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A Scientific Review of the Impact of UK Ruminant Livestock on Greenhouse Gas Emissions

Alan Hopkins and Matt Lobley

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A Report for the NFU

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Introduction and background

Climate change is a subject of global environmental concern. The UK has seen a progressive strengthening of political resolve to address the problems associated with emissions of greenhouse gases (GHGs), principally carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Although agriculture globally, and ruminant livestock production in particular, is a net contributor to GHG emissions, generalizations about impacts on climate change often fail to distinguish between different systems of production, advances in technology, and the role of extensive grazing lands in contributing to ecological services and food production in situations where other forms of farming are impractical.

Against this background, the overall aim of this review was therefore to conduct an independent desk-based analysis of the scientific evidence of the impacts of the UK's forage-based livestock sectors (beef, sheep and dairy production) on emissions of the three main GHGs: carbon dioxide, methane and nitrous oxide.

The study has been confined to impacts up to the 'farm gate' and it has examined and reviewed the evidence to answer the following questions:

- How do GHG emissions from UK beef, sheep and dairy production compare with the situation in other countries/regions, such as South America and NZ, and selected EU countries.
- Within the UK how do various intensive and extensive systems of dairy, beef cattle and sheep production compare in terms of their respective emissions balances?
- What are the research findings on measures that can or have been adopted to reduce net GHG emissions, and what is the potential for further adoption by the industry in the UK?
- What are the likely future impacts of climate change on the UK ruminant livestock industry, particularly in comparison with its competitors?

Main findings

Summary

- Total UK agricultural GHG emissions have decreased by 17% since 1990.
- Methane (CH_4) emissions have decreased by 52% since 1990, through a combination of reduced livestock numbers and more efficient feeding.
- There is evidence that UK ruminant agriculture compares favourably with other countries, and that the rate of reduction of total agricultural GHGs in the UK in recent years has been similar to, or greater than, several competitor countries.
- There is a wide degree of uncertainty over the exact levels of emissions of N_2O and evidence suggests that UK emissions are lower than those based on the IPCC methodology. The development of more precise GHG inventories will address these uncertainties.
- Increases in milk yields and technical feed improvements have been associated with reductions in GHG emissions per litre of milk.
- The UK beef sector has also benefited from technical feed improvements

- UK beef production, and increasingly also lamb production, is mainly carried out over a short production cycle; this contributes to reducing the GHG emissions per animal and thus per unit of output
- Livestock in upland and marginal areas may be associated with high CH_4 emissions per unit of output (due to relatively low quality forage) but low emissions per ha. Many of these areas also have a role in CH_4 capture, and their management via low intensity beef and sheep grazing is also important in achieving wider agri-environmental objectives.

In the UK, the total net GHG emissions attributed to agriculture account for a relatively low proportion (about 7%) of the country's total of GHG emissions. Agricultural GHGs occur mainly as nitrous oxide (N_2O) and methane (CH_4). Total UK agricultural GHG emissions have decreased by about 17% since 1990 but, given the UK government's ambitious targets to reduce all GHG emissions, further improvements in agricultural management are likely to be necessary (see Chapter 2). Importantly, these reductions will take place against a background of rising world population and an anticipated doubling in world food demands by 2050, together with the need to address energy security.

In agriculture, direct CO_2 emissions arise from sources such as soil disturbance and on-farm energy use, as well as indirectly through the energy intensive manufacture of inputs. On the other hand, pastures and other farmland vegetation store carbon that has been captured by photosynthesis. Methane is the second most significant GHG in the UK. It has a Global Warming Potential of 21 times that of carbon dioxide and, with around one-third of UK emissions derived from agriculture, methane represents a greater challenge for ruminant management. Methane emissions have decreased by 52% since 1990, partly through reduced livestock numbers and more efficient feeding. Enteric fermentation is the main agricultural source of methane, with emissions from slurry stores and livestock manure handing and spreading accounting for most of the remaining agricultural emissions. Nitrous oxide has a Global Warming Potential of about 300 times that of carbon dioxide, and because approximately 68% of UK emissions are derived from agricultural sources, measures to mitigate its emissions will be one of the areas where UK land managers can contribute to reductions in the overall national GHG emissions total (see Chapter 2).

Grassland and its associated vegetation occupies about two-thirds of UK agricultural land, with conditions in western and northern areas being advantageous for grass production, and ill-suited to cropping, due to climate, soil type and slopes. Ruminant production in the lowlands (for dairying and beef and lamb) is based on the technologically efficient management of improved grassland forage and supplementation with predominantly UK-sourced feeds. In the uplands it is based on extensive management (for sheep and suckler beef) of partially improved and semi-natural vegetation, and in these areas grazing by ruminants is an essential part of multifunctional land management. Despite declines in the number of dairy farms and number of dairy cows, increasing yields have kept milk output relatively stable, and the UK is currently the ninth largest milk producer in the world. Increases in milk yields have also been associated with reductions in emissions per litre of milk. The beef sector will also have benefited from some of the same technical feed improvements that have characterised the dairy sector. In upland and marginal grassland areas however, a significant proportion of diets will consist of forage that has a relatively low proportion of digestible organic matter. This implies that, under these conditions, there will be higher methane emissions per unit of output, though under low stocking rates emissions per ha will be low. The UK sheep population of some 32 million remains large by EU standards. As with beef, sheep gazing unimproved pasture are likely to be associated with higher methane emissions per kg of meat compared to lowland sheep on high quality diets. However, many of these areas have a role in methane capture and their management via low intensity beef and sheep grazing is also important in achieving wider agri-environmental objectives. (See Chapter 3 for further details.)

Nitrous oxide emissions associated with agricultural management, and ruminant production in particular, are linked indirectly to nitrogen inputs and recycled dietary nitrogen. Average nitrogen fertilizer inputs on UK grassland are now approximately half the rates of 20 years ago. There is a wide degree of uncertainty over the exact levels of emissions of N_2O in the context of the UK and research evidence suggests that UK emissions are lower than those based on IPCC methodology. The development of more precise GHG inventories will address these uncertainties. (See Chapter 3.)

Comparisons of GHG emissions from UK livestock farming relative to other countries remain inexact. There is a need for precise guidelines to take account of allocation between different sectors and there is also a lack of some key data. Some published comparisons appear to have used imprecise data resulting in conclusions that are not on a like-for-like basis and that may not stand up to scrutiny. In this review comparisons have been made with several countries that compete with UK farmers for market share (Ireland, Netherlands, New Zealand and South America). Our study concludes that in this respect there is evidence that UK ruminant agriculture compares favourably with other countries, and that the rate of reduction of total agricultural GHGs in the UK in recent years has been similar to, or greater than, countries with which it is compared. (See Chapter 4.)

Specific examples which indicate a relatively favourable emissions status are:

(i) for UK dairying, average CH_4 emissions from enteric fermentation in relation to milk produced will be lower than in countries where the average milk yield per cow is typically lower than in UK herds, and also, in some cases, in terms of N_2O emissions relative to countries that use higher inputs of nitrogen fertilizers per unit of output and/or where there is a longer outdoor grazing season;

(ii) for lowland beef and lamb production, enteric CH_4 emissions in the UK will be lower, per kg meat produced, than in countries that do not source beef calves from a dairy herd and/or where the production cycle for beef and lamb production is longer than in the UK. (See Chapter 4 for further details.)

The complexity of different livestock systems and sub-systems can make comparisons of emissions particularly complex. To date, few studies have been undertaken to determine the importance of regional or management-related differences in GHG emissions and differences in GHG emissions in relation to farming system, such as organic versus conventional farming, are inconclusive. The systems that characterize a large proportion of the UK's Less Favoured Areas are associated with low inputs of mineral N fertilizers, low stocking rates and low N excretion, and therefore low N_2O emissions per ha of land; however, where these systems have a long production cycle based on beef cows, emissions, particularly of enteric CH_4, will be greater per unit of output (but not necessarily on a per-ha basis). This also needs to be considered against the importance of a large proportion of LFA land in delivering ecosystem services.

In the UK a combination of improved forage genetic resources and knowledge and technologies for silage making and feeding, as well as improved knowledge of grazing management, have contributed to improved nutritional value of grazed and conserved forage enabling higher milk yields per cow and lower CH_4 emissions per litre of milk. UK beef production, and increasingly also lamb production, is mainly carried out over a short production cycle; this contributes to reducing the GHG emissions per animal and thus per unit of output (see Chapter 5).

There are several opportunities for reducing the emissions of GHGs from ruminant agricultural sources, as well as through enhancing removals and through displacing emissions (see Chapter 6), for instance through the use of CH_4 from livestock slurry in anaerobic digestion. It is also important to recognize the importance of the soils and vegetation of the UK's grasslands and rough grazing areas as a carbon store, and their possible role in methane mitigation, and to ensure that future management does not lead to further net carbon dioxide emissions. On cropland there is a need to increase the carbon storage of soils that currently have low soil organic matter.

Research has identified a number of potential GHG reduction strategies than can be implemented but these are not always cost effective for farmers and may suffer from a number of other barriers to uptake (see Chapter 6). In terms of limiting GHG emissions many research challenges and knowledge gaps remain and these need to be given a high priority at both national and international levels, particularly through focusing research effort on reducing N excretion from livestock and manipulating rumen ecosystems in order to limit the main sources of N_2O and CH_4 respectively.

In general, the most cost-effective and environmentally effective mitigation options are those which combine practices which deliver reduced GHG emissions with other environmental, animal-welfare and economic /production-related targets, of which anaerobic digestion is an example. Some measures which reduce emissions of one GHG or pollutant may increase that of another (the problem of 'pollution swapping') and outcomes need to be evaluated on a site-specific basis. When considering mitigation options it is important to distinguish between the maximum biophysical potential, the economically constrained potential and the socially/politically constrained potential of mitigation actions.

The effects of future climate change for the ruminant production industry in the UK, under low-medium GHG-emissions' scenarios to the 2050s, appear to be within the response capacity of the UK farming industry. Good production conditions are likely to continue for meat and dairy production in most parts of the UK where ruminant livestock farming is currently important. GHG emissions increases at the higher end of forecasts, especially in the longer term, carry greater uncertainties. Importantly, there are also issues of climate change affecting food security in some other parts of the world where livestock farming is important, and this implies reduced opportunities for the UK to source meat and dairy produce from imports. If areas such as southern Europe become unsuitable for livestock production, at a European level the UK has potential to take up some of that shortfall. (For further details see Chapter 7).

Research and policy implications

Summary

- Many research challenges and knowledge gaps remain. These need to be given a high priority at both national and international levels, particularly through focusing resources on reducing N excretion from livestock and manipulating rumen ecosystems in order to limit the main sources of N_2O and CH_4 respectively.
- Research is needed to determine the importance of regional or management-related differences in GHG emissions and differences in relation to farming system, such as organic versus conventional farming.
- GHG emissions from livestock production reduced still further through improved knowledge transfer to UK farmers. This requires resources and commitment commensurate with the national emission reduction targets recently set by government.
- Support for 'carbon sensitive farming': English agri-environmental schemes do not specifically reward or compensate actions that address GHG reductions. Reduction and mitigation measures which are additional to other environmental requirements, or which are otherwise not cost-effective for the farmer (such as dietary changes for ruminants) require a new support mechanism or could be incorporated within a revised ELS.
- Reducing GHG emissions from livestock in the UK by a contraction of the industry in order to reduce output and livestock numbers would simply 'export' our GHG emissions to other countries and lead to an increase in UK food imports. Such a policy would also threaten the continued delivery of environmental public goods, such as from Britain's hill farms.
- There is a need to establish international benchmarks for extended farm auditing and to ensure that retailers and consumers are aware of the capabilities and attendant costs of meeting challenging GHG reduction targets, in addition to raising awareness of the wider environmental role, including carbon storage, of the farmland used by the UK's ruminant livestock.
- Consideration should be given to the development of a 'low-GHG-emission' standard for marketing UK meat and dairy produce. However, the UK livestock industry needs to recognize that although there is scope to gain market share here, there is also potential for other countries to improve their GHG emissions.

The complexity of identifying sources of GHG emissions, quantifying emissions in comparable ways and identifying and evaluating mitigation options means that it is inevitable that there are various gaps in our knowledge. Some are simply due to lack of appropriate data either at suitable geographical scales or for specific livestock systems, others are because complex interactions between GHGs have not been fully explored, or because interactions between measures to limit GHG emissions and a range of other public good or ecosystem services have not been fully investigated. Nevertheless, a number of policy implications emerge from the review of evidence undertaken for this report.

Support for carbon sensitive farming: The present agri-environmental arrangements of ELS/HLS do not specifically reward or compensate for measures or actions that address GHG reductions. They do, however, include some measures such as management of extensive grasslands or habitat creation which can reduce net GHG emissions in addition to their principal objective. Future adoption of GHG reduction and mitigation measures which are additional to other environmental requirements, or which are otherwise not cost-effective for the farmer, such as dietary changes for ruminants, may require a similar support mechanism or be incorporated within a revised ELS.

However, in the context of policy development, it is important to note that the new environmentalism of mitigating GHG emissions can pose challenges to ‘conventional’ conservation thinking. For instance, many intensive livestock systems out perform extensive systems in terms of reduced GHG emissions (See Chapter 5). On the other hand, extensive livestock systems which can deliver a range of biodiversity and ecosystem services and support high value meat and dairy products can appear to be unfavourable in terms of GHG emissions per unit of product (though not necessarily on a per ha basis).

Some commentators have argued that reducing GHG emissions from livestock in the UK can simply be achieved by allowing or even encouraging a contraction of the industry in order to reduce output and livestock numbers, and seek alternative land-use options such as woodland or biofuels on grazing lands. This might theoretically contribute to UK national GHG reduction targets, but unless there were commensurate changes in the nation’s diets any emissions saved would be likely to be lost through the relocation of ruminant agriculture to other countries and an increase in food imports. As such logic would suggest contraction of the least efficient parts of the livestock sector would yield the greatest GHG benefits, it follows that such a policy would also threaten the continued delivery of environmental public goods, such as from Britain’s hill farms.

There has been progress in reducing GHG emissions from livestock production in the UK. There is potential to extend this further through research and improved knowledge transfer to UK farmers, and this requires resources and commitment commensurate with the national emission reduction targets recently set by government. In terms of knowledge transfer, there is a need to establish international benchmarks for extended farm auditing and to ensure that retailers and consumers are aware of the capabilities and attendant costs of meeting challenging GHG reduction targets, and to raise awareness of the wider environmental role, including carbon storage, of the farmland used by the UK’s ruminant livestock. In terms of research, reducing N excretion from livestock and manipulating rumen ecosystems in order to limit the main sources of N_2O and CH_4 respectively should be a priority (see Chapter 6).

There is clearly a potential for the livestock sectors in other countries as well as in the UK to reduce their GHG emissions. If this is done successfully and in ways that can be audited to the satisfaction of customers and major retailers, there is a scope for meat and dairy produce to be marketed to a ‘low-GHG-emission’ standard. The UK livestock industry needs to recognize that although there is scope to gain market share here, there is also potential for other countries to improve their GHG emissions even further.

1. Introduction

Summary
Climate change is a subject of global environmental concern. The UK has seen a progressive strengthening of political resolve to address the problems associated with emissions of greenhouse gases (GHGs), principally carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Although agriculture globally, and ruminant livestock production in particular, is a net contributor to GHG emissions, generalizations about impacts on climate change often fail to distinguish between different systems of production, advances in technology, and the role of extensive grazing lands to contribute to ecological services and produce food in situations where other forms of farming are impractical.

Climate change is a subject of global environmental concern and evidence that warming of the earth's atmosphere is now taking place seems unequivocal. The reports of the Intergovernmental Panel on Climate Change (IPCC, 2001a,b; 2007) conclude that most of the increases in global average temperature since the mid-twentieth century are 'very likely' (i.e. >90% probability) due to the radiative forcing effects of increased concentrations of atmospheric Greenhouse Gases (GHGs), principally carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), the anthropogenic emissions of which have increased greatly since the nineteenth century. Their increased atmospheric concentrations have been further exacerbated by land-use changes. The key indicators of climate change (increased mean temperatures, changes in patterns of precipitation, increased cloud cover, more frequent floods and other extreme events) are also widely accepted to be due mainly to the radiative forcing effects GHGs

In the UK there has been a progressive strengthening of political resolve, and of awareness raising and legislation to address the problems attributed to the increased emissions of carbon dioxide and other GHGs. For example, the potential risks of increased warming leading to a state of 'dangerous climate change' were highlighted in the outcomes of a Defra-sponsored scientific symposium in February 2005. This argued that the benefits of climate policy should be framed for decision makers in terms of the potential for climate policy to reduce the likelihood of exceeding 'dangerous' thresholds at which ecosystems and food productions systems cannot adapt, and sustainable development is threatened (Schneider and Lane, 2005).

In February 2008 the UK government announced its targets to reduce the UK's CO_2 emissions by at least 60 per cent (compared with 1990 levels) by 2050 would become a statutory duty under the Climate Change Bill, and in October 2008 the government raised the profile of climate change as a policy issue through the creation of a new Department of Energy and Climate Change. This department was immediately advised by the Climate Change Committee that the 60 per cent target should be raised to 80 per cent because of the 'huge potential threat to human welfare'. It is highly likely, therefore, that in the coming years all sectors of the UK economy, including farming and land use, will be required to contribute towards the goals of meeting these targets. It is imperative that actions taken are based on a sound understanding of the issues and that the consequences of reducing emissions in one sector or location are not offset by changes made elsewhere.

The reports of the Intergovernmental Panel on Climate Change (IPCC, 2001a,b; IPCC, 2007) detail the extent of recent global change. It is estimated that during the past century there has been a 0.74^{o}C increase in global average temperature. The effect has been most pronounced in recent years with 11 of 12 years during the period 1995-2006 ranking among the top 12 warmest years since records began in 1850. A series of model-based projections for the future has been developed, based on different socio-economic emissions scenarios, and for all these scenarios, over the next two decades a temperature increase of at least 0.2^{o}C per decade is projected. There is also an associated increase in the frequency of warm spells, heat waves and heavy rainfall events considered very likely (90% probability), and an increased incidence of droughts and cyclones considered likely (60% probability). Taking the example of the 'B1 scenario' (which has relatively low emissions and characterized by rapid economic growth, resource-efficient technologies and a large service economy, but with global population increasing to 9 billion by 2050), a 21st century increase in temperature of 1.8 ^{o}C is estimated, leading to a sea-level rise of 18-38 cm. However, higher emissions-scenarios are projected to lead to far greater increases in global temperatures and associated climate impacts: possibly leading to the 'dangerous climate change' outcome.

Although uncertainties surround the extent and seriousness of the effects of future climate change, including the impacts on agriculture, there is a general consensus that measures need to be adopted throughout the world to reduce the net global emissions of GHGs. Many of the world's governments have pledged to meet GHG reduction targets, largely through reduced carbon dioxide emissions. Economic drivers and fossil fuel availability and price in the wake of 'peak oil' production will provide additional incentives for achieving more efficient fuel use and substitution with biofuels and other renewables. The UK is committed to the United Nations Framework Convention on Climate Change, which was agreed in 1990 and came into force in 1994. The European Union countries adopted the Kyoto Protocol in 1997 and agreed a reduction of GHG emissions of 8% of 1990 levels by 2012, with targets for 2020 of a 20-30% decrease, with the UK agreeing to a reduction of 12.5% as part of the overall EU contribution. As noted above, the UK government's Climate Change Bill set reduction targets for CO_2 emissions of 60% (excluding international aviation and shipping emissions) by 2050 but, as we have noted, is now likely to be 80% for all GHGs, and of *c*. 30% by 2020, compared with 1990 baseline levels. Between 1990 and 2007 the UK has succeeded in reducing the total basket of GHGs by *c*.17%, including a *c*.12% reduction in methane of agricultural origin, but total CO_2 reductions over the same period were only 8%. However, when allowance was made for 'CO_2 consumption' through products or services from outside the UK it is reported that CO_2 emissions associated with the UK increased by 18% (Defra 2008,). These statistics underline the consequences of achieving domestic reduction targets through the mechanism of relocating high-GHG-emission activities such as heavy industry to emerging economies, with no resulting global emission reductions, and underline the fallacy of 'exporting' agricultural emissions by substituting imported food for UK produced food.

The contribution of world agriculture to climate change has also come under the spotlight, both for its direct GHG emissions and through the effects of land-use change. It is likely that governments and regulatory bodies in many countries will be considering further how agriculture generally, and the livestock sector in particular, can be improved in terms of GHG emissions balances. There have already been a number of calls for reduced consumption of meat and dairy products on the basis that the livestock industry in general, particularly ruminant agriculture, are net contributors to GHG emissions, particularly of N_2O and CH_4 (FAO, 2006). However, generalizations such as those in the Livestock's Long Shadow Report (FAO, 2006) often fail to distinguish between different systems of production, advances in technologies, or to recognize that in many parts of the world – notably rangelands and rough grazings such as occur in northern and western and upland areas of the UK – grazing enables agricultural utilization of lands that would otherwise be unable to support any other significant forms of food production. It is estimated that agriculture's contribution to the UK's net GHG emissions is about 7% of the total national inventory, mostly as methane (>30% of UK total methane) and nitrous oxide (>60% of total UK nitrous oxide) (Chadwick *et al.*, 1999; Brown *et al.*, 2001; Baggott *et al.*, 2007; Dragosits *et al.*, 2008).

Improving agricultural management to reduce emissions of these gases is therefore part of the overall package of measures to limit the extent of future climate change. However, this requirement coincides with both the anticipated growth in world population, which combined with economic growth is likely to lead to a near doubling in food demand by 2050, and the need to reduce dependence on fossil fuels - situations which have led to food security and energy security both becoming priority areas for policy makers (Defra, 2008; FAO, 2008a). Furthermore, there has been a decline in recent years in UK self-sufficiency in food, e.g. for indigenous-type food the proportion that was home produced fell from 85% in 1990 to 72% in 2006 (Defra website: https://statistics.defra.gov.uk/esg/datasets/selfsuff.xls*)*. Against the background of an expanding global population and many food exporting countries likely to be greatly affected by climate change, the possible strategic need to expand UK livestock and dairy output in future needs to be considered.

The overall aim of this review was therefore to conduct an independent desk-based analysis of the scientific evidence of the impacts of the UK's forage-based livestock sectors (beef, sheep and dairy production) on emissions of the three main GHGs: carbon dioxide, methane and nitrous oxide.

The study has been confined to impacts up to the 'farm gate' and it has examined and reviewed the evidence to answer the following questions:

- How do GHG emissions from UK beef, sheep and dairy production compare with the situation in other countries/regions, such as South America and NZ, and selected EU countries.
- Within the UK how do various intensive and extensive systems of dairy, beef cattle and sheep production compare in terms of their respective emissions balances?
- What are the research findings on measures that can or have been adopted to reduce net GHG emissions, and what is the potential for further adoption by the industry in the UK?
- What are the likely future impacts of climate change on the UK ruminant livestock industry, particularly in comparison with its competitors?

2. Greenhouse gas emissions and the role of ruminant production: an overview

Summary

In the UK, the total net GHG emissions attributed to agriculture account for a relatively low proportion (about 7%) of the country's total of GHG emissions. Agricultural GHGs occur mainly as nitrous oxide (N_2O) and methane (CH_4). Total UK agricultural GHG emissions have decreased by about 16% since 1990. Given the UK government's ambitious targets to reduce all GHG emissions, further improvements in agricultural management are likely to be necessary. Importantly, these reductions will take place against a background of rising world population and an anticipated doubling in world food demands by 2050, together with the need to address energy security. In agriculture, direct CO_2 emissions arise from sources such as soil disturbance and on-farm energy use as well as indirectly through the energy intensive manufacture of inputs. On the other hand, pastures and other farmland vegetation store carbon that has been captured by photosynthesis. Methane is the second most significant GHG in the UK. It has a Global Warming Potential of 21 times that of carbon dioxide, and with around one-third of UK emissions derived from agriculture, represents a greater challenge for ruminant management. Methane emissions have decreased by 52% since 1990, partly through reduced livestock numbers and more efficient feeding. Enteric fermentation is the main agricultural source of methane, with emissions from slurry stores and livestock manure handing and spreading accounting for most of the remaining agricultural emissions. Nitrous oxide has a Global Warming Potential of about 300 times that of carbon dioxide, and because approximately 68% of UK emissions are attributed to agricultural sources, measures to mitigate its emissions will be one of the areas where UK land managers can contribute to reductions in the overall national GHG emissions total. Variations in soils, fertilizer management, manure inputs and returns under grazing mean there is a wide degree of uncertainty on the exact levels of N_2O emissions from ruminant agriculture and estimations vary substantially. Recent research findings suggest the IPCC methodology has greatly overestimated the both the direct emissions from UK agriculture (estimates for grazed and ungrazed grassland sites in the UK of 18.7 Mt N_2O-N, cf. the IPCC-based values of 32.3 Mt) and also the and indirect emissions which the IPCC includes may also be considerably less than the IPCC framework suggests.

Ruminant agriculture contributes to emissions of carbon dioxide, methane and nitrous oxide and in the UK these collectively contribute *c*. 7% of the total national emissions when expressed in terms of CO_2- equivalents (Table 2.1). This is based on IPCC Global Warming Potential (GWP) values over a 100-year timeframe of 21 for CH_4 and 310 for N_2O, compared with a baseline value of 1 for CO_2 (Baggott *et al*., 2007; ATE, 2008). (Note that in its Fourth Assessment Report the IPCC revised its estimate of the 100-year GWP of methane from 21 up to 25 and of nitrous oxide down from 310 to 298 (IPCC, 2007)). Time series data are generally presented based on the earlier GWP values for consistency.

Table 2.1. Estimates of the total UK emissions of the main GHGs (for 2006) and the quantities and proportions attributed to agriculture

Source GHG	Total UK emissions as Mt of CO_{2-} e	UK agricultural emissions as Mt of CO_{2-} e (and as % in parentheses)
CO_2	*554.5	<0.1 (<1)
CH_4	49.4	18.4 (37)
N_2O	37.8	25 (66)
Total CO_{2-} e	641.9	43.5 (7)

Source: AEA (2008)
*2007 value was lower at 543.7 Mt (Defra website, Statistical Release 2008)

The emissions from UK agriculture have shown an overall decrease of *c.*16% since 1990, reflecting trends in livestock numbers and improvements in the efficiency of fertilizer application.

2.1 Carbon dioxide

Carbon dioxide is the principal GHG by virtue of its relatively high atmospheric concentration, currently *c.* 380 ppmv, having increased by over 30% since the mid-18th century mainly as a result of the combustion of fossil fuels. Land-use changes, especially forest clearance, will have exacerbated this situation (although in the UK most major land use changes occurred in pre-industrial times). In agricultural practice, direct CO_2 emissions are affected by the frequency and types of soil disturbance, the efficiency of mechanical operations, and other on-farm energy uses. Indirect CO_2 emissions arise from inputs of artificial (primarily N) fertilizers, the manufacture of which is an energy-intensive process, and agriculture accounts for some indirect emissions from other inputs (e.g. energy embedded in the manufacture of machinery, concrete etc). Present-day CO_2 emissions for UK agriculture account for a very small proportion (estimated at < 1%) of the UK total of CO_2 emissions. Dawson (2008) noted that there has been a near 100% reduction in the total energy input into UK agriculture since the early 1970s, particularly of direct energy (200% reduction). Lower energy use in fertilizer manufacture and improvements in energy efficiency and abatement technologies have potential to improve this further.

Pastures and other farmland vegetation (hedges, trees, scrub etc.) are a store for carbon that has been captured by photosynthesis. Bradley *et al.* (2005) describe a database of soil carbon and land use from which models of soil carbon dioxide emissions across the United Kingdom (UK) can be run based on information on soil types and land use on a 1 km grid across the UK. For 1990, the baseline year for the Kyoto Protocol on carbon emissions, the estimate is 4562 million tonnes soil organic carbon in the top 1 m of soil across the UK, with an average density of 18 kg m^{-2}.

The accumulation of carbon as organic matter in soils contributes to the temporary removal of CO_2 from the atmosphere. Where carbon entering the system through photosynthesis exceeds that leaving the system through respiration and harvesting etc (Weiske, 2007) this leads to the long-term sequestration of CO_2 from the atmosphere (Freibauer *et al.*, 2004; Smith, 2004). The formation of deep peaty soils is an extreme example of this. The Kyoto Protocol allows carbon emissions to be offset by demonstrable removal of carbon dioxide from the atmosphere and there is an extensive literature on the capacity to offset net GHG emissions through enhanced carbon sequestration (Cannell, 2003; Smith *et al.*, 2005). Natural

England recently undertook a wide-ranging review of the scientific evidence of how land managers can protect carbon stocks in soils and vegetation (Natural England, 2007; 2008). Over 10 billion tonnes of carbon (equivalent to 37 b t CO_2 e) is estimated to be stored in all UK soils, around half of this in organic soils, and *c*. 0.5 billion tonnes in the peat soils that cover only 3.3% of the land area (Natural England, 2008). Although soils and vegetation remove over 4.4 m tonnes of CO_2 per year (equivalent offset to 3% of UK GHG emissions) this was countered by 4 m tonnes of CO_2 emitted from soils due to cultivation, drainage and peat extraction. It was also noted that agri-environment schemes such as Environmental Stewardship contribute to carbon reductions especially through habitat creation options, such as conversion of arable land to permanent grassland. Natural England (2008) further notes that field margins and hedgerows are an important carbon store and their future management (e.g. allowing wider growth) has potential for further sequestration. The use of 6-m wide buffer strips are specifically identified as an effective short term mitigation option and suggest that they offer the potential to increase soil organic carbon storage from 256 t CO_2 e ha^{-1} on cropland and from 293 t CO_2 e ha^{-1} on grassland to 440 t CO_2 e ha^{-1} ; however, they further note that the evidence for permanent greenhouse gas benefits from such practices is weak.

Table 2.2. Areas of grassland and other agricultural land use in UK (as ’000 ha) [based on 2006 June Survey]

	England	Wales	Scotland	N. Ireland	All UK
Crops and tillage	3 840	66	1 566	187	5 659
Grass <5 years old	590	115	325	136	1 166
Grass >5 years old	3 330	982	910	676	5 898
Rough grazing in sole rights	640	221	3 340	149	4 350
Common rough grazing	395	180	598	29	1 202
Total agricultural land†	8 795	1 564	6 739	1 177	18 275

†excludes woodland on farms and set-aside land

Reduced tillage and the recycling or organic materials, including efficient use of animal manures and crop residues, have been promoted as possible measures for improving net-CO_2 sequestration and increasing/ maintaining soil organic carbon (Jones *et al*., 2006). The potential role for animal manures to be returned to cropland (the traditional practice in mixed farming systems) has been identified as leading to potentially greater soil organic matter accumulation and carbon sequestration than applying to grassland soils where soil organic carbon is already relatively high (King *et al.,* 2004). The benefits of reduced tillage include lower fuel use compared with conventional practices, but its potential to reduce net GHG emissions is unclear, especially as on poorly aerated soils there is an increased risk of higher nitrous oxide emissions (Bhogal *et al*., 2007).

The importance of grassland and rough grazings, the main feed resource of the UK’s cattle and sheep production, is shown in Table 2.2. The soil and root systems of grassland and rough grazing areas are important carbon sinks: Natural England (2007) quotes indicative soil carbon values for 1 m depth (attributed to Viner, 2006) of 180 t C/ha for grassland on mineral soils and 700 t C/ha on organic soils.

In terms of carbon balance, permanent pasture and reduced tillage systems are commonly favoured over annual cultivations. As sown grasslands age the amount of soil organic matter in the plough depth layer progressively increases (Clement and Williams, 1967) although this is dependent on edaphic conditions. Grassland that supports older swards, such as those aged more than 20 years, may no longer act as a C sink (Frank, 2002). The increase in soil C content usually observed after a shift from arable to grassland is partly explained by a greater supply of C to the soil under grass, mainly from the roots, but also from shoot litter (Soussana *et al.,* 2004). In contrast, organic matter is commonly lost from soils under cultivation. There are, however, uncertainties on the relative impacts on soil carbon of full cultivation vs. reduced tillage, depending on soil depths and depths of soil carbon stocks, leading at least one research team (Baker *et al*., 2007) to suggest than reduced tillage may not promote C sequestration. However, as was emphasized in the reviews of Natural England (2007, 2008) any future significant reduction in the area of grassland in favour of annual crops would be expected to lead to loss of soil carbon, with a 20% reduction in the grassland area leading to a theoretical loss of up to 2.35 Mt C/year, the equivalent to 0.08-1.4% of the UK's annual total CO_2 emissions. Recent studies on the potential for carbon sequestration capacity in the UK are considered further in section 6.3.

2.2 Methane

Methane, having a 100-year Global Warming Potential of 25 times that of carbon dioxide, and with around one-third of UK emissions derived from agriculture, represents a greater challenge for ruminant management. However, since 1990, emissions of methane have decreased by *c.* 50%, partly through reduced livestock numbers and more efficient feeding.

Enteric fermentation is the main agricultural source of methane, at 85% (comprising 39% from dairy, 48% from beef and 22% from sheep) with emissions from slurry stores and livestock manure handing and spreading accounting for most of the remaining 15% (Monteney *et al*., 2006; Dragosits *et al*., 2008). Methane is produced as a by-product of digestion of structural carbohydrates, due to the action of rumen microbes (bacteria, fungi and protozoa). During this digestion, mono-saccharides are fermented to H_2, CO_2 and volatile fatty acids (VFAs), and as part of this stage of ruminant digestion some of the microbes (methanogens) produce CH_4 (Hopkins and Del Prado, 2008). Several studies have formulated abatement strategies to mitigate CH_4 emissions (Jarvis, 2001). The methane lost can be up to 15% of the gross feed energy intake, and understanding dietary manipulation to reduce methane emissions has long been recognized as having economic implications for the livestock industry (Blaxter and Clapperton, 1965; Blaxter and Czerkawski, 1966).

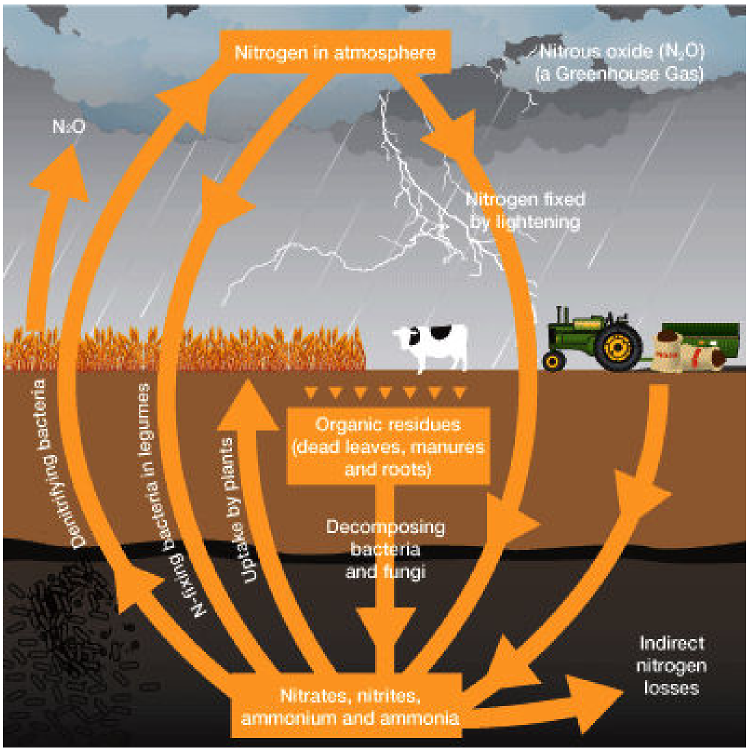
In the previous section the importance of grasslands and rough grazing lands, particularly on organic soils, was noted for their role in carbon storage. There is also research evidence that upland soils in particular are an important sink for methane; biological methane oxidation in soils is an important determinant of atmospheric methane changes, and that methane uptake by soils can be reduced by 60-75% when semi-natural vegetation is converted to crops (Boeck and Van Cleemput, 2001). The same paper notes that UK grassland soils have a high methane oxidation capacity, and that UK farmland compares favourably with most of the EU due to the UK having a high proportion of land used for livestock grazing, especially in the LFAs. Improved scientific understanding of land type and land management factors affecting variation in methane oxidation could offer potential for enabling UK farmland to achieve an improved methane emission balance.

2.3 Nitrous oxide

Emissions of nitrous oxide are uncertain because there are many small sources, both natural and anthropogenic. The main anthropogenic sources are agriculture, industrial processes and coal and oil combustion. In 2006, emissions of nitrous oxide were 38.2 Mt CO_2 equivalent, representing a decline of *c.* 40% since 1990 due to decreases in emissions from both the agricultural and industrial sectors (AEA, 2008).

The atmospheric concentration of nitrous oxide is low at about 319 ppb but because it has a Global Warming Potential of about 300 times that of carbon dioxide, and because *c.* 68% of UK emissions are derived from agricultural sources (see Table 2.1) measures to mitigate its emissions will be one of the areas where UK land managers can contribute to the overall national GHG emissions total.

Figure 2.1 Schematic representation of the nitrogen cycle in a farmland ecosystem



Source: http://www.farmingfutures.org.uk/Documents/Article%20Attachments/Nitrogen-Cycle.pdf

Nitrous oxide is formed in the soil through nitrification and denitrification (Fig 2.1). Denitrification is an anaerobic stepwise reduction of soil nitrate (NO_3) to gaseous nitrogen compounds, N_2O being an intermediate product, whereas nitrification is an aerobic process, which in most soils is controlled by the ammonium supply. These processes are controlled by a number of soil factors, including moisture content (del Prado *et al*., 2006c), temperature (Hatch *et al*., 2005), fertilizer additions (Chadwick *et al.,* 1999; del Prado *et al*., 2006c), pH (Merino *et al*., 2000), organic matter content (Smith *et al.,* 1997; Chadwick *et al*., 1998), nitrate and ammonium (Tiedje, 1988; Granli and Bockman, 1994). Knowledge gained on understanding these processes and effects enables measures to be introduced to reduce net emissions, particularly through improved fertilizer and manure management.

The principle sources of N to grassland come from recycled dietary N (urine deposition under grazing or in animal manures including slurry and muck spreading) and applied nitrogen fertilizers. It is generally easier to control the evenness and timing of fertilizer N sources than of N from organic manures, but improvements in the latter have been developed including controlled application of organic + inorganic N. In contrast, urine N deposited at grazing tends too be unevenly distributed, and the relative impacts of these two main N sources varies greatly between different countries and farming systems. N losses generally can be reduced by avoiding surplus dietary crude protein (Kulling, 2001). Legume feeds can also represent an important source of dietary N which requires a balanced input in the form of digestible sugars to minimize urinary N losses and eventual additions to the soil N pool which leads to nitrous oxide emissions. This is an important target in grass breeding (Pollock *et al*., 2005).

In view of the variations in fertilizer management, manure inputs and returns under grazing, as well as differences in soils, it is unsurprising that there is a wide degree of uncertainty on the exact levels of N_2O emissions from ruminant agriculture and estimations vary substantially. Chadwick *et al*., (1999) report emissions of half that of the IPCC method. Brown *et al.* (2001) also reported that the IPCC methodology was likely to have overestimated the emissions from UK agriculture and give values for grazed and ungrazed grassland sites in the UK of 18.7 Mt N_2O-N, cf. the IPCC-based values of 32.3 Mt. They further note that the indirect emissions which the IPCC does include may also be considerably less than the IPCC framework suggests.

3 Key features of livestock farming in the UK that relate to GHG emissions

Summary
Grassland and its associated vegetation occupies about two-thirds of UK agricultural land, with conditions in western and northern areas being advantageous for grass production, and ill-suited to cropping, due to climate, soil type and slopes. Ruminant production in the lowlands (for dairying and beef and lamb) is based on the technologically efficient management of improved grassland forage and supplementation with predominantly UK-sourced feeds. In the uplands it is based on extensive management (for sheep and suckler beef) of partially improved and semi-natural vegetation, and in which grazing by ruminants is part of a multi-functional land management. Despite declines in the number of dairy farms and number of dairy cows, increasing yields have kept milk output relatively stable and the UK is currently the ninth largest milk producer in the world. Increases in yields are associated with reductions in emissions per unit litre of milk. The beef sector will also have benefited from some of the same technical feed improvements that have characterised the dairy sector. In upland and marginal grassland areas however, a significant proportion of diets will consist of forage that has a relatively low proportion of digestible organic matter. This implies that, under these conditions, there will be higher methane emissions per unit of output, though under low stocking rates emissions per ha will be low. Furthermore, the role of semi-natural upland vegetation in methane capture is an important mitigating factor. The UK sheep population of some 32 million remains large by EU standards. As with beef, sheep grazing of unimproved pasture is likely to be associated with higher methane emissions per kg of meat than lowland sheep on high quality diets. However, many of these areas have a role in methane oxidation and their management via low intensity grazing is also important in achieving agri-environmental objectives.

Nitrous oxide emissions associated with agricultural management, and ruminant production in particular, are linked indirectly to nitrogen inputs and recycled dietary nitrogen. Average nitrogen fertilizer inputs on UK grassland are now approximately half the rates of 20 years ago. There is a wide degree of uncertainty on the exact levels of emissions of N_2O in the context of the UK and research evidence suggests UK emissions lower than those based on IPCC methodology. The development of more precise GHG inventories will address these uncertainties.

3.1 Introduction

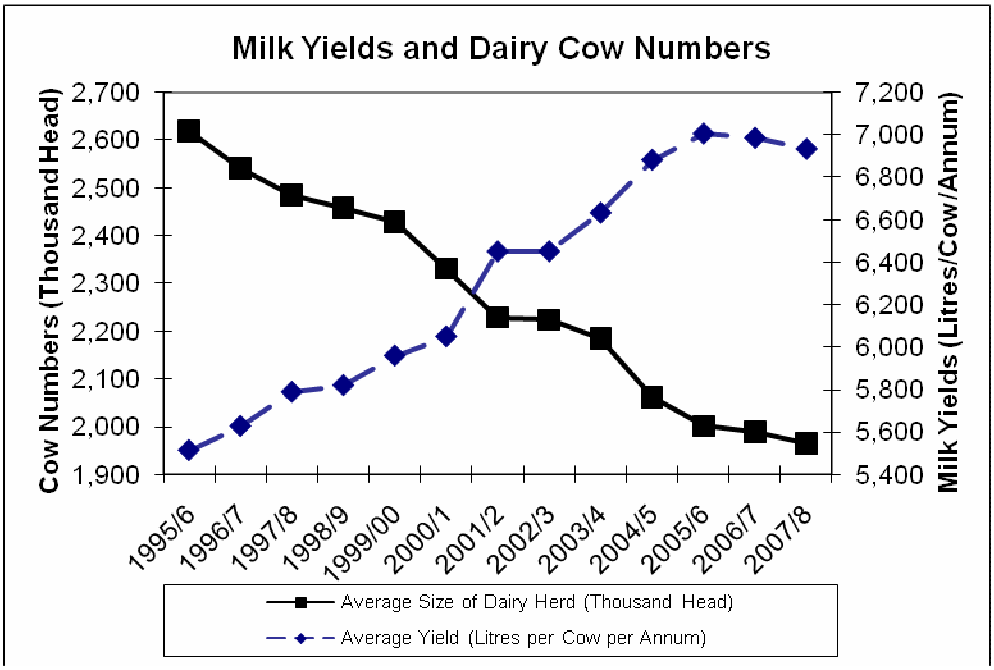
Conditions in the UK are very favourable for grass production, particularly in western areas where the maritime influence of the climate results in approximately 40% of the agricultural area having over 220 grass-growing days per year (Down *et al*., 1981). Since the 1980s it is estimated that the growing season has lengthened by approximately 1.7 days per year (Hulme et al 2002). The distribution of ruminant livestock production closely follows that of grassland and forage, with the greatest concentrations in northern and western areas, where soils and topography result in land that is generally ill-suited to arable cropping or frequent cultivation (Green, 1990). Dairy farming occurs predominantly in lowland western areas where soil and climate conditions are most suitable for sustaining high yields of quality forage production. Beef cattle are more widespread in their distribution, including farms on areas with relatively marginal conditions for forage production engaged in calf rearing by suckler cows, producing weaned calves for sale as store cattle for fattening on lowland farms. Sheep are also widely distributed, being most evident in hill and moorland areas where they are often the only, or the main, farm enterprise, but elsewhere are often integrated with other ruminant enterprises. Sheep and beef cattle are predominantly kept out of doors for all or most of the year, or housed in the winter months when grazed forage is unavailable or weather conditions create animal welfare problems for outwintered livestock. The need to move dairy cattle for (usually) twice-daily milking limits opportunities for outdoor winter grazing when there is an increased risk of soil and sward damage (poaching, compaction) but there has been an increasing (but unquantified) trend to extending the dairy cow grazing period in recent years, enabled to a large degree by advances in feed budgeting (Rath and Peel, 2005) but also reflecting earlier start dates and later end dates in the grass-growing seasons. UK livestock farming differs from the practices adopted in some southern hemisphere countries that try to maintain year-round grazing, and from those practised in many parts of mainland Europe where livestock are kept in buildings for all or much of the year.

3.2 The dairy sector

The UK is the ninth largest milk producer in the world and current annual production of *c*. 13.2 b litres, nearly half of which is sold as liquid milk, is similar to that of New Zealand (www.maft.gov.nz; www.mdcdatum.org.uk). Dairy farming is still widely distributed in the UK but remains concentrated in the areas where it has had traditional advantages associated with good grass-growing conditions: the south west of England, the lowland areas of south and south-west Wales, the north Midlands and north-west of England (centred on the counties of Staffordshire, Cheshire, Lancashire and the lowland areas of Cumbria) and the lowland areas of Northern Ireland and of south-west Scotland. The size and productivity of the dairy sector, and the distribution of UK dairy farms, have evolved in response to a number of historic, economic and environmental factors. These include market demand from a large, predominantly urban population for fresh milk and milk products, and the availability of inputs such as cattle feed by-products and fertilizers associated with other industrial and food processing industries. The suitability of over 1 m ha of lowland farmland, where grass-growing days can be in excess of 250 per year in the most favourable areas, and herbage production with optimum fertilization exceed 10 tonnes of dry matter per year (Hopkins, 2000) allow low-cost grass production over a long growing season.

Since the mid-late 1990s the dairy sector in the UK has undergone a transformation with the number of dairy farms falling by about 46% to fewer than 18,000 (MDC: www.mdcdatum.org.uk). Over the same period the number of dairy cows has also fallen by about 20% to stand at about 1.95 million, a trend that began in the early 1980s when the national herd was *c*. 3 million and there was over-production in the EU. These two trends have, however, been accompanied by an increase in the average milk yield per cow, from *c*. 5000L/cow in the late 1980s to *c*. 6900 L/cow at present (Fig. 3.1). Thus, despite these major structural changes, the total UK milk output has remained relatively stable. Dairy cow herd sizes are typically in the range of 80-120 (the 2007 mean was 112 cows). Defra statistics (www.defra.gov.uk/foodrin/milk/dairyindustry/index.htm) indicate that the UK is approximately self sufficient in dairy products but that the value of imports exceeds that of dairy exports by £800m.

Figure 3.1. Trends in UK dairy cow numbers and milk yield per cow



Source: Milk Development Council

The following points are relevant to the GHG emission/ sequestration potential of the dairy farming sector.

- A cow entering a dairy herd will have spent a period of growth before her first calving (at about 24 months, though this can be longer depending on conception rates). Within dairy herds milking cows are culled and replaced, typically after about four or five lactations due to declining milk yields, lameness or other health problems. Thus, for an average annual milk yield of 6900L per cow this equates to about 30,000L over her lifetime. GHG emissions (methane from enteric fermentation and manure, and nitrous oxide) will occur over the cow's entire life and thus the number of days of her life that she is not producing milk will affect the ratio of net GHG emissions per kg of milk produced over her lifespan. Therefore, in addition to improving the milk yield per cow in each lactation period, extending the number of lactations per cow and reducing the period from birth to first calving can also be considered as objectives for improving net GHG emissions from the herd.

- Most dairy cows on UK farms are kept on specialist dairy farms and UK dairy farming is generally regarded as being relatively intensive (Rath and Peel, 2005), usually based on grass that receives moderate or high rates of mineral nitrogen fertilizers (mean rates of about 120 kg N/ha on dairy swards, about 45% less than the amounts used in the mid-1990s as discussed below, (Defra and SEERAD, 2007 [and previous years]). Grassland swards on dairy farms include recently sown (usually ryegrass-dominated) leys as well as older grassland which, because of its management, often resembles sown leys in terms of its botanical composition, sward structure and response to N fertilizers (Hopkins, 2000). Feeding is based on grazing herbage that is leafy and of high digestibility, with surplus herbage from spring and summer conserved as silage for indoor winter feeding. Improved knowledge and technologies for silage making and feeding, and of grazing systems, have greatly improved the nutritional value of both grazed and conserved forage. Thus, compared with, say, 30 years ago when a national investigation revealed relatively low levels of *c*. 40 GJ of utilized ME/ha from UK dairy grassland (Forbes *et al*., 1980), UK dairy herds now derive a higher proportion of their intake from high quality forage. However, as the proportion of high genetic-merit cows has increased so has the reliance on the supplementary feeding with concentrates to enable the total feed intake to match the milk yield potential. The net effect has been a gradual reduction in 'roughage' feed supplied to dairy cows (i.e. hay, poor quality silage, and pasture grazed at a mature stage of growth or containing species of low digestibility) and this has had positive implications for methane reduction.

- The continuing improvement in genetic merit of dairy cows has been associated with improvements in diet quality so that methane yields per litre of milk, and N excretions per litre of milk, continue to decline. Results presented by Yan and Mayne (2007a,b) show a 16% reduction in methane, and a 9% reduction in manure nitrogen excretion, from the national UK dairy herd between 1995/6 and 2005/6 (with data adjusted for the small decrease in milk yield over the period). The authors of these papers also stress the higher costs and fuel use associated with high yielding cows.
- The reliance on nitrogen fertilizers has been pivotal in enabling high yields of quality grass for silage necessary for meeting dairy cow winter feed supplies, but its use has contributed, directly and indirectly, to nitrous oxide emissions (as well as increased nitrate leaching and ammonia emissions). Nitrogen use on the average dairy farm has always been considerably higher (typically two times the rate) than on grass swards on the average beef or sheep farm. However, in recent years the there has been a reduction in the use of N fertilizers on UK grassland generally. Since 1985 (Table 3.1) there has been a 45% decrease in the overall use of N fertilizers on grassland, with positive implications for nitrous oxide emissions. This has been driven by economic pressures to cut input costs, and needs to comply with environmental requirements, and from improved understanding of the efficiencies associated with fertilizer application timings and better understanding and utilization of farm manures.
- Most dairy herds are kept indoors during winter for up to 6 months, although there is a trend towards extending the grazing season; in practice this depends on soil types and weather conditions. In-wintered cattle are mainly kept in buildings from which most of their excreta are removed and stored as slurry. In the past, slurry was often regarded as a farm waste problem, rather than a nutrient resource. There is now a greater awareness of the value of slurry as a source of fertilizer, and of the importance of good slurry management and optimizing its application in ways that return nutrients and that minimize emissions, particularly of methane.
- The dairy sector is an important source of calves for onward rearing for beef, and accounts for more than half the calves entering the meat chain. These include the progeny of beef-bull sires on dairy cows, and well as the male progeny of dairy-bull sires on dairy cows. Therefore, a proportion of the GHG emissions associated with beef production can be attributed to the dairy system (or *vice-versa*).

Table 3.1. Changes since 1995 in mean rates of applications of fertilizer N to grassland of different ages and livestock use (as kg N/ha) with the proportion of the grassland area that received fertilizer N (as % in brackets) and for all grassland since 1985.

	1985	1995	2000	2005	2006
Mean for all GB grassland	131 (88%)	115 (86%)	99 (75%)	74 (75%)	72 (70%)
E & W: sown grass (<5 years) on dairy farms	--	220 (98%)	182 (85%)	179 (85%)	128 (84%)
E & W: older sown (<5 years) or permanent grass on dairy farms	--	166 (92%)	161 (90%)	117 (82%)	110 (86%)
E & W: sown grass (<5 years) on beef/sheep farms	--	134 (96%)	120 (92%)	92 (80%)	112 (91%)
E & W: older sown (<5 years) or permanent grass on beef/sheep farms	--	72 (81%)	55 (63%)	43 (58%)	39 (58%)

Source: Defra and SERAD (2007) British Survey of Fertiliser Practice (and previous years). *(N.B. in 1985 data were not reported for the different farm types and sward ages.)*

3.3 The beef sector

Beef production in the UK includes a number of different systems and therefore generalizations such as those made for the dairy sector are rather difficult. Individual beef cattle may move between several farms between birth and slaughter, particularly those reared in suckler herds on upland or marginal grassland before being fattened on lowland pastures or on concentrate-fed diets. There are also some producers operating relatively intensive systems based on beef bulls and beef-breed cows. The following general points are relevant to the GHG emission/sequestration potential of the beef production sector.

- In terms of feeding, many of the technical improvements in forage production and conservation as silage as described under the dairy sector above have also been adopted by beef producers. Thus we can presume that the forage part of beef cattle diets will, in many cases, have improved in recent decades. In the lowlands many former dairy farms have switched to beef and will have retained their improved feeding regimes. The adoption of wrapped bale silage in place of hay is one example of a practice that has enabled improved forage use in situations where silage was not previously possible or economic (Merry *et al*., 2000).
- The situation in upland and marginal grasslands is different. Extensive grassland in the UK is a multi-functional resource, and 44% of UK agricultural land is classified as

LFA (Peel and Rath, 2005). The adoption or retention of management practices consistent with other environmental objectives (e.g. biodiversity value of hay meadows and retention of old permanent grasslands) will not have resulted in the improved availability of quality feed, and a significant portion of diets will consist of forage (grazed or conserved) that has a relatively low proportion of digestible organic matter. This implies that under these conditions there will be higher methane emissions per unit of output, though under low stocking rates emissions per ha will be low. Furthermore, the role of semi-natural upland vegetation in methane capture is an important mitigating factor (Boeck and Van Cleemput, 2001).

- Fertilizer N use in most beef production systems is lower than on dairy farms and has also decreased in recent years (Table 3.1) Approximately 40% of the permanent and older sown swards on beef and sheep farms do not receive mineral N fertilizers (Table 3.1) which implies a greatly reduced potential for nitrous oxide emissions. This is particularly the case on upland swards. Although fertilizer-use statistics are not available for the uplands separately, reference to historic data from national grassland surveys conducted in 1970s and 1980s by the former Grassland Research Institute shows that fertilizer N inputs on enclosed grassland in the uplands was 30% lower than the mean rates for GB as a whole (Hopkins *et al*., 1988), and unenclosed grazing areas would normally receive none.
- The need to take beef cattle to slaughter weight within a short time period (30 months) avoids a situation of allowing weight loss during unfavourable feeding periods (something which occurs in some extensive beef systems elsewhere in the world and has occurred in the UK in the past). A shorter period from birth to slaughter can help reduce GHG emissions (particularly of enteric methane) per kg of meat produced.

3.4 The sheep sector

The UK sheep population at 32 million (15.5 m ewes) has decreased by about 10% over the past five years, although it remains large by European standards and accounts for 24% of the EU total (EUROSTAT, 2007). Sheep production systems in the UK are many and diverse but an important feature is the role of the uplands, which traditionally have accounted for half the output. Upland and lowland sheep production systems also have a complex interdependence. The following points are relevant to the GHG emission/sequestration potential of the sheep production sector.

- UK sheep are kept primarily for rearing lambs for slaughter, or for replacement ewes. Wool production (which in pre-industrial times was the main economic value of sheep) is a by-product, and dairy sheep (which are important in southern Europe) are limited to a few niche-market producers.
- Upland flocks derive a most of their feed from grazed grass and forages including a high proportion of relatively unimproved permanent pasture and rough grazing land. This implies that the methane emission per kg of feed intake might be greater than for lowland sheep on higher quality diets. However, many of these areas are important carbon sinks (e.g. upland peaty soils), and also have a role in methane oxidation (Boeck and Van Cleemput, 2001) as noted previously for suckler beef. They are also managed to deliver other environmental benefits according to agri-environment conditions. Many upland farms also have areas of improved pastures of higher

nutritional grazing (ryegrass and white clover) or kale needed to finishing lambs or maintaining ewe condition.

- Upland flocks supply draft ewes to lowland flocks where the better feeding conditions extend the productive life of the ewe. They also supply lambs for finishing on to better quality lowland pastures within a shorter period than would be possible on unsupplemented upland grazings.
- In recent years considerable improvements have been made in understanding and applying improved nutrition and grazing management for taking lambs to slaughter weight in a shorter period, for reducing lamb mortality, and for improving ewe fertility and productivity, and lambing percentage (increased proportion of twin lambs). As with the beef sector these improvements have been driven by economic considerations and enabled by improved technical knowledge, but they contribute to reduced GHG emissions (particularly of enteric methane) per kg of meat produced.

4. Greenhouse gas emissions from UK dairy, beef and sheep production and the situation in some other countries and regions

Summary
Comparisons of GHG emissions from the UK livestock farming relative to other countries remain inexact. There is a need for the international community to develop common guidelines to take account of allocation between different sectors and there is also a lack of some key data. Some published comparisons appear to have used imprecise data resulting in conclusions that are not on a like-for-like basis and that may not stand up to scrutiny. In this review comparisons have been made with several countries that compete with UK farmers for market share (Ireland, Netherlands, New Zealand and South America). Our study concludes that in this respect there is evidence that UK ruminant agriculture compares favourably with other countries, and that the rate of reduction of total agricultural GHGs in the UK in recent years has been similar to, or greater than, countries with which it is compared.

Specific examples which indicate a relatively favourable emissions status are (i) for UK dairying, average CH_4 emissions from enteric fermentation in relation to milk produced will be lower than in countries where the average milk yield per cow is typically lower than in UK herds, and also, in some cases, in terms of N_2O emissions relative to countries that use higher inputs of nitrogen fertilizers per unit of output and/or where there is a longer outdoor grazing season; (ii) for lowland beef and lamb production, enteric CH_4 emissions in the UK will be lower, per kg meat produced, than in countries that do not source beef calves from a dairy herd and/or where the production cycle for beef and lamb production is longer than in the UK.

4.1 UK emissions

A range of values have been reported for the three main GHGs from agriculture. In a modelling study (Defra project IS0205) Williams *et al.* (2006) provided a number of assessments for UK livestock systems (Table 4.1a and Table 4.3), broken down into methane and nitrous oxide. A subsequent project (Defra project CC0270; Dragosits *et al.*, 2008; see Table 4.2) brought together models from rumen processes to a range of scales (animal/herd/national) and assessed emissions of N_2O and CH_4 quantitatively for dairy cattle, beef cattle and sheep.

Table 4.1 (a). Dairy production: CH_4 and N_2O emissions in kg per cow per year from average milk yielding herd, and range for low / high yielding herds

	Average (kg/cow)	Emissions from Low / High yielding herds kg/cow
Methane (as kg CH_4)	119-132	101 / 162
Nitrous oxide (as kg of N_2O-N)	0.18	0.17 / 0.20

Table 4.1 (b) Dairy production: relative burdens of production of some alternative milk production systems (per 10,000 l milk)

Impacts/ resource use	Conventional	Organic	More fodder as maize	60% high yielders	20% autumn calvers
Primary energy used, MJ	25200	15600	23600	24200	23400
GWP_{100}, kg 100 yr $CO_{2\,e}$	10600	12300	9800	10200	10300
Land use, ha	1.19	1.98	1.18	1.14	1.21
N lost as N_2O-N (kg)	7.1	7.6	6.3	6.6	6.6

Table 4.2: Estimated baseline emissions of CH_4 and N_2O, (in kg per breeding animal*) from the herd/farm models and as t of CO_2 equivalents based on multipliers of 21 for CH_4 and 300 for N_2O

Animal type & management	CH_4	N_2O-N	CH_4 + N_2O-N converted to CO_2 equivalents (as tonnes)
emission kg (inc. followers)-1 yr-1*			
Dairy cows			
Extended Grazing	103.9-104.6	0.2-5	2.24-3.70
Conventional Intensive	113.9-115.2	0.4-12.2	2.51-6.08
Fully-housed Intensive	107.3-107.4	0.2-6.4	2.31-4.18
Beef cows			
Lowland	169.9-171.2	0.2-12	3.63-7.20
Upland	214-214.4	0.1-6	4.52-6.30
Sheep			
Lowland	25.1-25.1	0.02-0.7	0.53-0.74
Upland	20.2-20.2	0.02-0.4	0.43-0.54

Emissions relate to one adult dairy cow, beef cow or breeding ewe + the associated number of youngstock as calculated by applying typology-specific annual replacement rates. Ranges reflect different soil-climatic zones.

Values for CH_4 and N_2O are from Dragosits *et al.*(2008).

4.2 UK dairy

GHG emissions per unit of output vary with feeding system and intensity (being higher under organic feeding and lowest when maize is used in feeding) and with calving dates. Liquid milk models suggest an emission value of 1.06 kg CO_2-equivalent per litre (Williams *et al*, 2006), with values for methane and nitrous oxide shown in Table 4.1a and for energy, total CO_2e and nitrous oxide for different dairy farming systems in Table 4.1b. For example, changing from 80% to 20% autumn calving herds (i.e. more summer milk) reduces energy needs and GWP by about 5%, but there are 'pollution swapping' implications: nitrate leaching and hence eutrophication potential are increased by 8% and 3% respectively (Williams *et al*. 2006).

Dragosits *et al*. (2008) have modelled the potential of the relative impact of methane mitigation methods at the UK scale, and concluded that per-cow milk yield is the most important factor affecting methane emissions per litre of milk.

4.3 UK beef and sheepmeat

The summary findings reported for Defra project IS0205 (Williams *et al*. 2006) indicate average modelled GHG emission values of 15.8 kg CO_2-e per kg of beef and 17.4 kg CO_2-e per kg sheepmeat, as carcass deadweights (killing-out percentage values of 55 and 47 will approximately double these values when expressed as emissions per kg of meat). By comparison, the same study reports emission values of 6.4 kg and 4.6 kg CO_2-e for pig meat and poultry meat, respectively. As the UK beef industry is characterized by numerous finishing systems of various intensities, taking account of the finishing characteristics of purebred dairy calves, cross-bred calves from the dairy herd, and calves from beef suckler cows, a number of grass-fed and indoor feeding systems, as well as intensive cereal-based finishing, have been modelled. (The burdens are greater for 100% at suckler herd beef at 23.5 kg CO_2-e per kg of beef carcass weight reflecting the additional 'burden' of the suckler cow; further system-differences are considered in Chapter 5.)

Alternative scenarios for beef production show substantial difference between non-organic and organic production in the energy use, reflecting the difference between organic and non-organic grass, and assumed high and low reliance on clover, respectively (although in reality there is often high reliance on white clover in conventional production). However, this is associated with other environmental burdens from organic production, notably of nitrate leaching.

Table 4.3 Beef production: relative burdens of production of some alternative beef systems (per tonne) (source: Williams *et al.*, 2006)

Impacts/ resource use	Conventional	Organic	100% suckler	Lowland	Hill and upland
Primary energy used, MJ	27800	18100	40700	26800	29700
GWP_{100}, kg 100 yr $CO_{2\,e}$	15800	18200	25300	15600	16400
Land use, ha	2.3	4.21	3.85	2.28	2.41
N lost as N_2O-N (kg)	10.9	11.8	15.9	10.7	11.3

In addition to organic vs. conventional, three alternative beef production scenarios are shown in Table 4.3. The first considers producing all the calves by suckler cows rather than a proportion being the by-products of the dairy industry. The maintenance costs of lowland suckler cows are saved when dairy-bred calves enter the beef sector. This change increases all burdens by 40% to 60%.

The last two scenarios consider the alternatives of beef produced either on the lowlands or not on the lowlands. The results are similar, which is a reflection of the relatively poor land classes that are used in the lowlands for beef production.

Alternative sheep meat production systems also include organic as compared with conventional (Table 4.4). In the comparisons reported by Williams *et al*. (2006) the lower energy requirements and lower emissions of GHGs (as CO_2 equiv) per tonne of organic sheep meat is attributed to an assumed large clover proportion in the grass, whereas, with non-organic production the worst case assumption is made of no clover. One further alternative scenario considered is to increase the production of mutton, based on a revaluation of mutton to a price similar to conventionally produced lamb: this leads to a reduction in burdens by about 15%.

Table 4.4 Sheep production: relative burdens of production of some alternative sheep meat systems (per tonne) Williams *et al*. (2006)

Impacts/ resource use	**Conventional**	**Organic**	**Higher valuation of mutton**
Primary energy used, MJ	23100	18400	19400
GWP_{100}, kg 100 yr $CO_{2\,e}$	17500	10100	14600
Land use, ha	1.38	3.12	1.18
N lost as N_2O-N (kg)	8.9	13.4	7.6

Methane emissions expressed on a per-breeding-cow basis (as in Table 4.2) are greater from beef systems than dairy because they include the cow plus followers. They are also greater in upland than lowland situations because of the longer reproductive cycle. Conversely, methane emissions from lowland sheep systems were some 25% greater than upland systems on a per-ewe basis (Dragosits *et al*., 2008).

4.4 Comparisons between UK and other countries

Here we have focused on countries or regions that currently compete with the UK in the supply of ruminant products, including those that might have potential to increase their market share in the UK were the opportunity to arise (e.g. future curbs on UK livestock numbers in an attempt to reduce the UK 'national' GHG emissions by 'exporting' the problem to another country's inventory). Despite the use of IPCC methodologies some inconsistencies remain in reporting emissions and accounting differences, e.g. whether the emissions of the cow are included in beef production or whether any of the dairy cow's emissions are allocated to the calf, and the range of different systems that can operate within any one country. National inventories for agriculture also include emissions from other enterprises than cattle and sheep. However, one possible method for comparing countries is the trends in percentage changes of GHG emissions associated with agriculture as a sector (Table 4.5).

Table 4.5. Trends in agricultural emissions of GHGs (N_2O and CH_4 as Mt of CO_2 eq) for the UK and selected countries, totals and principal categories.

	2005	**1990**	**2005/1990 change as %**	**2000**	**2000/2005 change as %**
United Kingdom					
4A Enteric fermentation	15.9	18.4	**-15.6%**	17.4	**-9.3%**
4B. Manure management	3.8	4.4	**-17.4%**	4.1	**-9.6%**
4D Agric. soils	25.1	30.4	**-21.1%**	27.4	**-9.1%**
Total agric. Emissions	44.89	53.7	**-19.6%**	49.0	**-9.2%**
Ireland					
4A Enteric fermentation	9.0	9.3	**-3.2%**	9.4	**-4.0%**
4B. Manure management	2.6	2.7	**-3.3%**	2.7	**-4.2%**
4D Agric. soils	6.8	7.0	**-3.5%**	7.4	**-9.0%**
Total agric. Emissions	19.45	19.06	**-3.3%**	19.54	**-5.9%**
Netherlands					
4A Enteric fermentation	6.3	7.5	**-18.6%**	6.4	**-1.0%**
4B. Manure management	3.21	3.70	**-14%**	3.5	**-7.4%**
4D Agric. soils	8.61	10.8	**-25.3%**	9.9	**-15.2%**
Total agric. Emissions	18.17	21.98	**-21.0%**	19.78	**-8.9%**
New Zealand					
4A Enteric fermentation	23.9	21.8	**+8.8%**	23.3	**+2.6%**
4B. Manure management	0.80	0.628	**+22.0%**	0.70	**+8.5%**
4D Agric. soils	12.7	10.0	**+21.0%**	11.6	**+8.5%**
Total agric. Emissions	37.445	3.25	**+13.2%**	35.667	**+4.7%**

Source: IPCC data (http://unfccc.int/di/detailedby category.do)

The UK and Netherlands have experienced similar reductions in agricultural GHGs over the two reporting periods: 2005 cf 1990, and 2005 cf 2000 (Table 4.6). These changes reflect reduced livestock numbers, reduced N fertilizer inputs and changes in feeding regime, as well as improved on-farm management. The smaller reduction for Ireland reflects the more extensive reliance on forage in dairying. The increased emissions for New Zealand are more likely to reflect both increased cattle numbers and increased use of N fertilizers.

4.3.1 The Netherlands

Grassland-based agriculture in the Netherlands is strongly focused on dairying and has for many decades been among the most intensive and technically advanced in Europe. The Netherlands is a major exporter of dairy products and has potential to fill gaps in the UK market if UK dairy production were to contract further. The beef cattle and sheep sectors are relatively small at *c*. 150,000 and 1.36 m head, respectively. In recent years the country has had to introduce a range of measures to limit the environmental impacts associated with nutrient and gaseous emissions.

The trends, particularly in dairying, parallel those in the UK: between 1990 and 2005 total cattle numbers declined from 4.93 m to 3.98 m (-19.3%) and adult dairy cows from 1.88 m to 1.43 m (-24%). Milk yield per cow is higher than in the UK and rose 25% from 6050 kg in 1990 to 7568 in 2005. Improved genetic merit of cows combined with more intensive feeding regimes, as in the UK, underline these developments. However, there is a trend towards continuous housing of herds in response to the increasing proportion of larger herds and higher yielding cows (the proportion of herds with >70 cows having increased by over 50% since 2000 (Dutch Dairy Board, 2007). Compared with the UK the Netherlands has a smaller proportion of land supporting extensive grazing on permanent pastures and rough grazings, land types using for ruminant production that are recognized as an important carbon sink in the overall picture of UK grassland agriculture.

Enteric fermentation accounts for 35% of agricultural GHG emissions but methane from this source is reported to have declined by 16% between 1990 and 2006, largely as a result of fewer cows being kept. Methane from manure management is also reported to have fallen by 17% over the same period (though only by 8% for the cattle sector; the main reductions being from the pig/ poultry sectors). The trends in the dairy industry have led to increased methane from manure per cow, as a result of more time indoors and more feed per cow (from 27.7 kg CH_4 per head in 1990 to 38.3 kg).

Nitrous oxide emissions from manure management showed a small (5%) increase between 1990 and 2006, but the overall situation was an improvement as emissions from soils fell by 21% due to a 30% reduction in the use of N fertilizers over this period.

Climate change over the longer term could impact severely as rising sea levels threaten large areas of grassland in the Netherlands.

(Main references: Dutch Dairy Board (2007) and Van der Maas *et al*. (2008))

4.3.2 Republic of Ireland (ROI)

Livestock farming in the ROI has some features in common with the western parts of the UK, being predominantly grass based with over 80% permanent grassland (*c*. 4 m hectares) and the long grass-growing season enables annual grass production to exceed 12t dry matter/ha over much of the country (O'Mara, 2008). Beef farms are the most common, although dairy herds comprise 19% of farms; with a total cattle population more than 6.5 m, but only 4 m people, the ROI is heavily reliant on export markets including the UK (O'Mara, 2008). This dominance of the livestock sector is reflected in its national GHG emissions, with 27% attributed to agriculture and the largest source being enteric fermentation (EPA (2005) cited in Lovett *et al.* (2008).

Average milk yields of c. 4600 L/cow (O'Mara, 2008) are low compared with the UK mean of 6900 L/cow. This reflects the greater reliance on grazed grass, predominantly with spring calving, and with concentrate supplementation being generally confined to short periods rather than an integral part of the year-round feeding. Winter housing of dairy cows is based on slurry systems similar to the UK, with fewer opportunities for sourcing straw. The greater number of cows required to produce the same volume of milk does imply a greater potential emission of methane per litre of milk from the average herd in ROI than in the UK. Based on the modelled mitigation comparisons of Dragosits *et al*. (2008) a value of 15-18% more methane per litre is to be expected from a 4600L/cow herd than a 6900 L/cow herd.

Beef cattle are mainly kept under extensive rearing systems, with calves derived from the dairy herd or from specialist beef herds (as in the UK). It is difficult to determine the relative GHG impacts, because of the large amounts of variation in beef production systems in both the UK and ROI. Fertilizer N applications per ha are reported to be 'generally lower' in the ROI than UK, on both beef and dairy farms (O'Mara, 2008) but recent comparable data on fertilizer were not available to support this.

Several studies have sought to quantify GHG emissions from dairy cow production (e.g. Casey and Holden, 2005; Lovett *et al*., 2006; 2008) and from suckler beef systems (Casey and Holden, 2006) in ROI. Using a Life Cycle Assessment methodology for an average ROI dairy unit, Casey and Holden (2005) identified a total GHG emission of 1.50 kg CO_2-e per kg of milk. (This is a considerably higher emission than the average value of 1.06 reported by Williams *et al*. (2006) from the Defra IS0205 UK study) The authors note that scenarios leading to more efficient cows with extensive management, combined with eliminating non-milking animals could reduce GHG emissions by >28%, and that CAP-driven policies are likely to lead to higher output cows and help achieve these reductions. Lovett *et al*. (2008) comment on a number of anomalies that contribute to the low deliverable milk yields per cow: in addition to extensive grazing, many farmers maintain more cows than necessary and compensate by having a short lactation period motivated by the need to meet production quotas. These authors also cite a national inventory emission value of 1.383 kg CO_2-e per kg of 35 g/kg fat content milk which compares with values of less than 1.0 kg CO_2-e obtained in best practice (e.g. for the Moorepark and Kilmaley research station systems). As is noted by Lovett *et al*. (2006), the pasture-based system in ROI offers less potential to reduce annual GHG emissions through dietary manipulation unless the financial implications are addressed.

In the case of Irish suckler beef, a Life Cycle Assessment methodology was also used by Casey and Holden (2006) to quantify GHG emissions and CO_2-e per kg of animal liveweight was estimated at 11.26 kg/ year. (The authors considered that 'Irish beef has a similar GHG emission cost to beef produced elsewhere in Europe,' although it is a lower value than the average reported for the UK by Williams *et al*. (2006) in the Defra IS0205 study.) Because of the contribution of GHG from the cow is greater from beef-bred animals than from dairy-bred animals, they note that there is scope to reduce emissions from bovine production systems by adopting dairy-bred animals and thereby reducing the total number of bovines.

4.3.3 South America (Argentina, Brazil, Uruguay)

In much of South America, particularly Argentina, Uruguay and Brazil, a low-cost, export-oriented livestock industry operates, predominantly supplying beef. Land-use change to increase grazing, particularly in Brazil in recent decades, has been attributed as contributing significantly to a short-term CO_2 emission increase (FAO, 2006). Available information on GHG emissions trends in livestock agriculture is rather limited. Argentina attributes about 44% of its GHGs to agriculture, of which 67% is enteric methane (Hilbert *et al*., 2006). There are some features of management that provide qualitative indicators of the emissions relative to the systems of production that operate elsewhere.

First, the region is particularly important in world terms for its livestock, beef cattle in particular. Argentina has about 50 m cattle and 12.5 m sheep (Garbulsky and Deregibus, 2006), Uruguay has 11 m cattle, mainly for beef, and 10 m sheep (Berretta, 2006) and Brazil has 192 m cattle and over 14 m sheep, with beef exports alone worth over $US 1 billion per year (de Faccio Carvalho, 2006). Secondly, although in these countries there are variations in pasture quality and feeding systems, the reliance on unimproved grazings with generally little or no concentrate supplementation or use of conserved feed is a widespread feature. De Faccio Carvalho (2006) reports that until recently in Brazil the average age of beef cattle at slaughter was 48 months and the average age of a cow at first calving also was 48 months, and Berretta (2006) makes similar comments for Uruguay. This is now changing towards earlier slaughter, but there are still large differences compared with the UK situation. Systems that maintain large numbers of cattle in this way clearly result in a high proportion of metabolizable energy (ME) intake being used for maintenance, and when combined with forage of low digestibility value (as occurs through 'stockpiling' of seasonally surplus herbage), or periods when livestock experience temporary weight loss, there is clearly an increased likelihood that enteric methane emissions per unit of output will be relatively high. However, throughout this region there is scope for greatly improving livestock productivity and associated environmental standards. At present research into agriculture-related issues of GHGs and the application of GHG mitigation practices in the region appear to be limited (Barbaro *et al*., 2008).

4.3.3 New Zealand

New Zealand (NZ) has a population of only 4.3 m and its economy is heavily reliant on exports from its pastoral industry, which supports over 9 million cattle and 39 million sheep. Currently, NZ is a significant exporter to the EU with chilled and frozen meat products currently valued at NZ $1.6 billion (www.stats.govt.nz). Policy makers, farming interests and environmental groups in NZ are aware of the needs to reduce GHG emissions from livestock and to present to its overseas customers the impression of a farming economy that is addressing the needs to mitigate GHG emissions. NZ is also promoting measures towards greater sustainability and carbon neutrality, which includes land use changes measures to improve C sequestration (New Zealand's Challenge www.mfe.govt.nz).

The livestock industry is estimated to contribute almost 50% of the country's GHG emissions, mainly as methane from enteric fermentation (31%) and nitrous oxide (18%). In NZ, animal excreta deposited at grazing account for most of the N_2O emissions and are greatest in wet autumn and winter periods (de Klein *et al*., 2006). Although emissions can be lowered by reduced autumn grazing and use of field pads (standings), the general reliance on year-round grazing undoubtedly can exacerbate the N_2O problem on some soils. Although farm-scale N_2O mitigation strategies can be identified; researchers have noted that existing

IPCC methodology cannot easily account for reductions in N_2O emissions following their adoption (Clark *et al*., 2005; de Klein *et al*., 2006).

Two reports produced by the Agribusiness and Economic Research Unit of Lincoln University, NZ, present comparative estimates of the relative efficiency, in terms of energy and GHG emissions, of the UK and NZ dairy and sheep meat sectors (Saunders *et al*., 2006; Saunders and Barber, 2007). Information from summary tables is given in Table 4.6 below.

Table 4.6. Comparison of NZ and UK dairy farming GHG emissions (from Saunders and Barber, 2007)

	kg CO_2 eq/ha		kg CO_2 eq/kg milk solids	
	NZ	UK	NZ	UK
CO_2				
(from energy)	1145	2825	1.37	3.47
CH_4				
Fermentation & manure management	5320	5310	6.36	6.52
N_2O				
Direct emissions N fert to soil	320	815	0.39	1.00
Direct emissions N excretion to soil	1360	1150	1.63	1.42
Indirect emissions	695	1400	0.84	1.73
Total (based on 85% allocated to milk)	**7530**	**9775**	**9.01**	**12.01**

The authors concluded that overall the GHG emissions per kg of milk were >30% greater in the UK than in NZ. Our analysis suggests that the basis for accounting for these differences does not stand up to scrutiny. While some of the differences in nitrous oxide are related to the higher use of fertilizer N on UK dairy farms, it is less clear whether the indirect emissions in NZ fully take account of dietary excretal N derived from biologically fixed N from clovers. In the case of methane the report attributes considerably lower methane emissions per cow for NZ cows than the UK inventory values of Baggott *et al*. (2007) which it uses in its comparison (79.4 vs 103.5 kg CH_4 per head, respectively for NZ and UK). These differences do not seem consistent with the differences in cow diets between the two countries. However, most of the total difference in terms of kg CO_2e /kg milk solids is explained by CO_2 emissions as energy use: the NZ dairy sector was attributed only 42% that of the UK. Part of this was explained by the greater use of diesel fuel in the UK for field operations such as forage conservation, but indirect energy embedded in fertilizer N and particularly in feeds (silage and concentrates), of which there is greater use in the UK, account for most of this difference. This comparison seems flawed, notably in view of the apparent double costing of the energy in farm fuel used to conserve feed for silage as well as the energy value of the resulting conserved feed.

The report of Saunders *et al*. (2006) includes a comparison of the NZ sheep industry with that for the UK and focuses only on energy use and CO_2 implications (nitrous oxide and methane are not considered), the study seeking to address the food miles issue. Again, while a full critique has not been undertaken, it is apparent that the main finding that the kg of CO_2 per tonne of lamb carcass are 4 times higher in the UK (2849 for UK cf, 688 for NZ) are based on UK inputs of diesel fuel, fertilizer N and concentrates which are not representative of UK sheep production in general because of its reliance on low input upland grassland.

5. Respective emissions balances of the various intensive and extensive systems of dairy, beef cattle and sheep production in the UK

Summary
The complexity of different livestock systems and sub-systems can make comparisons of emissions particularly complex. To date few studies have been undertaken to determine the importance of regional or management-related differences in GHG emissions and differences in GHG emissions in relation to farming system, such as organic versus conventional farming, are inconclusive. The systems that characterize a large proportion of the UK's Less Favoured Areas are associated with low inputs of mineral N fertilizers, low stocking rates and low N excretion, and therefore low N_2O emissions per ha of land; however, where these systems have a long production cycle based on beef cows, emissions, particularly of enteric CH_4, will be greater per unit of output (but not necessarily on a per-ha basis). This also needs to be considered against the importance of a large proportion of LFA land in delivering ecosystem services.

In the UK improved forage genetic resources and knowledge and technologies for silage making and feeding, and of grazing management, have contributed to improved nutritional value of grazed and conserved forage enabling higher milk yields per cow and lower CH_4 emissions per litre of milk. UK beef production, and increasingly also lamb production, is mainly carried out over a short production cycle; this contributes to reducing the GHG emissions per animal and thus per unit of output.

5.1 Dairy systems

The 18,000 farms with dairy herds in the UK span a range of stocking densities, milk yields and input levels, although relatively few can be considered as extensive systems apart from some organic herds. Systems differences that can affect GHG emissions are also related to time of calving and of feeding regime. Comparisons have been made for conventional vs. organic systems. In addition there are a number of modelling-based studies which take account of N surpluses.

The Defra study IS0205 (Williams *et al*. 2006) includes modelled comparisons of low, average and high milk yielding herds for organic systems and for non-organic systems based on both autumn calving and spring calving. The outcomes indicate that methane emissions per cow are greater with spring-calving than autumn-calving herds, and that they are greater in high yielding cows. Nitrous oxide emissions are also greater for the high yielding cow but are not affected by calving date and no differences between organic and non-organic systems (See Table 5.1).

Table 5.1: Relative emissions of methane and nitrous oxide from different dairy systems

	Non-organic milk herd (autumn calving)			Non-organic milk herd (spring calving)			Organic milk herd		
	Low	Average	High	Low	Average	High	Low	Average	High
Methane as kg CH_4	101	119	150	113	132	162	119	126	143
N_2O as g N_2O-N	168	182	202	168	182	202	163	182	200

Source: Williams *et al*., 2006.

The modelled outcomes from the same study shows that the primary energy used, and GHG emissions, expressed per 1000 L of milk produced, differ between organic and the average non-organic systems: lower energy input to the organic (related to fertilizer use differences, though the effect may be based on extreme values that assume no N fixation vs. high N fixation), and about 16% greater GHG (CO_2 e) emissions from organic dairying (See Table 5.2). The outcomes summarized in Table 5.2 also indicate the potential GHG emission reduction from including maize in the diet, and from including a proportion of high yielding cows or a manageable number of autumn calvers.

Table 5.2: Energy inputs and emissions from various dairy systems (per 1000L of milk)

	Non-organic	Organic	With 20% fodder as maize	With 60% high yielding cows in herd	With 20% autumn calvers
Primary energy used (MJ)	25200	15600	23600	24200	23400
Total GHG emission (CO_2 eq) kg	10600	12300	9800	10200	10300
N_2O-N emission kg	7.1	7.6	6.3	6.6	6.6

Source: Williams *et al*. (2006)

The relative duration of the outdoor grazing and indoor housed periods of dairy cows also has implications for GHG and other environmental emissions. Webb *et al*. (2005), who were primarily addressing this issue in relation to ammonia emissions, noted that extending the grazing season to reduce ammonia loss would increase nitrate leaching with potential to indirectly increase indirect nitrous oxide emissions.

5.2 Beef production systems

Differences between non-organic and organic beef and sheep systems are less pronounced and more inconsistent than between organic and non-organic dairy systems, largely because there are a large number of beef and sheep farms operating extensively, with low fertilizer inputs, and many lowland organic beef farms have associated arable production. Farming systems differences in GHG emissions from beef production are related to whether the calves are produced from specialized suckler cow herds (in which case there is the GHG 'burden' of the cow to be included), or from dairy cows (when some or all of the GHG 'burden' of the cow is attributed to milk production). Systems differences also arise from the feeding and finishing regime (grazed grass/silage/cereal) and the time taken for the animal to reach its target slaughter weight.

The Defra IS0205 study (Williams *et al*., 2006) includes modelled comparisons for the total GHG, primary energy and methane and nitrous oxide emissions from a range of beef systems (see Table 4.3 in the previous section). The higher GHG emissions (CO_2e) of the suckler-bred system reflect the higher methane and nitrous oxide emissions associated with including the emissions from the suckler cow. Methane emissions were lowest from cereal finished beef and up to 50% higher with finishing at grass.

5.3 Sheep production systems

The complexity of the UK sheep system, with the interdependence of the upland and lowland flocks, makes systems-difference comparisons of GHG emissions rather problematic. There is clearly scope for using emission factors from different stages in the lamb production cycle to calculate these at a farm-system level but we have not come across this in the literature. The Defra IS0205 study (Williams *et al*., 2006) notes that for organic sheep systems N_2O emissions are higher from organic systems, but that the total GHG emissions are lower than for non-organic lamb production, due to differences in primary energy (assumed here to be based on an 'upstream' emission through fertilizers on the non-organic).

5.4 General considerations

Few studies have been made to determine the importance of regional or management-related differences in GHG emissions. In a one-year measurement study of paired-farm systems (organic and conventional) in England and four European countries (Austria, Denmark, Finland and Italy) it was reported that nitrous oxide emissions were higher (expressed on a per-ha basis, though not on a per-unit-output basis) under conventional than organic in four of the five countries investigated; however, these differences were related to N inputs (regression showing that 1.6% of N inputs were lost as N_2O (Petersen *et al*., 2006). This value is higher than the 1.25% lost from total N inputs that is used in the IPCC methodology. Other studies (e.g. Sneath *et al*., 2006) have reported annual CH_4 emissions from uncovered slurry stores were 19% greater from non-organic than organic farms, when expressed in terms of emissions per kg of milk produced, but with large uncertainties. The more aerobic FYM from organic dairy farms emitted only 10% of the CH_4 emitted by stored slurries on a per kg of milk basis.

6. Research findings on measures to reduce net GHG emissions and the potential for further adoption by the industry in the UK

Summary
There are opportunities for reducing the emissions of GHGs from ruminant agricultural sources, as well as through enhancing removals and through displacing emissions (e.g. through the use of CH_4 from livestock slurry in anaerobic digestion). It is further important to recognize the importance of the soils and vegetation of the UK's grasslands and rough grazing areas as a carbon store, and their possible role in methane mitigation, to ensure future management does not lead to further net carbon dioxide emissions. On cropland there is a need to increase the carbon storage of soils that currently have low soil organic matter.

Research has identified a number of potential GHG reduction strategies than can be implemented but these are not always cost effective for farmers. Many research challenges and knowledge gaps remain to limit GHG emissions and these need to be given a high priority at an international level, focusing on reducing N excretion from livestock and manipulating rumen ecosystems in order to limit the main sources of N_2O and CH_4 respectively.

In general, the most cost-effective and environmentally effective mitigation options are those which combine practices which deliver reduced GHG emissions with other environmental, animal-welfare and economic /production-related targets, of which anaerobic digestion is an example. Some measures which reduce emissions of one GHG or pollutant may increase that of another (problem of pollution swapping) and outcomes need to be evaluated on a site-specific basis. When considering mitigation options it is important to distinguish between the maximum biophysical potential, the economically constrained potential and the socially/politically constrained potential of mitigation actions.

6.1 Introduction

Smith *et al*. (2008) have recently reviewed opportunities for mitigating GHG emissions in agriculture, and recognize three broad categories:

(1) Reducing actual emissions (of CO_2, CH_4 and N_2O), e.g. through managing more efficiently the flows of carbon and nitrogen, especially through more efficient use of N fertilizers and other N inputs and managing livestock in ways that reduce methane emissions.

(2) Enhancing removals, especially through practices that lead to increased photosynthetic input of C, or that slow down C losses that occur through respiration or fire, thereby leading to net C sequestration of atmospheric CO_2, such as include conversion of cropland to permanent grassland or agro-forestry.

(3) Avoiding or displacing GHG emissions. Crops and agricultural residues (e.g. slurry) used as biofuel displace fossil energy or may convert an emission with a high GWP (methane) to a lower one (CO_2) as in anaerobic digestion. Avoiding cultivation of permanent grassland and non-agricultural vegetation, especially on peaty soils.

Smith *et al* (2008) can be considered as an awareness raising and agenda setting approach to the underlying science. However, in terms of identifying practical approaches that individual farmers, policy makers and technology deliveries can make, a recent review for Defra of research has identified best practices for reducing GHGs from agricultural land (IGER and ADAS, 2007) with methods that were classified into three broad categories:

1. Management practices and agronomy – where farmers improve on what they already do.
2. New or different technology – where farmers and land users make further changes.
3. Structural changes to the farming business – where farmers would need to make bigger changes in land management and manure management.

The eight main mitigation methods identified were:

1. Do not exceed crop N requirements (RB209/PLANET).
2. Make full allowance of manure N supply (MANNER).
3. Spread manure at appropriate times/conditions.
4. Increase livestock nutrient use efficiency.
5. Make use of improved genetic resources.
6. Make use of anaerobic digestion technology for farm manures and slurry.
7. Change land use - to establish permanent grasslands/woodlands.
8. Change land use - to grow biomass crops.

Methods 1 to 3 fall into the management practices category, 4-6 into the different technology section, and 7-8 into the structural changes category. This report did not consider measures that might reduce fossil fuel use on the farm (and thus reduce CO_2 emissions) but it did consider methods that have future potential subject to further research or regulatory changes.

These included:

1. Adapting reduced tillage.
2. Taking stock off wet ground to reduce N_2O.
3. Changing from solid manure to slurry systems to reduce N_2O (though CH_4 would increase).
4. Use of hormones and increased milking frequency (to reduce N_2O and CH_4).
5. Use of nitrification inhibitors to reduce N_2O.
6. Improved mineral fertilizer N timing strategies reduce N_2O.
7. Use of plants with improved N-use efficiency to reduce N_2O.

The following paragraphs summarize research findings on measures in relation to their potential to reduce net emissions of each of the three main GHGs associated with ruminant production, and the potential for enhancing removal and avoidance and displacement of emissions. An integrated approach also considers the whole production chain.

6.2 Measures for reduction of greenhouse gas emissions

6.2.1 Measures to reduce carbon dioxide emissions

Reduced direct emissions can be achieved through reduced or more efficient use of mechanical operations (and thus of fuel), and indirect (pre-farmgate) CO_2 emissions can be cut by reducing the inputs of artificial fertilizers. There are currently considerable variations in net emissions of CO_2 during fertilizer production depending on the methods used and the efficiency of the plant (Wood and Cowie, 2004) but Dawson (2008) notes that considerable improvements in efficiency of energy use have been made in recent years.

However, what is of paramount importance is maintaining the store of organic carbon present in soils and vegetation on UK farmland and associated habitats. The recent report of Natural England (2008) has highlighted the importance of long term vegetation in this context. Maintaining grassland as long-term pastures enables increased soil C storage from the decomposition of roots and shoot litter (Soussana *et al.,* 2004). However, there is a potential trade-off between maintaining soil C in long-term grassland, and resowing with nutritionally superior grasses or other forages that might help reduce enteric methane emissions compared with lower value forage. There is a need for further research to quantify the overall GHG balance of this choice on a site-specific basis. There is also currently considerable interest in genetic improvements in forage species with goals that include lower GHG emissions (Abberton *et al*., 2008).

In the UK there has been a reduction in the frequency at which UK grasslands are cultivated and resown. The introduction of agri-environment schemes from the late 1980s and the more recent requirement of an environmental impact assessment before ploughing or improving permanent pastures may have deterred some further ploughing of remaining old pastures. However, it is also widely recognized that permanent grassland can be highly productive if well managed, and on many livestock farms good quality permanent swards are highly valued especially under grazing (Hopkins, 2000). Despite improvements in the feeding value of modern grass varieties, the Seed Traders Annual Returns showing quantities of grass seed sold, and the data from Defra June agricultural surveys which record areas of grassland under 5 years, both suggest that annual grass-to-grass reseeding rates, have been considerably lower in recent years than say 20-30 years ago. In the 1970s, national grassland surveys found around 25% of the enclosed grassland in England and Wales was under 5 years old (Green, 1990) compared with about 15% at the present time (data from Defra June agricultural survey).

High organic-matter soils (especially peaty soils) are a particularly important carbon sink and their management to avoid C loss will be essential (Natural England, 2007, 2008, 2008b). Measures to avoid drying out are equally important in this context, as is the avoidance of fires, on heathlands for instance. Most peaty grassland areas, including moors and heaths, have been eligible for agri-environmental schemes since the late 1980s.

6.2.2 Measures to reduce nitrous oxide emissions

Nitrous oxide emissions from agriculture are calculated from N inputs and emission factors based on the IPCC methodology (IPCC, 1997) and according to this approach agriculture in the EU15 is estimated to contribute 65% of all anthropogenic N_2O emissions (European Environment Agency, 2001). In the UK, Chadwick *et al*. (1999) reported that fertilizer N use on conserved grassland is the main source of N_2O from dairying (25.3% of total) followed by manure storage and improving the efficiency of N use is crucial to reducing this emission.

N_2O emissions can be reduced by implementing practices aimed at enhancing the ability of the crop to compete with processes that lead to the escape of N from the soil-plant system (Freney, 1997). For instance, there are several methods for increasing the efficiency of the crop to remove mineral N from the soil. Simulations using the NGAUGE model suggest it is possible to reduce fertilizer N use by 33% without loss of herbage yield from grassland, and a more even seasonal distribution of fertilizer N also shown to result in a lower N_2O : N_2 ratio (Brown *et al*., 2005). Other approaches include optimizing methods and timing of applications (Dosch and Gutser, 1996), using ammonium-based fertilizers rather than nitrate-based ones (Dobbie and Smith, 2003a) and employing nitrification chemical inhibitors (Dittert *et al*., 2001; Merino *et al*., 2002; Macadam *et al*., 2003). Further improvements in fertilizer N use include tailoring the application rates and timings to the requirements of the crop, more accurate allowance for other N inputs, precision application using GIS-based systems that adjust rates within a field according to response potential, and greater use of forage legumes to replace mineral N. Given the dependence of N_2O emissions on microbially mediated transformations, a current breeding strategy under investigation at IBERS is based on preferential uptake of NH_4^+ by forage grasses to reduce the production of nitrate in the soil (Abberton *et al*., 2008).

Soil water-filled pore space is a controlling factor (Dobbie and Smith, 2003b) and increasing the soil aeration may significantly reduce N_2O emissions. Improving drainage would be particularly beneficial on grazed grassland (Monteny *et al*., 2006). A high proportion of the working soil drainage systems on UK grasslands were installed in the period 1940-1990, with many older schemes no longer functioning adequately, but further drainage work may conflict with other river basin management objectives including those under the Water Framework Directive. On imperfectly drained soils in particular, management that avoids compaction by traffic, tillage and grazing livestock may help to reduce N_2O emissions (Pinto *et al*., 2004).

Housing system and management will also influence N_2O emissions. Straw-based manure systems have been recognized as techniques to reduce ammonia emissions but they result in greater N_2O (and CH_4) emissions than slurry-based ones, mainly during the storage phase (Groenestein and Van Faassen, 1996; Yamulki, 2006). At the entire farm level the GHG emission reduction from daily (relative to 90-day interval) scraping, was reported to be 3.5-7.1% (Weiske *et al*., 2006) as well as having benefits for reducing ammonia emissions and improving hygiene standards in buildings. Minimizing the grazing period is likely to reduce N_2O emissions as long as the slurry produced during the housing period is uniformly spread. Livestock diets also affect the N_2O emissions from slurry subsequently applied to land: e.g., in experiments using slurries obtained from sheep fed either ryegrass, kale or lucerne the smallest losses of N_2O came from the ryegrass treatment (Cardenas *et al*., 2007).

6.2.3 Measures to reduce methane emissions

Several studies have formulated abatement strategies to mitigate CH_4 emissions. Mitigations aimed at enteric fermentation may be addressed at three different levels: dietary changes, direct rumen manipulation, and systematic changes (Jarvis 2001). The dietary changes involve measures which enhance the efficiency of feed energy use, an area which has potential implications for forage use in the future (Cardenas *et al*., 2007). Even assuming a constant percentage of methane loss, this strategy will decrease methane loss per unit of product and probably decrease CH_4 emissions in the long term (Johnson and Johnson, 1995). However, lack of understanding and potential concerns about the economic implications and uncertainties about side effects are likely to limit uptake in the short term.

A relatively natural way to depress CH_4 production is to manipulate the diet to give high rates of fermentation and/or passage through the rumen, affecting rumen volatile fatty acids (VFAs). These changes in VFA proportions have been associated with a decrease in the fibre content of the diet (e.g. by including maize silage). Ingestion of organic acids (aspartate, malate and fumarate) and yeast culture have been associated with reduced emissions in total

CH_4 per cow and also with beneficial increases in animal product (reviewed in Hopkins and Del Prado, 2007).

Research has demonstrated the potential of medium-chain fatty acids (MCFA) used either in esterified form (coconut oil, palm kernel oil or GM rape) or as non-esterified form (C12:0 and C14:0) to substantially reduce ruminant methanogenesis (Machmüller, 2006). Even at <3% in the diet, a 50% reduction in methane is possible. However, organic acids are not yet commonly used, and they may also trigger pH problems in the rumen.

The use of some plant extracts (i.e. tannins, saponins) has also been associated with CH_4 reduction (Sliwinski *et al.,* 2002; Hess *et al.,* 2003; Carulla *et al.,* 2005; Hu *et al.,* 2005; Puchala *et al.,* 2005). Dietary manipulation through feeding tannin-containing forages such as lotus (birdsfoot trefoil) has been shown to lower methane emissions from housed sheep (Ramirez-Restropo *et al*., 2005) and forage breeding strategies that lead to reduced methane emissions are likely to become increasingly important (Abberton *et al*., 2008). Agronomic and feeding trials the UK and elsewhere have shown there is potential for species such as birdsfoot trefoil both in grass-legume silage and in grazed swards (Sölter *et al*., 2007). Uptake has been minimal, largely due to seed availability of varieties adapted to UK situations and lack of knowledge and uncertainties about anti-nutritional effects (Teferedegne, 2000). For instance, in a study by Hess (2005), extracted tannins had a positive effect on feed rates and hence a possible reduction of CH_4 per kg product, whereas the use of shrub legumes rich in tannins resulted in decreased feed rates. Yeast culture, on the other hand, is a promising successful mitigation option as it is already in common use.

Direct rumen manipulation offers an alternative to dietary change; for instance, defaunation of protozoa decreases the number of methanogenic bacteria as an important proportion of rumen methanogenic bacteria are parasitic to protozoa (Takahashi, 2005). However, there are many drawbacks including risks of metabolic disorders. The ingestion of ionophores acts as propionate enhancers and hence increases the ratio of propionate: acetate. Their use is very limited as they are antibiotics. Some changes in the dietary fat contents of the ration have been described to reduce CH_4 emissions from ruminants (Johnson *et al.,* 2002; Giger-Reverdin *et al.,* 2003) as some fats alter the ruminal microbial ecosystem and, in particular, the competition for metabolic H_2 between the CH_4 and propionate production pathways (Czerkawski, 1972). Clearly, many research challenges exist before these approaches can be implemented.

Systematic changes involve identifying animal breeds which result in a reduction of CH_4 output per animal, though so far no clear evidence has been found (Münger and Kreuser, 2005). Increasing productivity per head (i.e. milk yield per cow), or increasing the number of lactations for which the average cow remains economically productive (i.e. optimizing the lifetime efficiency of the milking cow) would decrease CH_4 production per unit of milk. The most GHG-efficient herd management option would be to reduce the replacement rate to 30% and sell the surplus heifers for slaughter, giving a mitigation reduction potential of -11.2% (Weiske *et al*., 2006). However, this has farm-scale economic cost implications. Also, although more intensive forms of animal production tend to decrease total CH_4 output, they might not be compatible with other policy targets, including animal welfare considerations, both nationally and at particular farm-scale levels. An alternative approach that can enable dairying to deliver improved animal welfare together with reduced methane per unit of milk output, and meet economic requirements is the use of *Extended Lactation* as a production system whereby dairy cows are managed for increased lactation persistency and rebred to calve at around eighteen months rather than twelve; the emphasis is on modest daily yield sustained over a long period rather than on peak yield, enabled by simple management interventions (Knight, 2007).

Livestock manure is a significant source of atmospheric methane especially during liquid storage. In liquid manure (slurry) storages a surface crust may form naturally, or an artificial surface crust can be established beneath which there is potential for methane oxidation (Petersen *et al*., 2005). Other mitigations aimed at manure management include opportunities to decrease total CH_4 outputs from farming systems are limited to either increasing the O_2 supply to restrict methanogenesis, minimizing the release of CH_4 to the environment through lowering pH (Berg *et al*., 2006) or using anaerobic digesters to produce the CH_4 in a controlled environment and hence use it as a source of energy (section 6.4). This last technique could represent a sustainable option, and if the issues of high capital cost can be overcome this may become an important feature of future forage-based systems compatible with low CH_4 emissions without adversely affecting ammonia emissions (Amon *et al*., 2006).

Dragosits *et al*. (2008) modelled the potential of the relative impact of methane mitigation methods at the UK scale and concluded than only the method with a per-cow milk yield increase (of 30% more than the baseline) would result in a sizeable reduction in CH_4 emissions (-24%). The next most effective mitigation strategy was a high fat diet, which provides a 14% saving, followed by improved heat detection rate of cows at oestrus (-7%) and a high starch diet (-5%). Conversely, a reduction in the milk yield per cow by 30%, coupled with an increase in the number of cows to maintain national milk production, would result in a 15% increase in CH_4 emissions.

6.3 Measures for enhancing GHG removals

Agricultural ecosystems hold large amounts of stored C, mainly in soil organic matter and plant roots and leaf litter. Adoption of management practices that lead to increased photosynthetic input of C, or that slow down C losses that occur through respiration or fire, will lead to net C sequestration of atmospheric CO_2. Examples include conversion of cropland to permanent grassland or agro-forestry, establishment of unploughed buffer strips, new planting and maintenance of other farmland vegetation (hedges, trees, scrub etc.) and the addition of carbon as organic matter (animal manures, composts, sewage sludge) to soils can all contribute to the temporary removal, and in some cases to the long-term sequestration, of CO_2 from the atmosphere (Cannell, 2003; Freibauer *et al*., 2004; Smith, 2004; Smith *et al*., 2008; Natural England, 2008). However, some management measures (zero tillage, adding sewage sludge to soils) that lead to increased CO_2 sequestration can have environmental side effects including increased N_2O emissions (Freibauer *et al*., 2004).

The estimates of Cannell (2003) give a ‘realistic potential’ biological carbon sequestration capacity for the UK of 3-5 Mt C annually over a 50-100 year period, but suggest a ‘conservative achievable’ capacity of 1-3 Mt. These values represent only 0.5-3% of the total UK carbon equivalent emitted annually as CO_2 but they do indicate a potential to offset a significant proportion (up to 40%) of UK agriculture’s share of GHG emissions. Although Cannell (2005) also suggests greater ‘theoretical potential’ carbon sequestration capacity (30-70 Mt C per year) based on ‘aggressive afforestation’ of agricultural land, this would have the effect of reducing the area for UK food production and also conflict with other land use objectives and the delivery of other ecosystem services

Research papers on measures for enhancing atmospheric methane removal are considerably fewer than on carbon sequestration. However, the evidence that semi-natural vegetation and upland soils in particular are an important sink for methane (Boeck and Van Cleemput, 2001) warrants further consideration in terms of quantifying CH_4 oxidation capacity of the UK's rough grazing areas and, at a smaller scale, the areas of woodland and associated vegetation that form an integral part of the UK farmed landscape. Boeck and Van Cleemput (2001) also suggest that UK grassland soils have a methane oxidation capacity of 16,600 t CH_4 /year (if correct, we estimate this as equivalent to about 18% of the methane attributed to UK agriculture). UK grassland's CH_4 oxidation capacity is higher than in most of the EU due to its high proportion of land used for livestock grazing, particularly of extensive grazing on permanent pastures and semi-natural vegetation especially in the LFAs.

6.4 Measures that avoid or displace greenhouse gas emissions

Crops and agricultural residues (e.g. livestock slurry) when used as biofuel displace fossil energy or may convert an emission with a high GWP (methane) to a lower one (CO_2) as in the case of biogas production by anaerobic digestion (AD). Calculated model scenarios for AD have demonstrated that this can be a GHG-efficient mitigation option. In one study, modelled scenario emissions were reduced by up to 96% based on reduced actual emissions of CH_4 and N_2O as well as the effect from displacement of CO_2 reductions from fossil fuel that would otherwise be used (Weiske *et al.*, 2006). The use of livestock slurry in AD also allows the utilization of other non-farm (e.g. food industry) wastes as AD 'co-feed' which might otherwise contribute to methane emissions if disposed of differently. A number of reports to Defra have outlined the possibilities for these measures to be adopted as part of the overall package of reducing GHG emissions and addressing future energy needs (e.g. Warwick HRI, 2007). In this context the role of woodland areas on farms to supply biofuel as logs or wood chips for local heating systems is considerable. There have been considerable improvements in combustion technologies in recent years and good demonstration projects in place (Defra and Forestry Commission, 2006). The need to overcome problems of supply chains was identified by the Biomass Task Force report to government (Defra 2005) along with ambitious targets to enable biofuels to displace fossil carbon fuels, but this is a clear example of an opportunity that many livestock farms that have land under woodland of suitable for woody plantations to 'offset' at least some of their own GHG emissions through utilization of locally produced fuel to replace fossil fuels.

6.5 An integrated approach

The foregoing paragraphs have reviewed the evidence base showing that there are many practical and potential solutions that can help reduce these impacts of ruminant production on net GHG emissions. However, while adaptations such as optimizing nitrogen inputs are cost-effective 'win-win' solutions, some management changes imply technical improvements and increased costs that may be a barrier to adoption. Smith *et al.* (2005) distinguish between the maximum biophysical potential, the economically constrained potential and the socially/politically constrained potential of mitigation actions. Generally, the easier it is to adopt a new practice, and/or to modify existing behaviour, the more likely that the change in behaviour will occur. However, it is important to recognize that barriers to implementation exist in the form of transaction costs, uncertainty, knowledge and skills gaps, and availability of support (Lobley, 2008).

The modelling study of Weiske *et al.* (2006) noted that potential measures and strategies scaled up to the level of European regions show a combined effect of a 25% to >100% reduction in GHG emissions compared with the baseline model farms. The authors further concluded that a full implementation of the most effective strategy could result in very considerable GHG emission reductions, up to 50 Mt of CO_2-e per year for conventional dairy farms (based on the ‘Atlantic’ areas of Europe, including SW England). In general, the most cost-effective mitigation measures are those which simultaneously reduce emissions from several GHGs across the whole production chain, as with biogas from AD which can reduce farm-level methane and nitrous oxide and substitute for fossil fuel, while providing beneficial soil compost.

UK agriculture is also subject to other pressures in addition to the need to reduce GHG emissions, and it is required to deliver public ‘goods’ besides quality food, including environmental (landscape, biodiversity) maintenance and enhancement, socio-economic benefits, high levels of animal welfare and to play a key role in achieving rural sustainability. Progress in achieving these and future targets are highlighted, for example, in the Milk Roadmap (DSCF, 2008). However, the multiple roles of UK agriculture are thrown into sharp relief in the context of reducing GHG emissions. Thus, whilst a specific action may be targeted towards a reduction in a particular GHG, many actions can have positive or negative impacts on other GHGs as well as wider implications. For instance, peat restoration can lead to significant carbon savings but can also be associated with short term increases in CH_4 emissions, alongside improvements in biodiversity and other environmental services, including water quality and, possibly, flood risk mitigation (FRM).

Smith *et al*. (2007) argue that such ‘co-benefits and trade-offs’ may vary over space due to different underlying conditions and due to the way a mitigation action is implemented. Significantly, they go on to argue that, given the ‘complex, interactive effects on the environment’ stemming from individual GHG reduction actions that ‘the merits of a given practice … cannot be judged solely on effectiveness of mitigation’ (p.9). Given the complexity of the issues involved, identification of ‘win-win’ strategies that produce reductions in emissions as well as other benefits requires development of appropriate modelling systems together with the acquisition of field and farm data (Scholefield *et al.,* 2005). Modelling studies have been developed to:

(i) assess the effects of different dietary strategies on the sustainability of a grassland system (del Prado *et al.,* 2006a; del Prado and Scholefield, 2008),

(ii) evaluate the economic cost for implementing mitigation strategies for GHGs (Jarvis, 2001),

(iii) evaluate the impact of NO_3 leaching abatement measures on N_2O, NH_3 and CH_4 emissions (Brink *et al.,* 2005; del Prado *et al.* 2005),

(iv) assess successful mitigation strategies for GHGs (Schils *et al.* 2005),

(v) evaluate not only environment (N_2O, CH_4, NH_3, NO_3^- and P leaching) and economics, but other attributes which define the sustainability of a farm del Prado *et al*. (2006) .

For instance, using the $SIMS_{DAIRY}$ model (del Prado *et al*., 2006; del Prado and Scholefield, 2008) environmental losses, milk yield and milk properties have been compared for two typical dairy farms in the UK (2 LU ha^{-1}, 30.5 ha grazed grass, 16.5 ha cut grass and 3 ha maize) which differ only in terms of their past grassland management. Whereas the baseline farm had a history of long-term grassland with old swards (>11 years), the second farm had a history of short-term grass leys with new swards (2-3 years). The baseline farm’s past history would offer more opportunities for C sequestration than would the history of the second farm. However, if we compare the predicted environmental losses of the $SIMS_{DAIRY}$ model, we find that NO_3^- leaching (24%) and N_2O (6%) per L of milk were significantly lower from the second farm than from the baseline farm. Milk yield and milk properties (butterfat and protein) were also slightly improved, which may have a modest impact on the economy of the dairy farm.

In a further development of the model, Del Prado and Scholefield (2008) suggest that genetic-based changes offer greater scope than management-based ones to improve sustainability to an acceptable level (which includes GHG reductions). Those which decrease the crude protein content in plants and increase the dietary N partition to milk in the cow seem to be feasible in the near future without associated pollution swapping implications. The authors suggest that only measures which include genetic changes that result in a greater feed N use efficiency and increased cow fertility will also deliver economic gains, so animal breeding strategies need to be directed on achieving these traits in combination. Collectively, these findings provide some suggestions for the development of beneficial management practices that could, in the future, be promoted and supported under agri-environmental schemes.

7. Likely future impacts of climate change on the UK ruminant livestock industry

Summary

The effects of future climate change for the ruminant production industry in the UK, under low-medium GHG-emissions' scenarios to the 2050s, appear to be within the response capacity of the UK farming industry. Good production conditions are likely to continue for meat and dairy production in most parts of the UK where ruminant livestock farming is currently important. GHG emissions increases at the higher end of forecasts, especially in the longer term, carry greater uncertainties. Importantly, there are also issues of climate change affecting food security in some other parts of the world where livestock farming is important, and this implies reduced opportunities for the UK to source meat and dairy produce from imports. If areas such as southern Europe become unsuitable for livestock production, at a European level the UK has potential to take up some of that shortfall.

7.1 Key impacts

Previous sections of this report have summarized the effects of UK ruminant livestock and associated agricultural practices on GHG emissions and sequestration, the variation between livestock enterprises and systems of production, and the existing and potential measures for improving the environmental impact of ruminant production particularly through reducing CH_4 and N_2O emissions. There is clear evidence showing that emission reductions have taken place during recent years through greater environmental awareness and in response economic drivers, and that there is potential for further net GHG emission reductions. Thus, we need to consider the situation in which future mitigation measures by the ruminant livestock industry might be implemented by an industry that, compared with the present, could be very different in a few decades time largely due to climate change-induced effects.

The general consensus, based on the climate change scenarios for the UK (Hulme *et al.*, 2002) and on experimental investigations, modelling studies and reviews on how the industry might be expected to respond, is that under low-medium GHG-emissions' scenarios, in the timescale to the 2050s, good production conditions will continue for ruminant livestock production in most parts of the UK where livestock farming is important. The effects and potential problems as summarized in Table 7.1 are within the response capacity of the UK farming industry.

However, emissions increases at the higher end of forecasts, especially in the longer term, carry greater uncertainties. These uncertainties are of particular concern as they will affect food security in some other parts of the world where livestock farming is important. Areas of southern Europe may no longer be able to maintain forage-based livestock (IPCC 2001b; Olesen and Bindi, 2002). At a European level the UK has potential to take up some of the shortfall.

Table 7.1 Key effects of climate change on UK grassland and livestock farming

- Longer grass-growing season with potential increase of yields in summer. Challenges for out-of-season utilization due to soil saturation and increased poaching damage in wetter winters. This would require an increase in the amount of forage conserved.
- Autumn cultivations for grass reseeding will be affected by increased autumn rainfall, though the reduced flexibility of sowing dates not as critical as on arable farms. Land with well-structured soils will retain resilience to the effects of drought and heavy rain, but poorly structured soils will be vulnerable.
- Adaptations to summer drought required (irrigation if available, or a shift to non-grass feeds or other forage production e.g. larger areas for maize forage or 'whole crops'. Other options of buffer feeding or in-situ grazing of 'fodder banks'. Area with forage legumes likely to increase favoured by warmer spring temperatures that lead to improved N fixation, and deeper rooting legume species adapted to summer rainfall deficits.
- Potential problems with new weeds, pests and diseases, or from existing ones being favoured by environmental change. Unpredictable species change in semi-natural grazings and permanent pastures.
- Increased animal welfare concerns associated with heat stress and reliability of drinking water supplies. Increased risk of wildfires, particularly on moorland and other rough grazing areas.

Source: Report to Defra on project CC0366 (IGER, 2004)

7.2 Regional and sectoral effects

Within the UK, although climate change effects are likely to be accommodated through management responses there are potentially serious problems at a local level, especially on low lying coastal land at increased risk of marine inundation and in areas vulnerable to flooding or storms. Interactions between soil type and both drought and heavy rainfall also affect vulnerabilities at a local level (Defra project CC0359: Defra, 2003).

Both the type and extent of grassland therefore can be expected to change as a result of climate change. A modelling study which incorporated the effects of climate change elsewhere in the world on UK agriculture, as well as the effects of changes within the UK itself, was examined for various model scenarios (Defra Project CC0320). It was concluded that agricultural land use was likely to change more in the lowlands, with an increase of cereal production in the west and north. In a different integrated model, a general increase in forage yield was also predicted, particularly for western areas, as well as a marked northward shift in forage maize, continuing an existing trend (Defra Project CC0315). Future changes in CO_2 concentrations are an additional factor that may interact with changes in temperature and water availability: enhanced CO_2 can modify the responses to temperature and water, and lead to considerably increased dry matter yield, though uncertainties about forage quality the extent to which these benefits are transient or sustainable over the long term (Defra, 2003; Harmens *et al.*, 2004). A study which modelled the effects of a range of future climate change scenarios for different livestock farming areas that represent the main dairy, beef cattle and sheep farming areas reported the following:

Dairy farming areas: In western Britain (west Wales, south-west England, and the North-West / north-west Midlands), modelled outputs showed a net increase in grass DM yield under two fertilizer N rates (250 kg N/ha and 180 kg N/ha/year). On an annual basis this amounted to increases of *c*. 10-15% under the 2020s scenarios and 20-30% under the 2050s high emission scenario, cf. with 1999 baseline data. Grass-white clover swards also showed an increase under the climate change scenarios modelled, but skewed towards increased yield early in the season and reduced yield later, and on red clover and lucerne showed increases throughout the growing season. In the drier areas of Britain (Midlands/South East) where dairying is still practised, herbage production under the present (baseline scenario) is generally less than the more oceanic western areas. It is suggested that areas such as these are not likely to lose their competitive ability to grow forage resources to support dairy farming.

Lowland beef and sheep farming areas: These also showed a net benefit in terms of increased DM yield for silage production, but they experienced a reduction in the number of grazing days, particularly at the end of the grazing season and especially under the 2050 high-emissions scenario. These trends indicate there may be need to conserve more forage for indoor feeding, or for outdoor supplementation at pasture, under the conditions associated with the climate change scenarios examined.

Upland beef and sheep farming area: As represented by areas in Cumbria and Pennine Durham, there were also increases in forage yield in response to the modelled climate change scenarios - typically in the order +10-25% of DM production compared with the 1999 baseline. However, some reductions in the number of grazing days, as for lowland systems, indicated there may be need to conserve more forage for indoor feeding. There are few other agricultural land use options in these areas, but changes in climate may provide some opportunities for cropping on some of the better and more manageable sites.

8. Summary and Implications

Key findings

Summary

- Total UK agricultural GHG emissions have decreased by 17% since 1990.
- Methane (CH_4) emissions have decreased by 52% since 1990, through a combination of reduced livestock numbers and more efficient feeding.
- There is evidence that UK ruminant agriculture compares favourably with other countries, and that the rate of reduction of total agricultural GHGs in the UK in recent years has been similar to, or greater than, several competitor countries.
- There is a wide degree of uncertainty over the exact levels of emissions of N_2O and evidence suggests that UK emissions are lower than those based on the IPCC methodology. The development of more precise GHG inventories will address these uncertainties.
- Increases in milk yields and technical feed improvements have been associated with reductions in GHG emissions per litre of milk.
- The UK beef sector has also benefited from technical feed improvements
- UK beef production, and increasingly also lamb production, is mainly carried out over a short production cycle; this contributes to reducing the GHG emissions per animal and thus per unit of output
- Livestock in upland and marginal areas may be associated with high CH_4 emissions per unit of output (due to relatively low quality forage) but low emissions per ha. Many of these areas also have a role in CH_4 capture, and their management via low intensity beef and sheep grazing is also important in achieving wider agri-environmental objectives.

Climate change is a subject of global environmental concern. The UK has seen a progressive strengthening of political resolve to address the problems associated with emissions of greenhouse gases (GHGs), principally carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Although agriculture globally, and ruminant livestock production in particular, is a net contributor to GHG emissions, generalizations about impacts on climate change often fail to distinguish between different systems of production, advances in technology, and the role of extensive grazing lands in contributing to ecological services and food production in situations where other forms of farming are impractical.

In the UK, the total net GHG emissions attributed to agriculture account for a relatively low proportion (about 7%) of the country's total of GHG emissions. Agricultural GHGs occur mainly as nitrous oxide (N_2O) and methane (CH_4). Total UK agricultural GHG emissions have decreased by about 17% since 1990 but, given the UK government's ambitious targets to reduce all GHG emissions, further improvements in agricultural management are likely to be necessary (see Chapter 2). Importantly, these reductions will take place against a background of rising world population and an anticipated doubling in world food demands by 2050, together with both the problems arising from the effects of climate change in countries that are currently global food exporters, and from the needs of all countries to address their own food and energy security.

In agriculture, direct CO_2 emissions arise from sources such as soil disturbance and on-farm energy use, as well as indirectly through the energy intensive manufacture of inputs. On the other hand, pastures and other farmland vegetation store carbon that has been captured by photosynthesis. Methane is the second most significant GHG in the UK. It has a Global Warming Potential of 21 times that of carbon dioxide, and with around one-third of UK emissions derived from agriculture, methane represents a greater challenge for ruminant management. Methane emissions have decreased by 52% since 1990, partly through reduced livestock numbers and more efficient feeding. Enteric fermentation (methane production by the action of rumen bacteria in cattle and sheep) is the main agricultural source of methane, with emissions from slurry stores and livestock manure handing and spreading accounting for most of the remaining agricultural emissions. Nitrous oxide has a Global Warming Potential of about 300 times that of carbon dioxide, and because approximately 68% of UK emissions are derived from agricultural sources, measures to mitigate its emissions will be one of the areas where UK land managers can contribute to reductions in the overall national GHG emissions total (see Chapter 2).

Grassland and its associated vegetation occupies about two-thirds of UK agricultural land, with conditions in western and northern areas being advantageous for grass production, and ill-suited to cropping, due to climate, soil type and slopes. Ruminant production in the lowlands (for dairying and beef and lamb) is based on the technologically efficient management of improved grassland forage and supplementation with predominantly UK-sourced feeds. In the uplands it is based on extensive management (for sheep and suckler beef) of partially improved and semi-natural vegetation, and in these areas grazing by ruminants is an essential part of multifunctional land management. Despite declines in the number of dairy farms and number of dairy cows, increasing yields have kept milk output relatively stable, and the UK is currently the ninth largest milk producer in the world. Increases in milk yields have also been associated with reductions in emissions per litre of milk. The beef sector will also have benefited from some of the same technical feed improvements that have characterised the dairy sector. In upland and marginal grassland areas however, a significant proportion of diets will consist of forage that has a relatively low proportion of digestible organic matter. This implies that, under these conditions, there will be higher methane emissions per unit of output, though under low stocking rates emissions per ha will be low. The UK sheep population of some 32 million remains large by EU standards. As with beef, sheep gazing unimproved pasture are likely to be associated with higher methane emissions per kg of meat compared to lowland sheep on high quality diets. However, many of these areas have a role in methane capture and their management via low intensity beef and sheep grazing is also important in achieving wider agri-environmental objectives. (See Chapter 3 for further details.)

Nitrous oxide emissions associated with agricultural management, and ruminant production in particular, are linked indirectly to nitrogen inputs and recycled dietary nitrogen. Average nitrogen fertilizer inputs on UK grassland are now approximately half the rates of 20 years ago. There is a wide degree of uncertainty over the exact levels of emissions of N_2O in the context of the UK and research evidence suggests that UK emissions are lower than those based on IPCC methodology. The development of more precise GHG inventories will address these uncertainties. (See Chapter 3.)

Comparisons of GHG emissions from UK livestock farming relative to other countries remain inexact. There is a need for precise guidelines to take account of allocation between different sectors and there is also a lack of some key data. Some published comparisons appear to have used imprecise data resulting in conclusions that are not on a like-for-like basis and that may not stand up to scrutiny. In this review comparisons have been made with several countries that compete with UK farmers for market share (Ireland, Netherlands, New Zealand and South America). Our study concludes that in this respect there is evidence that UK ruminant agriculture compares favourably with other countries, and that the rate of reduction of total agricultural GHGs in the UK in recent years has been similar to, or greater than, countries with which it is compared. (See Chapter 4.)

Specific examples which indicate a relatively favourable emissions status are:

(i) for UK dairying, average CH_4 emissions from enteric fermentation in relation to milk produced will be lower than in countries where the average milk yield per cow is typically lower than in UK herds, and also, in some cases, in terms of N_2O emissions relative to countries that use higher inputs of nitrogen fertilizers per unit of output and/or where there is a longer outdoor grazing season;

(ii) for lowland beef and lamb production, enteric CH_4 emissions in the UK will be lower, per kg meat produced, than in countries that do not source beef calves from a dairy herd and/or where the production cycle for beef and lamb production is longer than in the UK. (See Chapter 4 for further details.)

The complexity of different livestock systems and sub-systems can make comparisons of emissions particularly complex. To date, few studies have been undertaken to determine the importance of regional or management-related differences in GHG emissions and differences in GHG emissions in relation to farming system, such as organic versus conventional farming, are inconclusive. The systems that characterize a large proportion of the UK's Less Favoured Areas are associated with low inputs of mineral N fertilizers, low stocking rates and low N excretion, and therefore low N_2O emissions per ha of land; however, where these systems have a long production cycle based on beef cows, emissions, particularly of enteric CH_4, will be greater per unit of output (but not necessarily on a per-ha basis). This also needs to be considered against the importance of a large proportion of LFA land in delivering ecosystem services.

In the UK a combination of improved forage genetic resources and knowledge and technologies for silage making and feeding, as well as improved knowledge of grazing management, have contributed to improved nutritional value of grazed and conserved forage enabling higher milk yields per cow and lower CH_4 emissions per litre of milk. UK beef production, and increasingly also lamb production, is mainly carried out over a short production cycle; this contributes to reducing the GHG emissions per animal and thus per unit of output (see Chapter 5).

There are many opportunities for reducing the emissions of GHGs from ruminant agricultural sources, as well as through enhancing removals and through displacing emissions (see Chapter 6), for instance through the use of CH_4 from livestock slurry in anaerobic digestion. It is also important to recognize the importance of the soils and vegetation of the UK's grasslands and rough grazing areas as a carbon store, and their possible role in methane mitigation, and to ensure that future management does not lead to further net carbon dioxide emissions. On cropland there is a need to increase the carbon storage of soils that currently have low soil organic matter.

Research has identified a number of potential GHG reduction strategies than can be implemented but these are not always cost effective for farmers and may suffer from a number of other barriers to uptake (see Chapter 6). In terms of limiting GHG emissions many research challenges and knowledge gaps remain and these need to be given a high priority at both national and international levels, particularly through focusing research effort on reducing N excretion from livestock and manipulating rumen ecosystems in order to limit the main sources of N_2O and CH_4 respectively.

In general, the most cost-effective and environmentally effective mitigation options are those which combine practices which deliver reduced GHG emissions with other environmental, animal-welfare and economic /production-related targets, of which anaerobic digestion is an example. Some measures which reduce emissions of one GHG or pollutant may increase that of another (the problem of 'pollution swapping') and outcomes need to be evaluated on a site-specific basis. When considering mitigation options it is important to distinguish between the maximum biophysical potential, the economically constrained potential and the socially/politically constrained potential of mitigation actions.

The effects of future climate change for the ruminant production industry in the UK, under low-medium GHG-emissions' scenarios to the 2050s, appear to be within the response capacity of the UK farming industry. Good production conditions are likely to continue for meat and dairy production in most parts of the UK where ruminant livestock farming is currently important. GHG emissions increases at the higher end of forecasts, especially in the longer term, carry greater uncertainties. Importantly, there are also issues of climate change affecting food security in some other parts of the world where livestock farming is important, and this implies reduced opportunities for the UK to source meat and dairy produce from imports. If areas such as southern Europe become unsuitable for livestock production, at a European level the UK has potential to take up some of that shortfall. (For further details see Chapter 7).

Research and policy implications

Summary

- Many research challenges and knowledge gaps remain. These need to be given a high priority at both national and international levels, particularly through focusing resources on reducing N excretion from livestock and manipulating rumen ecosystems in order to limit the main sources of N_2O and CH_4 respectively.
- Research is needed to determine the importance of regional or management-related differences in GHG emissions and differences in relation to farming system, such as organic versus conventional farming.
- GHG emissions from livestock production reduced still further through improved knowledge transfer to UK farmers. This requires resources and commitment commensurate with the national emission reduction targets recently set by government.
- Support for 'carbon sensitive farming': English agri-environmental schemes do not specifically reward or compensate actions that address GHG reductions. Reduction and mitigation measures which are additional to other environmental requirements, or which are otherwise not cost-effective for the farmer (such as dietary changes for ruminants) require a new support mechanism or could be incorporated within a revised ELS.
- Reducing GHG emissions from livestock in the UK by a contraction of the industry in order to reduce output and livestock numbers would simply 'export' our GHG emissions to other countries and lead to an increase in UK food imports. Such a policy would also threaten the continued delivery of environmental public goods, such as from Britain's hill farms.
- There is a need to establish international benchmarks for extended farm auditing and to ensure that retailers and consumers are aware of the capabilities and attendant costs of meeting challenging GHG reduction targets, in addition to raising awareness of the wider environmental role, including carbon storage, of the farmland used by the UK's ruminant livestock.
- Consideration should be given to the development of a 'low-GHG-emission' standard for marketing UK meat and dairy produce. However, the UK livestock industry needs to recognize that although there is scope to gain market share here, there is also potential for other countries to improve their GHG emissions.

The complexity of identifying sources of GHG emissions, quantifying emissions in comparable ways and identifying and evaluating mitigation options means that it is inevitable that there are various gaps in our knowledge. Some are simply due to lack of appropriate data either at suitable geographical scales or for specific livestock systems, others are because complex interactions between GHGs have not been fully explored, or because interactions between measures to limit GHG emissions and a range of other public good or ecosystem services have not been fully investigated. Nevertheless, a number of policy implications emerge from the review of evidence undertaken for this report.

Support for carbon sensitive farming: The present agri-environmental arrangements of ELS/HLS do not specifically reward or compensate for measures or actions that address GHG reductions. They do, however, include some measures such as management of extensive grasslands or habitat creation which can reduce net GHG emissions in addition to their principal objective. Future adoption of GHG reduction and mitigation measures which are additional to other environmental requirements, or which are otherwise not cost-effective for the farmer, such as dietary changes for ruminants, may require a similar support mechanism or be incorporated within a revised ELS.

However, in the context of policy development, it is important to note that the new environmentalism of mitigating GHG emissions can pose challenges to 'conventional' conservation thinking. For instance, many intensive livestock systems out perform extensive systems in terms of reduced GHG emissions (See Chapter 5). On the other hand, extensive livestock systems which can deliver a range of biodiversity and ecosystem services and support high value meat and dairy products can appear to be unfavourable in terms of GHG emissions per unit of product (though not necessarily on a per ha basis).

Some commentators have argued that reducing GHG emissions from livestock in the UK can simply be achieved by allowing or even encouraging a contraction of the industry in order to reduce output and livestock numbers, and seek alternative land-use options such as woodland or biofuels on grazing lands. This might theoretically contribute to UK national GHG reduction targets, but unless there were commensurate changes in the nation's diets any emissions saved would be likely to be lost through the relocation of ruminant agriculture to other countries and an increase in food imports. As such logic would suggest contraction of the least efficient parts of the livestock sector would yield the greatest GHG benefits, it follows that such a policy would also threaten the continued delivery of environmental public goods, such as from Britain's hill farms.

There has been progress in reducing GHG emissions from livestock production in the UK. There is potential to extend this further through research and improved knowledge transfer to UK farmers, and this requires resources and commitment commensurate with the national emission reduction targets recently set by government. In terms of knowledge transfer, there is a need to establish international benchmarks, for extended farm auditing and to ensure that retailers and consumers are aware of the capabilities and attendant costs of meeting challenging GHG reduction targets, and to increase awareness of the wider environmental role, including carbon storage, of the farmland used by the UK's ruminant livestock. In terms of research, reducing N excretion from livestock and manipulating rumen ecosystems in order to limit the main sources of N_2O and CH_4 respectively should be a priority (see Chapter 6).

There is clearly a potential for the livestock sectors in other countries as well as in the UK to reduce their GHG emissions. If this is done successfully and in ways that can be audited to the satisfaction of customers and major retailers, there is scope for meat and dairy produce to be marketed to a 'low-GHG-emission' standard. The UK livestock industry needs to recognize that although there is scope to gain market share here, there is also potential for other countries to improve their GHG emissions even further.

9. Glossary of terms and abbreviations

Ammonium (NH_4). A relatively immobile form of nitrogen in soil and an important nutrient of crops and grassland to which it is supplied as mineral fertilizers, manures and from natural soil processes. It forms the substrate for the nitrification process.

Anaerobic conditions. Conditions in an environment (soils, and also of a rumen) that are depleted of oxygen, and in the case of soils often waterlogged.

Anaerobic Digestion (AD) systems. Industrial or farm scale plants of a range of possible sizes used to convert livestock manures and other organic materials into methane and combustible gases for use as a fuel source, with compost as a by product.

CALM. Carbon Accounting for Land Managers. CALM is a web-based calculator to help land managers work out the balance of greenhouse gases emitted by their farming business, and carbon stored in their trees and soil.

Carbon dioxide (CO_2). The third most abundant gas in the atmosphere and the main Greenhouse Gas. It is essential for plant life and is released by respiration by living organisms and from combustion of carbon compounds principally from fossil fuels.

Carbon Dioxide equivalents (CO_2e). A reporting system to place all greenhouse gases on the same basis using a conversion factor called the Global Warming Potential (GWP). Rather than carbon dioxide equivalents, carbon equivalents, C(e), are sometimes quoted (to convert from CO_2e to C(e) multiply by 12/44).

Climate change. A change in the state of the climate and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. There is a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

Denitrification. Microbial processes responsible for the conversion of nitrate to gases including nitrous oxide.

Enteric fermentation. Anaerobic digestion processes by complex microflora in the rumens of cattle and sheep.

Global Warming Potential (GWP). Ratio of radiative forcing of 1kg of a Greenhouse Gas emitted to and mixed in the atmosphere, to that of 1kg of CO_2 over a given time period (commonly a period of 100 years).

Greenhouse gases. Those atmospheric gases capable of absorbing and trapping longwave radiation and contributing to global warming.

Intergovernmental Panel on Climate Change (IPCC). International body responsible for protocols for determining GHG emission factors and coordinating international knowledge on global warming and climate change.

LCA (Life Cycle Analysis). A complete investigation and valuation of the environmental impacts of a given product or service caused or necessitated by its existence.

LFA (Less Favoured Areas). Farmland in the EU for which there is a long standing provision within the Common Agricultural Policy for supporting farming in geographically defined areas adversely affected by physical or climatic limitations.

MANNER. A decision support system that can be used to accurately predict the fertiliser nitrogen value of organic manures on a field-specific basis. MANNER was developed using research on organic manure utilisation on agricultural land.

ME (Metabolizable Energy). The portion of the energy present in a feed that can be utilized by livestock for all metabolic functions (maintenance, growth, pregnancy, lactation) and commonly expressed in Joules (J) per kg or per ha.

Methane (CH_4). Greenhouse gas produced under anaerobic conditions notably in animals' rumens, manure stores, and wetlands including rice paddies; also emitted from coal mines and landfill sites. Methane has a high 100-year GWP at 25 times that of CO_2.

Mineral soil. Soil composed principally of mineral matter, in which the characteristics of the soil are determined more by the mineral content and texture than by the organic content.

Nitrous Oxide (N_2O). Greenhouse gas produced from manures and nitrogen fertilizer, and which has a very high GWP of *c*. 300 times that of CO_2.

Organic soil. A soil composed of materials that include at least 12% of organic carbon (or >18% on free-draining soils), thus ranging from organic loams and sands to peaty soils. Generally an organic soil contains at least 50% of organic soil materials in the top 80cm.

Radiative forcing. The changes in net (downward minus upward) irradiance (as W m^{-2}) at the boundary of the troposphere and stratosphere due to a change in a driver of climate change (e.g. CO_2 concentration).

RB209 / PLANET. Defra's industry-standard reference book on Fertilizer Recommendations (RB209) provides farmers and advisers with a quick and easy way of obtaining recommendations for arable, horticultural or grassland crops in each field, each year, taking account of the crop nutrient requirement as well as the nutrients supplied from organic manures, soil and fertilizers. PLANET is the computerized version.

Rough grazing. Land on a farm or estate that is in shared or sole ownership and which, because of climate and soil type, supports unproductive vegetation dominated by rough grasses, rushes, sedges, dwarf heath and associated plant types and is usually maintained by grazing at a low stocking density.

UME (Utilized Metabolizable Energy) from grass. The ME obtained from grazed or conserved grass on a farm, plus any surplus in conserved grass feed, and commonly expressed as Joules (or Gigajoules GJ) per ha.

10. Annex 1

The Carbon Baseline Survey Project (Natural England, 2008b) evaluated the first GHG benchmark of farms and farm types using the CALM (Carbon Accounting for Land Managers) tool http://www.cla.org.uk/Policy_Work/CALM_Calculator/

Some overall results taken from Natural England (2008b) are given in Table 10.1

Table 10.1. Average GHG emissions per ha by farm type from aggregated farm data supplied by CALM, expressed as tCO_2 e per ha.

Farm type	CO_2	CH_4	N_2O	Mean total GHG emissions	Mean CO_2 sequestered
Dairy	1.25	4.74	5.44	11.44	0.63
Grazing (LFA)	0.22	0.87	1.41	2.50	0.24
Lowland grazing	1.88	1.72	3.44	7.05	1.16

Using the CALM calculator we present below some case studies of the GHG emissions for different types of farm, based on actual or theoretical input values. Net emissions per ha are generally lower than the mean values for the livestock sectors reported in Natural England (2008b).

Dairy farms
Two examples of small specialist dairy farms are presented. Both relate to hypothetical lowland sites in Cardiganshire, Farm A being organic and Farm B being conventional. The basis for the input values is derived partly from a report of the Institute of Rural Studies, UWA (http://www.organic.aber.ac.uk/library/factsheets/DAIRYFINeng.pdf)

Farm A
Area: 63 ha (55 ha of improved long term grassland, 5 ha of winter cereals and 3 ha of broadleaf woodland).
Livestock: 76 organic dairy cows plus 20 replacement young stock
Milk yield: 6000 L/cow (456,000 L per year)
Fertilizer: none except for 20 t ground limestone
Grazing season: 230 days for all stock. Manure: FYM from straw-based housing
Energy use: nominal allowance of 2000 L of farm diesel and 10000 kwt hours electricity

Emissions	CO_2 (t)	CH_4 (t)	N_2O (t)	Total CO_2 e (t)
Energy	10.97	0	0	11
Fertilizer N	0	0	0	0
Lime	8.8	0	0	8.8
Cattle	0	9.43	0.04	212
Crops and grass			0.36	111
Total emissions	19.77	9.43	0.4	343
Total sequestered	33			33
Net emissions (farm)				310
Net emissions/ha				4.92
Net emissions per 1000L milk				0.68

Farm B
Area: 63 ha (60 ha of improved long term grassland and 3 ha of broadleaf woodland).
Livestock: 95 dairy cows plus 25 replacement young stock
Milk yield: 6400 L/cow (608,000 L per year)
Fertilizer: N at 100kg N/ha average, as ammonium nitrate, plus 20 t ground limestone
Grazing season: 230 days for all stock
Manure: slurry-based housing
Fossil energy use: nominal allowance of 2000 L of farm diesel and 10000 kwt hours electricity

Emissions	**CO_2 (t)**	**CH_4 (t)**	**N_2O (t)**	**Total CO_2 e (t)**
Energy	10.97	0	0	11
Fertilizer N	0	0	0.18	57
Lime	8.8	0	0	9
Cattle	0	11.78	0.05	264
Crops and grass			0.38	119
Total emissions	19.77	11.78	0.61	460
Total sequestered	33			33
Net emissions (farm)				427
Net emissions/ha				6.78
Net emissions per 1000L milk				0.70

Farm C
This example in SW England is based on a recorded farm in a former Grassland Research Institute research project. All cattle are purchased as young stores and sold either a fat cattle for slaughter or for finishing off the farm. The farm has 7 ha of woodland and 63 ha of grassland, of which 50% is over 20 years old and the rest is sown grass of various ages ('sown' grassland species account for half the forage resources on average across the farm). The farm obtains over 80% of cattle feed requirements from home grown grass
Area: 70 ha (63 ha of long term grassland and 7 ha of broadleaf woodland).
Livestock: SR of 1.8 LU/ha equivalent to 180 growing cattle of various ages with a mean weight of 300-350 kg each.
Fertilizer: N at 60 kg N/ha average, as compound
Grazing season: 215 days for all stock
Manure: straw based housing
Fossil energy use: nominal allowance of 2000 L of farm diesel and 500 kwt hours electricity

Emissions	CO_2 (t)	CH_4 (t)	N_2O (t)	Total CO_2 e (t)
Energy	5.63			5.63
Fertilizer N			0.11	34
Lime				
Cattle		7.27	0.22	222
Crops and grass			0.4	125
Total emissions	5.63	7.27	0.73	386
Total sequestered	78			78
Net emissions (farm)				308
Net emissions /ha				4.4

Farm D. This is an upland sheep farm in Cumbria, area of 290 ha of grazing and improved grassland and 10 ha of deciduous woodland. 200 ewes produce 300 lambs per year which spend an average of 6 months on the farm. Fertilizer N at 40 kg N/ha is applied on 40 ha of land and 20 t of lime applied.
Manure: straw based housing for up to 6 weeks per year
Fossil energy use: nominal allowance of 2000 L of farm diesel and 500 kwt hours electricity

Emissions	CO_2 (t)	CH_4 (t)	N_2O (t)	Total CO_2 e (t)
Energy	5.6			5.6
Fertilizer N		0.0	0.05	15
Lime	8.8	0	0	9
Sheep	0	2.08	0.13	84
Crops and grass	0	0	1.83	567
Total emissions	14.43	2.08	2.01	680
Total sequestered	111			111
Net emissions (farm)				569
Net emissions per ha				1.90

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