committed to continued (and potentially much greater) long-term change.

Source: Met Office Hadley Centre observation datasets, http://hadobs.metoffice.com/hadcet/.

12 The Government Office for Science (2010), *Foresight Land Use Futures Project Final Project Report*.

4. The role of land use, land-use change and forestry (LULUCF)

Emissions from LULUCF activities are made up almost entirely of emissions from the conversion of land to cropland and settlements, which are largely offset by land converted to forestry and grassland.

- CO_2 is released from soils and biomass due to land being converted to cropland, tillage practices and from forests following harvesting of wood.
- Conversely, 'sink' emissions arise from converting land to pasture or forestry from other uses. This helps to remove CO_2 from the atmosphere through increases in forest and organic matter in soils, and avoidance of degradation of these stores.

Emissions trends and projections

On a net basis, the LULUCF sector absorbed 2 $MtCO_2$ in 2008 (Figure 7.13). Net emissions have moved from increasing marginally, to reducing marginally the UK's total emissions between 1990 and 2008. From 2013 onwards, LULUCF is forecast to revert to a net emitter due to a decline in the historical planting rate.[13] LULUCF emissions projections to 2030 are not currently available (Figure 7.14).

In our 2008 report, we suggested that there is emissions reduction potentially available for this sector. We recommended that the UK Government and the devolved administrations should consider how the policy framework might be developed to unlock this potential and/or provide additional biomass supply as part of a broader forestry and land use strategy.

LULUCF abatement options – forestry

There are two key options for emissions reduction through forestry:

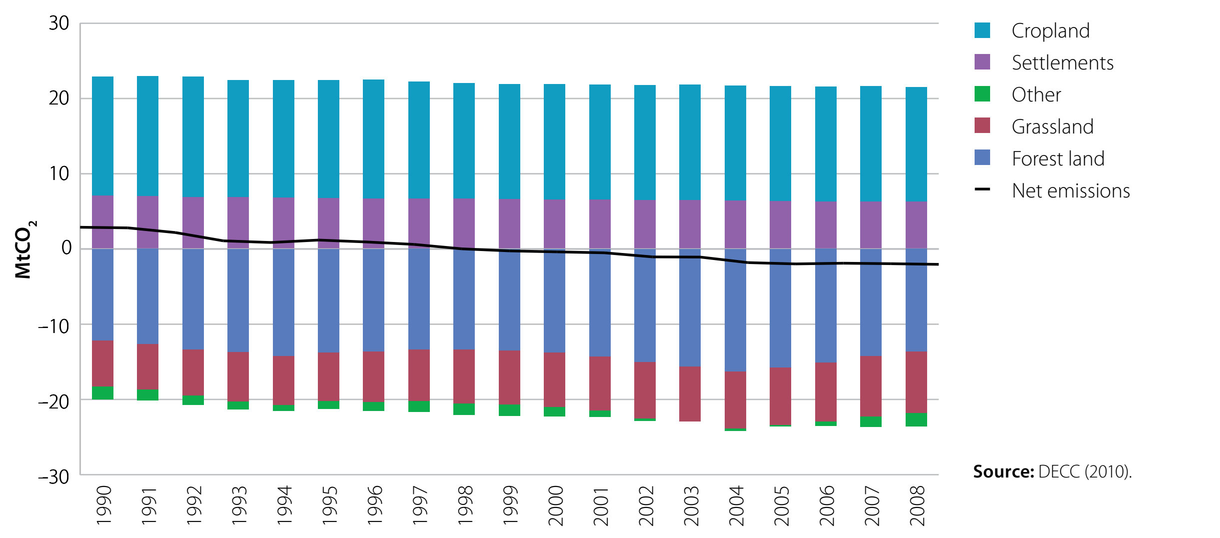
- Sequestration, whereby more trees are planted, removing and storing carbon from the atmosphere; this is a one-off measure, offering scope for reducing emissions until a forest reaches saturation point, beyond which no further carbon is absorbed.
- Substitution, such that biomass produced in the forestry sector can substitute for fossil fuels in other sectors (e.g. biomass for heat and energy and building materials); this allows ongoing emission reductions given that biomass crops do not reach saturation point.

Analysis by the Forestry Commission suggests that there is significant scope for emissions reduction through planting more trees (e.g. up to 3 $MtCO_2e$ in 2030, and 5 $MtCO_2$ in 2050) (Box 7.6). This is reflected in planned tree planting programmes in Scotland and Wales and which we reflect in our emissions scenarios.

We also note scope for increasing biomass production in the UK, which we include in our scenarios for power, transport, and buildings and industry emissions. Our scenarios for transport, heat and power in the 2020s assume around 300 TWh of primary energy use. Analysis by E4tech[14] suggests around 250 TWh of resource could be produced in the UK,

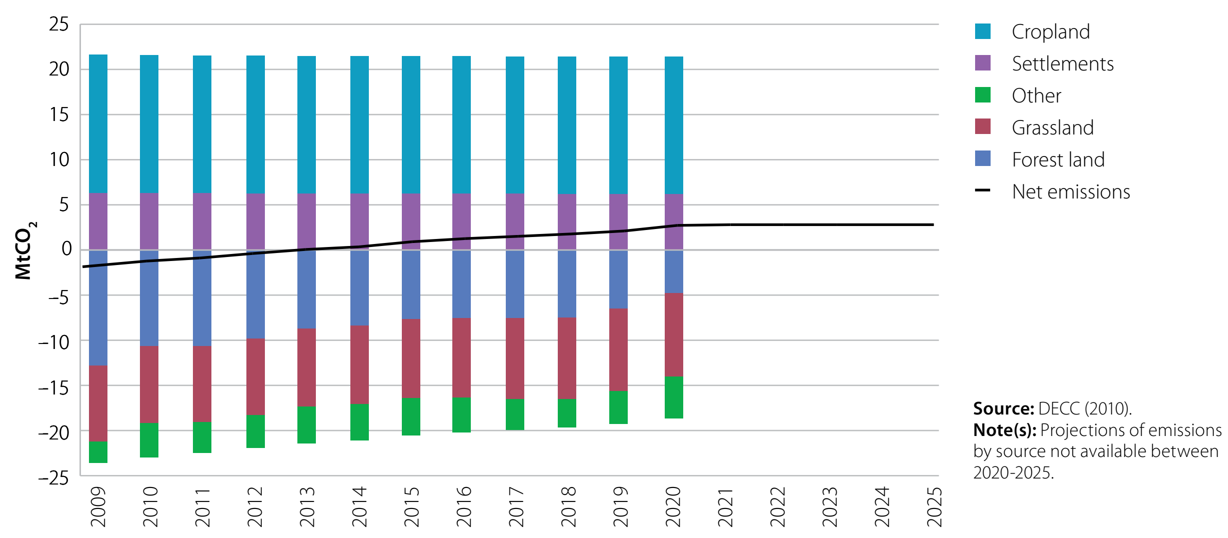
13 This may also reflect, in part, the cyclical nature of emissions from forestry and the method by which emissions are reported in the LULUCF inventory.
14 E4tech for DECC (2009), *Biomass supply curves for the UK.*

Figure 7.13: LULUCF emissions (1990-2008)



Source: DECC (2010).

Figure 7.14: LULUCF emissions projections (2008-2025)



Source: DECC (2010).
Note(s): Projections of emissions by source not available between 2020-2025.

mainly from wastes, manures, and residues, but including up to 85 TWh from energy crops and forestry, with an implied land take of approximately 1.2 million hectares. We will consider further scope for increasing UK biomass production in the context of our Bioenergy Review to be published at the end of 2011.

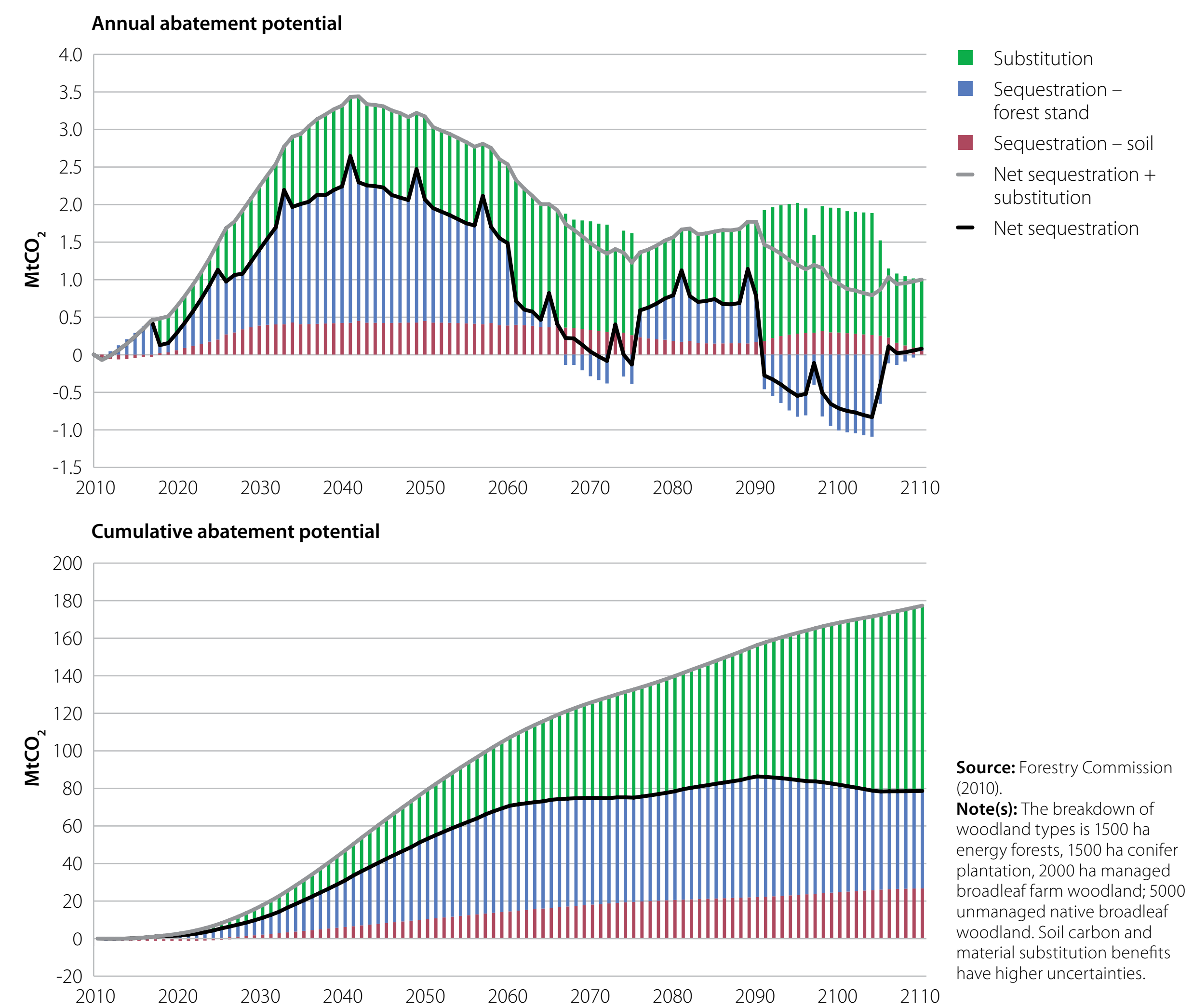
Box 7.6: Forestry Commission Read Report on Forestry

The Forestry Commission's Read Report on Forestry (November 2009) considers various forestry mitigation options and concludes that afforestation, or greater woodland creation, offers the greatest abatement opportunities in the medium to long term. The report examines two illustrative scenarios for a 15-year woodland creation programme that could deliver additional abatement potential through sequestration of carbon in soils and forest biomass and substitution for fossil fuels occurring in other sectors at a cost less than £70/tCO_2e:

- A 10,000 hectare per year woodland creation programme could cumulatively remove 53 MtCO_2 from the atmosphere through sequestration by 2050, rising to 80 MtCO_2 if biomass products were used to displace fossil fuels. This would result in an annual abatement level of 1 MtCO_2 being absorbed in 2030 and 2 MtCO_2 in 2050 (Figure B7.6).
- A 25,000 hectare per year programme could cumulatively remove up to 130 MtCO_2 through sequestration and 200 MtCO_2 in total including substitution by 2050. This would result in an annual abatement level of 3 MtCO_2 being absorbed in 2030 and 5 MtCO_2 in 2050.

The land requirements implied in the above scenarios is 150,000 – 375,000 hectares (at present UK forests encompass 2.8 million hectares). The report notes a range of additional unvalued benefits from forestry, with potential benefits in helping the UK adapt to climate change.

Figure B7.6: Estimated emissions abatement potential from a 15-year 10,000 ha woodland creation programme



Source: Forestry Commission (2010).
Note(s): The breakdown of woodland types is 1500 ha energy forests, 1500 ha conifer plantation, 2000 ha managed broadleaf farm woodland; 5000 unmanaged native broadleaf woodland. Soil carbon and material substitution benefits have higher uncertainties.

LULUCF abatement options – agriculture and other land management practices

Various land management practices can sequester carbon although it is not clear whether such practices result in additional abatement and thus whether they offer true additional mitigation potential[15]:

- Crop residues, manures and biosolids:
  - Application of crop residues, manures and biosolids can retain soil carbon, but are generally applied to land under baseline conditions and as such the additional mitigation benefits are unclear.
  - However, incorporating organic wastes such as paper crumble can be considered genuine additional carbon storage against baseline conditions.
- Reduced tillage: There is uncertainty regarding the effect of reduced tillage of agricultural soils on net GHG emissions (i.e. this practice would reduce the release of stored carbon but can increase the rate of oxidation of methane from the atmosphere).
- Biochar:
  - This is produced through the partial combustion of biomass (e.g. biofuels crops, straw or wastes) in limited oxygen.
  - The potential benefits of applying biochar to soils include a permanent increase in soil carbon, stabilisation of other soil carbon, suppression of other GHGs (e.g. N_2O emissions), and enhanced fertiliser-use efficiency.
  - These effects have yet to be widely demonstrated in the UK context although recent field-scale trials have indicated modest benefits.
  - There are potential risks associated with biochar production and use, including life-cycle emissions arising from combustion, land-use implications from sourcing biomass to produce biochar, and damage to soils.
- On-farm woodland planting: Trees in field boundaries, for example, can provide additional abatement, if permanent, or if managed for biomass.

Given uncertainties, we do not include any emissions reduction from these measures in our emissions scenarios, but will return to some of the issues above in our forthcoming Bioenergy Review.

15 Food Climate Research Network, Soil carbon sequestration workshop, January 2010.

LULUCF abatement options – peat restoration and reducing horticultural use of peat

Peat soils are organic soils that have accumulated in waterlogged conditions over thousands of years, and currently store around 5,500 Mt of carbon in the UK. When in good condition, peat soils sequester carbon from the atmosphere, but when degraded or damaged they can become net carbon sources, as well as release other greenhouse gases (methane and nitrous oxide). Carbon release from peat is estimated to have been at least 1.5 $MtCO_2$ in 2008, and possibly significantly higher (Box 7.7).

There is an opportunity to reduce peat emissions in future through less use of peat in horticulture (and therefore reduced peat extraction), and the restoration of degraded and damaged peatlands (i.e. raising the water table and re-establishing peat-forming vegetation).

However, the scale of quantifiable abatement potential in this area is uncertain, and emission reductions would not be well captured in the UK emissions inventory. Therefore our approach is to highlight the need for further work in order to better understand the scale of the opportunity, and to recommend that inventory measurement of peat emissions is revisited in order to accurately reflect emissions and emission reductions, so that any future progress in this area can contribute to meeting carbon budgets.

Box 7.7: Emissions and abatement from peat soils

Of the 10,000 Mt of carbon stored in UK soils, 55% are locked up in peat lands. UK peat soils have been degraded over time due to intensive agricultural practices (e.g. drainage, burning, over-grazing and cultivation), extraction for horticultural purposes and industrial emissions. There is some scientific uncertainty about current emissions arising from peat soils although it is generally felt that the LULUCF inventory underestimates emissions from peat. According to the UK inventory, emissions associated with peat soils were equivalent to 1.4 $MtCO_2$ in 2008:

- 1.1 $MtCO_2$ from historic drainage of lowland fen
- 0.3 $MtCO_2$ from extraction for horticulture use

Other analysis suggests that the figure is much higher. A recent study by Natural England finds that the majority (~75%) of England's peatlands are in a degraded condition and as such total emissions are likely to be of the order of 3 $MtCO_2$. Emissions arising from the drainage of peat lands located in the UK uplands are not covered in the LULUCF inventory because of lack of data.

In addition to mitigation benefits, peat restoration may also be an important adaptation measure, as the impacts of climate change may accelerate carbon losses from degraded peatlands in the future (through changes in soil moisture, water regimes and warmer temperatures), while providing a range of co-benefits, including improved water quality, reduced downstream flood risk and enhanced biodiversity.

Source: Natural England (2010), *England's peatlands: Carbon storage and greenhouse gases.*

5. Policies to support agriculture and LULUCF emissions reduction

Many of the options to reduce emissions from agriculture and LULUCF in the longer term would require marked departures from current policies. Given the long lead-time to 2030 there should be scope for technological advancement and the development of stronger policies to support behavioural change to reduce agricultural emissions. For LULUCF, long planning horizons mean that early action is required to deliver abatement potential.

Policies to support reduced emissions from soils and livestock

We have set out our assessment of policies to support greater uptake of soils and livestock measures in our 2010 Progress Report to Parliament, and we provide a summary here for completeness.

We have considered five policy options:

- **Voluntary agreements:** agreements between industry and the government to reduce emissions. Voluntary agreements are often backed up by the threat of legally binding rules or stringent monitoring and enforcement systems.
- **Information provision:** providing better information and advice to farmers on best practice to reduce GHG emissions, and developing a better understanding of emissions reduction opportunities by getting better information about the baseline state of farming practices.
- **Grants, subsidies, charges, levies and taxes:** encompassing a wide mix of incentives and penalties to encourage low-carbon farming, implemented at either the EU or UK level. For example, the EU Common Agricultural Policy, which is up for revision in 2013, could be reformed to link subsidies and incentives more closely to environmental objectives, including climate change mitigation. In addition, there is the possibility of an EU-wide carbon tax which could be extended to agriculture. Any UK charges, levies or taxes would have to address concerns about competitiveness impacts (e.g. through taxing at point of sale rather than upstream).
- **Cap and trade scheme:** placing a price on GHG emissions from agriculture and providing incentives to encourage farmers to find efficient ways to lower their emissions. To the extent that there are competitiveness concerns these could be addressed through issuing free allowances or recycling revenues.
- **Direct regulation:** introducing emissions standards or limits from agricultural practice or restricting/requiring certain farming practice.

The industry-led approach should strengthen incentives to action. However, stronger levers may be required, particularly to deliver more expensive measures.

In its response to our 2010 Progress Report the Government acknowledged that the industry-led approach will be supported by other policies, such as the EU Nitrates Directive and the UK Nitrate Action Programme or CAP reform, which could generate greenhouse gas emission benefits. The Government will need to consider whether further policy strengthening is required, particularly to encourage uptake of more expensive measures. It has committed to undertake a review in 2012 of progress made under the GHG Action Plan, which should consider the range of options for Government intervention to supplement industry action, in the event that the current voluntary approach does not deliver in full. This should include action at EU level since changes to the CAP provide a potential way to minimise any competitiveness impacts on UK agriculture.

We further note the potential role of environmental benchmarking, or comparing industry performance against good practices to promote efficiency improvements. Benchmarking is proving effective in other sectors, and is a big component of the Carbon Reduction Commitment where the use of performance league tables and mandatory reporting (ranking of performance in published tables) could provide reputational incentives to organisations to improve energy efficiency. Some food retailers are at present driving efficiency improvements in farming across energy, fertiliser and feed inputs through use of benchmarking tools. While not the full solution to promoting greater uptake of mitigation measures, benchmarking is likely to be effective for unlocking cost-saving measures.

Policies to encourage food waste reduction

Policies to reduce food waste include raising consumer awareness and working with the food industry to reduce food waste in the supply chain. WRAP has found initial success in reducing household waste through information campaigns and changes in retail environments (e.g. through focus on better storage and pack/portion sizes). Going forward, there is scope for further engagement with the food industry to reduce food waste (e.g. through improved demand forecasting and changes to contractual arrangements).

Policies to encourage changed diet

As for supply-side abatement, there is a range of potential policy options to encourage diet change, from awareness-raising to providing financial incentives:

- **Awareness-raising.** Progress has been made on developing guidelines for determining the carbon footprint of goods and services including food, although there are complexities relating to trade-offs between objectives (e.g. carbon and wider environmental, or animal welfare). The effectiveness of awareness-raising will depend on the extent to which people care about their carbon footprint, and whether this translates into action. Evidence suggests a likely limited response based on current attitudes and behaviours (Box 7.8); elsewhere in the food sector, evidence suggests that there has been some, but not comprehensive, response to health labelling and promotion of healthy foods.
- **Retail and supply chain leadership and/or agreements.** Retailers are examining opportunities to reducing emissions embedded in their products and the role of labelling in promoting alternatives to carbon intensive food. Given that UK grocery market share is concentrated amongst a small number of retail players, there should be scope for industry and government to work together to promote low-carbon food.
- **Choice editing.** Government and/or industry could influence the choices made by consumers by offering products with lower carbon intensities (e.g. smaller portion sizes, ready-made meals and sandwiches with lower meat content).
- **Introducing a carbon tax on food.** This would reflect the relative carbon content of different products and therefore provide a strong signal about full costs (resource and carbon) for consumer decisions (Box 7.9). It could be introduced at UK or EU levels. If a carbon price were introduced, risks relating to other objectives (e.g. affordability of basic foodstuffs, availability of nutritional substitutes, impacts on vulnerable groups) would need to be addressed. Emissions leakage could be avoided if levies were placed on goods at the point of sale. Carbon taxes on food could require retailers to know the footprint of all suppliers, which would require standardisation of footprinting methodologies.

From a general perspective, and based on experience in other sectors (e.g. uptake of simple energy efficiency measures) awareness-raising, whilst useful as a complement to other levers, is unlikely to result in deep cuts alone. Retail and supply chain leadership agreements could be useful (e.g. as in the case of phasing out incandescent light bulbs), but have again had limited impact in reducing emissions more generally (e.g. as regards purchase of efficient appliances). Therefore we recommend that the full range of measures, from awareness-raising to introduction of a carbon price for food, are seriously considered by Government in order to deliver the significant emissions reduction potential that we have identified on a pathway to 2050.

Box 7.8: Role of carbon labelling in influencing consumer behaviour

A number of UK food companies and retailers have in recent years chosen to voluntarily carbon label their own branded products. Some have worked with the Carbon Trust, using standardised methodologies, to calculate the carbon footprints of selected products, and have committed to reducing emissions over two years. While the primary role of labelling to date has been to provide incentives to companies to document and manage their supply chain emissions, researchers have examined the likely impact of carbon labelling on consumer behaviour, which reveals the following:

- Few people think about the environment when shopping
- Most shoppers take little notice of nutrition labels and would be no more likely to read carbon labels
- Many would not be willing to pay a premium for a carbon-labelled product, although labelling may be effective if the lower-carbon product is cheaper than a substitute
- Those who try to base purchasing decisions on environmental and ethical factors have limited understanding of how shopping relates to carbon emissions
- Many are puzzled by the use of grams (e.g. gCO_2/pack) as a measure of emissions
- People question the technical reliability of carbon labelling and some are cynical about the motives of companies that provide labelling

If carbon labelling is adopted more widely, surveyed individuals have recommended that approaches should be standardised across the food industry and should function to remove the most emissions-intensive products from shelves. Shoppers should be also be provided with better context as to what the information means and should be directed towards lower-carbon alternatives.

Source: Tyndall Centre Manchester (2009), *Carbon Labelling: Public Perceptions of the Debate*, Report to the Sustainable Consumption Institute, University of Manchester.

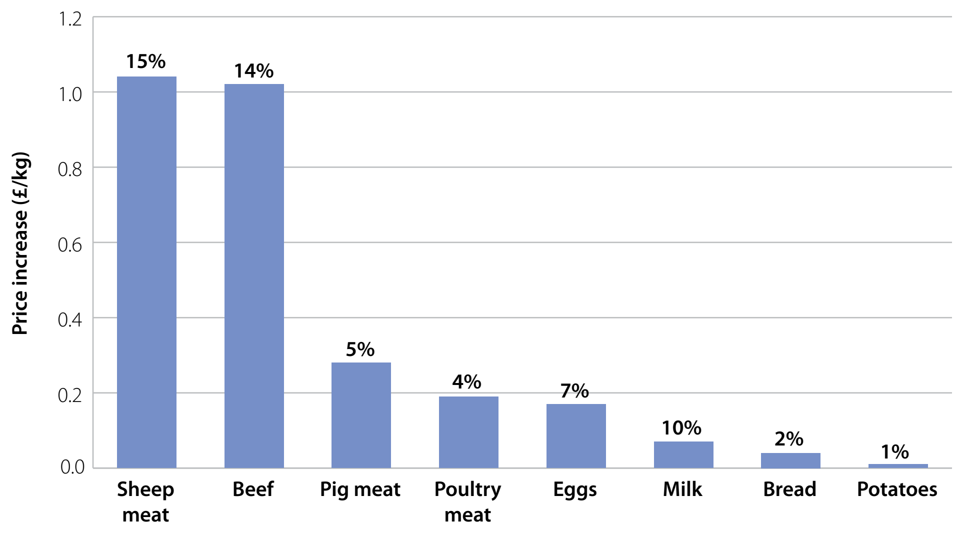
Box 7.9: The GHG impact of introducing a carbon tax on food

Changing diets is a controversial issue but one that could be effective at reducing the emissions and land-use impact of agriculture. Taxes have been effective in other sectors to change consumer behaviour (e.g. fuel duties have been shown to be powerful levers to affect choice of car and fuel use) and may also be an efficient instrument to reduce agricultural emissions. We consider below the emissions impact of introducing a carbon consumption tax on GHG intensive food commodities, using the following data sources:

- Life-cycle assessment data on the emissions intensities of food products (Cranfield University LCA model – Figure 7.9)
- Published demand price elasticity data for key food products (Defra (2000), *National Food Survey*)
- Typical UK weekly food basket and expenditures (Pretty et al., 2005)

The possible impact of a carbon price of £70/tCO_2e in 2030 on the price of key food commodities is summarised in Figure B7.9 below.

Figure B7.9: Potential increase in food prices as a result of a carbon tax, 2030 (based on average emissions per kg of food)



Source: Cranfield LCA models (2010); Pretty et al (2005), *Farm costs and food miles: an assessment of the full cost of the UK weekly food basket;* Defra (2000), *National Food Survey.*

A static high-level assessment suggests that a carbon price of £70/tCO_2e in 2030 could result in a direct emissions reduction of around 1.3 MtCO_2e (or a 6% reduction in emissions from the basket of goods considered). We have not conducted in-depth analysis to calculate the impact of substitution towards other food products, given a lack of specific data on cross-price elasticities. However the relatively lower emissions intensities of substitute products (e.g. cereals and vegetables) suggests an overall net reduction in GHG emissions is possible:

- A recent study (Wirsenius, Hedenus and Mohlin, 2009) finds a carbon tax of €60/tCO_2 on animal food products could reduce EU agricultural emissions by 7%, even while accounting for the emissions impact of substitute products.
- The Cranfield analysis (Section 3 above) finds that consumption change away from livestock products and towards plant-based substitutes results in a net reduction in GHG emissions (even while accounting for land-use change effects).

The above calculations are presented for illustrative purposes but suggest that carbon taxes on food could be an effective lever to curb emissions from agriculture in the long term.

Source: J.N. Pretty et al. (2005), *Farm costs and food miles: An assessment of the full cost of the UK weekly food basket*; Defra National Food Survey (2000); Cranfield LCA model (2010), Defra Research Project ISO0205; Wirsenius, Hedenus and Mohlin (in press), *Greenhouse gas taxes on animal food products: Rationale, tax scheme and climate mitigation effects, Climatic Change.*

Policies to encourage afforestation

Given long lead-times, encouraging abatement from afforestation will require a planned rather than reactive approach. In addition to existing regulatory powers, including the issuance of felling licenses and planning consents, policy options to support such an approach include:

- Encouraging private financing (e.g. through recognition of forestry projects in corporate reporting guidelines).
- Fiscal incentives, such as grants or tax incentives to encourage businesses or individuals to plant more trees.
- Changes to building regulations which encourage the use of wood in construction and which indirectly increase the demand for forestry products, some of which may come from UK forests.
- Research to reduce the future risks and to manage existing outbreaks of pests and diseases, including the development of appropriate and effective interception and monitoring systems to prevent the introduction of pests and pathogens.

6. Scenarios for agriculture and LULUCF to 2030

We now bring together our assessment of opportunities to reduce agriculture and LULUCF emissions:

- These reflect soils and livestock measures identified by the Scottish Agricultural College in the MACC analysis, excluding measures where SAC suggested there was a lower degree of confidence given remaining uncertainty.
- They include scope for emissions reduction from LULUCF.
- We do not explicitly include abatement from reducing on-farm CO_2 emissions, more radical supply-side options, avoided food waste, and rebalancing of diet; we regard these as options for additional abatement, or substitutes for other abatement in our scenarios should this not ensue.

Our scenarios result in a range of agriculture emissions from 38 to 41 MtCO_2e in 2030 (i.e. 21% to 15% below current levels – Figure 7.15).

- Our Low Abatement scenario includes:
  - All the measures in the pessimistic MACC, excluding measures where there is a lower level of confidence. This delivers 8.3 MtCO_2e (or 3.8 MtCO_2e in additional abatement relative to the 4.5 MtCO_2e identified in the LCTP).
  - Agriculture emissions in this scenario are 41.3 MtCO_2e in 2030.
  - Afforestation, which could deliver at least 1 MtCO_2.[16]
- Our Medium Abatement scenario includes:

16 We include abatement potential from LULUCF in our scenarios, but account for potential emissions reduction from afforestation in our economy-wide CO_2 scenarios (Chapter 3).

– The centre of the range for cost-effective emissions reductions provided by the Low and High Abatement scenarios. This delivers 9.9 $MtCO_2e$ (or 5.4 $MtCO_2e$ in additional abatement from agriculture during the 2020s); the vast majority of measures are available at negative cost (i.e. can save money for farmers) and all measures cost less than £70/tCO_2e.

– Agriculture emissions in this scenario are 39.7 $MtCO_2e$ in 2030.

– Afforestation, which could deliver at least 1 $MtCO_2e$.

- Our High Abatement scenario includes:

– All measures in the optimistic MACC, excluding all low confidence measures. This delivers 11.6 $MtCO_2e$ (or 7.1 $MtCO_2e$ in additional abatement).

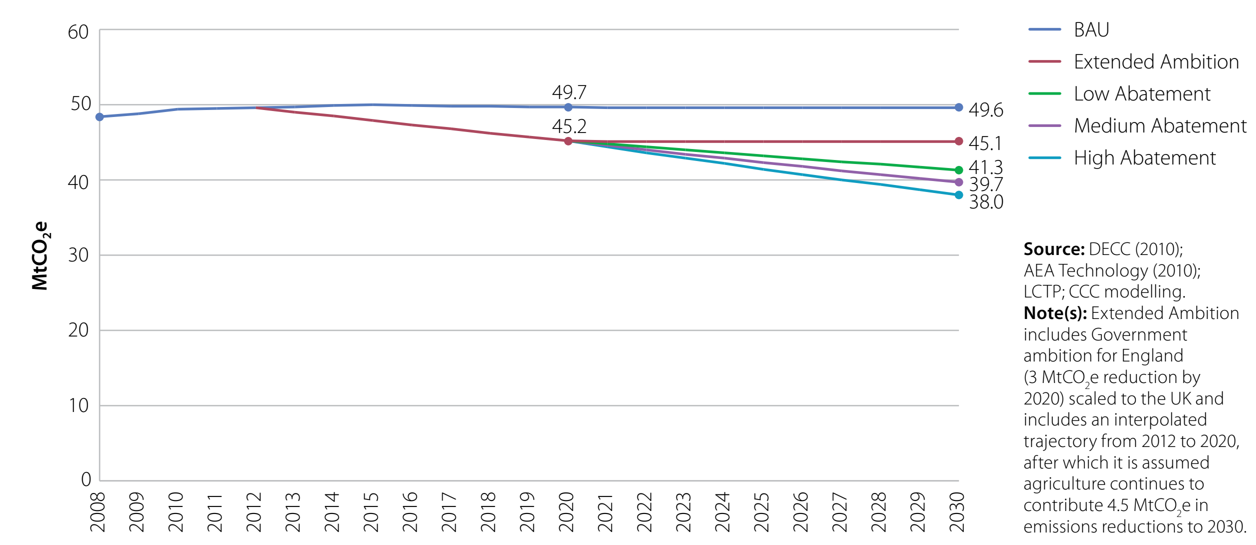
– Agriculture emissions in this scenario are 38.0 $MtCO_2e$ in 2030.

– Afforestation, which could deliver up to 3 $MtCO_2e$.

We reflect these scenarios in our Low, Medium and High Abatement economy-wide scenarios in chapter 3.

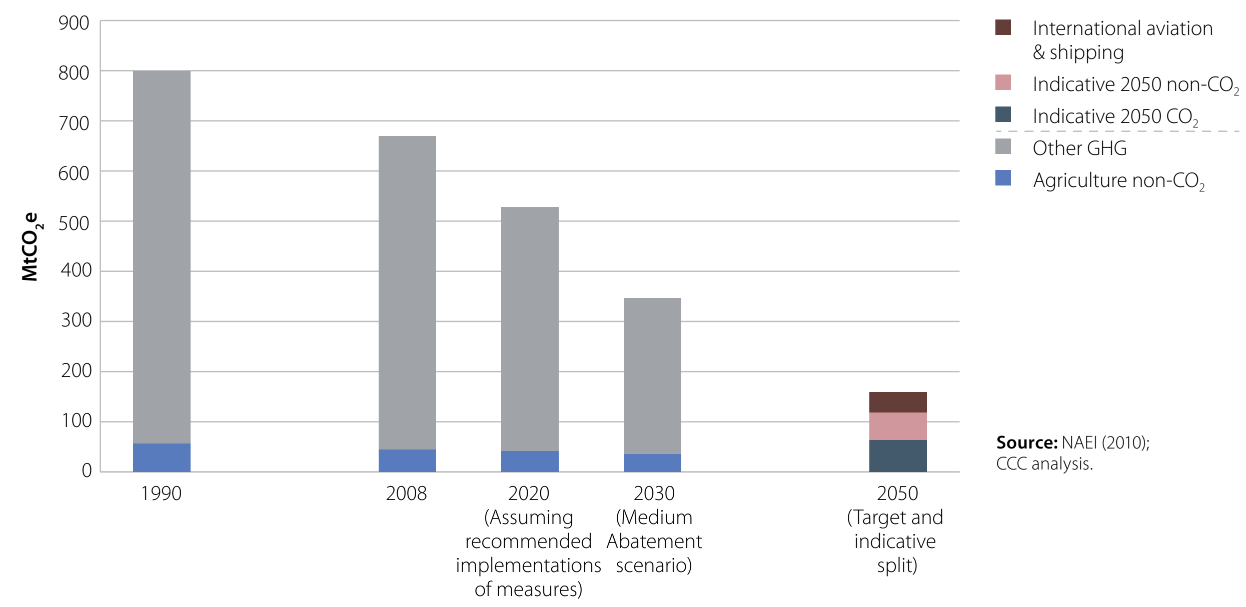
We provide the above scenarios as indicative trajectories for agriculture but recognise the high level of uncertainty over future emissions, both as regards business as usual emissions and the emissions impact of abatement measures. As uncertainties are resolved over time, we will revisit abatement potential in agriculture in the context of its contribution to the fourth carbon budget.

Figure 7.15: Abatement potential under agriculture scenarios (2008-2030)



Source: DECC (2010); AEA Technology (2010); LCTP; CCC modelling.
Note(s): Extended Ambition includes Government ambition for England (3 $MtCO_2e$ reduction by 2020) scaled to the UK and includes an interpolated trajectory from 2012 to 2020, after which it is assumed agriculture continues to contribute 4.5 $MtCO_2e$ in emissions reductions to 2030.

Figure 7.16: Agriculture sector emissions in the context of UK greenhouse gas emissions (1990-2030, 2050)



Source: NAEI (2010); CCC analysis.

Path from 2030 to 2050

Under the Medium Abatement scenario, agricultural emissions are 40 $MtCO_2e$ in 2030. Abatement options for further reductions from agriculture after 2030 include:

- Plant breeding and alternative approaches to cropping
- Further improvements to livestock feed efficiency through diets and/or use of additives and vaccinations to reduce enteric methane emissions
- Further improvements to livestock efficiency through breeding and health measures
- Improving soil management and carbon
- Precision farming
- Nitrification inhibitors
- Demand-side measures (e.g. reduced food waste and consumption change)

Given the very clear need for further agriculture emission reductions beyond 2030 on the path to 2050, these options should be explored further with research and development support provided as required. Failure to further reduce agriculture emissions would risk making the 2050 target unattainable. (Figure 7.16)

7. Implications for the first three budget periods

To deliver emission reductions from agriculture outlined in this chapter, there are a number of implications for action in the first three budgets:

- Implement measures to 2020 as targeted by the Government and industry in the GHG Action Plan
- Resolve uncertainties in agriculture, including:
  - The measurement of emissions via an improved Agriculture GHG Inventory
  - Estimated abatement potential from soils and livestock measures, both as regards the state of current farming practices and the emissions impact of measures
- Explore abatement potential from more radical options through research and technological development
- Consider the full range of policies to support further emission reductions, including:
  - For supply-side abatement, ranging from voluntary to EU-level to other approaches
  - For demand-side abatement (e.g. reducing waste along food chain and encouraging rebalancing of diets), ranging from information-provision to taxes

For LULUCF activities to contribute to emissions reduction in the fourth budget, the implications for action in the first three budgets are as follows:

- Resolve uncertainties in LULUCF activities including:
  - Afforestation: improve understanding and monitoring of soil carbon emissions and emissions savings from fossil fuel substitution
  - Agricultural land management practices: identify soil carbon sequestration practices that offer true additional mitigation potential
  - Peat soils: bring evidence together to understand the scale of the opportunity around peatland restoration/management
- Consider policies to support LULUCF activities, including the role of economic incentives, grants, and markets to promote private investment in woodland creation.

8. Key findings

Agricultural emissions currently 8% of the UK total.

8%

If left unabated beyond 2020, agriculture will account for 28% of permitted 2050 emissions.

28%

Possible to reduce 2030 emissions by 18% from current levels.

18%

Agricultural abatement potential in 2020s.

5.0 $MtCO_2e$

Share of abatement potential that also increases farmers profits.

70%

Potential agricultural GHG emissions in 2030.

40 $MtCO_2e$

Abatement potential in 2030 from forestry, if planting starts today.

1 $MtCO_2e$