Food, land and greenhouse gases

The effect of changes in UK food consumption on land requirements and greenhouse gas emissions

A report prepared for the United Kingdom's Committee on Climate Change

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Authors' note

The study uses the terms 'white meat' and 'red meat' to distinguish between meat from ruminants (e.g. cattle and sheep) and monogastric animals (e.g. poultry and pigs).

It is important to keep in mind that the study examines the effect of changes in the consumption of food commodities in the UK food system. The consumption data presented relate to commodity flows which include non-edible materials (e.g. bones and peelings), not just the food eaten. The consumption changes examined are at the commodity and food system level, not at the level of individual consumer diets.

Report revision in April 2011. This document is a revision of this report first published in December 2010. Tables 30 and 31 were changed following scrutiny of the original data relating to UK land use change effects. Errors in the presentation of the data used were identified. The relevant analyses were repeated.

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EXECUTIVE SUMMARY

1. Key findings

This study examines the land use and greenhouse gas implications of UK food consumption change away from carbon intensive products. It shows that the UK agricultural land base can support increased consumption of plant-based products arising from the reduced consumption of livestock products. A 50% reduction in livestock product consumption reduces the area of arable and grassland required to supply UK food, both in the UK and overseas. It also reduces emissions of greenhouse gases from primary production by 19%. A switch from beef or sheepmeat (red meat) to pork or poultry (white meat) reduces food consumption related greenhouse gas emissions and the land area required but increases overseas arable land use. With this exception, the release of arable land now used to grow animal feed exceeds the additional arable land required for increased plant based foods in both the UK and overseas. Reducing livestock product consumption also has the potential to enable delivery of other significant environmental benefits, for example, reductions in ammonia and nitrate emissions.

A 50% reduction in livestock product consumption reduces UK grassland needs for UK food production by several million hectares. This land could be used to supply livestock products for export markets although our scenarios assume that the proportions of imports, domestic production and exports remain constant. In these circumstances, some of the grassland released could be used to produce arable crops, including crops for biofuel production. Almost all of it could be converted to woodland or managed in other ways for biodiversity and/or amenity purposes. Conversion of this land resource to woodland has significant potential to increase soil carbon storage while supplying biomass for energy.

Scenario	Cropped area required, kha			Grassland area required, kha			Total area, kha	Greenhouse gas emissions, kt CO_2e/year *		
	UK	OS	Total	UK	OS	Total		UK	OS	Total
Baseline	3,388	4,458	7,846	11,228	1,944	13,172	21,018	51,693	29,001	80,694
50% reduction in livestock with land release priority:										
Uniform	3,123	4,131	7,254	4,161	700	4,861	12,115	36,282	29,456	65,738
Maximise non-tillable land release	3,123	4,131	7,254	2,905	700	3,605	10,859	36,246	29,451	65,697
Maximise release of tillable land	3,123	4,131	7,254	7,102	700	7,802	15,056	36,282	29,457	65,739
Red to white meat with land release priority:										
Uniform	3,443	4,908	8,351	3,879	486	4,365	12,716	45,812	27,575	73,387
Maximise release of non-tillable land	3,443	4,909	8,352	2,909	486	3,395	11,747	45,867	27,572	73,439
Maximise release of tillable land	3,443	4,908	8,351	6,947	486	7,433	15,784	45,878	27,575	73,453
50% reduction in white meat consumption:										
Uniform	3,201	3,735	6,936	11,228	1,944	13,172	20,108	49,525	28,500	78,025

* The greenhouse gas emissions do not include possible effects of land use change

Summary table. The area of land needed to supply UK food and the greenhouse gas emissions from food production under current circumstances and under the seven scenarios studied.

In a reduction scenario, concentrating remaining livestock production on different land types (e.g. concentrating on intensive production on lowland farms versus extensive production on lower quality land) has little effect on greenhouse gas emissions from primary production. This indicates that there is relatively little scope to reduce emissions by restructuring production (at least restructuring in relation to land use). It is further noted that concentrating livestock production on higher quality land would cause an almost complete closure of production for UK markets on land not suited to intensive grass or arable production, with biodiversity and economic impacts (discussed further below). The risks of unintended consequences with respect to greenhouse gas emissions are relatively low given the assumptions in the scenarios, but the actuality of such change will depend on future economic, social and political drivers. The report includes detailed analyses of land use and emissions data together with extensive discussion of a wide range of effects based on literature analysis.

2. Study objectives

This study was conducted for the UK Government's Committee on Climate Change (CCC) to examine if UK agriculture can support consumption change away from carbon-intensive food products. For the purposes of the consumption scenarios, it is assumed the relationships between imports, exports and domestic consumption remain constant for each of the commodities used by the UK food system. The following questions were addressed:

1. **Land needs:** Given land quality considerations (e.g. land capability and constraints), to what extent is it possible to support a change in the UK consumption of meat and dairy products with a corresponding increase in substitute goods from UK agricultural land? Can a reduction in meat and dairy product consumption release land for other purposes? To what use would this freed-up land be suitable (e.g. food production, biomass production, carbon sequestration, other ecosystem service provision, forestry, etc.)?
2. **Greenhouse gas emissions:** What are the implications of the transition in production for GHGs both in the UK and abroad (including soil carbon releases, sequestration, reduced production of feed, etc, as well as reductions in direct N_2O and CH_4 emissions?
3. **Other effects:** What are the other implications, including for water, other pollutants, farm incomes, availability of manure as a fertiliser input, public health, ecosystem services, biodiversity, and animal welfare?
4. **International implications:** If UK agricultural land cannot support consumption changes, what are the international implications in terms of agricultural production and land-use displacement (e.g. deforestation, land for biofuels, land for food), and GHGs?

3. Methods

We developed and used a combination of consumption and production scenarios to examine potential consequences of change. Life-cycle assessment (mainly life cycle inventory analysis) was applied to these scenarios to examine the overall effects of the consumption change on GHG and other emissions from primary production, in the UK and overseas. The production under the various scenarios was allocated to agricultural land resources by a combination of survey-based data analysis and model-derived calculations. Land use change (LUC) emissions (from changing soil C and biomass stocks) were calculated from data in the UK national inventory as well as from the UK Renewable Fuel Agency for overseas land types. Commodity flows as affected by consumption were calculated from FAOSTAT and Defra data.

The resulting emissions were allocated to the various inventories in which they are registered, e.g. the UK's GHG inventories for agriculture, LUC, energy use and industry, together with those from overseas that are made up by components from our UK consumption of food and drink.

Scientific literature relevant to the wider assessment of these scenarios was analysed (and an ecosystems services method was applied) to enable a qualitative assessment to complement the quantitative analysis.

Scenarios

We designed a range of consumption and production scenarios to examine options on both the demand and supply sides. These comprise three consumption and three production scenarios. The consumption scenarios are as follows:

Consumption Scenario 1. A 50% reduction in livestock product consumption balanced by increases in plant commodities.

Consumption Scenario 2. A shift from red meat (beef and lamb) to white meat (pork and poultry). Red meat consumption is reduced by 75%.

Consumption Scenario 3. A 50% reduction in white meat consumption balanced by increases in plant commodities.

It must be stressed that the nature of scenarios is such that they contain a variety of assumptions about possible future demands and supplies of agricultural commodities. The scenarios are not forecasts. The focus has been on the technical capacity of land and agricultural production, not on the market changes needed to enable change. It should be noted that the balance of supply from the UK and overseas is assumed to remain as it is now.

The 50% reduction in livestock products was not applied uniformly across these commodities. Under the reduction scenario (Consumption scenario 1), consumption of milk and eggs is 60% of current consumption, and meat consumption is 36% of current consumption. Sugar consumption is also reduced to align with healthy eating guidelines. Reduction in consumption of livestock products is balanced by increasing plant consumption on the basis of constant food energy supplied. Fruit and vegetable consumption was increased by 50% and basic carbohydrate (e.g. cereals, potatoes) and oil rich commodities (except palm oil) by 33%. Substitution was estimated on the basis of food energy use at the commodity level using FAOSTAT data. Expert opinion was obtained in relation to the viability of consumption change under Scenario 1. This indicated that diets at the consumer level under this scenario are viable from a nutritional viewpoint. It was also noted that Consumption Scenario 1 aligns with healthy eating guidelines in other countries. The production scenarios are focused on the intensity of use of different types of land. The result is a difference in the quantity and type of land 'released' from production from change that reduces land needs. The production scenarios are:

Production Scenario 1. Uniform land release - 'pro-rata' changes in land requirements across land types.

Production Scenario 2. Maximise release of tillable land - ruminant meat production concentrated on lower quality land.

Production Scenario 3. Maximise release of low quality land - ruminant meat production concentrated on high quality land.

The combination of consumption scenarios 1 and 2 and three production scenarios gives a total of 6 system scenarios. These are complemented by Consumption Scenario 3 giving a total of 7.

4. Results

Land needs

All consumption change scenarios reduce the total amount of land estimated as required to support the UK food system. A switch from red to white meat increases the need for overseas arable land, although a larger area of UK land that can be tilled is released.

Under a reduction scenario, the amount of extra land required for the direct consumption of plant products is less than the amount of arable land released from livestock feed production. The net effect on total overseas arable land needs is a reduction of about 311,000 ha and a net release of about 265,000 ha arable land in the UK. The need for grassland is greatly reduced. The release of grassland with some arable potential ranges between 1.6 to 3.7 million ha depending on where remaining production is concentrated. The release of grassland with no arable potential ranges from 0.7 to 6.9 million ha. Under a reduction scenario, concentrating remaining production on better quality land would almost entirely eliminate sheep and beef production for the UK from the hills, most uplands and less productive lowland areas.

Under Consumption Scenario 2 (a shift from beef and sheepmeat to white meat from pigs and poultry), the diet needs of pigs and poultry result in a net increase in demand for overseas grown crops, although considerably more potentially arable land is released in the UK. More arable cropping is needed both in the UK (an additional 55,000 ha) and to a much greater extent overseas (about an additional 466,000 ha), driven largely by soy. However, the release of arable quality grassland in the UK exceeds the increase in overseas arable landed needed for producing this feed. The result is a net release of between 1.6 and 2.9 million ha potentially arable land in the UK plus the release of 1.3 to 6.6 million ha of land suitable only for grassland.

Under Consumption Scenario 3 (a 50% reduction in white meat consumption balanced by an increase in plant products) the changes are much less complex with no changes in grassland needs. Increases in demand for arable land for direct human consumption amounted to about 154,000 and 172,000 ha (domestic and overseas respectively), but these are more than compensated for by the release of arable land from feed production (341,000 and 668,000 ha domestic and overseas respectively).

Focusing a reduced cattle and sheep industry on non-arable land would result in the release of substantially more tillable land (currently grassland). In a 50% livestock production consumption reduction scenario, maximising the use of lower grade land (semi-natural grassland, hill land etc.) releases 3.7 million of tillable grassland (including 1.3 million ha of good arable land). The opposite approach of withdrawing production from less capable land releases just 1.7 million ha of potentially arable land, with almost no release of the grassland well suited for to arable production. The land-use trade-off is therefore clear. Under a 50% livestock consumption reduction scenario, 2 million ha of tillable grassland is required to compensate for the withdrawal of cattle and sheep production from 6.9 million ha of non-tillable grassland.

A 50% reduction in livestock product consumption opens up the opportunity to release about half of UK land currently used for UK food supplies if remaining production is concentrated on the more capable land. If land is released uniformly, almost two-thirds of this release takes place on grassland not suited to arable production and the remaining third is grassland with some arable potential. There would be with higher levels of land release in Scotland, Wales and Northern Ireland than in England. Depending on where the remaining production takes place, a large proportion of land released may be very unproductive, but it can be assumed that about 5 million ha with potential for other agricultural uses would be available, for example for the production of livestock for export (if they did not reduce their livestock consumption), for producing arable biofuel crops, planted woodland and re-wilding (to natural woodland in many cases).

Greenhouse gas emissions

All consumption scenarios reduce greenhouse gas emissions from primary production. The largest reduction is from a livestock reduction scenario (Consumption Scenario 1): from 81 to 66 Mt CO_2e (19% reduction). The switch from red to white meat reduces emissions by 9% and a 50% reduction in white meat consumption by only 3%.

The net effect on emissions depends greatly on the alternative use of the grassland released from food production. The study indicates the range of possible consequences on soil and biomass fluxes. If all tillable grassland released from food production was converted to arable use, 8 to 17 Mt CO_2e per year would be released over 20 years through the effects of land use change.

Converting all released land with the potential to support good tree growth to woodland would cause a net carbon uptake equivalent to about 7.5 to 9.5 Mt CO_2e per year in soil and wood per year over 20 years.

Land use preference (e.g. focusing remaining production on high quality land) has little effect on emissions. This is an important result indicating that supply chain emissions are unresponsive to changes in industry structure with respect to the land used.

The location of emissions reductions (UK or overseas) was identified. Currently, we estimate that 36% of primary production emissions are overseas. All scenarios reduce UK emissions while Consumption Scenario 1 has little effect on overseas emissions and Consumption Scenario 2 reduces overseas emissions by 5%. None of the scenarios involve a net export of emissions and the GHG reduction benefits in the UK are proportionally greater than those overseas because of the tight link between UK livestock consumption and production.

OTHER EFFECTS

Other emissions

All consumption scenarios are expected to reduce other emissions. Consumption Scenario 1 halves ammonia emissions. Reductions in nitrate emissions, eutrophication emissions generally, and acidification are almost as large (*ca* 45%).

Biodiversity and carbon sequestration

It is widely asserted that grassland, especially semi-natural grassland, has a higher biodiversity value compared with other types of vegetation, natural climax vegetation for example. It is often claimed that the retention of these grasslands is important for the continued delivery of some ecosystem services, for example, carbon sequestration. In many other European countries, the uplands and hills are usually wooded. For example, 32% and 29% of the land area in Germany and France respectively are wooded compared with 12% in the UK. Thus conversion to climax woodland or other forms of forestry is one obvious alternative use for released grassland. Our study has identified benefits for carbon sequestration in soil when grassland is converted to woodland (there should also be potential benefits in the use of harvested wood).

Our analysis of land use statistics reveals the large proportion of UK land currently occupied by cattle and sheep. Without these livestock, this grassland (much of which is semi-natural grassland) would revert to the natural vegetation - deciduous woodland in many cases. Our results show that the use of livestock to retain semi-natural grasslands is not dependent on the current high level of livestock product consumption. A 50% reduction in demand still leaves a market which is large enough to support this activity. However, given how a declining market affects all suppliers, a livestock reduction scenario presents special challenges to the maintenance of semi-natural grasslands. Livestock systems provide a wide range of services that are currently used by society. In a reduction scenario, rural areas lose skills and employment in the livestock sector and there would be ramifications for linked industries such as the meat processing or veterinary sectors. Culturally important features, for example, hedgerows and stone walls, and much of the fauna and flora associated with grassland would be no longer needed. In the UK as a whole, land that is most likely to be taken out of production is associated with difficult production conditions. In England, upland moorland and common land now in a semi-natural state could change to fully natural vegetation cover. In upland areas, where the majority of re-wilding under Consumption Scenario 1 and 2 would be located, evidence suggests that various natural communities including scrub, bracken, bramble, and woodland with their own assemblage of flora and fauna are likely to develop, with potential increases in wild herbivores such as deer, hares, and rabbits. The majority of SSSIs currently under-grazed occur in lowland areas, for example in southern and eastern parts of England, and a lack of livestock results in difficulty in applying the grazing pressure required to maintain the semi-natural faunal and floral diversity.

Recreational access to the uplands, which is now facilitated by open grassland landscapes, may be impaired and evidence suggests that visitors view the loss of traditional semi-natural landscapes, with associated meadows, hedges, and stone walls, negatively.

Whilst a reduction in the current ecosystem service provision associated with livestock production from cattle and sheep can be expected under Consumption Scenarios 1 and 2, the net change is also dependent on the alternative use to which land is put. In upland SSSIs, overgrazing is often problematic and reducing grazing pressure may allow semi-natural habitats to recover, in particular dwarf shrub heaths, bogs, acid grassland and upland habitats. The release of large areas of land could also be used to diversify upland areas. For example, semi-natural upland woodlands have declined by 30-40% since the 1950s and the UK Habitat Action Plan has therefore included a target to increase the area of upland oak woodland through planting or natural regeneration of current open ground.

In the lowlands, approximately 10% of the current arable land could be released for other activities, such as bioenergy crops, woodlands, recreational land, wetland creation, nature reserves, flood protection, carbon sequestration, and urban development. Each of these land uses will have its own specific range and flow of ecosystem services associated with it. While in general, the release of agricultural land with high environmental value from food production is not viewed as positive, Defra has concluded that there are likely to be situations where positive outcomes can occur.

Economic considerations

The reduction in the amount of land needed to supply the UK goes hand-in-hand with a reduction in the value added by agriculture supplying UK consumed food. A 50% reduction in livestock product consumption (Consumption Scenario 1) reduces the UK farm-gate value of livestock products from £7.6 to 3.5 billion. The farm-level economic impact of a change along these lines will depend crucially on what replacement output is found for the land released and on market effects that are beyond the scope of this study. One economic response scenario is that the land resource released remains in agriculture serving export markets. Another strategy is to use the land for non-food purposes. Using biomass energy cropping as a benchmark and assuming a price of £40/tonne dry matter biomass wood, we estimate that replacing the value of the food output of higher quality land released will be challenging, although it is reported that biomass energy is an economically viable alternative to sheep production on uplands.[1]

POTENTIAL UNEXPECTED OR UNINTENDED CONSEQUENCES

Changes to UK crop production

The general conclusion that a reduction in livestock production consumption will have little effect in total arable land requirements masks some important regional effects. This scenario will reduce arable crop production for livestock feed and increase arable production for direct human consumption, including a 50% increase in fruit and vegetables. The increase of 0.6 million ha of UK crops for human consumption includes an increase of about 0.2 million ha in potatoes, field vegetables and fruit. Research indicates that agricultural change driven by healthy eating recommendations will result in expansion of production of these

[1] Heaton, R.J., Randerson, P.F., Slater, F.M. 1999. The economics of growing short rotation coppice in the uplands of mid-Wales and an economic comparison with sheep production. Biomass and Bioenergy 17: 59-71.

crops particularly in the south and east of England.[2] Many of these crops are irrigated and some are protected using for example poly-tunnels. Whilst the change in land use is small in absolute terms, the local effects on water resources and landscape could be significant. It should be noted however that the increase in fresh fruit and vegetable consumption in these scenarios arise from the full implementation of current UK healthy eating guidelines ('five-a-day') and are not just a consequence reduced livestock product consumption.

Potential unexpected or unintended consequences

Uneven distribution of economic effects

The effect of a contraction in the value of farm output for UK markets will be unevenly distributed. There will be many losers, but also some winners. Given regional land quality characteristics, almost all Welsh, Scottish and Northern Irish farmers would be affected by output contraction counterbalanced by output growth in the south and east of England.

Effects on overseas land use

The reduction in livestock product consumption will have little effect overall on net overseas land needs. Release of land in South America and the USA used for animal feed, especially soy, will be counter-balanced by increases in a wide range of crops elsewhere. The consumption changes also reduce the need for overseas grassland. This affects three countries in particular: Ireland (dairy products, beef), New Zealand (butter and lamb), and South America (beef). The effect on Brazil is now small as imports have dwindled in recent years but the change would close off the UK as a growth market for Brazilian beef in the longer term. The effects on Ireland are particularly significant.

5. Conclusion

This study has clearly shown that UK land can support consumption change that reduces greenhouse gas emissions from the food system. The reduction in land needed to supply the UK that comes with a reduction in livestock product consumption brings potential environmental benefits and significant opportunities to deliver other products, including other ecosystem services, from UK agricultural land. The study has shown that some risks currently argued as arising from consumption change are small. In particular the study shows that arable **land needs** will not increase if the consumption of livestock products is decreased. The risk that emissions will be exported is also shown to be small. The identification of the significant potential benefits of consumption change combined with the low risks of unintended consequences has far-reaching implications for guidance to consumers and the development of agricultural policy. The results are broadly applicable to other European countries which means they are relevant to international policy development, for example the reform of the Common Agricultural Policy.

[2] Jones, P.J. and Tranter, R.B. 2007. Modelling the impact of different policy scenarios on farm business management, land use and rural employment Project Document No. 13. Implications of a nutrition driven food policy for land use and the Rural Environment. Work package No. 5, Report No. 02

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MAIN REPORT

1. Scope and background

This study was conducted for the United Kingdom Committee on Climate Change (CCC) to examine the impact of changes in UK food commodity demand, as affected by changes in consumption, on the land required for UK food and greenhouse gas emissions arising from its production.

Livestock, and the land required to feed them, occupy just over half of all the land in the UK and account for 57% of greenhouse gas emissions from food production in the UK.[3] Thus the focus is livestock product consumption. The research is aimed at informing any position the Committee might take on options for reducing emissions from agriculture, including changes in consumption.

Livestock product consumption is at the nexus of a range of issues that affect the sustainable development of the food system, agriculture, the rural economy, and public health. The Committee has previously explored the potential for production-based on-farm resource efficiency measures to deliver emissions reductions within the agriculture sector. In the light of the evidence already available, the Committee has noted that consumption change is an obvious option for the sustainable development of food systems but has recognised that a number of complex questions arise. These range from increased reliance on other types of land use to support changes in consumption patterns, re-wilding of semi-natural grasslands, and effects on the wider economy. In addition, there are also the effects of restructuring the livestock sector that might result from consumption change to reduce greenhouse emissions.

Our analysis of the Committee's requirements resulted in our identification of the following specific questions:

1. Given land quality considerations (e.g. constraints and opportunities), to what extent is it possible to support a change in the UK consumption of meat and dairy products and an increase in substitute goods from UK agricultural land? Can a reduction in meat and dairy consumption result in release of land for other purposes? To what use would this freed-up land be suitable (e.g. food production, biomass production, carbon sequestration, ecosystem services, forestry etc)?
2. What are the implications of the transition in production for land use and greenhouse gases (GHGs) both within the UK and abroad (including soil carbon releases, sequestration, reduced production of feed, etc, as well as reductions in direct N_2O and CH_4 emissions)?
3. What are the other implications, including for water, other pollutants, farm incomes, availability of manure as a fertiliser input, public health, ecosystem services, biodiversity, animal welfare, etc.?
4. If UK agricultural land cannot support consumption changes, what are the international implications in terms of agricultural production and land-use displacement (e.g. deforestation, land for biofuels, land for food), and GHGs?

We investigate various consumption and production scenarios to assess the wider potential land use consequences of consumption change. In addition to three consumption change scenarios, three production scenarios were developed to examine the effect of changes in production practices and sector structures, for example the degree of reliance on low quality grazing vs. higher quality land that is arable or potentially tillable land. Drawing on our previous work and the literature, we also consider the effect of greater resource conservation in agriculture on emissions and land use. It is important to appreciate that this study is a technical assessment of the feasibility and extent to which UK land can support the commodity substitutions that arise from consumption change to reduce greenhouse gas emissions. Quantitative analysis lies at the core of the work, supported by qualitative assessment of other aspects, e.g. other pollutants, effects on other ecosystem services. This is done against the background of a growing body of assessments and analyses of the role of the livestock sector in the UK economy and the long-term considerations for land use planning.

This report develops and uses scenarios to examine the potential consequences of consumption change. This is coupled with assessments of the overall effects of the substitution on GHG emissions, including direct

[3] Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope for reduction by 2050. How low can we go? WWF UK and the Food Climate Research Network.

emissions (e.g. enteric methane (CH_4) or soil nitrous oxide (N_2O), energy-use related emissions (e.g. tractor diesel or fuel for grain drying) together with upstream emissions from major inputs such as fertiliser production and machinery manufacture, and LUC emissions (mainly from changing soil C and biomass stocks). These are allocated to the various inventories in which they are registered, e.g. the UK's GHG inventories for agriculture, LUC, energy use and industry, and inventories overseas. The effects on overseas land are also assessed. Our analysis is quantitative as far as the data and the modelling tools we have permit.

Tasks

1. Scenario design. A detailed description of the scenarios: a set of detailed commodity substitutions following consultation with external experts and wider stakeholders.
2. Current land use. Calculation and description the current land used (both within and outside the UK) for UK food and drink consumption.
3. Effects on land requirements. Analysis of the effects of commodity substitution on land use both within and outside the UK, but with a focus on land within the UK.
4. Effects on GHG emissions. Analysis of the effects of changes in commodity production on greenhouse gas (GHG) emissions, broken down into separate UK and non-UK inventories.
5. Wider environmental, economic and social impacts. Assessment of other environmental, economic and social factors apart from GHG emissions resulting from commodity substitution.

Greenhouse gas emissions from food

The life-cycle emissions of food commodities are now well understood. Emissions arising from the production a range of food commodities on a life cycle basis have been quantified by our research group based at Cranfield University.[4] In addition to life-cycle assessment, that research used a combination of mechanistic models to estimate specific emissions from biological processes. We also developed farming sector models to simulate the major resource flows through various forms of livestock production in the UK. That work drew attention to the carbon-equivalent intensity of livestock products in general, and for ruminant meat (beef and sheepmeat) in particular. Studies in other European countries also show that the livestock sector accounts for a high proportions of emissions from the food system – ranging from about 60 to 80%.[5] These findings have been confirmed by numerous studies world-wide in other agri-food systems and there is now consensus in the global scientific community that livestock products are emissions intensive on a carbon equivalent basis.[6] [7] It is also clear that emissions arising from livestock product supply chains are dominated by primary production – i.e. growing feed crops and the rearing of livestock. Methane from ruminants and manure and nitrous oxide from the nitrogen cycle, including emissions from excreted nitrogen, dominate.

Our WWF/FCRN supported study[8] drew on the earlier Cranfield University work and a large number of other life-cycle studies to examine the greenhouse emissions from the entire UK food system and how these might be significantly reduced by 2050 to contribute to the UK's 80% emissions reduction target. That study included the first detailed audit of the whole of the UK food related carbon footprint, including emissions

[4] Williams, A., Audsley, E. and Sandars, D. 2006. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Defra project report IS0205.

[5] Osterburg, B., Nieberg, H., Rüter, S., Isermeyer, F., Haenel, H-D., Hahne, J., Krentler, J-G., Paulsen, H-M., Schuchardt, F., Schweinle, J., Weiland, P. 2009. Erfassung, Berwertung und Minderung von Triebhausgasemissionen des deutschen Agrar- und Ernährungssektors. Arbeitsberichte aus der vTI – Agrarökonomie.

[6] Steinfeld, H, Gerber, P, Wassenaar, T, Castel, V, Rosales, M and C de Hann. 2006. *Livestock's long shadow*. FAO.

[7] Gerber, P., Vellinga, T., Opic, C., Henderson, B. and Steinfeld, H. 2010. Greenhouse gas emissions from the dairy sector. A life-cycle assessment. FAO.

[8] Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope for reduction by 2050. How low can we go? WWF UK and the Food Climate Research Network.

overseas embedded in food imports. It concluded that food directly accounts for 20% of UK emissions on a consumption basis. New techniques were used to allocate a proportion of the world's deforestation emissions to UK food consumption, This increases the food carbon footprint to 30%. It is clear from that study that the carbon footprint of UK food is dominated by emissions from the livestock sector. Livestock products directly account for about 57% of emissions from primary production (farm production etc.) while providing less than a third of the food energy in UK food. In looking at mitigation strategies, the study showed that reducing livestock consumption offers the single most effective way of reducing the carbon footprint of our food consumption. The study concluded that the reduction in livestock product consumption could play an important role in a deep and long-term abatement strategy. Consumption change could also ease pressures on the demand for agricultural land, contributing to a reduction in pressures driving land use change worldwide.

Increasing production efficiency has a role to play in reducing emissions from agriculture but the scope is limited. Defra research[9] has examined the effect of potential changes in the size and configuration of the livestock sector could have on reducing emissions to air in order to best meet current GHGs and ammonia emission targets, while achieving the required levels of productivity. The results are summarised in Table 1 below.

Table 1. Estimates of the maximum potential output and forecast livestock numbers as a % of 2006 output that would enable 20% reductions in gaseous emissions (from Defra research project report AC0208).

Sector	Current alternative systems	Feasible improvements	Current forecast of livestock numbers by 2020
Dairy	83.6	84.1	92.8
Beef	85.0	82.9	90.8
Pigs	86.4	87.5	97.0
Poultrymeat	80.7	82.2	104.6
Eggs	83.5	89.3	104.6
Sheep	86.4	NA	97.2

The Defra study concluded that while there are many techniques for reducing ammonia emissions, the same is not true of GHGs. The key problem with mitigating GHG emissions from agriculture is that the losses occur throughout the year, and in the case of N_2O, comprise only a very small proportion of the source. Whereas means to abate other agricultural emissions, such as nitrate (NO_3) and ammonia (NH_3), are conceptually simple and lend themselves to straightforward abatement approaches, such as reduced-emission manure spreading or improving fertiliser practice, enabling large reductions of GHG emissions is difficult. It may be that, ultimately, the only means of substantially reducing GHGs from livestock production, without simply exporting the emissions to other countries, will be to substantially reduce consumer demand for livestock products.

The difficulty of mitigating production emissions is acknowledged in the policy community.[10] The Government's Low Carbon Transition Plan anticipates only a 6% reduction in agricultural emissions on 2008 levels by 2020.[11]

It is thus clear that food production is directly a major source of greenhouse gas emissions. Food production worldwide is also a driver behind land use change such as deforestation. Our earlier work showed that radical change is required if the food system is to make a contribution to reductions in line with wider climate policy. This will involve combining different approaches from farm to bin. An 80% reduction in the carbon emissions from the wider economy will reduce food chain emissions by about 50%, simply by reducing the carbon emissions from the supporting economy.[12] Changes to consumption and to farming itself are

[9] Defra, 2008. The limits to a sustainable livestock sector in the UK. Defra research project report AC0208.

[10] Defra 2006. The UK Climate Change Programme

[11] HM Government 2009. The UK low carbon transition plan.

[12] Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope for reduction by 2050. How low can we go? WWF UK and the Food Climate Research Network.

required if the food sector is to contribute more actively to reductions more in line with 80% reduction sought by the Climate Change Act 2008.[13]

The role of the livestock sector in the UK economy and land use

The UK livestock sector is focused on domestic consumption. The UK is 72% self-sufficient in indigenous foods and 59% self-sufficient overall. The UK has particularly high levels of self-sufficiency in the livestock sector. According to Defra statistics for 2009, these are: pigmeat, 52%; beef 81%, sheepmeat 88%, eggs 79% and poultry 91%. FAOSTAT trade data indicate that self-sufficiency in milk and milk products is ca. 92%. The farm-gate value of the major agricultural commodities is about £15.7 billion. Livestock commodities account for 60% of this output. Beyond the farm-gate, it is reasonable to assume that livestock products account for at least half of the total value of the £80 billion post-farm agri-food sector. The livestock sector from farm to fork is ca. 3.3% of the economy.[14]

In 2009, 73% of the UK land area was used for agriculture with ca. 84% of this area devoted to either grassland or arable crops for animal feed. Since about 70% of UK agricultural land is grassland of various qualities and the UK livestock sector is highly focused on domestic markets, consumption change focused on livestock products could have far-reaching consequences for land use, both in the UK and in other countries.

The UK's government's Land Use Futures Project[15] marks a milestone in the development of scientific evidence and opinion available to those charged with land use policy. It examined major challenges relevant to land use over the next 40 years and examined how land management can be changed to unlock more of the true value of land in relation to the welfare and well being of the UK population. It informs the long-term choices faced by government in particular.

A comprehensive account of that report cannot be provided here. It is noted here though that the report indicates further radical changes to both agricultural and planning policy. It highlights that current policies are leaving much of the value of land in terms of all ecosystem services supporting the wellbeing of UK society unused. It points to a more coherent set of interventions that directly influence land use and reward the delivery of public goods embedded in all policies influencing land use. Despite being charged with looking to a future strongly influenced by climate change policy, the Foresight Land Use Futures Project did not look at the potential role and consequences of consumption change. It did however consider the consequences of climate change – both mitigation and adaptation. It recognised that meeting the EU 2020 target for renewables may lead to greater competition for land, and changes to landscape character. It concluded that policies are needed to make better use of the land across the UK for climate change mitigation and for supporting the transition to a low-carbon economy, as well as managing the impacts of changing climatic conditions.

2. Scenario design

We developed scenarios to explore the potential consequences for land requirements of reducing consumption of carbon intensive food products. The scenarios would involve significant consumption change that may appear unlikely or 'extreme' today. However, we need scenarios that examine consumption patterns that go far enough to enable us identify the potential consequences of consumption change that the study seeks to explore (i.e. land requirements, land-use change, soil carbon release, displacement of emissions, etc.).

The assessment of substitution effects was a major consideration in developing our scenarios. Furthermore, reducing a commodity like sheepmeat could be achieved by a uniform reduction in the whole UK sector and imports. This is unlikely to occur in the real world because a variety of pressures would cause different degrees of change in different parts of the supply chain. Plausible arguments could be provided for reduction focussed on hill or lowland flocks, which would release both different quantities and qualities of land for substitutes and/or different enterprises. Another option might be a radical reduction in stocking rates in situ. The same could apply to much of beef sector. Changes in the proportion imported would have implications for food security.

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[13] http://www.opsi.gov.uk/acts/acts2008/ukpga_20080027_en_1, accessed 26th July 2010

[14] UK Government 2010. Agriculture in the United Kingdom 2009.

[15] Foresight Land Use Futures Project (2010). Final Project Report. The Government Office for Science, London.

We designed a range of consumption and production scenarios to examine a range of options on both the demand and supply sides. A meeting with a range of experts and other stakeholders on the 29th January 2010 in London provided external input. The participants are listed in Annex 1.

The scenarios we developed comprise three main scenarios interacting with three production scenarios. The combination of consumption scenarios 1 and 2 and three production scenarios gives a total of 6 system scenarios. These are complemented by consumption scenario 3 giving a total of 7.

The main consumption scenarios are as follows:

1. A 50% reduction in livestock product supply balanced by plant commodities.
2. A shift from red meat to white meat.
3. A 50% reduction in white meat supply balanced by increases in plant commodities.

It is important to note that the consumption data and scenarios relate to the flows of food commodities entering the UK food system, not food eaten. These data are obtained from Defra statistics but are also compiled in complete datasets by the FAO. The FAO database used in the study (2005) aligns imports, exports, home production, consumption and all the associated protein, fat, energy content of food commodities. That is, we assessed current patterns of food commodity supply to UK consumers (domestic production minus exports plus imports) and then estimated the effects of reducing the supply of meat, dairy, eggs, etc. in the various scenarios and increasing supply of substitute products (plant-based commodities).

Consumption Scenario 1: a 50% reduction in animal product consumption

Following consideration of various approaches such as 50% reduction across all commodities and reductions guided by health i.e. bigger reductions in dairy, it was decided to adopt an approach based on assessments of the likely reductions as affected by the role of commodities in real consumption patterns. This means that dairy and egg consumption is reduced less than meat. This is based on patterns observed in Turkey, Croatia, Bosnia and Cuba. These are rare examples of countries where per capita food energy supply is about 3000 kcal per day or more and animal product intake is about half that of the UK. The FAOSTAT data for these countries generally show the resilience of dairy and egg consumption in a low livestock product diet. We call this a 'consumer-led' approach to developing the reduction scenario.

Thus the chosen main scenario 1 is as follows (the consumption of products compared with the actual consumption in 2005 (Table 2).

Table 2 The consumption of products compared with the actual consumption in 2005 for consumption scenario 1

Item	Relative consumption	Comments
Milk and eggs:	60%	Lower reduction because of culinary role
Meat	36%	
Sugar:	70%	To align with healthy eating guidelines
Vegetables/fruit/pulses	150%	
Cereals/potatoes	133%	
Vegetable oils (not palm)	133%	
Beer, wine, beverages, cocoa, palm oil, fish.	100%	Unchanged

Consumption Scenario 2: a switch from red to white meat

White meat includes pigmeat. Substitution of one meat for another is complicated by uncertainties and differences in the energy content of meats, especially at the commodity level. We are using FAOSTAT data for the energy content of the carcase meat supplied in the UK. Inspection of these data revealed uncertainties over the energy values, fat and protein contents of beef and pigmeat in the FAOSTAT data for the UK. We replaced these very uncertain energy content data with corresponding more reliable data for Ireland.

Some red meat will remain in the diet so a 75% reduction in red meat matched by a corresponding increase in pig and poultrymeat was examined. The experience of the last twenty years in the UK in which poultrymeat consumption almost doubled while commodity supply was more stable in terms of energy (5% increase) than protein (10% increase) points to a focus on energy in substitution. Removing 75% of red (i.e. beef and lamb) meat reduces the commodity food energy supply by 103 kcal/day. This is compensated by a 45% increase in pig and poultrymeat.

Consumption Scenario 3: white meat consumption reduced by 50%

White meat accounts for 24% of livestock food commodity energy. This can be substituted for by a 10% increase in plant based commodities while allowing for a 10% reduction in sugar (to align with health guidelines). This 10% increase applies to cereals, fruit, vegetables and vegetable oils (except palm oil). Alcohol and beverages remain unchanged.

Throughout these scenarios, the current ratios between UK and imports will be maintained – i.e. a halving of consumption results in a halving of the associated net imports. The effects of the main scenarios on macro-nutrient supply are set out in Table 3.

Table 3 Per capita macro-nutrient commodity supply as affected by the consumption change scenarios.

Production scenarios	Livestock product supply, kcal/day	Total energy supply, kcal/day	Protein supply, g/day	Fat supply, g/day
UK in 2005	957	3291	103	128
50% reduction in animal products	482	3325	89	111
Switch from red to white meat	956	3290	105	120
50% reduction in white meat	843	3314	97	125

The effects of consumption scenarios are largely determined by the effect on livestock demand.

These are set out in Table 4

Table 4 The production of livestock commodities (thousand tonnes per year) in the UK as affected by consumption scenarios (based on FAOSTAT data for 2005).

Consumption scenario	Pig meat	Chicken meat	Turkey meat	Beef	Sheep meat	Milk	Eggs
Base consumption	674	1,281	207	762	317	14,442	498
50% reduction in livestock	243	461	75	274	114	8,665	299
Red to white meat	977	1,857	300	191	79	14,442	498
50% reduction in white meat	337	641	104	762	317	14,442	498

The simplest implementation of the consumption scenarios is to assume that each commodity can scale independently to suit demand. This has the advantage that qualitatively there is no change to the commodity, e.g. a tonne of beef, (which has the same proportions of culled dairy cows, reared calves from the dairy herd, culled beef cows and reared calves from the beef herd) which consists of the same fraction of suckler beef and dairy bred beef, etc. The disadvantage is that if beef is downscaled relative to milk, then there will be surplus culled stock and calves from dairy cows that do not enter the meat market.

The principal purpose of production scenarios is to examine the effect of industry structure and change within each consumption scenario, particularly with respect to red meat and dairy production. The production scenarios are applied to Consumption Scenarios 1 and 2. The production scenarios are focused on the intensity of arable land use in supporting livestock production as affected by sector structure and related factors. The production scenarios are:

Uniform land release

Current sector structures maintained with no change in land preferences – 'pro-rata' changes in land requirements. This could be considered to be vertical slicing of the production sectors.

Maximise tillable land release

This affects ruminant production and maximises the use of lower quality land for livestock production. This tends to be higher in altitude, such that proportionally more use is made of hill and upland grasslands for sheep and beef, but lower quality grassland may be also on low lying land. It is worth stressing that at no point do we assume that the absolute amount of any type of land increases over the baseline, thus additional land is not brought into agriculture. Dairying is assumed to continue on the best quality grassland (generally lowland). The sheep and beef sectors are re-structured to determine concentrate-feed demands. This results overall in the maximum release of tillable land (some of which may be already used as arable). The term tillable is used to indicate the inclusion of land that may already be used for arable activities (for human food crops or forage crops) as well as land that has some potential to be used for long-term arable, including food crops and biofuel crops (some of which may be perennial). There is no change in poultry or pig production.

Maximise low quality or non-tillable land release (i.e. mainly grassland)

Ruminant meat production is concentrated on higher quality land. Dairying remains on the same quality grass. The sheep and beef sectors are re-structured to determine concentrate demands. This results overall in the maximum release of grassland (some of which will be land of poor or very poor quality). There is no change in poultry or pig production.

Substitution

Consumption patterns are balanced on the basis of energy (e.g. food calorie supply). The modified commodity supplies are calculated from FAOSTAT food supply statistics for 2005 accessed in early 2010. 2005 is the latest year for which a full range of FAOSTAT data is available. These statistics combine commodity consumption with per capita supplies of energy, protein and fat for each commodity allowing substitution strategies to be developed. The resultant patterns of supplies are used to modify a standard data set of commodity imports, exports and UK product for 2005. This FAOSTAT dataset was accessed in early 2008 and has been carefully checked with national statistics and formed the basis of previous research. It still remains the latest complete data set of this kind available for the UK.

Using energy as the lead parameter recognises energy as the key determinant of total food intake and avoids extreme substitution scenarios, for example a large increase in one component to substitute for the reduction in a minor food component, e.g. a vitamin.

Assessment of proposed scenarios

Consultation with external experts (Annex 1) revealed general agreement that the consumption scenarios proposed by the CCC provide an appropriate basis for the study. The final scenarios, as presented above, avoid undue reliance on substitute products (e.g. meat analogues). They combine consideration of healthy eating recommendations and observations of consumption patterns in countries that combine low incidences of under-nutrition with low intakes of animal products from inspection of FAOSTAT statistics. They also recognise the role of dairy products and eggs in vegetarian or other low meat diets.

The potential nutritional impact of the proposed consumption scenarios was discussed with experts in depth. Further consultation with Professor Joe Millward (University of Surrey) confirmed that the scenarios are credible from a macro-nutritional perspective. The scenarios also pose negligible risk to micronutrient intake, although we acknowledge that this is a more difficult issue to assess.

Implications for the consumer

These consumption change scenarios arise from debate about the changes required to realise a low carbon economy. While the scenarios are neither predictions nor recommendations of low carbon diets, they reflect contemporary drivers and observations of the patterns of commodity flows in countries with adequate supply of food and low consumption of meat. In such countries, it is observed that dairy and egg consumption remains relatively high in a low livestock product diet. Thus, consumption of eggs and dairy was reduced less than meat in Scenario 1 (50% reduction of livestock products). This pattern is also observed in most vegetarian diets.

Defra[16] described such consumption change as a matter for *"some groups that advocate a diet with less meat as a way for consumers to reduce the environmental footprint of their diet*". Some researchers also

[16] HMG 2009. Food 2030.

regard consumption change as an issue driven by lobbying NGOs.[17] From these positions, it might be concluded that this type of consumption change is unlikely.

It is important to appreciate that just like the baseline consumption pattern, the changed patterns do not apply to each individual. The change for individuals will vary greatly – ranging from an increase in the number of people practicing vegetarian diets to some individuals whose diet remains unchanged. However, for the typical consumer there will be an increased reliance on dairy substitutes (e.g. margarine and cheese analogues), low fat milk with a greater proportion of milk fat going to butter, more meat free days, and smaller portions of meat. In particular, most of the livestock product energy not consumed is replaced by carbohydrate rich foods – e.g. bread, pasta and potatoes balanced by a general increase in fruit and vegetables. Such patterns are well established in other culinary traditions, including some in Europe.

There may also be a move towards eating more fish as an alternative to meat. The GHG emissions from most farmed fish production and from caught fish is not markedly less than from livestock production and there are clearly concerns about the sustainability of global wild fish stocks. This was why fish consumption was maintained at it is current level in the scenarios. Another trend could be to move towards more products such as industrially fermented microbial based protein, textured vegetable protein or tofu. Consumption scenario 1 accommodates such a change with increases in the consumption of the relevant raw materials. The reduction in commodity protein supply from 103 g/day to 89 g/day still leaves protein intake well above recommended minimum levels. However, protein energy supply drops from 12.5 to 10.7% of total energy supply. This may be challenging for some of the population that has become accustomed to higher levels of protein intake. In these circumstances, intake of pulse (e.g. beans and peas) based foods may increase more than 50%. Part of the implications for consumers, however, is the reaction of the food manufacturing industry and the retail and food service sector to changing supply and demand.

In some respects, the switch from red to white meat may cause a greater culinary change than the 50% reduction in livestock products. Reducing red meat consumption to 25% of the baseline would radically change the type of beef used with a large proportion coming from culled dairy cows. Apart from mince (which is already 50% of the red meat market[18]), red meat would become a rarity.

However the study did not conduct an in-depth assessment of impacts to macro and micro-nutritional intake and we note that there may be concerns as to the implications of scenarios on more vulnerable groups (children, elderly, etc.)

Thus these consumption changes may seem remote. However, there are two major reasons why consumers might adopt consumption change on the basis of self-interest: health benefits and food costs. In addition, the debate about livestock production consumption is growing across Europe where livestock production is more closely associated with intensive production practices and environmental degradation that it is in the UK.[19]

It is notable that there is a striking alignment between healthy eating and the consumption reduction scenarios we have examined. High livestock product consumption is associated with serious health problems in the developed economies.[20] Evidence of negative effects of excess livestock product consumption emerged in the 1960s when for example it was observed that high life expectancy at 45 years of age in Japan and Greece was associated with low intakes of meat and dairy products.[21]

World-wide, some consumer protection agencies are explicit about desirable levels of livestock product consumption. The German Society for Nutrition recommends a weekly intake of meat of 300–600g[22] (compared with an average intake of 1,200g per week in the UK). In a study examining the alignment of climate and health policies, McMichael *et al*.[23] conclude that "*particular policy attention should be paid to the*

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[17] Gill, M., Smith, P. and Wilkinson, J.M. (2009). Mitigating climate change: the role of domestic livestock. Animal 1-11.

[18] http://www.telegraph.co.uk/foodanddrink/foodanddrinknews/7975887/Mince-now-most-popular-cut-of-beef.html

[19] Streck, M and Draf, S. 2010. *Esst weniger Fleisch* (Eat less meat). Cover of the news magazine Stern No. 22.

[20] Tukker, A., Bausch-Goldbohm, S., Verheijden, M., de Koning, A., Kleijn, R., Wolf, O., Dominguez, I.P. 2009. Environmental impacts of diet changes in the EU. JRC European Commission.

[21] Nestle, M. 1999. Animal v. plant foods in human diets and health: is the historical record unequivocal. Proceedings of the Nutrition Society 58: 211-218

[22] http://www.dge.de/pdf/10-Regeln-der-DGE.pdf

[23] McMichael, AJ, Powles, RW, Butler, CD and R Uauy. 2007. Food, livestock production, energy, climate change, and health. *The Lancet* 370 (9549),1253–1263.

health risks posed by the rapid worldwide growth in meat consumption, both by exacerbating climate change and by directly contributing to certain diseases. To prevent increased greenhouse gas emissions from this production sector, both the average worldwide consumption level of animal products and the intensity of emissions from livestock production must be reduced". The study goes on to advocate an average intake of 630g per week, with no more than 300g from ruminants.

3. Current land use and management practices

The second task of this study was to calculate and describe the current land used (both within and outside the UK) for UK food and drink consumption.

Current land required to support UK food consumption patterns was calculated from the Cranfield LCA systems model[24] together with national and international statistical information. The Cranfield LCA determines all the resources required to produce a tonne of each commodity, including industry sector structures. This identified the direct land and type required by different grazing systems and the land required to produce inputs to the production system such as barley and soya, as well as to produce crops that produce by-products such as rapeseed meal and maize gluten meal.

In the original life cycle inventories (LCI) model, emissions intensities for several feed crops were developed, but new ones were required for this project. This is because the original included a cut off point where crops representing less than 5% of feed were not included. This is normal practice in LCA for individual commodities, but when aggregated to national totals it became apparent that some major crops and by-products that are present in current and changed consumption patterns were omitted. So, new LCI were created for this study for sugar beet, sugar beet pulp, synthetic amino acids, distillers' grains, brewers' grains, palm kernel meal, palm oil, sunflower meal and oil, oats, oatfeed, malt culms and molasses (cane and beet).

The LCI for soy meal and maize (plus by-products) were also updated given that the balance of exporting countries from which we receive these commodities has changed appreciably since the original model was developed, likely due to GM restrictions. The concentrate formulations for livestock were also modified with the aid of industry data on formulations, as well as national statistics, in order to reconcile national use of crops in concentrates and for direct feeding on farms. Crops and crop by-products use in concentrates are subjects to market conditions. As such average values over at least three years were used whenever possible. The LCI for all crops include land use from average yields in the UK or overseas, together with allocations for land use for by-products. These were used to determine the land needs for animal feed crops.

The ruminant LCA models also divide pasture requirements into different qualities of land (e.g. based on site classes, which define levels of grass productivity). These were originally tuned to the balance of grazing livestock in England and Wales, although much would be applicable to Scotland and Northern Ireland. Although changes in the balance of systems give indicative results of the change in grass demands, these are constrained in reality by the types of grassland actually available. The method for estimating current (and future possible) grassland use was thus based on the analysis of actual grassland statistics coupled with other bio-physical information as follows.

Parallel to this 'bottom-up' LCA based approach above, the land availability and suitability was examined through an analysis of the existing, publically available land use maps, and soil survey data. There are a number of approaches to categorising agricultural land based on general capability (Grade), suitability for grass production, and vegetation cover. None of these alone was entirely suitable for our purposes. We developed an integrated system based on estimates of capability as arable and grassland and most of our results are presented in terms of six classes of land in the UK: three arable (good, moderate and marginal) and three for grass (good grassland not suitable for arable, poor grassland and very poor grassland. In addition we also classify land outside the UK as either overseas arable or overseas grassland.

The allocation of the wide range of grazing lands to ruminant production presented a particular challenge. We used biophysical data, such as soil type and rainfall, and calculated the proportions of grass site classes in 5 km^2 grid squares. These proportions are applied to the actual grassland recorded in Defra's June census-survey, with adjustments made for the areas of arable crops and forage maize. Grazing livestock

[24] Williams, A., Audsley, E. and Sandars, D. 2006. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Defra project report IS0205.

numbers are taken from the census data and converted into livestock units by type and hence grazing demands are estimated. The amounts of grass of different qualities were then allocated in a cascade from the poorest to the highest starting with sheep and ending with dairy. More detail follows in the next sub-section.

Allocation of different types of grassland to livestock and estimating how much can be released under new scenarios.

To allocate different types of grassland to livestock (and thus assess how much land can be released under new scenarios) we relied on a number of data sources to determine what activity is currently carried out on what soil type and in what climate. For England & Wales, the common unit is 5 km^2 grid squares. All the data sources are approximate surveys of what actually takes place in a grid. Part of this is caused by the need to make data anonymous in accordance with the *Data Protection Act 1988*.[25] The data will thus always 'disagree' – in some cases by a small amount and in others by much greater amounts.

The soil map of England and Wales is based on soil polygons and was intersected with the grids. This gives the percentage of each soil association in each grid cell, which can be converted to the percentage of each soil type. Some soil types are potentially arable, some can only be permanent grassland and some are not suitable for agriculture. An analysis has also been carried out by the National Soils Resources Institute (NSRI) at Cranfield University to determine the suitability of soils in each location for different crops. We used the winter cereal suitability which can be well, moderate or marginally suited, or can be unsuited, which can be further defined as due to soil moisture or temperature. As a minimum therefore this land can be used to produce wheat bioethanol crops though not necessarily at the level of yield normally associated with current wheat lands.

Grassland is also allocated to grassland site classes based on rainfall, temperature and altitude. This indicates the grass productivity of this soil in this location.

The land cover map of England and Wales defines 18 land use types. For our purposes, the ones of interest are tilled, managed grass and other grass types such as heathland grass. The method seeks to allocate soils to each land use according to their appropriateness. Thus, the worst soils are allocated to "Other" uses and the best soils to tilled land such that that grassland sits on soils which are just unsuitable for tilling. However, this covers a wide range from soils which are very suitable for tilling but which for other reasons such as climate or history are used for livestock, to soils which are barely suitable for livestock.

The Defra census data (from a census every 10^{th} year) were allocated to 5 km^2 grid squares (Figure 1). Because the data are reported from farmstead locations, and farms may cover a wide area, there can be substantial disagreements with the above spatial data sources. For example one 5 km^2 grid in Wales contained over 5,000 ha of grassland (5 km^2= 2,500 ha).

As before the land was allocated to the land uses and soils. The livestock of different types (cows-calves-cattle, ewes-rams-lambs) were combined using livestock unit values to dairy, beef and sheep livestock units (LU) respectively. Given the number of livestock and the soils of different site classes, we determined by regression the LU supported by the different land types. Grassland on each soil was therefore analysed in terms of its LU size.

Finally, the livestock of each type were allocated progressively to the decreasing qualities of land, starting with sheep on rough grazing and ending with dairy cows on the best quality grassland and with forage maize.

In Scotland and Ireland, a similar procedure was followed but only soil grades were available and it is assumed that grade 3a or better is well suitable for arable, 3b moderate and 4 marginal. In Northern Ireland the grid unit is the county.

A more detailed worked example of the procedure is given in Annex 5.

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[25] http://www.statutelaw.gov.uk/content.aspx?activeTextDocId=3190610, accessed 2/07/2010

•Soil type and suitability

Soil 1046(24%)
Soil 1435 (15%)
Soil 2250 (9%)
Soil 0237(8%)
…etc (44%)

•Land use

Managed grass(45%)
Tilled (25%)
Other grass (15%)
Urban (8%)
Other uses (7%)

•Defra census

Arable (432ha)	Dairy livestock (423 LU)
Permanent grass (257ha)	
Temporary grass (102ha)	Beef livestock (222 LU)
Rough grazing(18ha)	Sheep livestock (341 LU)
…etc	…etc

Figure 1 Illustration of the survey data available for each 5 km^2 grid

Changing the scenarios results in different proportions of demand for grazing for dairy, beef and sheep. Making the assumption that stocking densities (due to land quality) remain the same in any grid, the amounts of grassland that can be released are then calculated by grass type. The changes are summarised at the top level in tables while plots show how land is released spatially. Note that this is a different approach from that used from the LCA model, which changes the demand for land non-spatially.

The grass land released is situated on soils of varying types. In England and Wales, the soils are defined as suitable for arable, ley, permanent grassland or non-agriculture. For arable-suitable soils, a procedure has been developed to define whether these soils are:

- Well suited to arable cropping
- Moderately suited to arable cropping
- Marginal suited to arable cropping
- Unsuitable for arable cropping because of
    - soil moisture deficit
    - temperature
    - other reasons.

Thus grassland released can be categorised as either of these arable categories and the grassland qualities were, thus, divided into the following corresponding categories:

- Good grass, suitable for arable
- Moderate for arable
- Marginal for arable
- Grass, but not fit for arable
- Poor Grass, but not fit for arable
- Very Poor grass, but not fit for arable

In addition, land already used for forage maize must be of arable quality, although other factors may mean that is it not more that moderately suited.

Land use for crops eaten directly by humans

This was determined by a combination of the LCI data in the Cranfield model for crops such as bread wheat, potatoes, oil seed rape, apples and tomatoes, national statistics on other crops, and FAOSTAT data on crops grown overseas. Average yields were used that are most representative of areas from which we import food. For example, given that most maize comes from France, a higher yield than the world average (including some very poor developing countries), was appropriate. Crops are grown in several ways and these were set into the following categories.

- Arable crops (e.g. wheat, potatoes)
- Horticulture (e.g. tomatoes, strawberries)
- Orchards (e.g. apples, grapes)
- Plantations (e.g. tea, palm oil)
- Paddy rice (rice only, a sub-set of arable crops)

Errors and uncertainties in data on crop and land use

Apart from any errors in national and international statistics, there is some uncertainty about other uses of land and crop consumption. There are about 250,000 horses in the UK along with much smaller numbers of grazing livestock, such as farmed deer and alpacas. These occupy some agricultural land and consume some feed crops (and straw for bedding), but with very variable quantities and qualities per animal. Some crops (and animal by-products) also enter the pet food market, but these are likely to have a much smaller effect. Some land that is reported in the annual census as being agricultural may be used for private purposes (e.g. horses).

Current land use

The UK has ca. 18.5 million ha of agricultural land (18.7 million ha in 2009)[26] of which 17.8 million hectares is used for crops and livestock (see

Table 5). Estimates of wooded land vary. A combination of the Inventory of Woodlands[27] and a report on the nature and extent of forest cover[28], and the Defra statistics presented in

Table 5 indicate that woodland accounts for about 2.5 million hectares, including 584,000 hectares of wooded agricultural land.

Table 5 Summary of agricultural land use in the UK from Defra statistics (average of 2004-2006)

Land use	Area, kha	Proportion
Total crops	4,469	24%
Uncropped arable land	650	4%
Temporary grass	1,192	6%
Grass over 5 years old	5,766	31%
Sole right rough grazing	4,390	24%
Common rough grazing	1,238	7%
Woodland	584	3%
All other land	273	1%
Total agricultural area	18,562	100%

[26] http://www.defra.gov.uk/evidence/statistics/foodfarm/general/auk/documents/asiyp08.pdf, accessed 27/07/2010

[27] Forestry Commission 2003. National inventory of woodlands and trees.

[28] UK Clearing house mechanism for biodiversity: Nature and extent of UK forest cover.

The development of agricultural land use over the last century is characterised by specialisation at the farm, regional and national scale (Figure 2). The result is that grassland farming has concentrated in the west and arable farming in the east. The reasons for this are numerous: tractors have replaced horses, improved communications (railways and roads) allow production and consumption to be geographically separate, specialisation at farm and regional level allows costs at the individual commodity level to be reduced. Specialisation also simplifies farm management. The use of fertilisers allows crops to be grown in all-arable rotations. Technologies such as slatted floor housing allow intensive livestock keeping without cereal straw for bedding. The structure of UK agricultural production continues to move towards specialisation. Angus et al.[29] provide an overview of agricultural land use in the UK and insight into recent and potential future changes.

Agriculture accounts for about 77% of the total area of the UK, compared with an average 50% for the EU27. Of the 17.5 million ha used for agriculture, about 28 per cent is allocated to crops, and 67 per cent is grassland. The grassland includes 4.4 million ha of sole-owned rough grazing and 1.1 million ha of common land in mainly upland “disadvantaged areas,” primarily used for beef and sheep production. Thus the UK is characterised by a high proportion of land and thus landscapes shaped by farming, particularly livestock farming. Figure 2 depicts changes in livestock production across the UK between 1931 and 1991.

On the basis of crop cover, just over half of English farmland is arable land and this accounts for 68% of UK arable land. Scotland is dominated by rough grazing and Welsh agricultural land is dominated by permanent (improved) grassland. The proportion of arable land is particularly low in Wales.

The use of land on agricultural holdings as well as common rough grazing is summarised in

Table 5. Grassland of varying qualities dominates land use and accounts for 68% agricultural land use.

Land can be categorised in terms of agricultural capability using various methods. The systems in England, Wales and Northern Island apply 5 grades (1 to 5, best to worst), with sub-divisions of grade 3 into A and B. The Scottish system extends the grades to 7 and has more sub-divisions. The descriptions of the grades 1 to 5 are such that that there is a close functional correspondence with England grades 1 to 5. Land in the rest of the UK that could fall into the Scottish classes 6 and 7 would be in class 5. The full descriptions are in Annex 2.

The agricultural land is graded according to the degree to which its physical characteristics impose long-term limitations on agricultural use. The limitations operate in one or more of four principal ways. They may affect the range of crops which can be grown, and the level of yield, the consistency of yield and the cost of obtaining it. The ability to grow a wide range of crops (including grass) whether actual or potential, is given considerable weight but it does not outweigh the ability to produce consistently high yields of a somewhat narrower range of crops.

The main physical factors which have been taken into account are climate (particularly rainfall, transpiration, temperature and exposure), relief (particularly slope) and soil (particularly wetness, depth, texture, structure, stoniness and available water capacity).

The grading of agricultural land is on the basis of physical quality alone. Other less permanent factors such as the standard and adequacy of fixed equipment, the level of management, farm structure and accessibility are not taken into account. Land grade is thus not a complete indication of the relative values of farms located on them, either as a source of income or capital, since these values will usually depend largely on such shorter term factors. A summary of land grades and uses is provided below:

- **Grade 1** is usually use for the highest value crops, e.g. field horticulture. The largest concentration of Grade 1 land is in the fens of Lincolnshire and Norfolk.
- **Grade 2** is often used for horticulture or arable, but may also be used for grazing.
- **Grade 3** land includes both arable and highly productive managed grassland. 95% of grade 1 land is in England. This has implications for the ability of regions to respond to an increase in the demand for horticultural produce. England accounts for 77% of land well suited to arable crop production (grades 1 – 3a).

[29] Angus, A., Burgess, P.J., Morris, J. and Lingard, J. 2009. Agriculture and land use: Demand for and supply of agricultural commodities, characteristics of the farming and food industries, and implications for land use in the UK. Land use policy 26: 230-242.

- **Grade 4** is more limited in its ability to support crops (often only forage crops and with variable yields) and is generally more likely to be managed grass.
- **Grade 5** supports negligible arable activity and may include rough grazing.

England represents about 54% of total land area, Scotland 32%, Wales 9% and Northern Ireland 6%, but about 68% of Scottish land falls into Grades 6 and 7. *These areas support very little agriculture, but may support animals for sport, e.g. deer and grouse.* England has higher proportions of Grades 1 and 2 land within the country than the other countries and also has the vast majority *per se* in the UK. The areas and proportions of land in the UK by country and grade are summarised below in Tables 6, 7 and 8.

Table 6 Areas of land in the UK by grade (all land), kha

Class or Grade or Category	**England**	**Scotland**	**Wales**	**NI**	**UK Total**
1	355	4	4	9	371
2	1,849	172	41	64	2,126
3	6,292	1,172	338	675	8,476
4	1,840	822	827	333	3,822
5	1,101	1,427	640	206	3,374
6		3,732			3,732
7		255			255
Other (e.g. water)	657	75	170	75	976
Urban	952	123	58	55	1,189
Grand Total	13,046	7,782	2,078	1,416	24,322

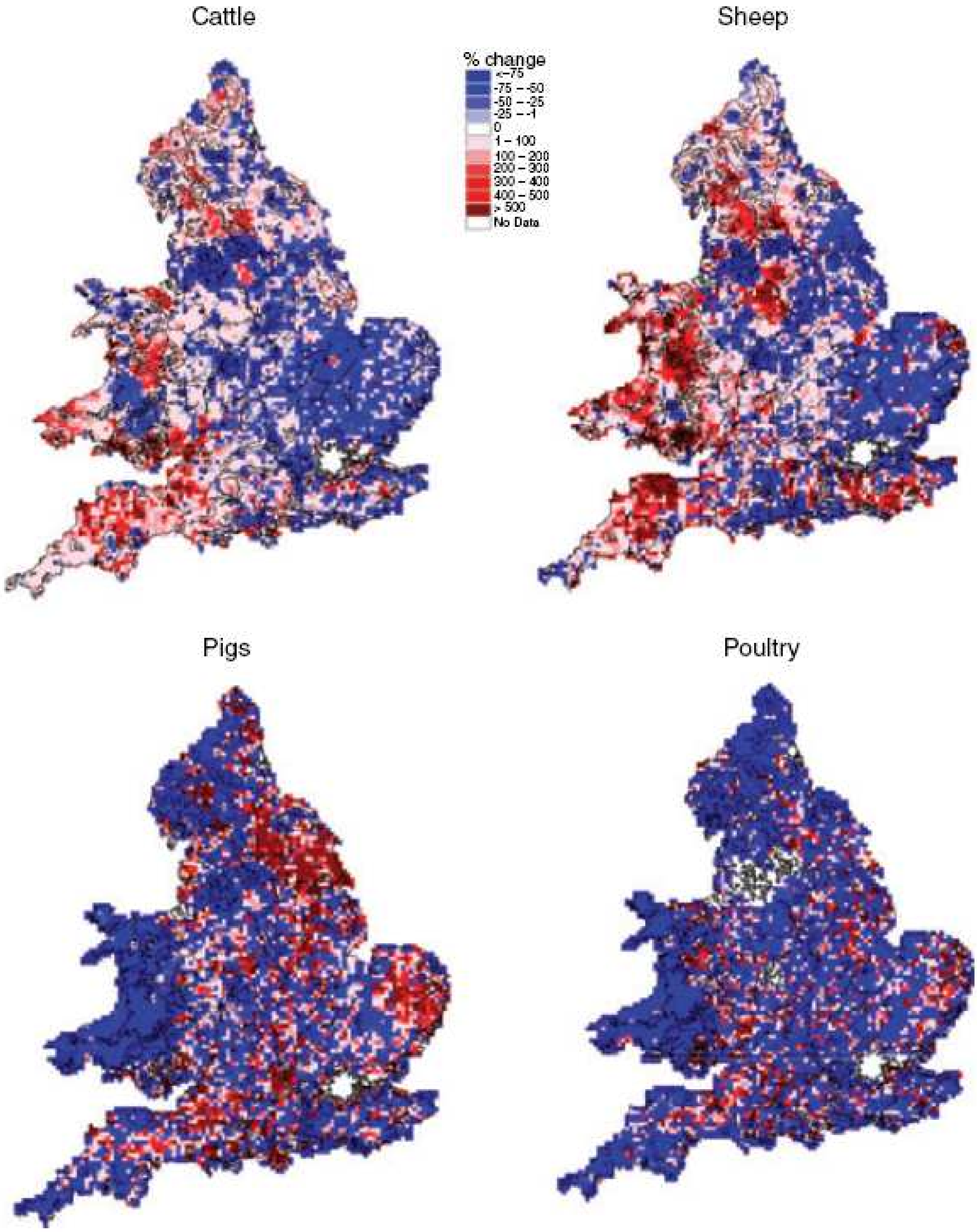
Table 7 Proportion of land by grade in the UK regions

Class or Grade or Category	England	Scotland	Wales	NI	UK Total
1	2.7%	0.1%	0.2%	0.6%	1.5%
2	14%	2.2%	2.0%	4.5%	8.7%
3	48%	15%	16%	48%	35%
4	14%	11%	40%	24%	16%
5	8.4%	18%	31%	15%	14%
6		48.0%			15%
7		3.3%			1.0%
Other (e.g. water)	5.0%	1.0%	8.2%	5.3%	4.0%
Urban	7.3%	1.6%	2.8%	3.9%	4.9%
Grand Total	100.0%	100.0%	100.0%	100.0%	100.0%

Table 8 Locations of graded land in the UK by proportion

Class or Grade or Category	**England**	**Scotland**	**Wales**	**NI**	**UK**
1	95%	1%	1%	2%	100%
2	87%	8%	2%	3%	100%
3	74%	14%	4%	8%	100%
4	48%	22%	22%	9%	100%
5	33%	42%	19%	6%	100%
6		100%			100%
7		100%			100%
Other (e.g. water)	67%	8%	17%	8%	100%
Urban	80%	10%	5%	5%	100%
Grand Total	**54%**	**32%**	**9%**	**6%**	**100%**

Figure 2 Percentage change in the number of farm livestock in England and Wales, 1931–1991[30].



[30] Johnes, P., Foy, R., Butterfield, D. and Haygarth, P.M. 2007. Land use scenarios for England and Wales: evaluation of management options to support 'good ecological status'. Soil use and management 23: 176-194.

Land used to supply UK food commodities

The amount of land currently used to support UK food consumption patterns were calculated by the methods described earlier. The results (Table 9) show that we use about 4.6 million ha for crops that we eat directly, 3.2 million ha for animal feed crops and about 12 million ha of grass for grazing stock. There is substantial interaction between uses, e.g. land for flour is allocated to humans and wheatfeed, which is a residue from flour milling, to animals, although the actual crop is grown in one physical location.

It must be stressed that these areas are not weighted by productive capacity and much of the land is not functionally interchangeable. The productive potential of land types is addressed later where we examine the ability of UK land to support production changes brought upon by the scenarios.

Table 9 Land used to supply UK food commodities as determined by Cranfield model for the baseline case

Type	Crops eaten by humans, kha			Arable land used for concentrate feed production, kha			Total grassland of all qualities (equally weighted), kha		
	UK	OS *	Total	UK	OS	Total	UK	OS	Total
Arable crops	1,756	722	2,478						
Paddy rice		130	130						
Horticultural crops	102	63	164						
Orchards	19	1,050	1,069						
Plantations		739	739						
Dairy				354	92	445	1,691		1,691
Beef				288	160	449	4,311	562	4,873
Sheep				47	17	64	5,225	58	5,282
Poultrymeat				416	684	1,100			0
Pigs				265	652	917			0
Eggs				118	125	242			0
Totals	1,876	2,704	4,561	1,512	1,754	3,265	11,228	1,944	13,172

* OS = Overseas

Agricultural land management practices (see Annex 6)

Angus *et al*.[31] set out data for UK land use and livestock numbers over the last thirty years. Even over the short period from 1979-81 and 2008, there has been significant change in land use and livestock numbers illustrating the responsiveness of agriculture to policy and market signals. The increase in wheat and oilseed rape reflects the intensification (and specialisation) of arable production in England driven by markets, technical change and policy. Conversion of rough grazing has led to increases in permanent grassland. Livestock numbers also reflect public policy. The milk quota combined with technical change has reduced the dairy cow population and the fluctuation in the sheep flock is clear evidence that hill and upland farmers respond to signals.

We consider below the industry structure of current UK livestock and crop systems. More detail is provided in Annex 6.

Dairy production

The UK is self-sufficient in milk for direct consumption, and about 90% self-sufficient for milk and milk products overall. Dairy farming is the largest single sector of agriculture in the UK, representing about 22%

[31] Angus, A., Burgess, P.J., Morris, J. and Lingard, J. 2009. Agriculture and land use: Demand for and supply of agricultural commodities, characteristics of the farming and food industries, and implications for land use in the UK. Land use policy 26: 230-242.

of UK agricultural production by value. Geographically, dairy farms are frequently found in areas such as the western UK where grass production is favoured by higher rainfall and a milder climate.[32] Milk production is generally associated with intensive grassland management with higher rates of nitrogen fertiliser applied compared with that for other uses of grassland[33]. The industry is based on the delivery of 13,208 million litres of milk from 1.8 million cows[34] (in 2009).

The dairy sector is closely linked to the beef sector with about half of the animals in the rest of UK cattle herd originating from the dairy sector.

Beef production

The UK cattle herd of about 10.1 million produces about 850,000 tonnes of beef per year. About half of this output is derived from calves reared for beef from the dairy herd, with some from culled dairy cows. The other half originates from calves reared for beef from 1.6 million beef suckler cows. In all cases, finishing can be grass/silage or cereal based, or a mixture of these. Grass based diets are the most common in the UK. Summer grazing cattle on grass pasture often supplies all of the needs of the growing animal. Cereal based concentrate rations are used to supplement grass particularly in winter and/or to supplement forage in the finishing phase. Ruminants are particularly useful consumers of industry co-products, which generally provide protein, and which are available as residues after extraction of the target product. For example, the extraction of oil from rapeseeds results in over 50% by weight of oilseed meals. Rape is a major UK crop also used to produce bioenergy. Similarly sugar (16% content) results in sugar beet pulp, wheat results in wheatfeed, and barley results in brewers' grains.

Table 10 Summary of UK beef production systems

Diet type	Breed type/sex	Age of slaughter
Intensive cereal beef	Continental and dairy breeds/bulls	12 months
Intensive grass silage beef	Dairy cross and beef breeds/bulls & steers	16 months
Mixed grass/concentrate fed beef	Dairy cross / steers & heifers	18-20 months
Mixed grass/concentrate fed beef	Dairy cross & beef / steer	22-26 months
Forage based suckler beef	Beef breeds / steers and heifers	18-20 months

So the beef industry is complex, with a wide range of animals being reared on different feeding systems in a wide range of environments. This complexity was reflected in the models we used. Sheep production

The sheep sector produced 314,000 tonnes of carcase meat in 2009 from a production base of 15 million ewes. This carcase meat output came from the slaughter of 14 million lambs and 2 million other sheep, mainly culled ewes. The UK sheep sector is structured to exploit the range of UK land resources on hills, uplands and lowlands. This stratification is an adaptation to UK land that has evolved over centuries. It is based on a network of pure and cross-bred flocks. UK lamb is available throughout the year, generally as follows:

- 'Easter' lamb: Born in December/January on lowland farms, reared intensively for 10-16 weeks (including using concentrate feeds), sold in March to May.
- Summer lamb: Born in spring on lowland farms, ewes and lambs grass-fed, sold in June/October.
- Autumn lamb: Born in spring on upland and hill farms, sold in November/December following intensive feeding on concentrates or lowland grass.
- Hoggets: Sheep ('yearling lamb') that are than one year old, available in spring, generally from hill or upland flocks, over-wintered on lowland farms on grass, finished partly on forage and concentrates.

Pigmeat production

UK pig production declined by about one third between 2000 and 2005 and has now stabilised at 700,000 tonnes per annum. 400,000 sows are the basis of this production. A sow will typically produce about 6 litters in total. Feed costs make up 70 per cent of the production costs within the growing and finishing stage

[32] The Dairy Supply Chain Forum 2008. The Milk Roadmap.

[33] Defra 2007. British Survey of Fertiliser Practice. Fertiliser use on farm crops for crop year 2006. Defra, York, UK.

[34] Defra 2010. Agriculture in the United Kingdom 2009.

of pig production. Normally pig rations comprise cereals, soy, minerals and vitamins in a compound form. Various co-products of the food industry are used, including bakery waste and food that has exceeded its sell-by date. The target is to achieve 100kg liveweight at 140 days old at a food conversion ratio of 2.4kg feed intake to 1kg liveweight gain.

Poultrymeat production

The UK is a major producer of poultrymeat and this sector expanded rapidly during the 1990s in response to increasing demand. This production is dominated by the output of 800 million chickens, each producing on average a 2.2kg carcase at about 43 days of age. Apart from free-range production which accounts for less than 1%, production is highly specialised in large production units with highly regulated housing environments and feeding regimes. Poultry have a feed conversion efficient of about 2:1. This means only about 2kg of feed are required for each kg liveweight gain. The feed is made up mainly of cereals and a relatively large supplement of imported soy meal (about 25%).

Egg production

The UK egg industry is based on about 27 million hens producing 9.4 billion eggs. The egg industry also produces about 55,000 tonnes of spent hen poultrymeat. There are three production systems used: free-range, barns and caged flocks. Caged hens produce more eggs per kg feed compared with free-range and barn housed hens. It takes about 150g of a feed based on wheat and soy to produce one (60g) egg.

Table 11 Feed in kg required by livestock production derived from Cranfield LCA model

	Concentrates	Grass	Forage maize	Barley
Beef (kg)	2.1	11.4		2.1
Sheep (kg)	2.1	25.5		0.1
Pigs (kg)	4.2			
Poultry (kg)	3.1			
Eggs (kg)	3.1			
Milk (l)	0.3	0.9	0.1	

Cereal production

Crop production in the UK is dominated by the cereal crops of wheat, barley and oats. UK cereal yields are very high by world standards due to climate and suitable soil. The average yield of wheat is 8 tonnes per hectare. . The UK produced 21 million t in 2009 and is more than self-sufficient in cereals. Exports of feed quality cereals exceed imports of bread-making quality cereals. The 21 million t produced comprises: wheat, 14.9 million t from 1.8 million ha; 5.5 million t of barley from 1 million ha; and 0.5 million t of oats from 91,000 ha. About half of the wheat crop is used for animal feed, the other half for flour (41%), seed (2%) and other uses such as distilling. Almost two thirds of the barley crop is used for animal feed, the balance is mostly used for beer and distilling. Two thirds of the oat crop is used for human consumption.

The use of fertiliser nitrogen is the most important issue from a resource use and emissions viewpoint for all crops including grass. About 180kg N per ha is applied to winter wheat for feed purposes with an additional 40kg applied to winter wheat for bread-making. Protein concentration and quality are important determinants of the quality of the flour and this additional nitrogen is used to support higher protein levels in the grain destined for bread-making. About 150kg N are applied to winter barley for feed purposes. About 20kg less is applied to malting barley to help reduce protein levels in the grain, which is a malting quality criterion. About 100kg N per ha are applied to spring sown barley.

In addition to these fertiliser applications, like all crops, cereals must be supplied with adequate potassium and phosphorus to replace the off-take in the grain. Sulphur is also increasingly applied.

Oilseed rape

The UK produces 1.9 million t of oilseed rape from about 0.75 million ha. The average yield is 3.4 tonnes of rapeseed per ha. From a resource use and LCA viewpoint, the production of oilseed rape is similar to winter wheat. About 200kg nitrogen fertiliser per ha is applied.

Sugar beet

The UK is about two-thirds self-sufficient in sugar. UK sugar is provided by 120ha of sugar beet yielding about 10 tonnes refined sugar per ha (70 tonnes of sugar beet/ha). It is nowadays grown in the eastern side of England only on good arable soils and close to the remaining large sugar factories. Sugar beet is harvested in September to November.

Potatoes

6.4 million tonnes potatoes were produced on 149,000ha in 2009. This production makes the UK 84% self-sufficient in potatoes. As with sugar beet, production is concentrated on the best soils. Pesticides are also intensively used, mainly against fungal diseases and slugs.

Peas and beans

These are pulse crops harvested as dry seeds using combine harvesters, i.e. as with cereals. In 2009, they comprised 190,000ha beans that produced 722,000 tonnes and 28,000ha peas that produced 141,000 tonnes. These crops 'fix' nitrogen in soil which is supplied to subsequent crops and are also a 'break' crop providing a disease free entry for cereals. Peas are used for human consumption and animal feed, while beans are largely used for animal feed. As protein rich pulses, they substitute some imported high protein soy. Pesticide use is generally low.

Field fruit

UK fruit production is based on 18,000ha of orchards and 10,000ha of soft fruit (e.g. strawberries). Scotland is renowned for raspberry and black currant production. Most of the remaining fruit production is located in England. The UK is only 12% self-sufficient in fruit. UK production was 415,000 tonnes in 2009, out of a total consumption of 3.5 million tonnes.

Field vegetables

This category of produce covers a wide range of crops including root vegetables such as carrots, cabbage, broccoli, cauliflowers, lettuce, onions and leeks. The UK is 59% self-sufficient in vegetables producing 2.6 M t from 123,000ha. This includes 1,000ha of protected crops, for example tomatoes and mushrooms. Production practices are diverse but generally characterised by the use of the highest quality land, high rates of nitrogen application and some irrigation.

Determining effects of consumption scenarios on land requirements

Our LCA systems models were used to determine the land required for each of the consumption and production scenarios, in conjunction with the statistics based method for grassland release. To test the effect of production scenarios, the area required was allocated to the land available, with land first being allocated where no change is required (e.g. arable land used for animal feed production converted to arable land for human consumption) and then progressively to land which requires change but is most suitable for other uses. There is large number of combinations of production and land use options, especially in the production of beef and sheepmeat. There are different ways of calculating the effect on land requirements where scenarios reduce land needs. Grassland released could be hill, upland or lowland. But there are constraints. It is difficult to produce finished lambs and beef cattle on uplands. It is also necessary to achieve a supply of finished lambs throughout the year, which is most obviously achieved by a pro-rata reduction in the land types used. There are also important constraints within beef production. Beef from culled cows is lower in quality compared with beef from beef cattle. The dairy sector also produces surplus calves which, unless they are simply killed at birth, are reared for meat. Greater use of dairy calves for beef would, combined with a reduction in demand, reduce the need for suckler cow based systems. This would reduce the supply of well-conformed prime beef carcases in particular which means that such a change requires a complementary shift in demand patterns as well as an overall reduction. Production options for producing beef from dairy calves range from intensive feeding based on cereals to grass-based systems, with corresponding land requirement implications. Our production scenarios avoid an infinity of solutions by focusing on two alternative land uses that maximise the release of arable land and the release of grassland respectively.

Reductions in the requirements of a land type were allocated pro-rata across countries. The possible use of released land was considered on the basis of quality, needs and opportunities. For example, hill land may be used for forestry, recreation or non-agro-forestry ecosystem service (NAFES) provision. In contrast, much land currently used for dairy grass production could be used for arable cropping for food or bioenergy (some possibly being perennial).

As the previous section shows, farming systems comprise interdependent production activities for the many different commodities that are produced. Half of beef production is based on dairy bred calves and nearly 20% of beef is derived from culled cows. The sheep industry is stratified with hill and upland flocks, each adapted to their own habitats, supplying breeding stock with hybrid vigour to the lowland flocks that produce the terminal generation of lambs for finishing. Thus, the LCA model contains a lot of constraints to reflect these interdependencies that characterise the structure of the livestock industry in particular. The production scenarios modelled modify the structure of farming and thus the constraints. The production scenario involving reductions distributed evenly in relation to current land used is straightforward to implement as land used for commodities is scaled down according to the demand to commodity. The grazing model used in our LCA models contains three pasture grades for lowland, upland, and hill, each of which is composed of a mosaic of different grass yield site classes. In our model, suckler beef cattle and sheep are the only classes of stock to use upland and hill grassland. The analysis assumes that lowland is potentially suitable for arable whereas upland and hill are not.

For examining production scenario 2 (maximise tillable land release, i.e. maximise use of grassland and land of lower quality for ruminants) the proportion of beef suckler herds in the lowlands is reduced until the area required by the upland and hill based sucker herd exceeds the area in the baseline case. Again this assumes that there will be no qualitative change due to different breeds being favoured in different areas. This is less straight-forward with sheep where lowland 'type' flocks cannot simply be moved up to the uplands and hills without changes in performance.

Our examination of production scenario 3 (maximise grassland release, i.e. maximise use of better quality land for ruminants) focused also on sheep and beef production options. Modelling the effect of options for the beef suckler herds involves changing the proportion of herds in the different areas. It could be argued that this will mean a change in carcase conformation as different breeds of beef are suited to different habitats, e.g. the heavier better conformed continental breeds are more common on the lowlands. However, it should be noted that conformation quality is not correlated with eating quality.[35] The intensive beef finishing systems remain in the lowlands.

Modelling the changes in sheep production under production scenario 2 is complicated by the genetic interdependencies of flocks in the three habitats. To preserve this genetic structure the different elements have their diet changed to allow them to be fed hill, upland, or lowland pasture, but to continue to perform the same role, i.e. hill 'type' flocks supplying 'broken mouthed' ewes to cross breeding upland 'type' flocks and both now located in the lowlands if need be. The sheep consume the pasture by the kg dry-matter so stocking rate adjusts automatically, but other aspects of performance, such as fecundity, are assumed not to change due to changing diet and habitat conditions.

One assumption made is that the beef suckler and sheep industries cannot exceed the area of each grass site class that they currently have in the baseline scenario. This approximates to a requirement that even if the uplands and hills are cleared that the area of lowland used by them does not exceed current amounts to ensure that other commodity demands on lowlands are not infringed.

4. The analysis of land needs

Uncertainties

A description of uncertainty estimation is provided in Section 8. Results are presented here without uncertainty estimates, but it should be remembered that the estimates in the UK are assumed to have a coefficient of variation of 5% and those overseas of 10%.

Location of data tables

A summary of the land requirements for baseline and all scenarios is shown in Table 13 along with a summary of changes in land requirements in Table 14 and Table 16 The same level of detail as in the baseline description (Table 12) is given for each of consumption scenarios 1 to 3 in Table 60 to Table 66, along with tables of the changes in Table 67 to Table 73. Maps showing the areas of land release are shown subsequently. Descriptions of the effects of these changes under scenarios are associated with

[35] Richardson, R.I. 2005. Improving the eating quality of beef: optimising inputs in production and processing. The science of beef quality. British Society of Animal Science. http://www.bsas.org.uk/downloads/BQ_May05.pdf

summary tables (Table 14 to Table 16). The detailed tables are otherwise presented without individual comment.

The land released has been presented in tables on a UK basis in the main report, but the baseline land used and land released are also given in tables in Annex 3. The demand for food is broadly similar between the four parts of the UK. The potential for land release is determined by a combination of demand and land supply. Given the inter-connectedness of the UK food system and the assumptions about the scenarios and uncertainties, it seemed more appropriate to assume that the release of land applies to a uniform change in demand, so that grassland would be released as determined by the scenarios in proportion to *de facto* livestock numbers. For example, a chicken eaten in Wales could be produced in Northern Ireland with feed crops grown in Scotland and England, while the sheep flocks in England, Wales and Scotland are commercially and genetically linked. The releases of grassland are best seen in the maps of grassland release.

The location where current arable land is released from feed production was not considered spatially as there would not necessarily be a change in land use.

Land requirements for the consumption scenarios

The land requirements for each scenario are presented first, followed by the potential changes in land requirements. The requirements and changes are shown in tables and changes are shown graphically. A summary of land use for the current food system is provided above in Table 9 and an expanded version is shown in Table 12. Table 12 indicates the types of grass quality currently used in the UK food system, with about 60% being completely unsuited to arable and about 40% with some arable potential. Sheep use more grassland than other sectors, but the sheep sector has been developed to make use of lower quality land. They also use much smaller proportions of arable land than any other stock.

The nature of animal diets has a major influence on the location of land used for feed crops. Poultry and pig production use much soy, which is relatively low yielding and hence increases the proportion of overseas land required compared with ruminant feeds.

Land needs

Consumption Scenario 1

Under Consumption Scenario 1 (50% reduction in livestock product consumption), there is an increase in demand for arable land for crops eaten directly by humans of about 584,000 ha in the UK and 762,000 ha overseas to compensate for reduced livestock product consumption. This is exceeded by land released from animal feed production (ca 1.0 and 0.9 million ha overseas and in the UK respectively). The amount of grassland released varies with production scenarios. The release of grassland with some arable potential ranges between 1.7 and 3.7 million ha (unweighted) and that fit only for grassland ranges between 0.7 and 6.9 million ha (unweighted) (Table 14). The quality of land, of course, differs and therefore yield potential weighting factors (Table 15) were applied to the areas of grassland released (Table 16). This analysis suggests that the release of current arable land is about 250,000 ha (weighted) and the grass with arable potential ranges from 1.0 to 2.9 million ha (weighted) with 2 million ha released under the uniform land release production scenario. Grassland released suitable for grass only ranges from 0.3 to 1.7 million ha, with the uniform release at 1.1 million ha (weighted). The production scenario with maximum release of grassland would almost entirely eliminate sheep and beef from hill, most uplands and some poor quality lowland areas.

Consumption Scenario 2

Under consumption scenario 2 (a shift from beef and sheepmeat to pork and poultrymeat), the changes are substantially different, with no change in existing arable for direct human food crops. The different dietary needs of monogastrics mean that more arable cropping is needed both in the UK (about 55,000 ha) and to a much greater extent overseas (467,000 ha), driven largely by soy and some by-products, such as sunflower meal. The weighted release of arable quality grassland considerably exceeds the increase needed for concentrate feed production, ranging between 1.3 and 2.4 weighted million ha (1.8 million ha for uniform release). The release of grassland unsuitable for arable (weighted) ranged from 0.6 to 1.5 million ha. This consumption scenario (irrespective of production variations) causes a net increase in demand for overseas crops, although considerably more potentially arable land is released in the UK. No doubt, some equivalents of imported feed crops could be grown domestically, although soy is currently not one.

Consumption Scenario 3

Under consumption scenario 3, (a 50% reduction in white meat consumption) the changes are much less complex with no changes in grassland requirements. Increases in demand for arable land for direct human consumption amount to about 0.3 million ha, but both domestic and overseas demands are more than compensated for by the release of land from feed production. Of course, overseas cropping land is far from uniform and the release of land from producing soy may occur in South America, while the increased demand for more cereals, fruit and vegetables could be met by production in the North America and the Mediterranean region.

Table 12 Baseline land requirements for current food consumption in the UK (in kha)

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			Total potentially and actually tillable land of all qualities (NB: equally weighted)		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor Grass	Very Poor grass	All qualities
Arable crops	1,756	722	2,478						1,756	722				
Paddy rice		130	130							130				
Horticultural crops	102	47	148						102	47				
Orchards	19	1,050	1,069						19	1,050				
Plantations		739	739							739				
Dairy				354	92	521	618	240	1,734	92	272	38	2	
Beef				288	160	575	1,101	484	2,448	160	738	692	722	1,776
Sheep				47	17	233	339	202	821	17	401	749	3,301	168
Poultrymeat				416	684				416	684				
Pigs				265	652				265	652				
Eggs				118	125				118	125				
Totals	1,876	2,704	4,581	1,512	1,754	1,330	2,057	926	7,701	4,458	1,412	1,478	4,025	1,944

OS = Overseas

Table 13 Summary of land requirements for current food consumption in the UK and under alternative consumption scenarios and production scenarios (in kha). The detailed changes for each scenario in the format of Table 12 can be found in Annex 7.

Scenario	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			Total potentially and actually tillable land of all qualities (NB: equally weighted)		UK non-arable grassland			Overseas grass-land
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor Grass	Very poor grass	All qualities
Baseline	1,876	2,704	4,581	1,512	1,754	1,330	2,057	926	7,701	4,442	1,412	1,478	4,025	1,944
50% reduction in livestock with land release priority:														
Uniform	2,460	3,466	5,926	663	689	591	870	380	4,963	4,131	551	500	1,269	700
Maximise non-tillable land release	2,460	3,466	5,926	663	689	1,291	1,554	60	6,028	4,131	0	0	0	700
Maximise release of tillable land	2,460	3,466	5,926	662	688	71	421	360	3,974	4,129	968	1,257	4,025	700
Red to white meat with land release priority:														
Uniform	1,876	2,704	4,581	1,567	2,220	715	965	404	5,527	4,909	542	370	883	486
Maximise release of non-tillable land	1,876	2,704	4,581	1,567	2,221	1,330	1,027	240	6,040	4,910	272	38	2	486
Maximise release of tillable land	1,876	2,704	4,581	1,567	2,220	521	584	260	4,809	4,909	717	840	4,025	486
50% reduction in white meat consumption with land release priority:														
Uniform	2,030	2,876	4,906	1,171	1,086	1,330	2,057	926	7,514	3,962	1,412	1,478	4,025	1,944

OS = Overseas

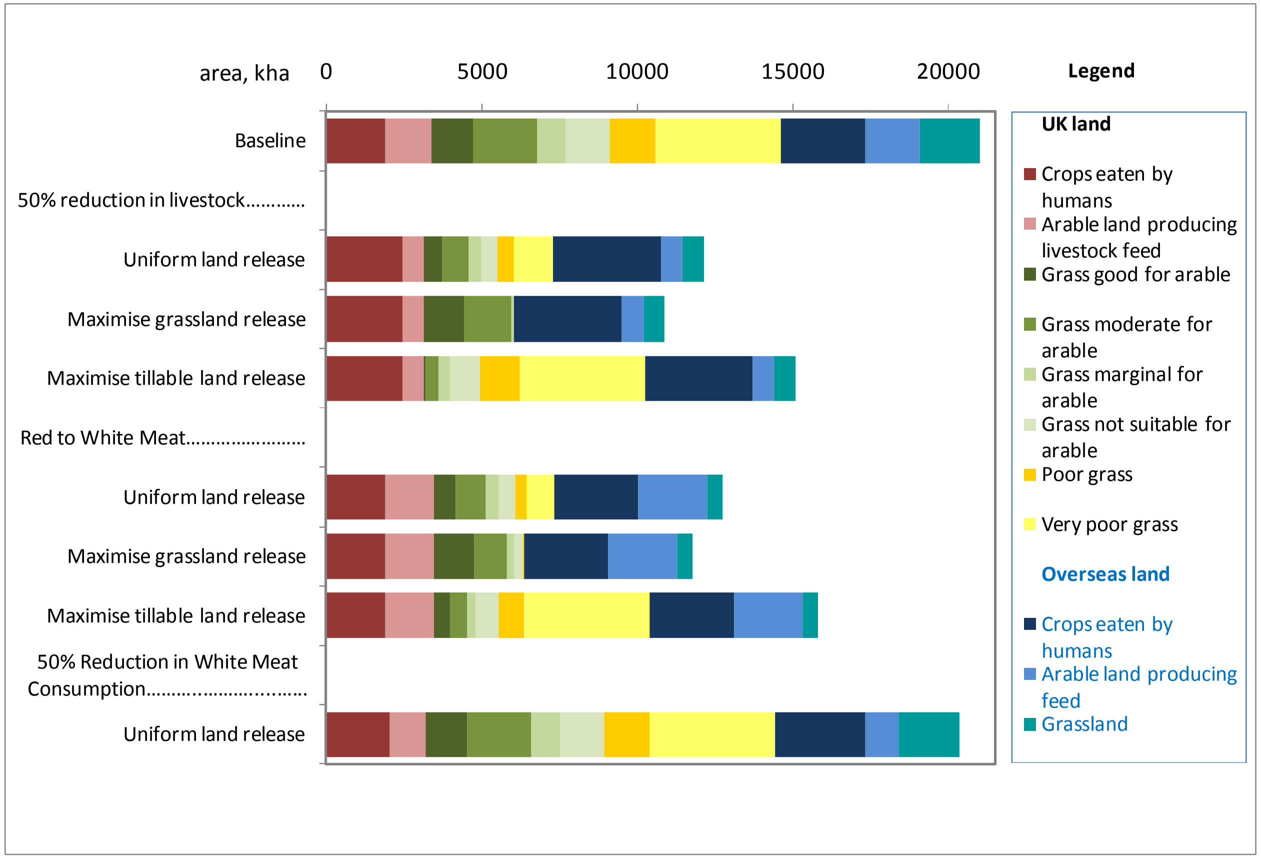


Figure 3 Summary of land requirements for current food consumption in the UK under alternative consumption and production scenarios (in kha)

Table 14 Summary of *changes* in land requirements for current food consumption in the UK and under alternative consumption scenarios and production scenarios (in kha). Note that positive values indicate land released and negative values an increased demand. The detailed changes for each scenario in the format of Table 12 can be found in Annex 7.

Scenario	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			Total potentially and actually tillable land of all qualities (NB: equally weighted)		UK non-arable grassland			Overseas grass-land
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor grass	Very poor grass	All qualities
50% reduction in livestock with land release priority:														
Uniform	-584	-753	-1,337	849	1,054	739	1,188	546	2,738	301	861	978	2,755	1,244
Maximise release of non-tillable land	-584	-753	-1,337	849	1,054	39	504	866	1,673	301	1,412	1,478	4,025	1,244
Maximise release of tillable land	-584	-753	-1,337	850	1,057	1,259	1,636	566	3,727	304	444	221	0	1,244
Red to white meat with land release priority														
Uniform	0	0	0	-55	-467	615	1,092	522	2,175	-467	870	1,109	3,141	1,458
Maximise release of non-tillable land	0	0	0	-55	-468	0	1,031	686	1,661	-468	1,140	1,441	4,022	1,458
Maximise release of tillable land	0	0	0	-55	-467	808	1,473	666	2,893	-467	695	639	0	1,458
50% reduction in white meat consumption with land release priority														
Uniform	-153	-172	-325	341	668	0	0	0	188	496	0	0	0	0

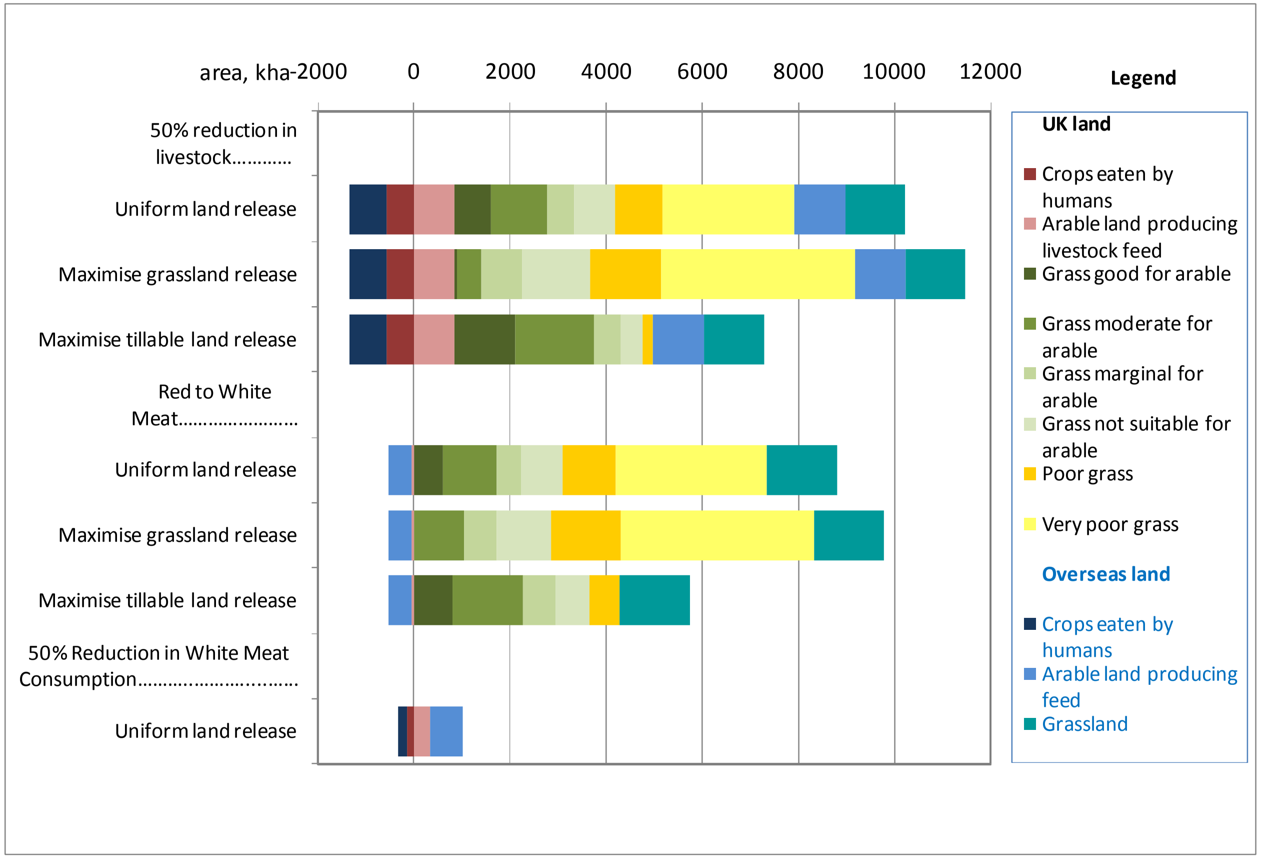


Figure 4 Summary of changes in land requirements for current food consumption in the UK and under alternative consumption and production scenarios (in kha). Note that positive values indicate land released and negative values an increased demand.

Table 15 Weighting factors used to adjust physical areas of land to reflect yield potential of arable or grassland. These were used to derive the adjusted land areas in

Table 16

Land type	Quality or function	Arable yield weighting factors	Land type	Quality or function	Grassland yield weighting factors
Current arable	Crops eaten by humans	1	Non-tillable current grassland	Grass not for arable	0.65
	Animal concentrate production	0.98		Poor grass	0.25
Tillable current grassland	Good for arable	0.95		Very poor grass	0.1
	Moderate for arable	0.8			
	Marginal for arable	0.65			

Table 16 Summary of grassland released under Scenarios 1 to 3, with the physical areas scaled by yield factors for arable or grass

Land released in the UK under different consumption change scenarios: weighted for yield potential	Current Arable, UK	Potential Arable (Ex grassland), UK	Grassland (not fit for arable), UK
Scenario	Weighted total, kha	Weighted total, kha	Weighted total, kha
50% reduction in livestock with land release:			
Uniform	248	2,007	1,079
Maximise release of non-tillable land	248	1,003	1,690
Maximise release of tillable land	249	2,873	344
Red to white meat with land release			
Uniform	-54	1,798	1,157
Maximise release of non-tillable land	-54	1,270	1,503
Maximise release of tillable land	-54	2,379	611
50% reduction in white meat consumption with land release			
Uniform	181	0	0

Extensification of production and resource conservation under Consumption Scenario 1

Extensification

Since there is now spare grassland, it is thus physically possible to use the grassland more extensively, though not necessarily economically. To analyse this it was assumed that the grassland with fertiliser was replaced by grassland with clover, but that otherwise the management was as intensive as before, (Table 17). Introducing grass-clover leys under consumption scenario 1 reduces greenhouse gas emissions by a further 1,683 t CO_2e due to the reduced burden of fertiliser production. Land requirements increase by 337,000 reducing the land released by reducing meat consumption.

Table 17 Impact on land use and greenhouse gas emissions of switching to more extensive production based on grass-clover swards

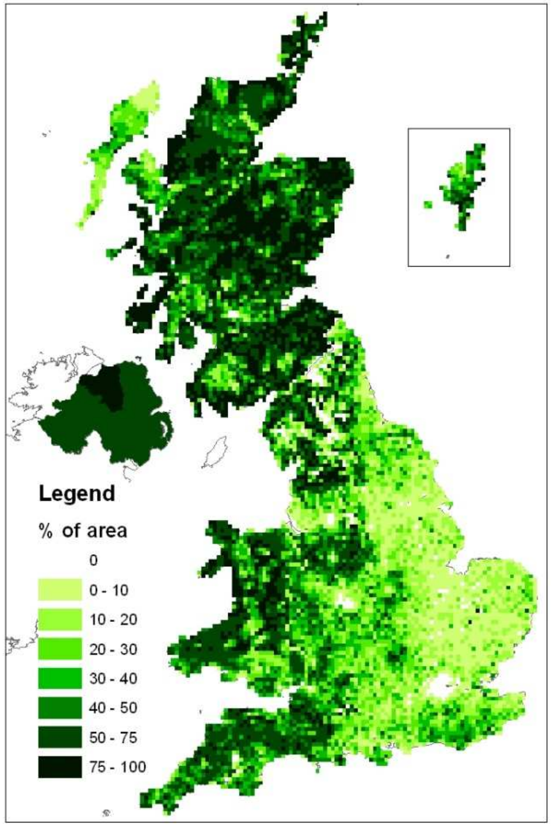
Effect of no grass fertiliser	Beef meat	Sheep and goat meat	Milk, whole, fresh	TOTAL
Total GWP 100, kt CO_2e	-390	-138	-1155	**-1683**
	Increase in area of land required			
Site Class 1, 000 ha	0	-0	8	**9**
Site Class 2, 000 ha	5	1	58	**64**
Site Class 3, 000 ha	14	2	161	**177**
Site Class 4, 000 ha	67	10	-17	**60**
Site Class 5, 000 ha	15	8	-3	**20**
Site Class 6, 000 ha		8		**8**
Site Class 7, 000 ha	-0	-0	0	**-0**
Total land, 000ha	102	28	208	**337**

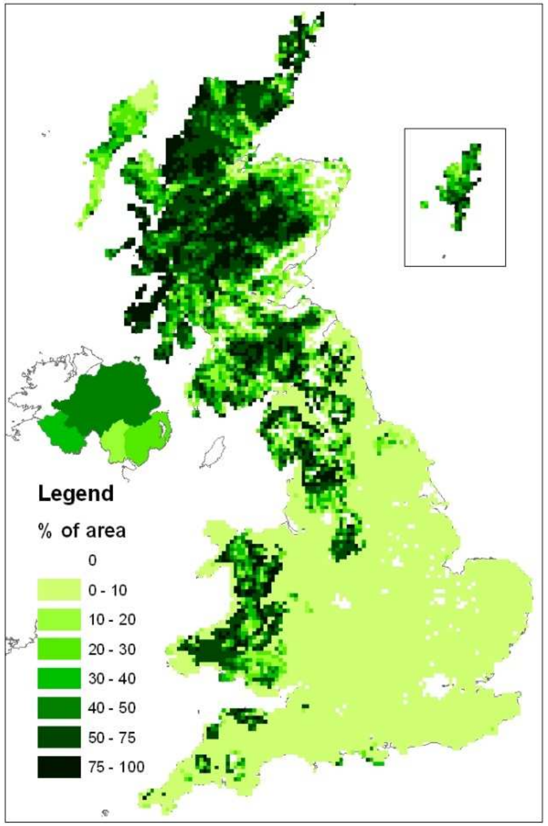
Resource conservation

All livestock, and beef production in particular, consume co-products of commodities. One such commodity is rapemeal which is produced when the oil is extracted from rapeseed. It is a high protein feed. Quantities available have increased in recent years as more rape oil has been produced for use as biodiesel. Consumption scenario 1 implies increased production of rape oil and thus increased quantities by-product. Rapemeal could thus be substituted for other feed products, which would imply reduced soya requirements. However, a significant increase in rapeseed use will present challenge in some parts of the livestock industry. Although rapemeal and soya meal have similar crude protein contents, they do not have the same profile of amino acids and rapeseed has anti-nutritional properties. These constraints may be overcome in the medium to longer term by advancing feed production techniques and by plant breeding.

Table 18 Impact on land requirements and GWP of substituting rapemeal for soyameal in order to use the amount available from rape oil consumption (under Sonsumption Scenario 1)

Reduction due to using up rapemeal	Pig meat	Poultry meat	Beef	Sheep and goat meat	Milk, whole, fresh	Eggs (incl. hen eggs)	Total
GWP, kt CO_2e – UK	56	52	6	4	13	6	138
GWP, kt CO_2e – overseas	88	235	58	21	216	85	702
Total GWP , kt CO_2e	144	287	65	25	228	91	840
UK arable grade 3a, 000ha	-19	-19	-3	-1	-12	-2	-56
Overseas arable, 000 ha	64	63	8	5	29	8	176
Overseas other land, 000 ha	0	0	0	0	0	0	0
Total land, 000ha	45	43	5	3	17	5	120





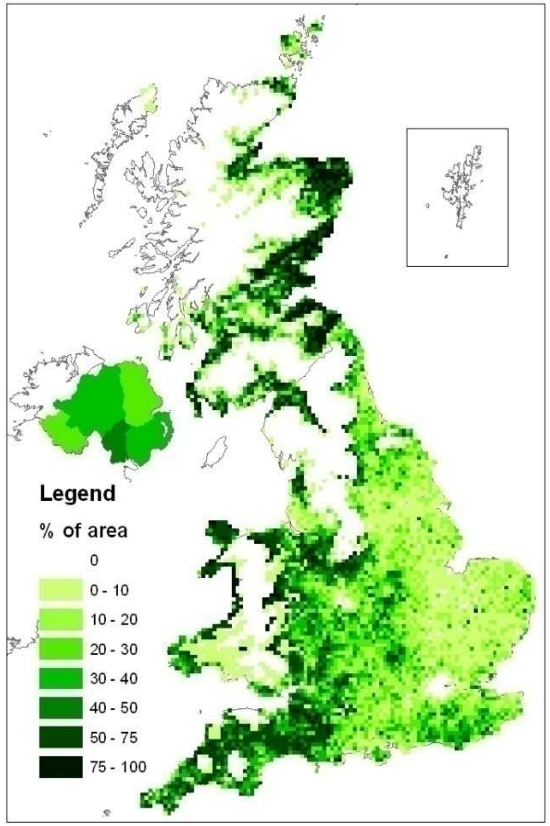
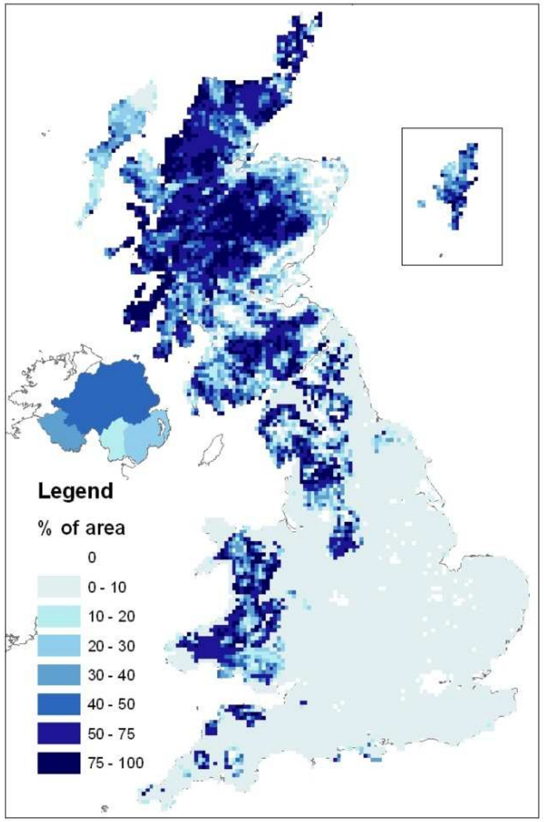
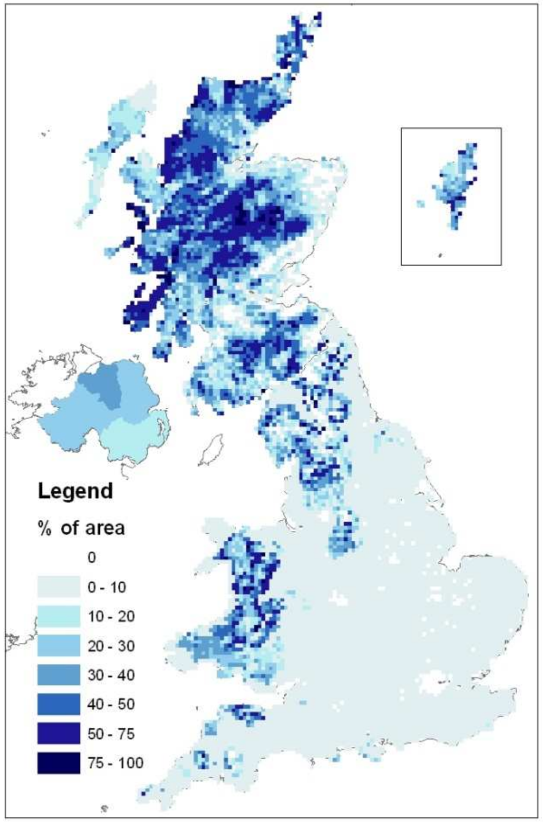


Figure 5 Baseline location of grassland for grazing livestock in the UK.

Left: All qualities of grassland.
Middle: Non-tillable grassland.
Right: Potentially tillable grassland.
The scale is the percentage of all land per 5 km^2 grid square (or county in Northern Ireland).





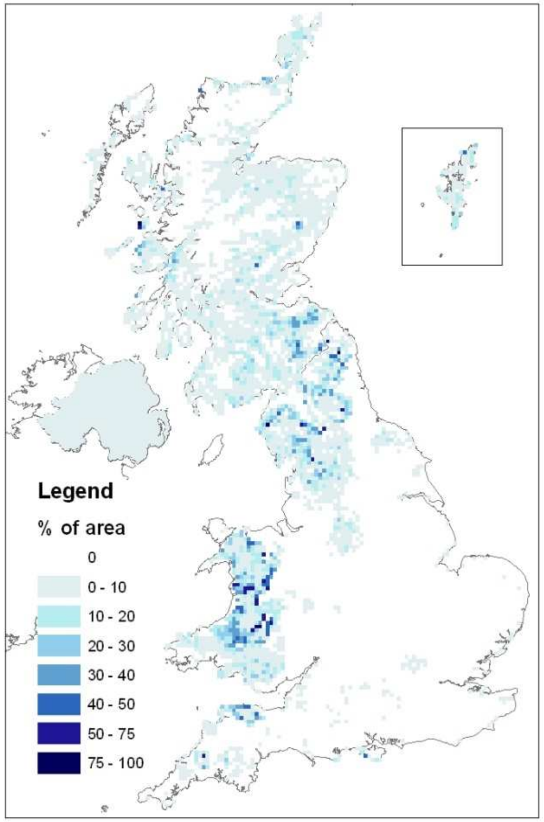


Figure 6 Release of non-tillable grassland (as a proportion of existing land) currently used for grazing livestock in the UK under consumption scenario 1 (50% reduction in livestock product consumption) and under three production scenarios

Left: Maximising non-tillable land release
Middle: Uniform grassland release
Right: Maximising tillable land release

The scale is the percentage of all land per 5 km^2 grid square (or county in Northern Ireland) that is released.

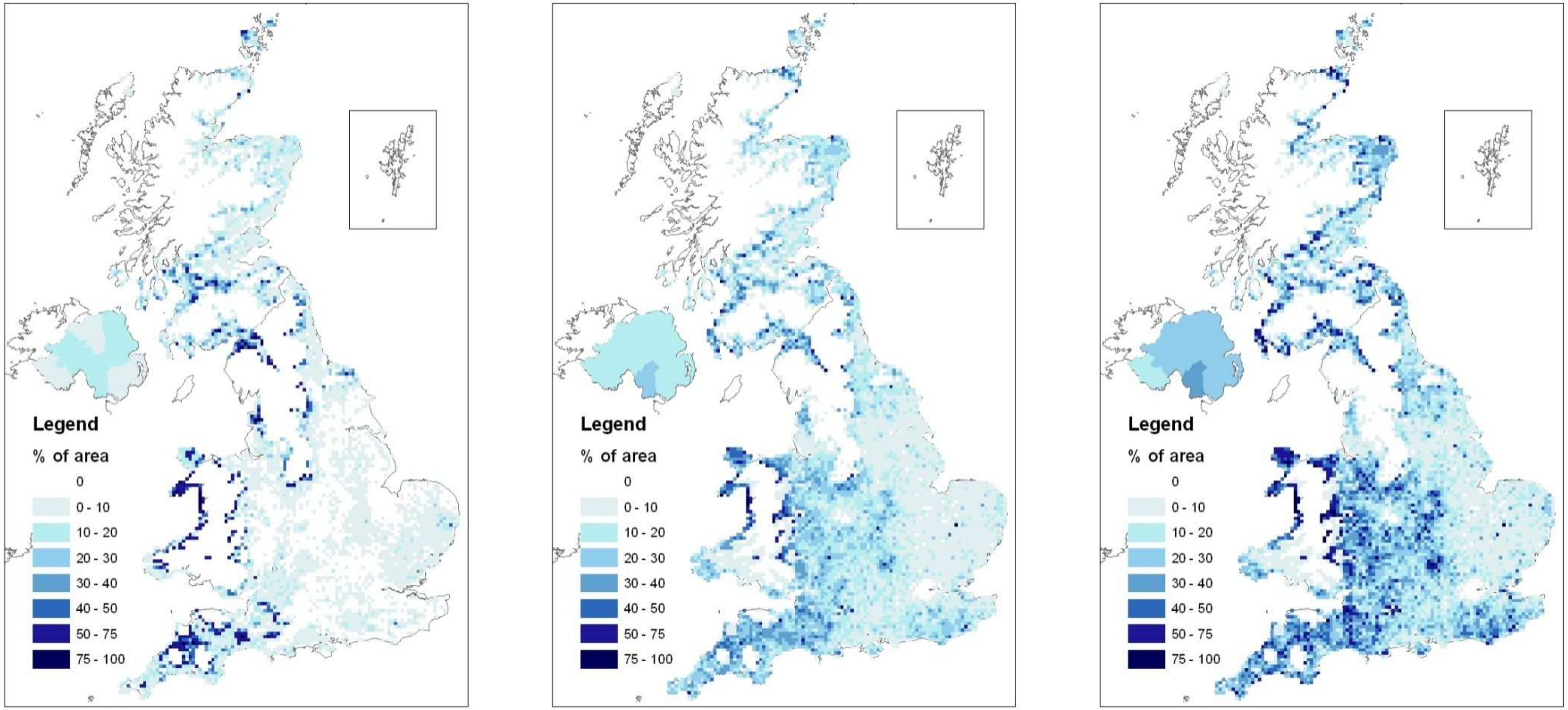
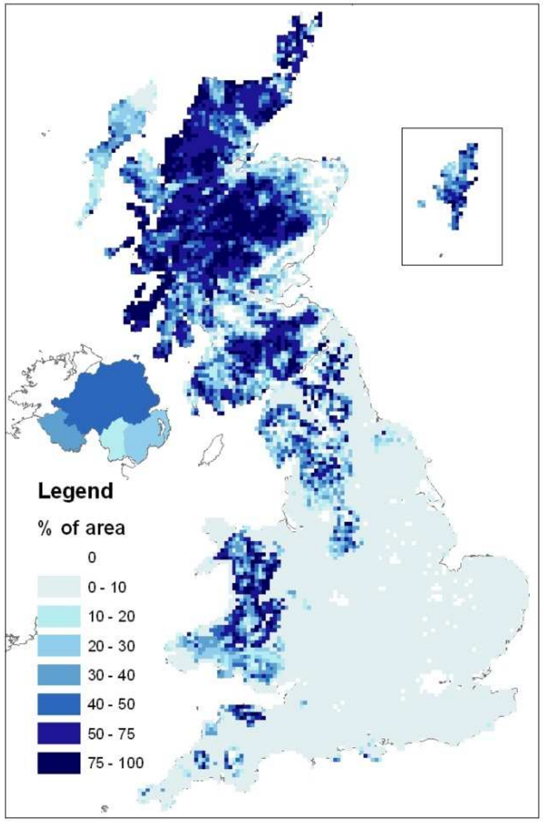
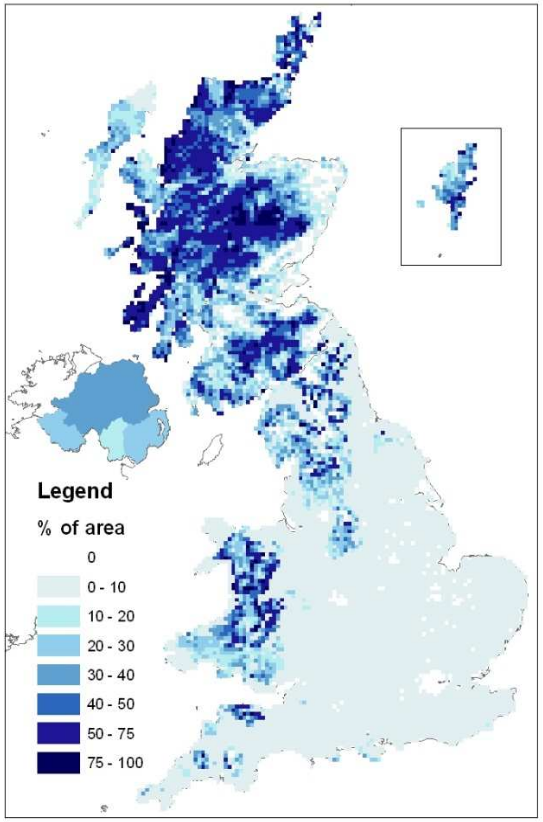


Figure 7 Release of tillable grassland (as a proportion of existing land) currently used for grazing livestock in the UK under consumption scenario 1 (50% reduction in livestock product consumption) and under three production scenarios

Left: Maximising non-tillable land release
Middle: Uniform grassland release
Right: Maximising tillable land release

The scale is the percentage of all land per 5 km^2 grid square (or county in Northern Ireland) that is released.





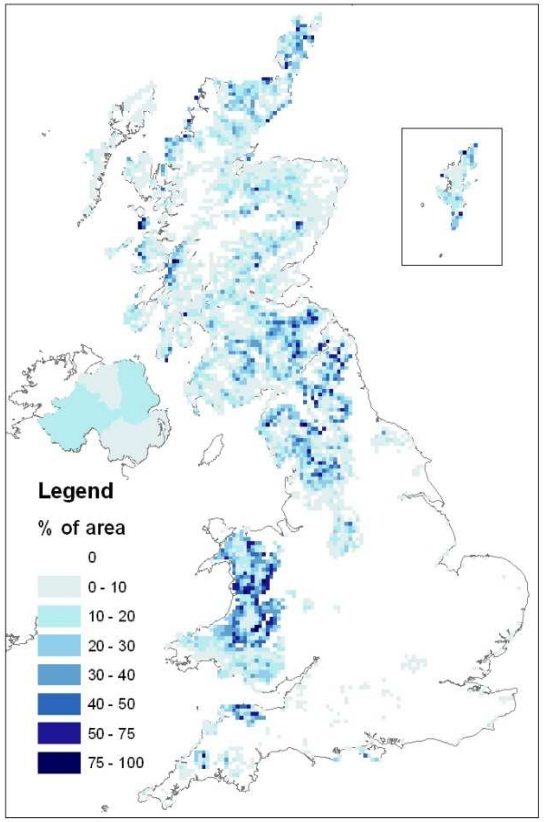
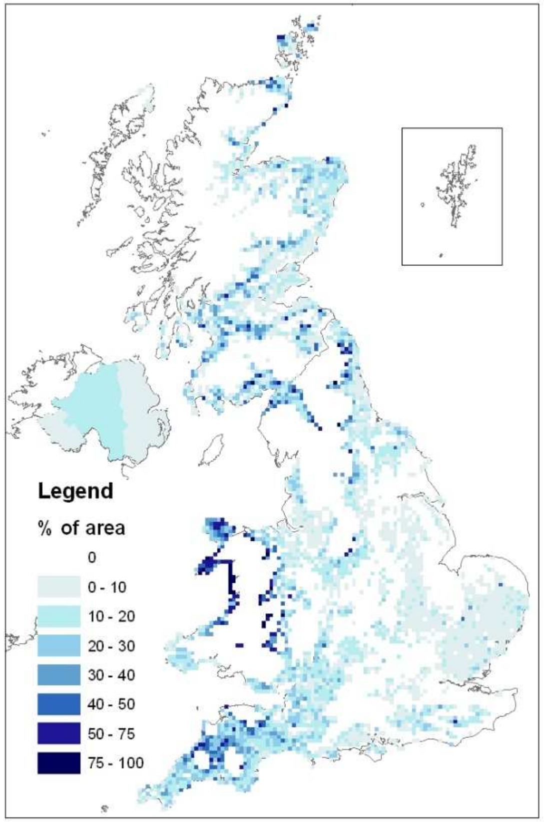
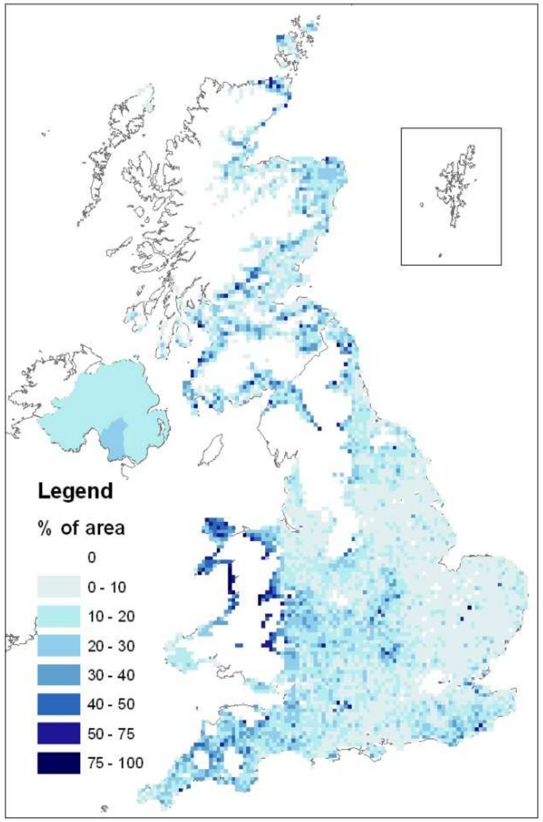


Figure 8 Release of non-tillable grassland (as a proportion of existing land) currently used for grazing livestock in the UK under Consumption Scenario 2 (Red to white meat consumption) and under three production scenarios

Left: Maximising non-tillable land release
Middle: Uniform grassland release
Right: Maximising tillable land release

The scale is the percentage of all land per 5 km^2 grid square (or county in Northern Ireland) that is released..





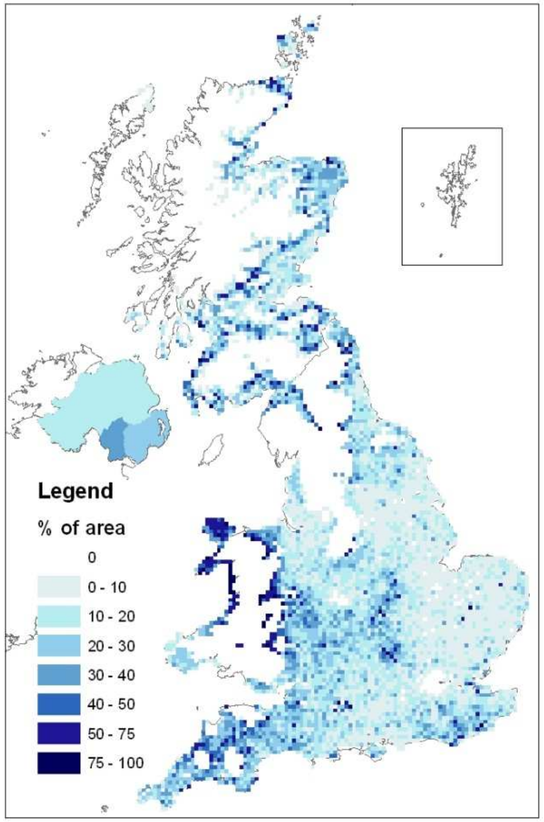


Figure 9 Release of tillable grassland (as a proportion of existing land) currently used for grazing livestock in the UK under consumption scenario 2 (Red to white meat consumption) and under three production scenarios

Left: Maximising non-tillable land release
Middle: Uniform grassland release
Right: Maximising tillable land release

The scale is the percentage of all land per 5 km^2 grid square (or county in Northern Ireland) that is released..

5. Analysis of direct greenhouse gas (GHG) emissions

This section assesses the potential impact of the scenarios on direct GHG gases within the UK and abroad. In the UK food system, direct GHG emissions arise from primary production (UK and overseas), distribution and processing, further distribution for sale, food preparation, consumption and disposal. These were analysed and reported by Audsley et al (2009).36 We assume that the emissions from food processing and distribution will not appreciably change between the scenarios being analysed in this project and thus focus on impacts to emissions arising from primary production as related to current and changed UK consumption patterns.

GHG calculation methods

Life-cycle GHG emissions for crops and animal products were calculated using the methods of Audsley et al. (2009), but with some improvements. In brief, life cycle inventories (LCI) of GHG emissions were based on the Cranfield LCA model where possible and thus include all upstream activities and well as all inputs (fertilisers, fuels, machinery etc) and direct emissions (e.g. enteric CH4, field N2O). Where other crops and commodities exist in food system (over 80) these were modelled by de novo analysis using data from the literature, by proxy with adaptations for distance or taking values from the literature with adaptations for distance etc. The range of our LCI has expanded somewhat since 2009 and other features were changed for this project, e.g. reformulation of concentrates to represent more closely the national consumption level. It should be noted that one average emission factors for enteric methane production, is used for animals be they on the hills or on the lowlands and the changes of diet that that involves. Even though this still allows the effect of differences in animal performance to be estimated through variation in days to maturity, it is a simplification. It is the best possible approach given the lack of data because the environmental performance of animals and land under hill conditions has not been studied with the same intensity as lowland systems.

Emissions estimates from manufacturing, distribution, retail, the service sector, food waste and disposal were derived from other LCA studies, national statistics and process models. It is apparent that some estimates were less precise than others owing to the paucity of data in some areas, e.g. the food service sector (part of which is being addressed in studies funded by Defra and the Waste & Resources Action Programme, WRAP).

Given the nature of the food system, identifying the location of emissions and allocating them to specific national inventories poses some difficulty. Most direct emissions from manufacturing, retail, the service sector and domestic consumption occur in the UK, but emissions from fertiliser manufacture are multinational. Soy and maize are produced overseas, but fuel for imports could be allocated to the exporting or importing country. Soy may be processed into meal in the country of production, the UK or a third country, e.g. the Netherlands. Some emissions are unequivocal, for example direct methane emissions from UK livestock and N_2O from UK crop production. There is, however, inevitably some blurring at the edges, and the analysis uses best estimates were made of the location and nature of emissions.

Current direct emissions

GHG emissions from primary production in the current UK food system and under future scenarios are summarised in Table 19. Current direct emissions are about 81 Mt CO_2e/year with 52 Mt CO_2e /year occurring in the UK and 29 Mt CO_2e occurring overseas. Crops directly eaten by humans emit about 40% of current emissions and livestock products emit about 60%. Additional tables on livestock are provided in Annex 7 which break these emissions down further by commodity: milk (22%), beef (16%), pigmeat (7%), poultrymeat (7%), sheepmeat (6%) and eggs (2%).

[36] Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope for reduction by 2050. How low can we go? WWF UK and the Food Climate Research Network.

Table 19 Direct greenhouse gas emissions from primary production for all scenarios. Locations are the sources of GHG emissions, e.g. feed crops grown overseas for UK consumption are included in the overseas columns.

Scenario	Human eaten crops, kt CO_2e/year			Livestock products, kt CO_2e/year			Total, kt CO_2e/year		
	UK	Overseas	Total	UK	Overseas	Total	UK	Overseas	Total
Baseline	13,517	19,199	32,717	38,176	9,802	47,977	51,693	29,001	80,694
50% reduction in livestock with land release									
Uniform	18,110	25,522	43,632	18,172	3,934	22,107	36,282	29,456	65,738
Maximise release of grassland	18,110	25,522	43,632	18,136	3,929	22,065	36,246	29,451	65,697
Maximise release of tillable land	18,110	25,522	43,632	18,172	3,935	22,107	36,282	29,457	65,739
Red to white meat with land release									
Uniform	13,517	19,199	32,717	32,294	8,376	40,670	45,812	27,575	73,387
Maximise release of grassland	13,517	19,199	32,717	32,350	8,372	40,722	45,867	27,572	73,439
Maximise release of tillable land	13,517	19,199	32,717	32,360	8,376	40,736	45,878	27,575	73,453
50% reduction in white meat consumption with land release									
Uniform	14,784	20,590	35,375	34,741	7,909	42,650	49,525	28,500	78,025

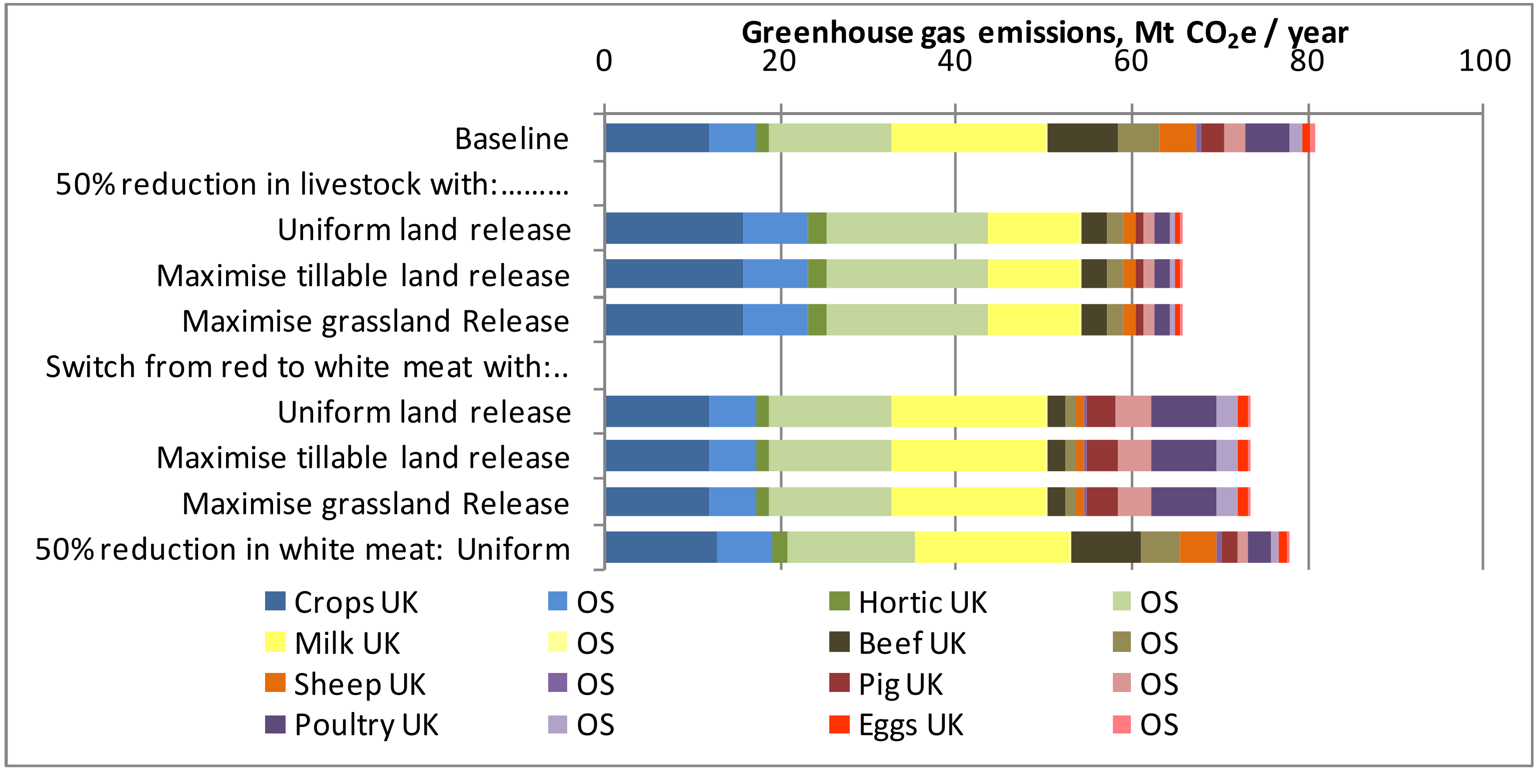


Figure 8. Greenhouse gas emissions from primary food production.

Table 20 Summary of changes in direct greenhouse gas emissions from primary production for all scenarios. Locations are the sources of GHG emissions, e.g. feed crops grown overseas for UK consumption are included in the overseas columns.

Scenario	Human eaten crops, kt CO_2e/year			Livestock products, kt CO_2e/year			Total: human-eaten crops and livestock products, kt CO_2e/year		
	UK	Overseas	Total	UK	Overseas	Total	UK	Overseas	Total
50% reduction in livestock with land release									
Uniform	4,592	6,322	10,915	-20,003	-5,867	-25,871	-15,411	455	-14,956
Maximise release of grassland	4,592	6,322	10,915	-20,040	-5,872	-25,912	-15,447	450	-14,997
Maximise release of tillable land	4,592	6,322	10,915	-20,004	-5,866	-25,870	-15,411	456	-14,955
Red to white meat with land release									0
Uniform	0	0	0	-5,881	-1,426	-7,307	-5,881	-1,426	-7,307
Maximise release of grassland	0	0	0	-5,826	-1,429	-7,255	-5,826	-1,429	-7,255
Maximise release of tillable land	0	0	0	-5,815	-1,425	-7,241	-5,815	-1,425	-7,241
50% reduction in white meat consumption with land release									
Uniform	1,267	1,391	2,658	-3,435	-1,892	-5,327	-2,168	-501	-2,669

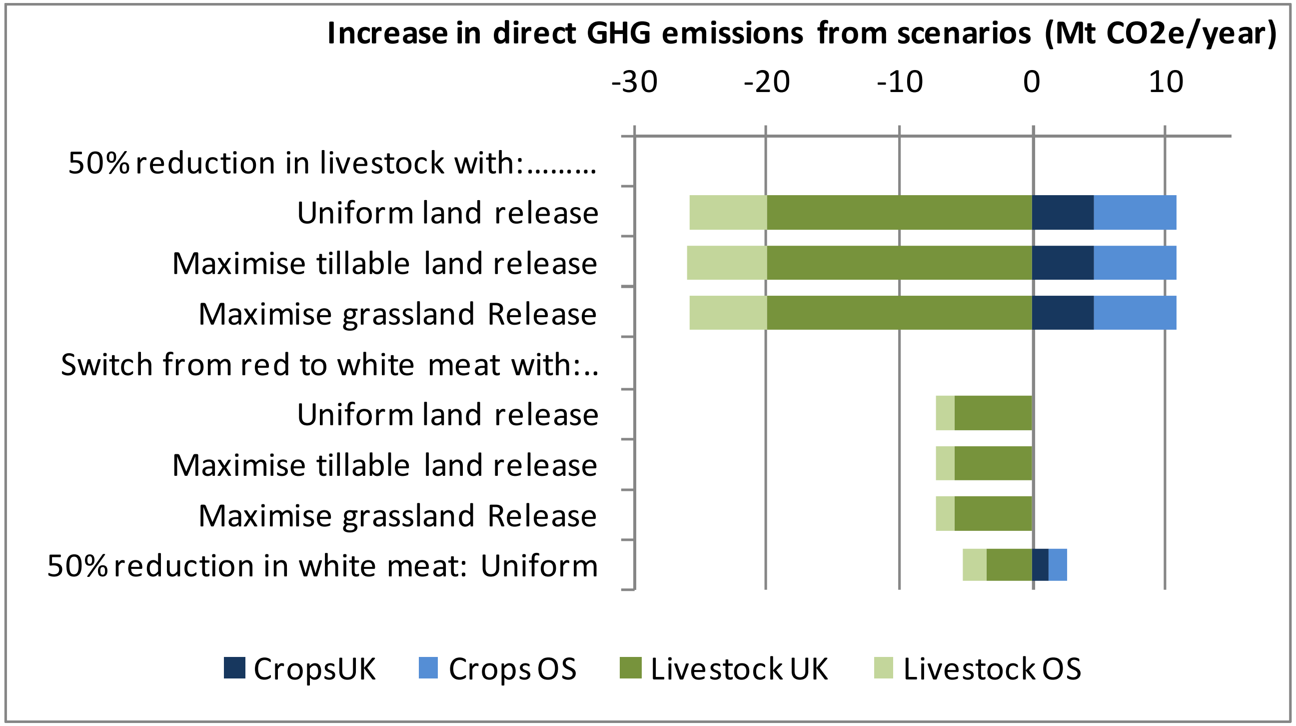


Figure 9. Effect of consumption and production scenarios on greenhouse gas emissions from food production for the UK

6. Analysis of LUC greenhouse gas (GHG) emissions

Audsley et al (2009)[37] provided a top-down estimate of indirect emission from LUC. That work used novel analytical techniques to estimate land use change emissions arising directly and indirectly from the UK food system. The consumption change scenarios could result in land use conversion and associated LUC emissions due to:

- Potential increases in demand for animal feed crops (e.g. soy in the red to white meat scenarios).
- Potential increases in demand for direct human crops (e.g. all three scenarios).
- Potential change in the UK from grassland to other uses.

LUC in the UK

The methodology to calculate potential LUC emissions in the UK considers the potential effects of converting grassland into arable or forested land. It is based mainly on the methods used in the UK GHG inventory for Land Use, Land Use Change and Forestry (LULUCF) (Thomson et al., 2008).[38]

The basic principles in calculating LUC emissions are that any land use system will reach an equilibrium state of soil and biomass C density if continued for long enough. A change between two land uses results in changes in the C densities. A reduction in C density implies CO_2 emissions and an increase in C density implies a negative emission of CO_2 or C storage. Changes in vegetative biomass density following land use change occur quickly, but the soil C changes may take many decades to reach equilibrium (Thomson et al., 2008). Most of the greenhouse gas (GHG) emissions are CO_2, although some trace gases may also be emitted. Several factors influence soil C equilibrium densities and the rate of change between equilibrium states. These are mainly the soil texture (especially the clay content), temperature, the balance of rainfall and evaporation and the alternative land uses.

Changes in C stocks, and the associated greenhouse gas (GHG) emissions, resulting from LUC are not trivial to calculate and are associated with high uncertainties for several reasons, such as:

- Soil C densities may not be well characterised (both for woodland and agriculturally managed soils).
- Above and below ground biomass densities may not be well characterised.
- Methods of clearing above ground biomass lead to different proportions of C being burned (hence CO_2 plus unwelcome trace gases like NO), incorporated in soil or harvested as wood.
- Changes in soil C are not instantaneous. The typical loss from a hierarchy of woodland > grassland > arable land may take about 100 years to reach a new equilibrium (assuming other factors remain constant) and depending on the soil type and climate. Year on year measurement to determine differences is not easy owing to soil heterogeneity coupled with the expanse of sampling and analysis.
- The current (and well established) scientific understanding is that the rate of change of soil C between land use states follows 1st order kinetics and results in an exponential pattern of change (i.e. it is non-linear), with an example given in Figure 10.

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[37] Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope for reduction by 2050. How low can we go? WWF UK and the Food Climate Research Network.

[38] Thomson, A.M. (editor), D.C. Mobbs, R. Milne, U. Skiba, A., Clark, P.E. Levy, N. Ostle, S.K. Jones, M.F. Billett, M. van Oijen , N. Ostle, B. Foereid, W.S. Fung, P. Smith, Alice Holt: R.W. Matthews, E. Mackie, P. Bellamy, M. Rivas-Casado, J. Grace, C. Jordan, A. Higgins, R.W. Tomlinson (2008). Inventory and projections of UK emissions by sources and removals by sinks due to land use, land use change and forestry. Annual report for Defra Project GA01088

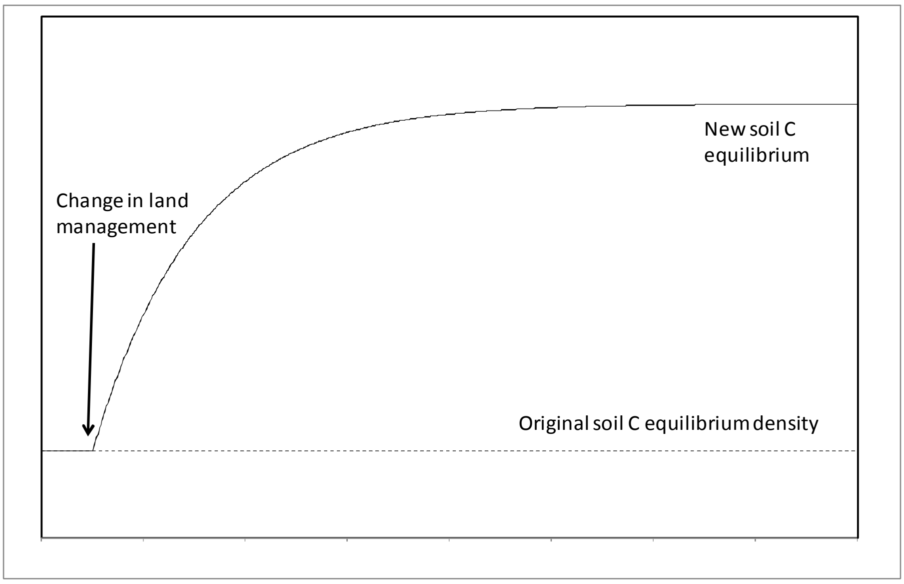

Figure 10 Example of soil C density dynamics following change in land assuming the original land use was in equilibrium and the new use occurs under uniform conditions.

The basic equation follows, in which C is the soil C density at time t, C_f is final equilibrium concentration and k is the rate constant. It is structured such that k is positive so that –k implies a loss of soil C.

$$\frac{dC}{dt} = -k(C_f - C)$$ (Equation 1)

This equation has the solution:

$$C_t = C_f - (C_f - C)e^{-kt}$$ (Equation 2)

One practical difficulty faced in calculating the inventory is identifying the exact history of each parcel of land in the country, as well as making best estimates of soil C densities.

In contrast, over-ground biomass changes are usually assumed to occur in one year (except the continuing accumulation in woodland).

Land management affects equilibrium soil carbon. For example, various cultivation techniques and different proportions of crop residues returned to the soil and or larger changes through activities such as drainage have differing impacts on soil carbon levels.

The current UK inventory includes a matrix of land uses together with soil and biomass C equilibrium densities across the UK. It also includes estimates of the time taken for 99% of the complete change between equilibrium states to occur for different classes of LUC in different parts of the UK. The rate constants (k) can be readily derived from these values. Thomson et al. (2008) provide ranges for the rate of change, e.g. 50 to 150 years for the 99% completion of loss of soil C following conversion of grassland to arable. These are influenced in practice by factors such as temperature (positive correlation with reaction rate constant), soil moisture (positive correlation with rate constant) and clay content (negative correlation with rate constant). Integration of these terms in the estimate can be achieved explicitly with a model such as RothC[39], but this requires knowledge of where LUC will occur so that the correct soil type and climatic data can be selected. As we cannot be specific about the locations of potential LUC, we estimate more general calculations.

Integration time scales

The potential time during which CO_2 fluxes from or into soils may occur is great (Table 21 and Table 22), but the rate decreases with time (Figure 10). In practice, much is achieved within 20 years and this was used in

[39] Jenkinson DS and Coleman K (1994) Calculating the annual input of organic matter to soil from measurements of total organic carbon and radiocarbon. European Journal of Soil Science, 45, 167-174

the study as the basis for estimating average soil and biomass fluxes. The driving force for the changes in soil C were taken from Thomson et al. (2008)[40], using the weighted equilibrium values for the parts of the UK (Table 23). Negative values indicate a loss of soil C. Changes in soil C densities were calculated over 20 years using equation 2 with both the fast and slow rate constants (Table 22). Averages of these were used to give the average annual rate of soil C change over 20 years after which no further change is assumed.

Table 21 Rates of change of soil carbon for land use change transitions. ("Fast" & "Slow" refer to 99% of change occurring in times shown in Table 22)

		Final use			
		Cropland	Grassland	Settlement	Forestland
Initial use	Cropland		Slow	Slow	slow
	Grassland	*fast*		Slow	slow
	Settlement	*fast*	Fast		slow
	Forestland	*fast*	Fast	fast	
This is Table 1-27 from Thomson et al., 2008					

Table 22 Range of times for soil carbon to reach 99% of a new equilibrium value after a change in land use in England (E), Scotland (S) and Wales (W) and the equivalent rate constants (k)

	Low (years)	High (years)	k, Low	k, High
Carbon loss ("fast") E, S, W	50	150	0.0921	0.0307
Carbon gain ("slow") E, W	100	300	0.0461	0.0154
Carbon gain ("slow") S	300	750	0.0154	0.00614
This is Table 1-28 from Thomson et al., 2008				

Table 23 Weighted average change in equilibrium soil carbon density (kg m^{-2}) to 1 m depth for changes between different land types in the UK (from Thomson *et al*., 2008)

	England	**Scotland**	**Wales**	**Northern Ireland**
Grassland to forest	25	47	23	94
Grassland to arable	-23	-90	-38	-74

Changes in vegetative biomass densities in grassland are assumed to occur in the year of LUC to arable. The equilibrium biomass C densities were taken from Thomson *et al*., 2008[41] (Table 24). In contrast to soil C, the equilibrium for arable is higher than pasture. The changes in biomass C are more rapid than for soil C, but to be consistent with soil C changes the biomass changes were amortised over 20 years and added to soil C changes. Hence, the total effect of LUC from grassland to arable represents a linearization of both changes in soil and biomass C densities after which no more changes occur.

The effects on biomass of conversion of grassland to forestry occur over a longer period than grassland to arable as trees continue growing for many years. Estimates for conversion of grassland into forestry were made using the values for young plantations in the CALM calculator (CLA, 2009).[42] Annual C uptakes were

[40] Thomson, A.M. (editor), D.C. Mobbs, R. Milne, U. Skiba, A., Clark, P.E. Levy, N. Ostle, S.K. Jones, M.F. Billett, M. van Oijen , N. Ostle, B. Foereid, W.S. Fung, P. Smith, Alice Holt: R.W. Matthews, E. Mackie, P. Bellamy, M. Rivas-Casado, J. Grace, C. Jordan, A. Higgins, R.W. Tomlinson (2008). Inventory and projections of UK emissions by sources and removals by sinks due to land use, land use change and forestry. Annual report for Defra Project GA01088.

[41] Thomson, A.M. (editor), D.C. Mobbs, R. Milne, U. Skiba, A., Clark, P.E. Levy, N. Ostle, S.K. Jones, M.F. Billett, M. van Oijen , N. Ostle, B. Foereid, W.S. Fung, P. Smith, Alice Holt: R.W. Matthews, E. Mackie, P. Bellamy, M. Rivas-Casado, J. Grace, C. Jordan, A. Higgins, R.W. Tomlinson (2008). Inventory and projections of UK emissions by sources and removals by sinks due to land use, land use change and forestry. Annual report for Defra Project GA01088.

[42] CLA (2009) http://www.calm.cla.org.uk/

taken from the average of uptake rates over 20 years and added to the average soil C changes. Hence, this also represents a linearization of both soil and biomass changes over 20 years. In contrast to the changes from grassland to arable, the potential for biomass accumulation beyond 20 years exists. No projections beyond 20 years are, however, included in this report.

Table 24 Equilibrium biomass carbon density (kg m^{-2}) for different land types (except forestry) in the all parts of the UK

Land use	Biomass carbon density (kg m^{-2})
Arable	0.15
Pasture	0.10
Natural	0.20

Table 25 Annual rates of accumulation of C by trees and implied emission offset.

Age, years	Conifer		Broadleaf	
	C m^{-2} yr	t CO_2e $ha^{-1}yr^{-1}$	C m^{-2} yr	t CO_2e $ha^{-1}yr^{-1}$
0 to 10	0.0382	-1.4	0.0196	-0.7
10 to 20	0.586	-21	0.398	-15
Negative values for CO_2e represent sequestration				

Application of method to LUC overseas

The same basic method described above in 7.3 was used for calculating LUC emissions overseas, but with different data sources available and a different context, modifications were also needed. With the UK LUC, we project the emissions over time to a unit area, but with overseas LUC, the aim is to associate the LUC emissions with particular crops in particular areas of the world. This is potentially a vast task, so it had to be limited to a narrow selection of crops to give an indication of the range of values. It is important to note that some increases in demand as result of the consumption scenarios (e.g. for winter vegetables) could be met by increased production in countries in which soil and biomass stocks are intrinsically low, e.g. the Almeria region of Spain in which most crop cultivation is on very sandy soil with negligible humus. Indeed, Williams et al. (2009)[43] showed that potato production in the Negev region of Israel resulted in increases in soil C stocks since 1947. These cases apart, the main crops of interest in this study are soy for white meat and egg production and (sub-) tropical plantations for fruit like bananas. Combined values for biomass and soil C changes for representative areas were taken from the Renewable Fuels Agency guidelines[44], which represent the marginal effects of LUC on GHG emissions. These are provided on the basis of annual discounting over 20 years (as used in PAS2050[45]). These values were coupled with FAOSTAT statistics on areas harvested and yields in a simple model to calculate the annual increase in LUC from one state to another. This was initially applied to soy from Brazil and Argentina going back to a baseline in the early 1970s when production was relatively small (indeed zero in Argentina) and rates of LUC were slower. The model integrates emissions for each unit area converted over 20 years and hence calculates the overall LUC per ha or per t soy. This means that historic LUC is accounted for and an increase in the rate of LUC results in higher emissions, while increasing yield decreases it. It was assumed that LUC was simply from grassland or forest and the proportions converted were derived from national statistics on rates of LUC. The reality is, especially in Brazil, that deforestation may be physically initiated by beef producers and then

[43] Williams, A.G.; Pell, E.; Webb, J.; Tribe, E.; Evans, D.; Moorhouse, E.; Watkiss, P. (2009) Comparative Life Cycle Assessment of Food Commodities Procured for UK Consumption through a Diversity of Supply Chains. Final Report to Defra on Project FO0103.

[44] Renewable Fuels Agency (2010) Carbon and Sustainability reporting within the Renewable Transport Fuel Obligation. Technical Guidance Part One. Version 3.2 April 2010. Year 3 of the RTFO 15 April 2010 – 14 April 2011

[45] PAS 2050 - Assessing the life cycle greenhouse gas emissions of goods and services. BSI. http://www.bsigroup.com/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050

pasture is subsequently converted to soy production. This method used is acknowledged to be a simplification of reality, but it is pragmatic, responsive to changes in input variables (rate of LUC, crop yield and land types). It applies the values used to calculate marginal LUC emissions, but ensures that these are integrated with historic trends to be more realistic.

Our sourcing of soy meal is about 46% each from Argentina and Brazil with the rest from other countries like the USA and Canada, in which no LUC is assumed to occur. The proportions of land types considered and the annualised LUC emission values are shown in Table 26.

Table 26 Factors used in estimating LUC from soy production

Location	Argentina	Brazil
Proportion converted from forest	50%	75%
Proportion converted from grassland	50%	25%
Annual emissions for 20 years from ex-forest, t CO_2e/ha	17	37
Annual emissions for 20 years from ex-grassland, t CO_2e/ha	2	11

If the rate of increase of soy production in Brazil and Argentina stay the same as now to meet increased demand for soy under the consumption scenarios, then we can expect LUC to account for an additional 3.2 t CO_2e/t soy produced (although this would increase if land use change rates in Brazil and Argentina increase).

Table 27 LUC emissions for soy as imported into the UK

	Proportion	Emission per unit soy harvested, t CO_2e/t
Brazilian	46%	5.3
Argentinean	46%	1.6
North American or similar	8%	0
Weighted total for soy beans		3.2

It should be noted that these estimates are based on the Intergovernmental Panel on Climate Change (IPCC) Tier 1 default values for LUC. There is much apparently contradictory research about long term soil C stock changes in South America using different cultivation techniques and with different pasture management techniques. Cerri et al. (2007)[46] reported that soil C could increase or decrease in soy cultivation depending on whether zero tillage or plough-based tillage was applied. Grace et al (2006)[47] report a wide range on initial values for C stocks in biomass and soil in the Cerrado, which is a main land type used for soy cultivation in Brazil. Cerri et al. (2003) showed how soil C in well managed pasture could actually exceed that in the original forest soil from which it was converted (although the huge loss of above-ground biomass would still have occurred). Again, we must stress that the actuality of C fluxes from LUC are complex and it is not possible to quantify all fluxes to the accuracy that we all would wish. Some things are unequivocal: deforestation emits much CO_2 and trace gases and few if any of the subsequent agricultural uses can replace that C store.

The method described above was derived for a major crop and was then used as a proxy for others, while recognising that this is a considerable simplification of what may occur in reality. The actual locations in which additional cropped areas may be situated are simply unknown. In order to provide a basis for the estimation, one value was used for other crops: a weighted average of those calculated for soy together, giving an estimate of 6.9 t CO_2e ha^{-1} y^{-1} (Table 28).

Table 28 Land types used to calculate general LUC when the actual location of future LUC is unknown

	Proportion of land type used for increased UK demands	**LUC term, t CO_2e ha^{-1} y^{-1} ***
No LUC, but different crops on cultivated land	20%	0
Brazil from high forest	20%	11.9
Brazil from Cerrado	20%	3.5
Argentina from high forest	20%	17.0
Argentina from grassland	20%	2.0
	100%	**6.9**

46 Cerri, C.E.P., Easter, M., Paustian, K., Killian, K., Coleman, K., Bernoux, M., Falloon P., Powlson D.S., Batjes, N. H.), Milne, E. Cerri, C. C. (2007) Predicted soil organic carbon stocks and changes in the Brazilian Amazon between 2000 and 2030. Agriculture Ecosystems & Environment, 122 (1), 58-72.

47 Grace J, San Jose J, Meir P, Miranda H.S., Montes R.A. (2006) Productivity and carbon fluxes of tropical savannas Journal of Biogeography, 33 (3), 387-400

Table 29 Land types used to calculate general LUC when the actual location of future LUC is unknown

	Proportion of land type used for increased UK demands	LUC term, t CO_2e ha^{-1} y^{-1} *
No LUC, but different crops on cultivated land	20%	0
Brazil from forest	20%	11.9
Brazil from Cerrado	20%	3.5
Argentina from forest	20%	17.0
Argentina from grassland	20%	2.0
	100%	**6.9**

7. Effects of LUC on soil and biomass C for future LUC in the UK

The results are presented in two parts: the effects per unit area of converting current grassland to arable or forestry and the magnitude of possible changes under the scenarios. A description of uncertainty estimation is in Section 8. Results are presented here mainly without uncertainty estimates (owing to the great numbers of values), but it should be remembered that all calculated values are associated with uncertainties.

Emissions from LUC across the UK

The results for soil and biomass C changes (Table 30 and Figure 11) show that there are substantial differences in the effects of LUC across the UK, reflecting mainly the differences in soil types as well as climate. Most of the effects are from the changes in soil C equilibria. The effects of converting grassland to arable are similar in magnitude in England and N. Ireland, but opposite in direction to conversion for forestry. The magnitudes of changes in Scotland and Wales are larger for conversion to arable than to forest. This results from different soil and climates. The emissions from conversion of grassland to arable range from 2.6 to 11 t CO_2e ha^{-1} $year^{-1}$, while the uptake in forestry ranges from 9 to 19 t CO_2e ha^{-1} $year^{-1}$ (or a gain of 2.5 to 5.2 t C ha^{-1} $year^{-1}$. These estimates are based on a 20 year timescale and the soil C densities could continue to move towards their destination equilibria. Given that forecasting the actual land use is uncertain, it seems reasonable to limit these estimates to 20 years.

The role of biomass in the conversion of grass to arable is small, contributing a maximum of 0.3% of the emissions. The effects of trees are greater, ranging from 51% to 87%, depending on tree type and location (Table 31). Caution is needed when comparing the values that include biomass because the results are highly dependent of the assumptions made, e.g. neither option includes any estimate of the act of cultivation or harvesting or of the uses of crops or harvested wood.

Table 30 Summary of effects of LUC on annualised changes in vegetation and soil C on CO_2 emissions in the UK *

LUC effect in t C ha^{-1} yr^{-1}	England	Scotland	Wales	N. Ireland
Grass to arable	-0.72	-2.9	-1.2	-2.4
Grass to broadleaf forest	2.6	2.5	2.6	4.1
Grass to conifer forest	3.7	3.6	3.6	5.2
LUC effect in t CO_2e ha^{-1} yr^{-1}	**England**	**Scotland**	**Wales**	**N. Ireland**
Grass to arable	2.6	11	4.4	8.7
Grass to broadleaf forest	-9.6	-9.3	-9.5	-15
Grass to conifer forest	-13	-13	-13	-19

Negative values for CO_2e represent sequestration and positive are emissions

* All values presented are based on 20 years of emissions, except that those for forestry may continue for as long as the management supports further biomass accumulation

Table 31 Summary of effects of LUC on annualised changes in soil C density and CO_2 emissions in the UK *

LUC effect in t C ha^{-1} yr^{-1}	England	Scotland	Wales	N. Ireland
Grass to arable	-0.75	-2.9	-1.2	-2.4
Grass to forest	0.54	0.45	0.50	2.0
LUC effect in t CO_2e ha^{-1} yr^{-1}	**England**	**Scotland**	**Wales**	**N. Ireland**
Grass to arable	-2.7	-10.7	-4.5	-8.8
Grass to forest	2.0	1.6	1.8	7.5
Negative values for CO_2e represent sequestration and positive are emissions				

* All values presented are based on 20 years of emissions, except that those for forestry may continue for as long as the management supports further biomass accumulation

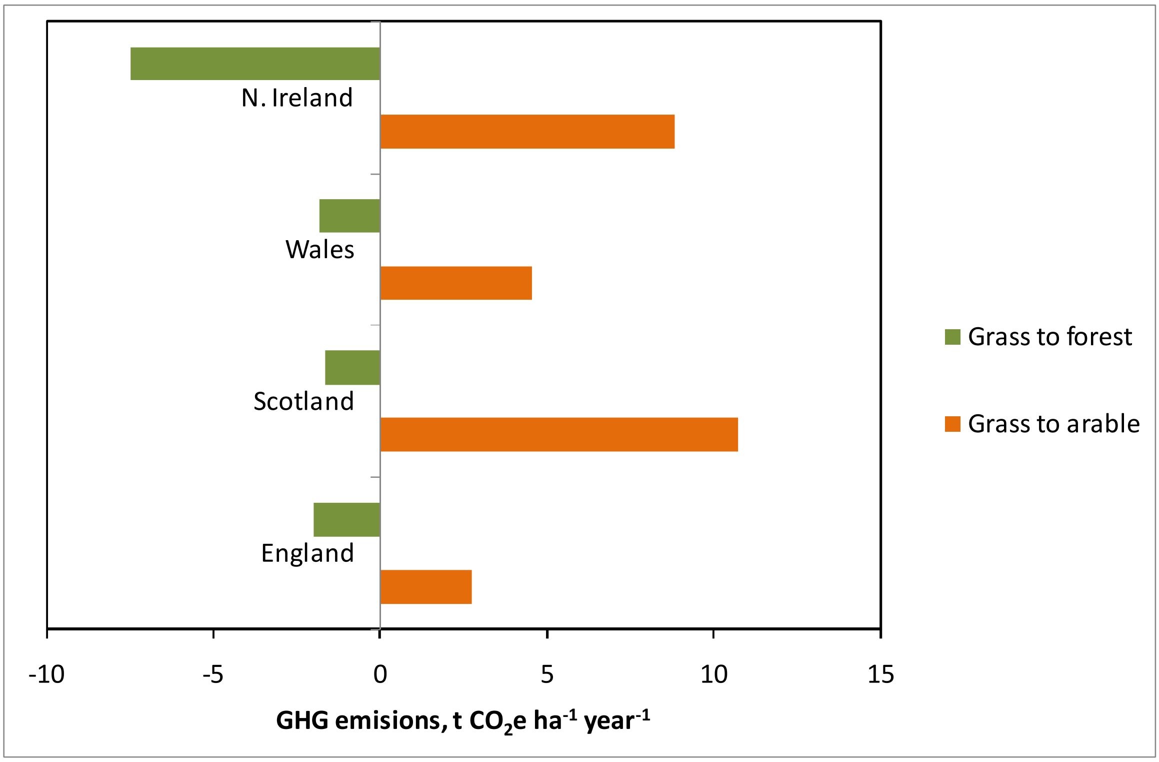

Figure 11 Effects of LUC on annualised changes in soil C in the UK expressed as CO_2 emissions (this represents data shown in Table 31)

The effect of CO_2 uptake by trees is of course positive while the trees are growing, but the ultimate fate of the trapped CO_2 depends on what the purpose the trees are ultimately put. It is beyond the scope of this project to model all the possible future outcomes, but these considerations should be noted. While growing trees clearly act as C sink. If harvested for fuel, the CO_2 liberated would be emitted to the atmosphere and, being biogenic, should not be counted in inventories. This fuel should also reduce the need to use fossil fuels for the same purpose. The degree of success in this is a matter of speculation, but we should not assume a simple 100% substitution as it is very likely that some resources will have been used on the harvesting and processing.

Thus, the net direct long-term effect of the biomass is about neutral in its effects on the atmosphere, but the flows of CO_2 have an important temporal dimension that must be recognised. Wood can also be used for construction, furniture, paper etc. In all these cases, a proportion of the biogenic C will be released quickly followed by a declining tail. Consider a medieval cathedral: these contain large pieces of ancient wood, but the smaller contemporary pieces will have almost entirely returned to CO_2 long since. The effects on soil under forestry should be much longer lasting, even allowing for harvesting and replanting. Of course, a return to grassland or move to arable would cause CO_2 emissions from the soil C that had been accumulated.

The subsequent calculations are thus limited to soil C only.

Potential extreme effects of LUC in the UK

The changes in demand for arable land use as a result of the consumption scenarios are small, with arable land needs decreasing by 8% and 6% in consumptions scenarios 1 and 3 respectively and increasing by 1.6% in consumption scenario 2 (Table 13). However the scenarios also release land that could be used for other purposes which might lead to LUC emissions. It is not possible in this study to forecast how land use will actually change under any of the consumption change scenarios, but we can indicate the range of possible consequences on soil and biomass fluxes. Actual demand for future land use will depend on many factors, such as world and domestic prices, competiveness of agriculture in the UK in world markets (and within the UK), national and international government and trading policies, consumer demand for non-food products (e.g. biofuels and products from industrial crops) and UK agriculture's response to changes in demand for livestock products. The last point is vital to remember, because the scenarios applied here include the assumption that the balance of overseas and domestically produced crops and animal products remain the same under each scenario. It is unlikely that the economy would develop in such a way, but it is beyond the scope of this study to generate such forecasts using economic modelling.

We assume therefore that any surplus arable land is most likely to be used for other crops (e.g. biofuels, industrial crops or crops for export). This is not expected to incur any soil or biomass C changes.

The main potential changes thus apply to released grassland. This may be converted to arable or forestry, which cause opposite GHG fluxes. Grassland may also be maintained as grassland for recreation, wildlife habitats or left to revert to wilderness. Although re-wilding will eventually result in woodland in most cases, none of these changes would have effects of the same magnitude over the first 20 years as conversion to arable or forestry and thus would be included with the assessment of the extreme changes that could occur.

Three possible interpretations were made in which we consider the following possibilities in which land is put to maximise productive potential.

- All potentially tillable land is converted to arable.
- All potentially tillable land and the best quality non-tillable grass is converted to coniferous forest.
- The best quality non-tillable grass is converted to coniferous forest and all potentially tillable land is converted to arable.

Neither option includes the effects of biomass or any estimate of the act of cultivation or harvesting. We assume that land remaining as grassland, but not in agricultural use does not change its soil and biomass equilibrium state, although this is a matter of debate. The land areas considered are in Table 32.

One particular case of increasing arable land was also included: to accommodate the extra demand for arable land in consumption scenario 2. The extra land requirement is 55,000 ha. This could potentially be met almost anywhere in the UK, but we assumed that it would be distributed in the UK in proportion to the current areas of arable quality land (77%, 12%, 3% and 7% in England, Scotland, Wales and NI respectively). This distribution combined with the values in Table 31 gives an emission of 4.2 t CO_2e ha^{-1} $year^{-1}$ and hence a total emission of 0.23 Mt CO_2e $year^{-1}$. This effect must be placed in the context of the possible alternative land uses that are addressed below.

Table 32 Potential areas (thousand ha) in the parts of the UK that could be converted from grassland to forestry or arable. This is related to the potential LUC emissions estimate in Table 33

Scenario	England			Scotland			Wales			N Ireland		
	All grass-land with arable potential	Non-tillable grass-land assumed forest potential	All grass-land with forest potential	All grass-land with arable potential	Non-tillable grass-land assumed forest potential	All grass-land with forest potential	All grass-land with arable potential	Non-tillable grass-land assumed forest potential	All grass-land with forest potential	All grass-land with arable potential	Non-tillable grass-land assumed forest potential	All grass-land with forest potential
50% reduction in livestock with land release:												
Uniform	1,469	303	1,773	335	328	663	249	235	485	208	170	377
Maximise release of non-tillable land	943	521	1,465	587	97	683	23	339	362	372	65	437
Maximise release of tillable land	1,907	138	2,045	436	240	675	397	197	594	255	128	383
Red to white meat with land release												
Uniform	1,301	277	1,579	380	315	695	235	225	459	333	170	502
Maximise release of non-tillable land	947	363	1,310	574	196	770	78	292	370	351	110	461
Maximise release of tillable land	1,712	143	1,855	0	0	0	307	246	552	0	0	0

Note: the Data relate to conversion on land well suited for forestry. There is a larger area of land (especially in Scotland) that would re-wild to woodland but with lower tree growth rates.

The results show greatly contrasting outcomes (Table 33 to Table 35 and Figure 12 to Figure 14). Converting all potentially tillable land to arable could result in emissions up to about 8 to 17 million t $CO_2e\ yr^{-1}$ over 20 years, with the 50% livestock product reduction (Scenario 1) with the maximum release of tillable land emitting the most (Table 33). It cannot be stressed too much that this represents an upper bound and is not a firm expectation for the future. It is clear that the demand for extra land under Scenario 1 that incurs 0.23 million t $CO_2e\ yr^{1}$ is small in the context of the overall possible conversion of grassland to arable.

In contrast, the option of maximum forestry could lead to annual sequestration rates in the range of about 7.5 to 9.5 million t $CO_2e\ yr^{-1}$ (Table 34). One approach combining all tillable land being converted to arable with the best non-tillable land converted to forest reduces the net emissions from conversion in the range 8% and 43% (Table 35): about 20% on average. There are clearly an infinite number of possible solutions to how land may be used, but these few options are indicative of the scale and direction of the possibilities. Each possibility would also be accompanied by a different range of outputs from the land.

Table 33 Potential greenhouse gas emissions over the first 20 years if all tillable land is converted to arable use (soil C only, not vegetation biomass)

Scenario	LUC effect in million t $CO_2e\ yr^{-1}$				
	England	Scotland	Wales	N Ireland	Total
50% reduction in livestock with:					
Uniform land release	4.0	4.5	1.1	2.5	12
Maximum release of grassland	2.6	3.6	0.1	1.8	8.1
Maximum release of tillable land	5.2	6.3	1.8	3.3	17
Red to white meat with:					
Uniform land release	3.6	4.7	1.1	2.2	12
Maximum release of grassland	2.6	4.1	0.4	2.9	10
Maximum release of tillable land	4.7	6.2	1.4	3.1	15

Note: positive values are net emissions and negative values indicate net sequestration

Table 34 Potential carbon (as CO_2) emissions (negative values represent sequestration) if all tillable land and best quality non-tillable grassland converted to forest (soil C only, not vegetation biomass)

Scenario	LUC effect in million t $CO_2e\ yr^{-1}$				
	England	Scotland	Wales	N Ireland	Total
50% reduction in livestock with:					
Uniform land release	-3.5	-1.0	-0.9	-3.0	-8.4
Maximum release of grassland	-2.9	-1.1	-0.7	-2.8	-7.5
Maximum release of tillable land	-4.1	-1.1	-1.1	-3.3	-9.5
Red to white meat with:					
Uniform land release	-3.1	-1.1	-0.8	-2.9	-7.9
Maximum release of grassland	-2.6	-1.1	-0.7	-3.8	-8.2
Maximum release of tillable land	-3.7	-1.3	-1.0	-3.4	-9.4

Note: positive values are net emissions and negative values indicate net sequestration. Much of the land could also be converted to deciduous trees with slightly lower growth rates and sequestration potentials

Table 35 Potential carbon (as CO_2) emissions (negative values represent sequestration) if best quality non-tillable grassland is converted to coniferous forest and all tillable land is converted to arable (soil C only, not vegetation biomass)

Scenario	LUC effect in million t $CO_2e\ yr^{-1}$				
	England	Scotland	Wales	N Ireland	Total
50% reduction in livestock with:					
Uniform release	3.4	4.2	0.7	1.7	10.0
max release of grassland	1.6	3.1	-0.5	0.6	4.7
max release of tillable land	5.0	6.1	1.4	2.8	15.3
Red to white meat with:					
Uniform land release	3.0	4.3	0.7	1.3	9.2
Maximum release of grassland	1.9	3.6	-0.2	1.7	6.9
Maximum release of tillable land	4.4	5.8	0.9	2.3	13.5

Note: positive values are net emissions and negative values indicate net sequestration

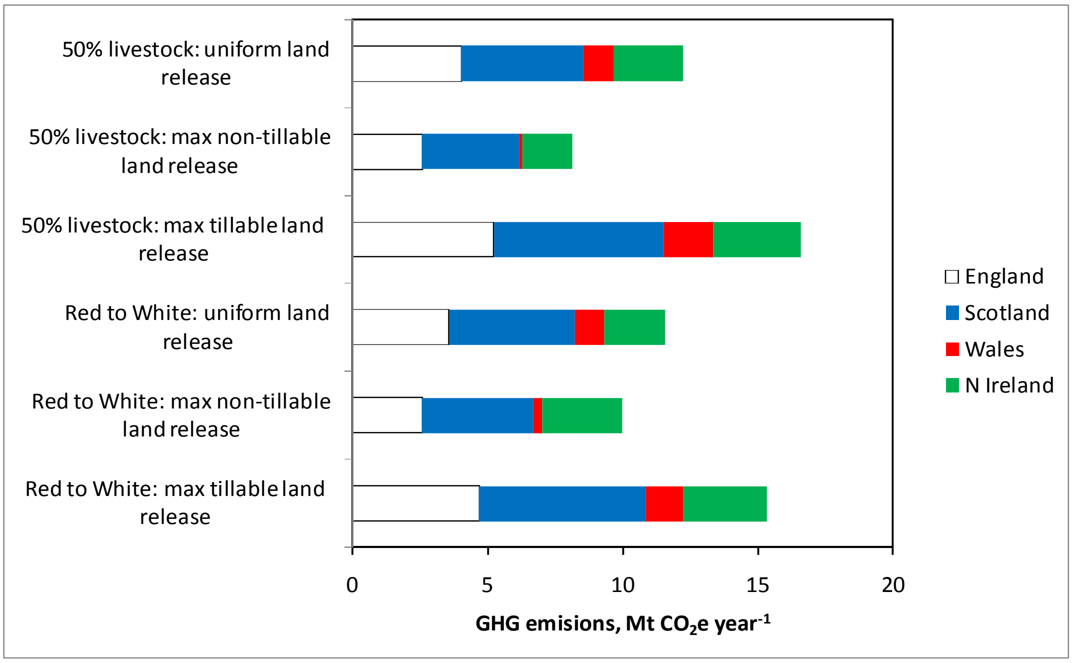

Figure 12 Potential soil C fluxes as (CO_2 emissions) if all tillable land is converted to arable use (from Table 33)

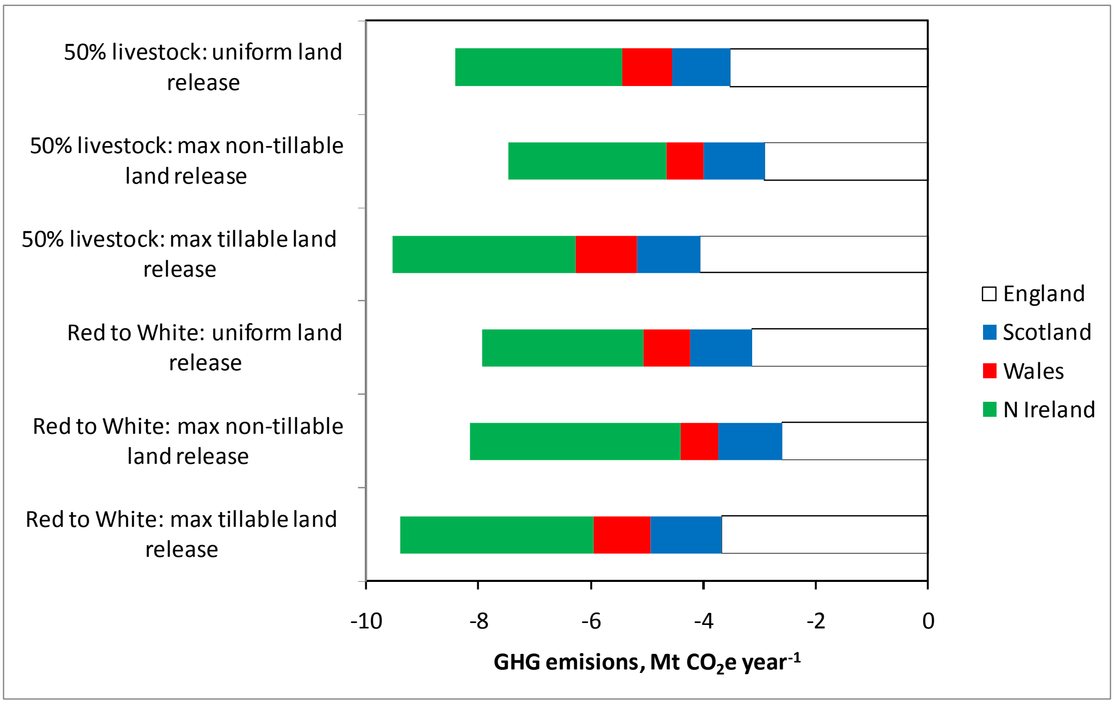

Figure 13 Potential soil C fluxes, as CO_2 emissions, (negative values represent sequestration) if all tillable land and best quality non-tillable grassland converted to coniferous forest (from Table 34)

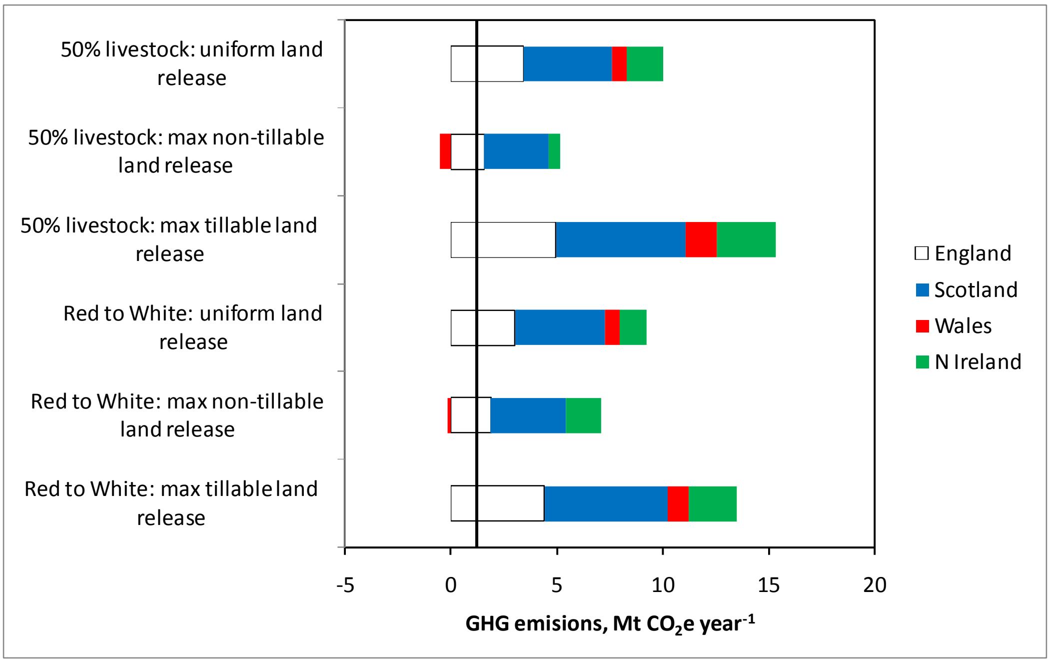

Figure 14 Potential soil C fluxes, as CO_2 emissions (negative values represent sequestration) if best quality non-tillable grassland is converted to coniferous forest and all tillable land is converted to arable (from Table 35). The sum in all cases represents emissions, not sequestration.

Overseas LUC and GHG emissions

Estimating the way LUC would actually occur overseas is even more speculative than that in the UK. There are three land uses that we quantified: crops eaten by humans, feed crops and grassland for ruminants. For much of recent history, an increased demand for crops or grassland has been met by deforestation and conversion of managed or unmanaged grassland to arable land. In a future in which UK consumption of animal products is reduced, the actual effects on land use overseas will depend hugely on the demands for land from global markets and how they respond. We are presented with the forecasts of net releases of arable land in consumption scenarios 1 and 3 of 576 and 894,000 ha respectively, but an increase in demand of 521,000 ha under Consumption Scenario 2. The latter is simply an extra demand of overseas feed crops for pigs and poultry, mainly soy. The net values in consumption scenarios 1 and 3, however, results from reduced demand for feed crops, but a concurrent increase in demand for human edible crops. Hence the question arises as to whether the same land would be substituted for one crop rather than another or if some more complex land use swapping would occur. The fate of grassland is even more open to question. There are three main sources of grassland included in the overseas totals: New Zealand pasture for lamb, European pasture for beef (mainly in Ireland) and South American pasture for beef. Given the geographies of NZ and Ireland, most of the pasture not used for supplying the UK is unlikely to be converted to arable cropping. In contrast, there has been much conversion of pasture in South America into arable land, but whether this would actually occur will depend on market and political factors.

Using Ecometrica's[48] method to estimate LUC emissions suggests that consumption scenarios 1 and 2 would incur reduced LUC emissions of about 50%, but only about 3% for consumption scenario 3 (Table 36). This approach is not however explicitly dynamic and while the magnitudes are indicative of the potential differences, the actuality may be quite different. The method is based on the allocation of a fraction of current world-level LUC emissions to UK food consumption using land areas per commodity, together with some economic allocation. Overall, a reduced demand for livestock produced overseas should decrease deforestation pressures. Reducing demand for livestock feed that is used in the UK (or indeed overseas) should also reduce pressures to convert pasture or forest to arable land.

Table 36 Potential emissions from LUC using the top down approach

Scenario	LUC effect in Mt CO_2e yr^{-1}	Reduction in emissions from baseline
Base consumption	102	
50% reduction in livestock consumption	49	52%
A switch from red to white meat	51	49%
50% reduction in white meat	98	3%

We can be more confident about some likely changes than others, e.g. in consumption scenario 2 (red to white meat), soy use will increase and this will dominate the demand for extra arable land needed for UK production. In addition, the demand for overseas arable crops for livestock also includes crops for animal products that are produced overseas. These will range from more soy through to European wheat for pigmeat production (for example in Denmark) and maize for chicken production in Brazil. Applying the general factor of 6.9 t CO_2e $ha^{-1}yr^{-1}$ (Table 28) for overseas crops gives an increase of 3.2 million t CO_2e yr^{-1}. This evidently differs substantially from the top down estimate for consumption scenario 2. Some of the difference comes from the allocation of LUC emissions to grassland use that is applied in the top down approach. About 1.5 million ha grassland are also released in consumption scenario 2 and could be used for grazing livestock for other markets, converted to arable or forestry, or not managed for agriculture. Hence the LUC emissions from these alternatives could be neutral, positive, or negative.

The actual future uses of land will depend on economic and political influences that are beyond the scope of this project to quantify, but the magnitude of possibilities could be illustrated as follows. If we simply assume that the same LUC factors apply to overseas grassland LUC as to that in the UK, then a 1st order estimate

[48] Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope for reduction by 2050. How low can we go? WWF UK and the Food Climate Research Network.

can be made. The weighted UK factors are 50 t CO_2e $ha^{-1}yr^{-1}$ for grass to arable and -59 t CO_2e $ha^{-1}yr^{-1}$ for grass to forestry. Thus, the range of LUC emissions for grassland in consumption scenario 2 is -86 to 73 million t CO_2e yr^{-1} (Table 37).

Applying the same approach to consumption scenario 1 (and assuming that released arable land will be used for some other cropping) leads to the estimate of -73 (sequestration) to 62 (emission) million t CO_2e yr^{1} for conversion to forestry or arable. These are summarised in Table 37, together with estimates of uncertainty. Given the high uncertainties at every stage, it was assumed that the errors in land areas changes had a coefficient of variation of 30% and the CoV of the emission factors was 70%. The overall effect is that the confidence intervals for the possible changes with positive or negative emission factors overlap so that there is no significant differences between them even though the magnitudes are high (Table 37).

Table 37 Estimates of uncertainty for LUC emissions from possible changes in use of overseas grassland

	Area of overseas grassland, kha	CoV	LUC EF, t CO_2e ha^{-1} $year^{-1}$	CoV	Mean	s.d.	Lower CI	Upper CI
Consumption scenario 1	1,244	30%	50	70%	62	49	-36	161
	1,244	30%	-59	70%	-74	58	-190	43
Consumption scenario 2	1,458	30%	50	70%	73	58	-42	188
	1,458	30%	-59	70%	-86	68	-222	51

It cannot be stressed too highly that the potential effects of these consumption change scenarios on overseas land use are very speculative and uncertain. The changes in demand for other commodities will have complex effects and consequences. For example, in consumption scenario 1, the area of plantation crops outside Europe is expected to fall slightly, but within this there is an increase for crops like bananas and a decrease in cane-sugar. A conversion from one to the other may be feasible, but the actuality would depend on many factors (e.g. land quality). Furthermore, the land areas estimates were based on average world yields from the FAOSTAT. The actual yields of bananas vary widely (between about 4 t/ha in the Congo and Burundi and 43 t/ha in Costa Rica). Also, in countries from which we import bananas, the yield trends are opposed, .e.g. yields in the Cote d'Ivoire were 13 t/ha in 1980 but rose to 45 t/ha by 2008. Thus for an area such as the Ivory Coast, production has almost doubled, but land area harvested has remained roughly constant. Some areas, such as Columbia show a marked decrease in yield from 52 t/ha to 26 t/ha over the same period. This could be due to an initially high soil fertility following conversion from tropical forest, which has gradually degraded towards a new equilibrium. Thus, the actual effects on LUC will be markedly different from wherever new demand is met.

If the increase in requirement for fruit and vegetable commodities is met mainly by European production, LUC emissions may be minimal, particularly if the change is from grassland or pasture to perennial cropping such as grapes, olives. The increase required in olives, grapes and citrus fruits alone accounts for at least 250,000 ha, the majority of which is likely to be met by European production. A land use change from grassland to perennial cropping suggests LUC emissions of 0-1 t CO_2e/ha/year.[49] It is possible that a conversion to groves and vines may even increase above and below ground biomass. The more major concern with further increases in European agricultural production, (particularly in the Mediterranean basin) is water scarcity and the requirement for irrigation. It may simply not be possible to meet increased demand in some areas because of this. Water stress is not confined to the European side of the basin and countries of North Africa, Turkey and Israel that currently supply a variety of fruit and vegetables are all highly water stressed areas. Water stress is also of concern in parts of the UK, mainly in the drier South East and East Anglia. Water stress is not apparently such a large problem in the areas of field cropping in South America from which we derive crops like soy. There is little doubt, however, that water stress will generally become

[49] Table 37 of the Renewable Fuels Agency Guidance (2010)

an increasing problem in the world as populations increase and demand for water for different purposes will also increase.

8. Uncertainties

There is uncertainty in all numerical estimates of land requirements, direct GHG emissions and LUC emissions. In this work, the main uncertainties relate to estimation of land use and GHG emissions and all the intermediates that contribute to the final estimates.

The uncertainties in the land use calculations include errors in survey data (e.g. occasional excess of 2,500 ha recorded for grid squares of that size, livestock numbers, imports of feed commodities and animal products), animal feed use rates and crop yields (especially overseas). In addition, errors occur in the assumptions and data used to convert grassland types into the land with arable or grassland suitabilities.

The direct GHG emission calculation errors include the emission factors that were developed by the IPCC for agricultural activities, emission factors for fossil fuel use together with all the associated activity data. Some of these are processed further so that there may be some modelling errors, e.g. the conversion of livestock production to crop needs by the feed conversion ratio.

In the LUC calculations, the errors include parameter values (e.g. soil C rate coefficients and equilibrium concentrations), estimates of the soil type areas in the UK, estimates of C uptake by trees and noting that the overseas soil and biomass change parameters are the same for potentially widely differing land types.

Audsley et al.[50] examined errors in the UK food system inventories using Monte Carlo simulations and quantified uncertainties using the coefficient of variation (CoV). The CoV is the standard deviation divided by the mean (and is usually expressed as a percentage). The upper and lower 95% confidence intervals of the mean (m) are given by:

Lower 95% CI = m (1 – 2 CoV)

Upper 95% CI = m (1 + 2 CoV)

The same results are essentially applicable to the ongoing GHG emissions reported here. The results were that the CoV of the overall estimate of the UK consumption inventory (253 Mt CO_2e) was 7% (Table 38) so the 95% confidence intervals are 217 and 289 Mt CO_2e. The largest term is for LUC, which is associated with high uncertainties in the emissions for specific changes, the areas actually affected and the economic allocations applied.

Table 38 Estimated means and errors of the main UK consumption-oriented food inventory

Item	Mean	Std. Dev.	CV	Lower 95% CI	Upper 95% CI
Primary production	86	8	9%	70	102
Processing distribution and consumption	66	5	7%	57	76
LUC	101	15	15%	71	131
Grand total	**253**	**18**	**7%**	**217**	**289**

It should be noted that these are the overall errors. Relatively small changes between outputs of components of the analysis may still be statistically significant because of uncertainties being highly correlated. However, the scope and scale of the project did not allow these to be quantified.

[50] Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope for reduction by 2050. How low can we go? WWF UK and the Food Climate Research Network.

There are additional GHG emission errors to be considered in this report: namely the specific aspects of LUC that were quantified. Specific LUC emissions carry high uncertainty. Wiltshire et al. (2009)[51] estimated the errors in LUC emissions from tropical forest to cocoa plantation as having a CV of about 40%, although the CV for individual terms, like soil C and biomass C was 45%. This was based on IPCC Tier 1 default values, which are generally associated with high uncertainty. The LUC calculations within the UK, however, are based on more measured values and the LULUCF includes some estimates of uncertainty for particular terms. These were applied in Monte Carlo simulations to calculate the overall uncertainty of LUC emissions, assuming that the error in the change in equilibrium states was 11% and was implemented as a triangular distribution. The rate coefficient was also implemented with a triangular distribution assuming that the lower and upper bounds were 0.5 and 1.5 times the mean respectively. The overall result was that the uncertainty for LUC between grassland and arable in each part of the UK was estimated to have a CoV of 9.1%.

The uncertainties of estimates of LUC emissions overseas are greater than in the UK and were estimated to have a CoV of 30% (except for one specific example with very high uncertainty applied in Section 0).

The uncertainty associated with calculating land areas is not easy to define. Errors should be random and decrease with aggregation (especially when using gridded census data). Expert judgement was applied and a CoV of 5% was applied to estimates of UK land areas and 10% to overseas land areas.

Combining the uncertainties for land areas and LUC emission estimates from changing grassland use in the UK, results in overall uncertainties in each part of the UK as having a CoV of 10%, but reducing to 6% when results were aggregated to the UK level.

Apart from the conventional uncertainties described above, various values used for this analysis will be subject to change over time. Emissions from processes such as N fertiliser manufacturing should decrease with time as a result of reduced N_2O emissions and better energy efficiency. Energy efficiency of most processes should also decrease with time. The emission factors used for UK agriculture should all become better quantified in the next few years as a result of Defra-funded research to improve the UK agriculture GHG inventory. This new knowledge should reduce the uncertainties with which we may calculate emissions from UK agriculture, but we cannot say which factors will increase or decrease. The large challenge in using uncertainties in this type of work is that from overseas agriculture, especially in the developing world, where activity data tends to be of poorer quality and the Tier 1 emission factors used by the IPCC are less likely to be suitable than in the developed world, where they were mostly calculated.

9. Wider environmental, economic and social impacts

In addition to quantifying the potential and use and GHG implications of consumption change, this study provides a qualitative, and where possible, quantitative assessment of the potential environmental, social and economic impacts of the scenarios. We introduce an approach to estimating ecosystem services offered by current UK land systems to assess the impact of changed systems.

An ecosystems approach

This evaluation makes use of the ecosystems framework described by de Groot[52] to provide a means of evaluating the scenarios described in the previous sections of this report. In Section I, we provide a broad description of the ecosystem framework described by de Groot.[52] In Section II, we then describe the broad positive and negative impacts of the different livestock sectors. In Section III we identify the key positive and negative impacts described in the baseline in Section II, frame this within the ecosystem framework as described in Section I and use this evaluative tool to compare the relative differences between the baseline and the CCC scenarios.

Table 39 The ecosystems framework as proposed by de Groot

[51] Wiltshire, J, Tucker, G, Williams, AG, Foster, C, Wynn, S, Thorn, R and D Chadwick. 2009. *Scenario building to test and inform the development of a BSI method for assessing GHG emissions from food*. Defra research report FO0404.

[52] De Groot, R., 2006. Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. Landscape and Urban Planning 75, 175–186.

Function	Use	Indicator of change in provision
Regulation	The capacity to regulate essential ecological processes and life support systems such as climate, water, soil, ecological and genetic systems	Carbon sequestration, methane oxidation, ammonia, methane, and nitrous oxide emissions
Production	The capacity to provide resources such as water, food, raw materials, and energy	Food production or employment
Habitat	The capacity to provide a refuge for plants and animals, helping with the conservation of genetic, species, and ecosystem diversity	Floral and faunal diversity and abundance
Information	The capacity to contribute to human well-being through spiritual experiences, aesthetic pleasure, and recreation	Net change in provision of culturally important landscapes and features
Carrier	The capacity to provide space and a suitable substrate for human activity such as habitation, cultivation, energy generation, conservation, recreation	Net change in energy production, recreational use, etc

From an economic perspective, the environment is valuable in so far as it provides for human welfare. Whilst some of the benefits it provides, such as food and raw materials are obvious and traded in the market place (commanding prices that reflect their value in use), many of the benefits are non-market goods and services which are enjoyed as public rather than private goods. Problems arise when beneficial yet often hidden flows of goods and services are lost due to over use or damage, with consequences for human welfare. In this context, the concept of ecosystems functions and services has emerged as a means of explicitly linking natural capital with social welfare. Natural capital supports a number of interrelated ecosystem functions (production, regulating, habitat, carrier, and information functions) which produce a variety of ecosystem goods and services that have value for humans (Table 39).

Defra is committed to embedding the principles of an ecosystems approach in policy- and decision-making to deliver on its natural environment Public Service Agreement. Defra has commissioned research to identify how this can be done. Here we undertake an environmental evaluation of the livestock industry using the ecosystems framework to capture the wider ranges of costs and benefits associated with the different scenarios against the baseline. We view the livestock industry as producing an array of both private and public benefits that are provisioned at the expense of an array of costs, both of which can be evaluated using indicators (Table 39).

Positive and negative ecosystem service impacts of the livestock sectors

We consider in turn the ecosystem services offered by as well as negative impacts of the beef/dairy, sheep, pigs and poultry production systems in the UK.

Beef and dairy systems

Since beef and dairy cattle are often kept together on it is difficult to attribute their environmental impacts to either milk or beef. In the lowlands, beef cattle may be managed with arable crops, dairy livestock and sheep. In uplands, beef cattle may be managed with sheep. Beef cattle, particularly the more traditional breeds, are frequently used on nature conservation sites in National Parks and Sites of Special Scientific Interest (SSSI) to maintain the existing vegetation. It is sometimes claimed that grazing livestock systems in particular deliver environmental benefits.[53] Ecosystem service benefits claimed include:

[53] ADAS 2007. The environmental impact of livestock production. Report for Defra.

- Production:
  - milk, meat, and leather
  - rural and urban employment opportunities in milk processing and production plants, feed manufacturing, vets, abattoirs, and on farms themselves.
  - Use of a large number of co- and by-products from food and allied industries.
- Carrier:
  - Hedges provide wildlife corridors, food, and shelter for a range of wildlife.
  - Cattle are unselective grazers and can therefore foster floristically diverse pasture important to a range of invertebrates and bird species. Beef cattle can be used to help maintain important semi-natural habitats in the UK, including in Sites of Special Scientific Interest (SSSI)'s, Areas of Outstanding Natural Beauty and National Parks.
  - In woodlands, cattle provide biodiversity benefits if grazed at low densities breaking up vegetation mats which benefits tree regeneration and therefore helps to support an increased diversity of vegetation types and associated invertebrate and bird assemblages.[54]
  - On moors and heathland, cattle eat coarse vegetation and dead plant material. They avoid heather, unless grasses and sedges are unavailable, and at appropriate stocking rates can be used to promote the development of heather and associated species[55], in contrast to sheep, which preferentially graze the growing tips of plants.
  - In calcareous grasslands, cattle maintain an open, species-rich sward, and prevent the development of rank grasses and scrub.[56] This is important since the rich flora in such grasslands are a habitat for many species of conservation interest, notably a number of rare butterflies, such as the Northern Brown Argus (*Plebeius artaxerxes*) and the Small Blue (*Cupido minimus*).[57] Upland calcareous grasslands provide a feeding and breeding area for a number of declining bird species including the Stone-curlew (*Burhinus oedicnemus*) and coastal grasslands, which require cattle to maintain grass swards of different heights and create footprint hollows to provide feeding grounds for wild birds such as the Pink-footed Goose (*Anser brachyrhynchus*) and Whooper Swan (*Cygnus cygnus*) and nesting habitat for breeding waders, such as the Common Redshank (*Tringa totanus*) and the Eurasian Oystercatcher (*Haematopus ostralegus*).[58]
  - On wet and acidic grasslands, grazing cattle can help to create a mosaic of sward vegetation that promotes a range of aquatic flora, wetland birds, and invertebrate assemblages.[58]
- Information
  - Hedges and dry stonewalls associated with cattle production are of cultural value in the farmed landscapes

There are disbenefits. The negative impacts of dairy are similar to beef in general.

- Regulation
  - Soil can be degraded by grazing cattle, slurry spreading, maize production and harvesting, and silage operations.

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[54] Armstrong, H.M., Poulsom, L., Connolly, T. and Peace, A. (2003). *A survey of cattle-grazed woodlands in Britain.* Report to Forestry Commission.

[55] Adamson, H.F. and Critchley, C.N.R. (2007) *Appendix 1a.1 Literature Review: Grazing of Heather Moorland Vegetation. In: Determining Environmentally Sustainable and Economically Viable Grazing Systems for the Restoration and Maintenance of Heather Moorland in England and Wales*. Defra report BD1228.

[56] ADAS (2008) The Environmental Impact of Livestock Production. Report for Defra FFG.

[57] English Nature, (2005). *The importance of livestock grazing for wildlife conservation*. ISBN 1 85716 861 5.

[58] Evans, N., Gaskell, P. and Winter, M. (2003). *Re-assessing agrarian policy and practice in local environmental management: the case of beef cattle*. Land Use Policy. **20**: 231–242.

- The emission and subsequent re-deposition of ammonia (NH_3) from cattle housing, grazing land and manure spreading can lead to soil and water acidification and nutrient enrichment of sensitive habitats
  - Microbial fermentation in the rumen and anaerobic decomposition in slurry storage units are significant sources of methane (CH_4) emissions.
  - Grassland on dairy farms is generally more intensively fertilised than on beef enterprises, increasing nitrate leaching and nitrous oxide emissions.
  - The demand for drinking and parlour wash down water is high as dairy herds consume >90 litres per day per animal on average.
  - Veterinary medicines may reduce microbial and invertebrate activity and hence, the degradation of dung, which subsequently reduces invertebrate, bird, and bat populations; they may also reduce the quality of aquatic habitats.
- Habitat
  - Excessive grazing reduces the quality of nesting habitat and leads to a reduction in pollen and nectar and thus, in food resources available for insects and birds.

Sheep

Sheep are typically kept in either extensive upland grazing systems or in more intensive lowland grassland systems with a wide range of sheep breeds and production systems in use across the UK. Sheep deliver environmental benefits where appropriate agricultural management practices in certain habitats emphasise the preservation of biodiversity, semi-natural habitats and archaeological sites.

- Production
  - agricultural products, notably meat and wool
  - rural and urban employment opportunities in processing and production plants, feed manufacturing, abattoirs, vets and on farms themselves.
- Habitat
  - Sheep are a vital tool in maintenance of important semi-natural upland and lowland habitats across the UK. In Scotland and Wales, preventing undergrazing is a requirement of cross compliance for the Single Payment Scheme (SPS) and, for example, in Scotland farmers should "avoid undergrazing at a level where the growth of scrub or coarse vegetation is detrimental to the environmental or agricultural interest in the field".[59]
- Carrier
  - Appropriately managed sheep grazing can result in a diverse, short structured vegetation sward capable of supporting a range of rare species. Sheep can push their way through scrub and browse saplings reducing new growth of young trees. [57] [60] [61]
- Landscape
  - The hedges and dry stonewalls associated with this type of farming contribute to the landscape character of the countryside. Hedges provide wildlife corridors, food and shelter for a range of organisms.

Sheep production can have significant negative environmental impacts.

- Habitat

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[59] Rural Development Service (2006). Predicted Changes in Livestock Farming in England, Possible Environmental Impacts and Problems of Undergrazing. Report prepared for the Department for Environment, Food and Rural Affairs, Exeter, UK. 51pp.

[60] Rook, A.J., Dumont, B., Isselstein, J., Osoro, K., WallisDeVries, M.F., Parente, G and Mills, J. (2004). *Matching type of livestock to desired biodiversity outcomes in pastures – a review*. Biological Conservation, **119:** 137–150.

[61] Boschi, C. and Baur, B. (2007). *The effect of horse, cattle and sheep grazing on the diversity and abundance of land snails in nutrient-poor calcareous grasslands.* Basic and Applied Ecology. **8:** 55—65.

- o Excessive winter grazing on forage crops can be detrimental if poorly sited or in bad weather conditions. High stocking rates on sensitive habitats can similarly be detrimental.[62]

- Regulation
  - o Soil degradation can be caused through soil erosion from overgrazing and grazing of root crops. Localised soil compaction also occurs, which can significantly increase flood risk at local scales because of reduced soil infiltration.
  - o Veterinary medicines can be distributed in faeces and subsequently impact microbial and invertebrate activity and associated ecosystems.
  - o Potential nitrates, fertiliser, faeces and urine contamination of watercourses through surface water runoff, which has the potential to lead to eutrophication and acidification of aquatic habitats.
  - o Sheep dips can pollute watercourses, however this impact has been minimised through advice to farmers, legislation and enforcement.

Pigs

The UK pig industry is a part of the European intensive animal production sector that relies on imported feed and concentrated production. This activity causes significant local and regional environmental problems in the relevant countries, especially the Netherlands, Belgium, Germany and Denmark. All pigs are housed at night and virtually all food consumed by pigs is grown on arable land. Most manure is spread on arable land.

- Production
  - o Agricultural products.
  - o Employment opportunities in abattoirs, meat-processing plants, feed merchants, pharmaceutical companies and associated suppliers.
  - o Use of co- and by-products from food and allied industries.
- Regulation
  - o The use of manure and slurry increases soil organic matter and soil nutrient reserves of arable land thus improving soil fertility and reduce the quantity of chemical fertilisers required.
  - o Bacterial pathogens can be transferred to water bodies through manure storage and land applications of manure.
  - o Bacterial pathogens can also be spread via airborne dust particles and bio-aerosols. Particulate matter is emitted from indoor systems from the handling of bedding, delivery of feed and straw muck systems.
  - o Malodours can be released from indoor systems during manure spreading impacting significantly on the quality of life in rural areas.
  - o Pigs are responsible for 9% of agricultural ammonia emissions.[63] Because production is concentrated, this emission can have significant impacts on local habitats.
  - o Because of the reliance on housing and concentrate feedstuffs, pig and poultry production is not necessarily connected to the land resource base it uses. This enables concentration of production leading to local and regional nutrient excesses.[64]

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[62] Milsom, T.P., Aegerter, J., Bishop, J.D., Allcock, J.A., Barker, D., Boatman, N.D., Hill, V., Jones, N., Marshall, J., McKay, H.V., Moore, N.P. and Robertson, P.A. (2003). *Review of hilledge habitats in the uplands of England and Wales*. Project No BD1235. Report to Defra.

[63] Misselbrook, T.H., Chadwick, D.R., Chambers, B.J., Smith, K.A., and Williams, J. 2008. Inventory of ammonia emissions from UK agriculture 2007. Inventory submission report to Defra – Defra project AC0112

[64] UNEP and WHRC. 2007. Reactive Nitrogen in the Environment: Too Much or Too Little of a Good Thing. United Nations Environment Programme, Paris, 2007.

Pigs are normally associated with intensive methods of production with negative environmental impacts. Outdoor pig production addresses this effect of intensive housed production. However, outdoor systems also have significant impacts. Environmental impacts of outdoor pig production units are increasing as this production system increases in popularity, whilst those of indoor production are declining.

- Regulation
    - Outdoor pigs typically remain in a single enclosure for one to two years. On grass, the ground cover can be rapidly damaged through trampling and rooting. The extent of soil erosion associated with these enclosures depends on site-specific factors such as soil type, soil moisture and slope.[65]
    - Outdoor enclosures are commonly established on free-draining soils, which are known to be vulnerable to leaching and erosion.[66] Soil erosion and compaction results from excessive grazing, slurry spreading and the creation of dust/water bath areas.
    - Watson and Edwards[67] demonstrated that un-ringed sows reduced vegetation cover by 90 percent within one month thus increasing the likelihood of water contamination, N and P leaching and ammonia volatilisation.[68] Destruction of vegetation negatively affects the biodiversity of invertebrates and birds associated with pig farming.
    - Heavy metal accumulation in soils results from pig feed and veterinary medicines and may lead to reduce rhizobial and microbial activities.

However, extensive systems where hardy, traditional breeds of pig are grazed on semi-natural vegetation at very low stocking rates can have benefits.

- Habitat
    - Un-desirable scrub vegetation (e.g. bracken) can be controlled when pigs are kept in free-range extensive stocking rotations.[69] [70]
    - Pannage is an ancient right of common (the practice of turning out domestic pigs in a wood or forest) still exercised in the New Forest and the Forest of Dean. In these regions pigs are valued for the speed at which they clear up acorns thereby reducing the likelihood of acorn poisoning in other livestock such as cattle and ponies.

Poultry

The high technical performance and concentration of the poultry industry is the foundation of its success in reducing the consumer price of poultry meat. All poultry are housed indoors at night and virtually all poultry feed is grown on arable land. Although, the majority of poultry are kept indoors, the number of free-range poultry operations is increasing. As is the case in pig production, concentration leads to a number of environmental problems. This is exacerbated by the tendency for intensive pig and poultry production to develop in the same locations driven by the availability of low cost feedstuffs, infrastructural and social factors and the reliance on common specialised knowhow.

- Production
    - Agricultural products.

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[65] MAFF 1999. *Site suitability for outdoor pig farming*. Pamphlet PB 4444, MAFF Publications London. Admail 6000, London SW1A 2XX.

[66] Evans, R. 1990. *Soils at risk of accelerated erosion in England and Wales*. Soil Use and Management. **6**: 125-131.

[67] Watson, C.A. and Edwards, S.A. 1997 Outdoor pig production: What are the environmental costs? Environmental & Food Sciences. Research Report. Scottish Agricultural College, Edinburgh. pp. 12-14.

[68] Hermansen, J.E., Strudsholm, K. and Horsted, K. 2004. *Integration of* organic animal production into land use with special reference to swine and poultry. Livestock Production Science. **90**: 11– 26.

[69] Read, H. (1994). *Native breeds in Burnham Beeches*. Enact. **2:** 4-6.

[70] Kennedy, D. (1998). *Rooting for regeneration*. Enact. **6:** 4-7.

- o Employment opportunities in abattoirs, meat-processing plants, feed merchants, pharmaceutical companies and the associated suppliers.
  - o Poultry litter is also incinerated in power stations to generate electricity.
- Regulation
  - o Soil organic carbon levels and soil fertility can be improved through regular applications of poultry litter to soil.
  - o Vegetation growth can be increased in areas where suitable range is provided for free-range poultry.
  - o The majority of manure on organic farms is used internally on arable land for fertility. On non-organic farms, most of the manure produced will be spread on arable land, but some broiler litter goes to power stations.
  - o Poor management of poultry systems can lead to pollution of groundwater, nitrate leaching, runoff of phosphorous and potassium, eutrophication of aquatic habitats, human and animal health impacts, high chlorine concentrations in water bodies, flies and odour nuisance and nutrient imbalance.[71]
  - o The spreading of manure can lead to soil compaction.
  - o Free-range poultry can exacerbate soil compaction and erosion through the removal of vegetation.
  - o Zinc from poultry feed and veterinary medicines can accumulate in soils and water bodies at rates greater than for other livestock sectors.
  - o Veterinary medicines distributed in faeces can affect microbial and invertebrate activity and thereby reduce nutrient cycling of terrestrial and aquatic habitats.
  - o The risk of nitrate leaching is greater from poultry operations than other livestock sectors due to its high N content. Manure heaps can be a substantial source of pollution to watercourses through leaching and runoff.
  - o Pathogens can be transferred to water bodies through manure storage and land applications of manure. Pathogens also have the potential to be spread via airborne dust particles and bio-aerosols. Dust emissions can be released in indoor systems from the handling of bedding, feed and straw muck systems and housed broilers produce 30% of the total fine dust emissions in the UK.[72]
  - o Ammonia emissions and nuisance odours are released from damp litter and from the spreading of manure on land.

The relative impact of the scenarios against the baseline

The key impacts of the livestock sector from the baseline description of the positive and negative effects of the livestock industry can be summarised within the ecosystems framework described by de Groot[73] as shown in Table 40.

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[71] Edwards, D.R. and Daniel, T.C. (1992). *Environmental Impacts of On-Farm Poultry Waste Disposal A Review.* Bioresource Technology **41:** 9-33.

[72] ADAS 2007. The Environmental Impact of Livestock Production. Report for Defra FFG

[73] De Groot, R. 2006. Function-analysis and valuation as a tool to assess land use conflicts in planning for sustainable, multi-functional landscapes. Landscape and Urban Planning 75, 175–186.

Table 40 Summary of key impacts of the baseline environmental description within an ecosystems framework.

Function	Uses	Welfare benefits	Welfare costs
Production	Livestock products	Rural employment	
		Meat	
Regulation	Gas / Climate regulation	Carbon sequestration	
		Methane oxidation	
			GHG
	Water regulation, supply and quality		Eutrophication potential
			Nitrate
			Pesticides
			Silage effluent
			Particulates
			Oestrogen
			Water contamination
	Soil retention & formation	Soil organic matter	
		Carbon sequestration	
			Acidification
			Soil degradation
			Soil compaction
	Nutrient regulation	Soil fertility	
			Nitrogen
			Zinc
			Copper
	Biological Control		Pathogens
			Diseases
			Veterinary medicines
Habitat	Refugium	Invertebrates	
		Mammals	
		Amphibians	
	Nursery	Moorland birds Woodland birds	
Carrier	Habitation	Hedges and stonewalls	
		Pasture vegetation	
Information	Aesthetic pleasure	Landscape	
		Archaeology	

This table is used with a simple scoring metric in a qualitative capacity to describe the differences of each scenario relative to the baseline. These scenarios are:

- Consumption scenario 1: 50% reduction in livestock
- Consumption scenario 2: Red to white meat
- Consumption scenario 3: 50% reduction in white meat

Table 41 shows that the main trend in land use associated with the different scenarios is linked to the cattle and sheep sector, and this has major implication in terms of the flow of ecosystem goods and services from these two sectors, particularly in scenarios 1 and 2. Whilst in scenario 3, there is a 50% reduction of white meat, the production of white meat, such as poultry and pigs, is associated with housed systems, and very intensive production on small areas of land, thereby reducing land use change implications.

Table 41 The relative use of land and emission of a variety of environmental burdens under the different food supply scenarios

All agriculture for food	50% reduction in livestock			Red to white meat			50% reduction in white meat
	Uniform land release	Maximum release of tillable land (generally lowlands) preferentially	Maximum release of grassland (generally hills and uplands) preferentially	Uniform land release	Maximum release of tillable land (generally lowlands) preferentially	Maximum release of grassland (generally hills and uplands) preferentially	Uniform land release
For UK land use only – relative change to baseline							
Arable land (food crops)	132%	132%	132%	100%	100%	100%	108%
Arable land (concentrates)	47%	43%	44%	104%	104%	104%	77%
Total arable land	92%	90%	90%	102%	102%	102%	93%
Total tillable grassland	43%	20%	67%	48%	32%	60%	100%
Land with no arable potential	34%	90%	0%	26%	81%	5%	100%
For UK and overseas land use – relative change to baseline							
Eutrophication potential.	51%	51%	51%	92%	92%	92%	86%
Acidification potential	54%	56%	53%	85%	86%	84%	89%
NH_3	50%	49%	50%	91%	91%	91%	86%
NO_3	55%	58%	53%	79%	81%	78%	91%
Pesticides used,	84%	84%	84%	108%	108%	108%	89%
GHG emissions	80%	81%	81%	91%	91%	91%	95%

Implications of scenarios for current benefits and costs of livestock production

The area of arable land use remains broadly similar within the UK (from 90 to 102% of the current baseline) implying generally little change in terms of the ecosystems goods and services provided by arable land. However, there is a major reduction in the area of land used currently for grassland in both scenarios 1 and 2, whilst in scenario 3, where only a reduction in white meat is envisaged, grassland use remains at current levels. Major changes in the flow of ecosystems goods and services provided by livestock systems in these areas are therefore envisaged.

The livestock industry provides a range of economic benefits to society. In 2006, the direct value of the UK livestock industry was estimated to be £7,712 million, about 13% of the total value of agricultural production.[74] Of this, cattle accounted for £1,657 million, sheep for £628 million, pigs for £735 million, and poultry £1,215 million. Milk production was valued at £2,830 million and egg production at £410 million.[74] The reduction of the cattle and sheep sector especially in scenarios 1 and 2 will be associated with a loss of employment and skills in rural areas. There will also be ramifications within linked industries such as the meat processing or veterinary sectors in areas where the red meet sector is important.

A large proportion of the cultural landscape, for example landscape characterised by hedgerows and stone walls and their fauna and flora are associated with livestock systems and open farmed landscapes. Research shows that there is a marked social preference for these existing landscapes and a reluctance to allow them to change.[75] This social preference is part of the reason for the support that is provided for maintaining such features through the Entry Level and Higher Level Stewardship Schemes.

In scenarios 1 and 2, the reduction in area occupied by the cattle and sheep sector would have consequences for a range of habitat and carrier benefits against the current baseline. Depending on where remaining production would take place, hedges and dry stonewalls could fall into disrepair and disappear altogether, reducing the cultural value of the landscape, especially in upland areas. There could be a reduction in the floristically diverse pastures that are fostered by extensive unselective cattle grazing with ramifications for the range of invertebrate and bird species. Maintenance of some wetland areas could suffer, impacting wetland bird populations and invertebrate assemblages. On moors and heathland, coarse vegetation could inhibit the development of heather and its associated species. Undergrazing could become problematic for landscape quality and biodiversity leading to a change of habitat associated with the loss of desirable species. In the event of long-term release from agriculture, there would be a total change of the landscape to one that would be dominated by natural climax vegetation such as woodland with the associated woodland flora and fauna.[76]

The environmental costs currently associated with the livestock sector could also decrease in these scenarios against the current baseline, dependent on the alternative use. Improved grassland is a hostile environment for wildlife and dense swards of ryegrass, often artificially drained and intensively grazed or cut for silage, provide few food sources or nesting sites. The area of ryegrass-dominated swards required for silage-making would be reduced, possibly releasing such land for more diverse land uses. The area of maize production, which because of late crop emergence increases the risk of soil erosion and contamination of water courses, would be reduced. Upland areas that are overstocked are also prone to erosion and this would be reduced. By implication, the reduction of overgrazing by cattle and sheep would allow *Culluna vulgaris* and similar dwarf shrub heath species to recover, therefore also increasing insect and bird species. Also by implication, livestock impacts on amphibian populations would be reduced because conditions would become more suitable and, for example, the natterjack toad (*Bufo calamita*) which is intolerant of acidic waters, might return to heathland sites in the southeast of England.[77 78]

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[74] Nix, J.S. 2008. Farm Management Pocketbook (38th edition). The Andersons Centre, Imperial College London, Wye Campus.

[75] Willis, ICG. and Garrod, G.D., 1992. Assessing the value of future landscapes. *Landscape and Urban Planning.* 23:17-32.

[76] Denmark European Environmental Agency. 2003. Europe's environment: the third assessment. Report no. 10. Copenhagen, Denmark, 344 pp.

[77] ADAS. 2008 The environmental impact of livestock production. Report for Defra FFG.

[78] Beebee, T.J.C., Flower, R.J., Stevenson, A.C., Patrick, S.T., Appleby, P.G., Fletcher, C., Marsh, C., Natkanski, J., Rippey, B. & Battarbee, R.W. 1990. Decline of the Natterjack toad *Bufo calamita* in Britain: Palaeoecological documentary and experimental evidence for breeding site acidification. Biological Conservation, 53, 1-20.

Environmental burdens (except for pesticide use in consumption scenario 2) of meeting food requirements under each scenario would be reduced. As much as 60% of the nitrogen (N) and 25% of the phosphorus (P) in water bodies is from livestock, leading to eutrophication.[79] This is reduced in all the scenarios, but especially in consumption scenario 1, where a reduction of almost 50% in eutrophication potential (kg PO_4 equivalent) is in evidence. Agriculture is responsible for 80% of the UK's national inventory of emissions of ammonia, with 86% of the agricultural total coming from livestock production.[80] Ammonia, after deposition on land or water leads to acidification and eutrophication of ecologically sensitive areas and this has resulted in substantial ecological degradation.[81] Acidification potential (kg SO_2 equivalent) is reduced in all the scenarios, but again, especially in scenario 1. Livestock are also a significant source of Greenhouse Gases (GHG), predominantly methane and nitrous oxide. GHG emissions are reduced in all the scenarios, but once again, it is particularly in scenario 1 that this is most pronounced, although in comparison with reductions in the eutrophication and acidification potentials in scenario 1, this is relatively moderate. Sediments, heavy metals, pathogens, and veterinary medicines also cause problems.[81] These pollutants mainly originate in the 90 million tonnes of manure per year generated from livestock which require application to land.[82] The reduction in manure is likely to be most significant in scenario 1, where there is the greatest reduction in protein supplied from meat. A qualitative summary of the impacts and their relative change in direction and magnitude is provided in Table 42. It is worth bearing in mind that these are somewhat indicative and that more research is needed support these conclusions and in particular to establish the relative importance of these different ecosystem impacts through a framework capable of evaluating them through use of a common index. Economic valuation of these impacts provides one possible approach and establishing the required data for this is currently the focus of a number of Defra projects.

[79] Eftec/ IEEP. 2004. Framework for Environmental Accounts for Agriculture. Final Report to Defra, Department of Agriculture and Rural Development (Northern Ireland), Scottish Executive and Welsh Assembly Government.

[80] NAEI (National Atmospheric Emissions Inventory), 2005. AEA Energy & Environment, Harwell

[81] Eftec/ IEEP (2004) Framework for Environmental Accounts for Agriculture. Final Report to Defra, Department of Agriculture and Rural Development (Northern Ireland), Scottish Executive and Welsh Assembly Government.

[82] Defra (2008). The Environmental Impacts of Livestock Production. Review of Research and Literature. Report prepared for the Department for Environment, Food and Rural Affairs. London, UK. 96 pp.

Table 42 Estimate of environmental impact of consumption scenarios relative to the current baseline

Function	Uses	Welfare benefits	Welfare costs	Relative change against baseline from consumption scenario:		
				1	2	3
Production	Livestock products	Rural employment		X X X	X	X
		Meat		X	X X X	X X X
Regulation	Gas / Climate regulation	Carbon sequestration				
		Methane oxidation				
			GHG	√√	√	√
	Water regulation, supply and quality		Eutrophication potential	√√√	√	√
			Nitrate	√√√	√	√
			Pesticides	√√	X	√
			Silage effluent	√√	√√	-
			Particulates	√√	√√	-
			Oestrogen			
			Water contamination	√√	√√	-
	Soil retention & formation	Soil Organic Matter				
		Carbon sequestration				
			Acidification	√√√	√	√
			Soil degradation	√√	√√	-
			Soil compaction	√√	√√	-
	Nutrient regulation	Soil fertility		X	X	-
			Nitrogen			
			Zinc			
			Copper			
	Biological Control		Pathogens	X	X	-
			Diseases	X	X	-
			Veterinary medicines	√	-	-
Habitat	Refugium	Invertebrates		X	X	-
		Mammals		√√	√√	-
		Amphibians		√	√	-
	Nursery	Moorland birds		X X	X X	-
		Woodland birds		√√	√√	-
Carrier	Habitation	Hedges and stonewalls		X X X	X X X	-
		Pasture vegetation		X X X	X X X	-
Information	Aesthetic pleasure	Landscape		X X X	X X X	-
		Archaeology		X	X	-

Withdrawing land out of farming

So far, concern regarding releasing land from agriculture appears to have been more significant in Europe than in the UK, where it is mostly overgrazing that has tended to impair the flow of ecosystem benefits to society.[83] The Third Assessment of Europe's Environment[84] notes that withdrawal of farming from land in

[83] Rural Development Service (2006). Predicted Changes in Livestock Farming in England, Possible Environmental Impacts and Problems of Undergrazing. Report prepared for the Department for Environment, Food and Rural Affairs, Exeter, UK. 51pp.

Europe has resulted in "forest and shrub encroachment on flower-rich grassland areas and a consequent loss in biodiversity. The problem has been severe enough to have prompted a number of European conferences (e.g. Land Abandonment, Biodiversity and the CAP; Effects of Land Abandonment and Global Change on Plant and Animal Communities; Workshop on Land Abandonment, Land Abandonment and its Role in Conservation).[85]

In the UK as a whole, land that is most likely to be released from food production is associated with poor natural conditions and difficult logistics.[85] Currently, there are no specific cross compliance requirements in England to prevent under-grazing or reversion to a wild state. However, one condition (GAEC 12) relating to management of land not in agricultural production states that land "should be in such a condition that you can readily return the land to agricultural production by the next growing season" and that scrub or rank vegetation should be cut at least once every five years.[86]

In England, upland moorland and common land will be most vulnerable to release. Much of this is currently LFA designated, mostly in the north and south-west of England and the borders of Wales. In Northern Ireland, Scotland and Wales LFAs comprise a much larger proportion of agricultural land than in England. It is likely that under-grazing and land abandonment will be tackled through LFA and agri-environment measures. Currently for example, LFA regulations stipulate a minimum stocking density of 0.12 LU ha^{-1} in Scotland and 0.2 LU ha^{-1} in Northern Ireland to try and tackle the environmental problems caused by undergrazing.[85] However, it should be remembered that in the main scenarios studied, the same stocking rates as exist now were expected to prevail, although no forecasting of actual changes were made.

The upland areas most sensitive to change appear to be dwarf shrub heath and bogs. The lowland habitats most affected are likely to be dwarf shrub heath, neutral and calcareous grassland and sand dunes.[59] Existing evidence suggests that there is likely to be an increase in the area of scrub and woodland. In upland areas, where the majority of land release under consumption scenario 1 and 2 combined with production scenario 2 will be located, evidence suggests that various scrub, bracken, bramble, and woodland communities with their own assemblage of flora and fauna are likely to develop[59], with potential increases in wild herbivores such as deer, hares, and rabbits.[87] For example, in Dunkery Hill in Exmoor, birch trees from adjoining woodland are encroaching into adjacent heathland; in West Penwith, heathland and grassland are developing into bramble and bracken scrub communities; in the North York Moors birch and conifer encroachment has been observed.[59] Interestingly, the majority of under-grazed SSSIs currently occur in lowland areas, for example in southern and eastern parts of England, where the lack of livestock results in difficulty in applying the grazing pressure required to maintain faunal and floral diversity. The loss of appropriate infrastructure (stockproof fencing, water, access, and handling facilities) makes this situation more challenging.[88]

There is also concern that under-grazing and withdrawal of grazing livestock will damage the historic environment, especially in the uplands, both in physical terms as scrub and bracken communities develop and in terms of aesthetic pleasure, as these features become obscured by the growth of vegetation.[59] A further impact may be in terms of recreational access to the uplands, which is facilitated by open landscapes. Evidence suggests that visitors to upland areas value the current livestock landscapes relatively highly in comparison with other potential landscapes and any change is likely to be viewed negatively, especially by visitors who already associate a particular landscape with such areas.[59] The loss of skills and labour in rural areas as farmland is released from food production may result in low maintenance of cultural features such as stone walls and traditional hay meadows, leading to a general look of neglect in the landscape that may reduce visitor numbers. This may reduce income generating opportunities in other industries, such as the tourism and catering industry.

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[84] European Environmental Agency (2003). Europe's environment: the third assessment. Report no. 10. Copenhagen, Denmark, 344 pp.

[85] Moravec, J and Zemeckis, R (2007) *Cross Compliance and Land Abandonment*, Deliverable D17 of the CC Network Project, SSPE-CT-2005-022727.

[86] DEFRA (2006) *Single Payment Scheme Cross-compliance Handbook for England 2006 Edition.* Defra, London.

[87] Morris J, Audsley E, Wright IA, McLeod J, Pearn K, Angus A, Rickard S. 2005. *Agricultural Futures and Implications for the Environment.* Main Report. Defra Research Project IS0209. Bedford: Cranfield University. Available on hppt//www.silsoe.cranfield.ac.uk.

[88] Wooley and Company (2005) *Grazing Management of Isolated Grassland Sites in the East of England*. Woolley and Co., Frechenham.

Whilst a reduction in the current ecosystem benefits associated with livestock production from cattle and sheep can be expected under these scenarios, the net benefit is also dependent on the alternative use to which land is put in comparison with current land use. In the upland SSSIs, overgrazing is often much more of a problem then undergrazing[59], and reducing grazing pressure may allow a range of habitats to recover, in particular dwarf shrub heaths, bogs, acid grassland and montane habitats[89] [90]. However, the release of large areas of land could also be used to diversify upland areas. For example, semi-natural upland woodlands have declined by 30-40% since the 1950s and the UK Habitat Action Plan has therefore included a target to increase the area of upland oak wood through planting or natural regeneration of current open ground.[91]

In the lowlands, approximately 10% of the current arable land could be released for other activities, such as bioenergy crops, woodlands, recreational land, wetland creation, nature reserves, flood storage, carbon sequestration, and housing development. Each of these land uses will have associated with it, its own specific range and flow of ecosystem services. Whilst in general, the release of agricultural land with high environmental value from food production is generally not viewed as positive, Defra[92] has concluded that withdrawal of land from food production is not to be avoided in all instances, and that there are likely to be situations "where the overall impact is positive".

Ammonia

Ammonia (NH_3) in the atmosphere results primarily from the decomposition and volatilisation of animal wastes. The subsequent deposition of ammonia leads to the nitrogen enrichment of habitats. Agriculture accounts for about 86% of the emissions, with 72% arising directly from animals, housing and facilities and animal wastes. Even if only the trends in animal numbers are accounted for, NH_3 emissions are estimated to have at least doubled over the last century across Europe. Deposition may occur local to the emission source but a significant proportion may be transported over long distances, crossing national boundaries, prior to deposition. Concern over the impacts of this trans-boundary transport has led to legislation under the UNECE Gothenburg protocol and the EC National Emissions Ceilings Directive.

Figure 15 shows the distribution of ammonia concentrations across the UK in 2005. This pattern is by no means static, but it clearly shows an association between livestock production and emissions with concentrations in areas with intensive beef and dairy production and more localised concentrations associated with intensive pig and poultry production in the east. Consumption scenario 1 halves emissions of ammonia from food production.

[89] Robertson HJ and Jefferson RG (2000) *Monitoring the condition of lowland grassland SSSIs, 1 English Nature's rapid assessment method. English Nature Research Report No. 315.* English Nature, Peterborough.

[90] Robertson HJ, Crowle A and Hinton G (eds) (2001) *Interim assessment of the effects of the foot and mouth disease outbreak on England's biodiversity. English Nature Research Report No. 430.* English Nature, Peterborough.

[91] JNCC (2006) *UK Biodiversity Action Plan, Upland Oakwood Habitat Action Plan*. Available from www.ukbap.org.uk

[92] Defra (2006). *Rural Development Programme for England: 2007- 2013, Upland Reward Structure, Consultation Document.* Defra, London.

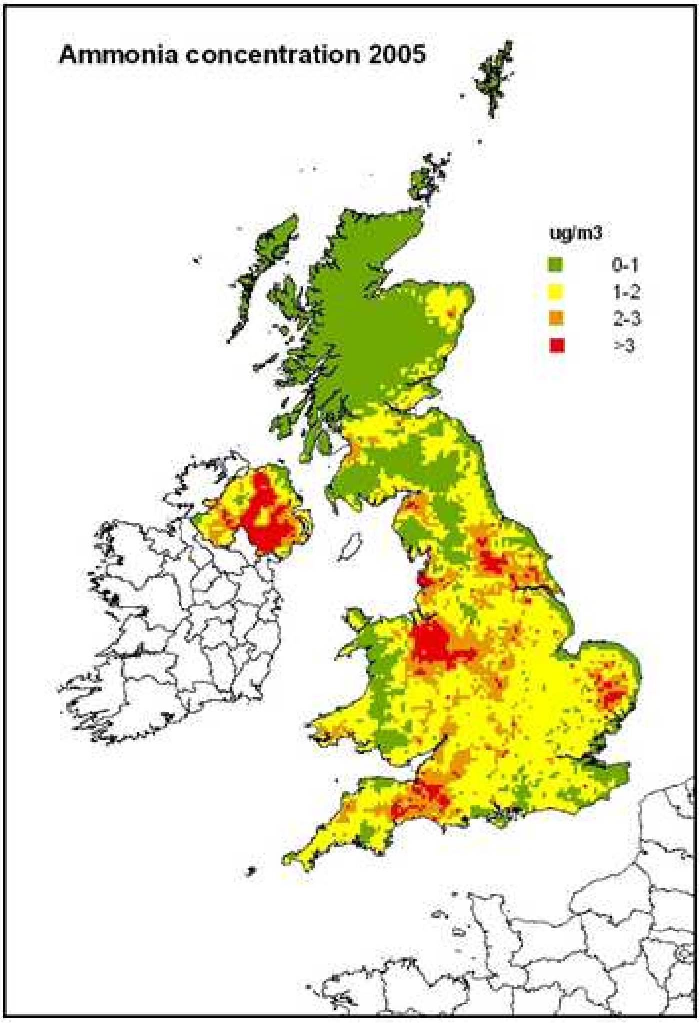


Figure 15 Atmospheric ammonia concentrations across the UK in 1995 [93]

Nitrate

Nitrate is probably the first eutrophication pollutant to receive serious attention in public policy. It is emitted from all soils in drainage water. Concerns over impacts on human health from nitrates in drinking water are the prime reason for regulation to date. EU legislation requires controls to limit concentrations in surface waters to 50 mg nitrate per litre.

Agriculture is estimated to be responsible for 61% of nitrates in water in England[94] and is generally the source of 50 – 80% of the nitrate load in Western Europe.[95] The contribution from agriculture is particularly high in Belgium, Denmark, and northern Germany due to the concentration of pig and poultry production. Emissions to water bodies generally arise from the decomposition of organic matter (including manures) in soil rather than directly from artificial fertilisers. Organic matter decomposition rates are high in well aerated and moist soils in the late summer and early autumn when crop uptake is low. Rainfall in autumn and early winter carries a large proportion of the nitrate released in summer and autumn from the soil into drainage water and thus the environment. The resultant concentration in water bodies depends greatly on rainfall – the higher the surplus rainfall the greater the dilution leading to lower concentrations for a given emission. Thus, water bodies in the drier east of the UK are much more prone to high concentrations compared with

[93] Air Pollution Information System. Accessed on 24 May 2010. http://www.apis.ac.uk/overview/pollutants/overview_NH3.htm

[94] ADAS 2006. Nitrates in water – current status in England. ADAS report to Defra.

[95] EEA (2005a). The European Environment — State and Outlook. European Environment Agency, Copenhagen, Denmark.

the wetter west. In East Anglia, an emission of only 15 kg N ha^{-1} as nitrate is sufficient to exceed the 50 mg nitrate per litre where excess rainfall is less than 150 mm per year.[96] Therefore, even though artificially fertilised arable crops have low total nitrate emissions, concentrations in water from arable land in England can be high in low rainfall areas (Figure 16). Concerns about the state of European waters led to the introduction of the EU Water Framework Directive that came into force in 2006.[98]

Key trends identified the challenge presented to agriculture by the Water Framework Directive.[97] That analysis indicates the importance of animal agriculture as a contributor to the total diffuse agricultural nutrient loading on English and Welsh waters, and the overwhelming need to bring these sources under control if conditions suitable for sustaining 'Good Ecological Status' in these waters are to be generated. Overall, consumption scenario 1 is estimated to almost halve the emissions of nitrate to water.

The economic impact of scenarios

This section qualitatively assesses the possible economic implications of the three consumption scenarios, namely:

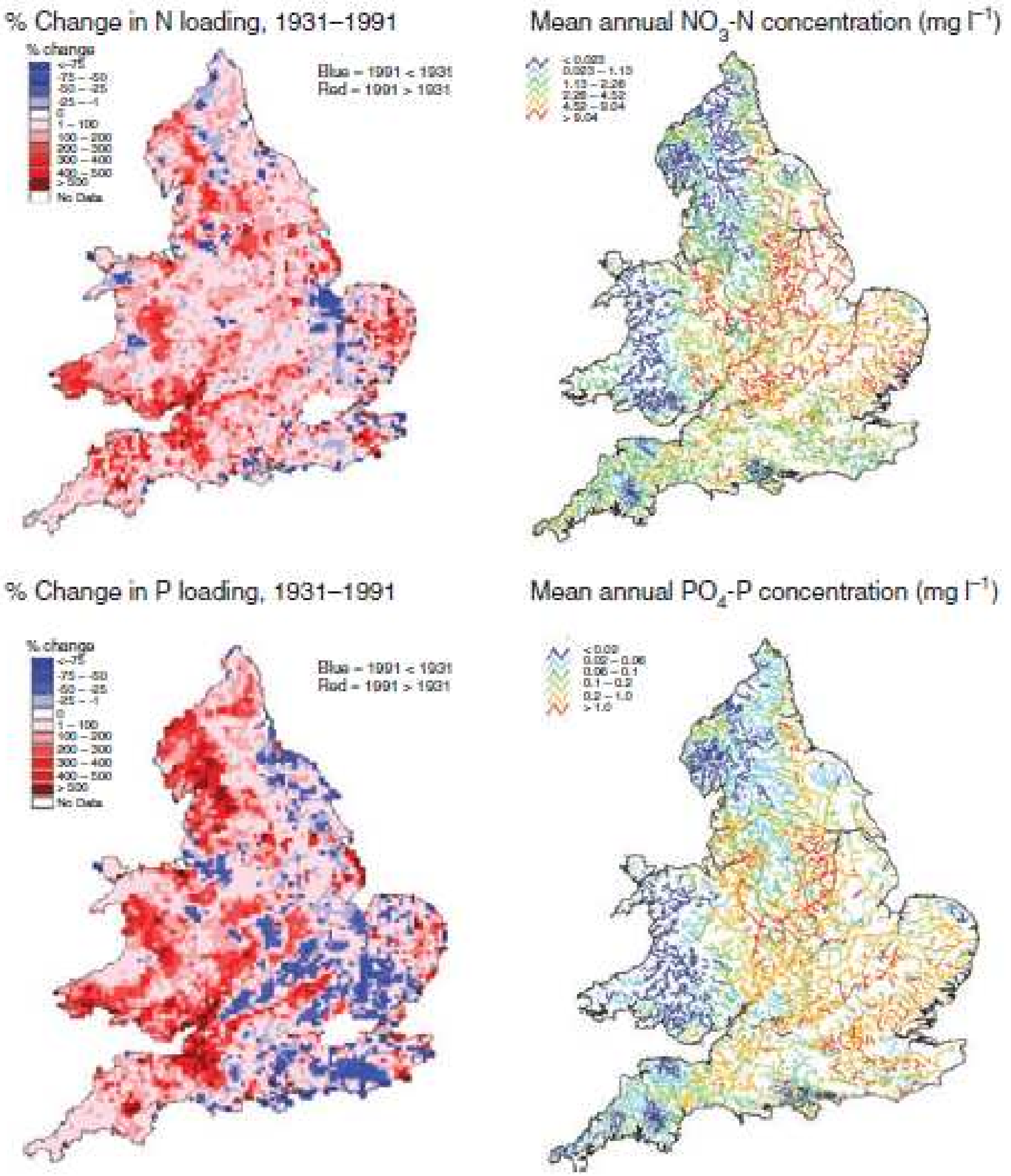
1. A reduction in livestock product supply balanced by plant commodities.
2. A shift in consumption from red to white meat and
3. A 50% reduction in white meat balanced by increases in plant commodities.

Undertaking an economic assessment of the above scenarios is difficult, as they involve large voluntary reductions in production and consumption of meat and meat products, which is unprecedented in recent history. The lack of historical data excludes the possibility of econometric modelling, which depends on past data to extrapolate trends into the future. Furthermore, economic analysis is best suited to situations where there is a small marginal change in the price of a good, or the quantity of good supplied or consumed over a specific period of time. Consequently, this analysis is qualitative, exploratory and speculative, rather than a detailed economic forecast. Without detailed statistics relating how changes in UK livestock production and consumption would affect international prices, it is difficult to project the particular impacts of each scenario. Instead this economic assessment will consider the impacts of a general reduction in the quantity of meat production and a switch from red to white meat.

[96] The Government's Strategic Review of diffuse water pollution from agriculture in England. Paper 1: Agriculture and water: a diffuse pollution review

[97] Johnes, P.., Foy, R., Butterfield, D. and Haygarth, P.M. 2007. Land use scenarios for England and Wales: evaluation of management options to support 'good ecological status' . Soil use and management 23: 176-194.

Figure 16. Percentage change in nutrient export from diffuse sources 1931–1991, compared with mean annual river nitrate and phosphate concentrations, 2000 (Environment Agency data, General Quality Assessment)[98]



[98] Johnes, P.., Foy, R., Butterfield, D. and Haygarth, P.M. 2007. Land use scenarios for England and Wales: evaluation of management options to support 'good ecological status' . Soil use and management 23: 176-194.

A significant reduction in livestock production would have a large economic impact on UK agricultural output. Livestock production currently accounts for about 50% of the value of output of UK farms, occupying just over 60% of the total agricultural area, excluding rough grazing. In addition, in the 2008/09 season approximately 10 million tonnes (about 47%) of total cereals (Table 43), was fed to domestic livestock, adding to the economic importance of livestock production (HGCA, 2009[99]; Defra 2010[100]).

In 2007 meat production contributed about £4.4 billion or 28% of the total UK agricultural output and other livestock products (primarily milk and eggs) contributed a further £3.2 billion (21% of agricultural output). However, the livestock sector also receives tax payer support. In 2009, £3.6 billion of subsidies was paid to UK farmers, including livestock enterprises, mainly in the form of income support, agri-environment and diversification payments. The European livestock sector also derives a degree of price protection because of some import levies on livestock products entering the EU (Shuai and Cheng, 2007)[101]

Table 43 UK Domestic consumption of major cereals in the 2008/09 season (000 tonnes)

	(a) Human and industrial consumption (H&I)	H&I of which home grown	(b) Usage as animal feed (AF)	AF of which home grown	(c) Seed	(d) Other	Total domestic consumption(sum of columns a, b, c and d)
Wheat	6,836	5,627	6,729	6,645	322	86	13,973
Barley	1,769	n/a	3,070	n/a	160	31	5,030
Oats	419	399	238	238	19	4	680
Column total	9,024		10,037		501	121	19,683

Source: HGCA, 2009[99]

In common with other developed countries, the proportion of economic output attributable to agriculture has declined over time, because as people become wealthier, the proportion of their income spent on agricultural products declines. However, the livestock sector supplies the UK agri-food sector, which includes food processing, marketing and retail activities. This extended sector contributed 6.5 per cent of total UK GDP and employed 13.7 per cent of the UK workforce in 2009 and has become increasingly important for UK and EU trade. The EU is a net importer of raw agricultural commodities but a net exporter of processed food and drink. Analysing the impacts of a reduction in meat and meat product output on the agri-food sector goes beyond the scope of this current project, but is likely to be more significant in terms of economic output than the loss of output from the livestock sector.

The economic importance of the livestock sector varies between regions in the UK, mainly associated with variations in climate, soils and topography. Grassland production is concentrated primarily in the northern and western parts of the UK, with typically large areas of upland being used for grazing livestock. For instance, in 2009, permanent grassland constituted 21% of Scottish agricultural land, with rough grazing constituting a further 60%. In Wales 61% of land in 2008 was permanent grassland, while a further 24% was rough grazing. This contrasts with England, where in 2008 approximately 50% of agricultural land was classified as grassland (including rough grazing). Therefore, the economic impacts of changes in livestock production are likely to be more significant in the north and west of the UK, with the south and east being relatively unaffected.

To some extent livestock production is already on a downward trend as EU agriculture becomes more exposed to world markets. Agriculture in the UK is heavily influenced by the EU Common Agricultural Policy (CAP), in particular by the scale and structure of subsidies. In 2005 the EU took steps to decouple support for farm incomes from direct subsidies for agricultural production. Under the current CAP regime, farmers

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[99] HGCA (2009). Supply and demand.
http://www.hgca.com/content.template/16/0/Markets/Markets/Markets%20Home%20Page.mspx Accessed 27/5/2010.

[100] Defra (2010a). Agriculture in the UK 2009.
http://www.defra.gov.uk/evidence/statistics/foodfarm/general/auk/latest/excel/index.htm Accessed 27/5/2010.

[101] Shuai, C. and Cheng, G. (2007). World agri-trade policy readjustment since the Uruguay round and the policy implications. *Outlook on Agriculture*, 36, 87-92.

receive single annual payments, known as the Single Farm Payment (SFP), which are paid on the basis of historical entitlements. In return, farmers are required to maintain their land in 'good agricultural and environmental condition'; thus famers receive income support that is independent to actual production. Agricultural commodity prices in the UK are now largely determined by world market conditions, although in some cases, including for some livestock products, some import restrictions still provide a degree of protection. The removal of production subsidies has made farmers more responsive to market conditions, which in some sectors has caused a decline in production. UK Government statements are supportive of market oriented agriculture, with subsidies now mainly linked to environmental management, rather than food production. Therefore, the UK agricultural sector is likely to be increasingly influenced by market prices.

Table 44 shows that the number of livestock reared in the UK has generally declined, in particular, between 1983 and 2008, the number cattle and calves fell by 24%; pigs by 42%, total sheep and lambs by 5%; and total poultry by 2%. Despite these declines, the beef herd increased by 23%, outweighed by the fall in the dairy herd and although total poultry numbers have decreased over the period, the number of table fowls increased by 87%. Furthermore, some of the declines in numbers have been partially offset by increases in productivity. For instance, per cow yield of milk has increased by about 60% since 1973; egg yields per bird have also increased and there have been substantial increases in the carcass weight of cattle, pigs, and poultry. Only for sheep does there appear to be no upward trend in productivity. The removal of direct subsidies for beef and sheep production and the switch to the (SFP) has accelerated the decline in numbers and has led, as expected, to a sector of largely extensive upland and hill farming and more intensive lowland systems.

Table 44 Livestock numbers in the UK ('000 head)

	1983	1985	1990	1995	2000	2005	2008	Change over period
Total cattle and calves	13290	13028	12192	11856	11134	10413	10107	-24%
Dairy herd	3333	3150	2848	2603	2336	2065	1909	-43%
Beef herd	1358	1359	1632	1840	1842	1768	1670	23%
Total pigs	8174	7967	7548	7627	6482	4864	4714	-42%
Sows in pig and for breeding	746	729	671	655	5378	403	365	-51%
Gilts in pig	110	113	110	101	73	67	55	-50%
Total sheep and lambs	34985	35824	44469	43303	42264	35 517	33131	-5%
Total breeding flock					20449	16990	15161	-26%
Lambs under 1 year old	17181.	17676	22380	21350	20857	17532	16574	-4%
Total poultry					169773	173928	166199	-2%
Total fowls	117854	120071	125357	125981	154504	160528	154180	31%
Growing pullets	11828	12578	10530	10098	9461	10929	9313	-21%
Total laying flock	41127	39670	33624	31692	28687	29550	25940	-37%
Total breeding flock	6012	6177	7258	7570	10667	8562	9068	51%
Table fowls	58887	61645	73944	76621	105689	111487	109859	87%
Turkeys, ducks, geese, other poultry					15,269	13,400	12019	-21%

Source: Defra, Agriculture in the UK (2008a)102

The future implications of a market orientated UK agricultural sector was analysed by Morris et al. (2005)[103]. They projected land use in England and Wales in 2050 under different economic scenarios. Table 45 shows their forecasts for livestock numbers in a business as usual scenario (BAU) and a scenario that modelled UK agriculture under a liberal market system (world market scenario). Overall they predict that under the BAU and WM scenarios, there will be an overall reduction in numbers of dairy cows, but an increase in beef and

[102] Defra (2008a). Agriculture in the United Kingdom 2008. https://statistics.defra.gov.uk/esg/publications/auk/2008/default.asp Accessed, 17/06/2009.

[103] Morris, J., Audsley, E., Wright, I.A., McLeod, J., Pearn, K., Angus, A., Rickard, S. (2005). *Agricultural Futures and Implications for the Environment.* Defra Research Project IS0209. Cranfield University, Bedford.

sheep numbers. Furthermore, in both scenarios there is a movement of livestock production from northern and western regions, to more fertile lowland areas, such the Eastern region, suggesting that in the absence of EU subsidies the production of livestock in some regions is unprofitable.

Table 45 Number of animals in business as usual (BAU) and world market (WM) scenarios in 2050 by region (per cent of current)

	Current ('000 head)	BAU (%)	WM (%)
Dairy			
North East	21	0	0
North West	304	75	70
Yorks & Humber	110	85	2
East Midlands	105	138	24
West Midlands	205	50	45
Eastern	31	147	70
South East	103	118	87
South West	495	111	80
Wales	272	77	74
Total	**1645**	**91**	**63**
Beef			
North East	303	110	0
North West	555	118	115
Yorks & Humber	429	125	6
East Midlands	361	146	42
West Midlands	527	156	76
Eastern	196	210	195
South East	389	120	177
South West	1100	111	154
Wales	861	109	111
Total	**4720**	**125**	**104**
Sheep			
North East	21	147	16
North West	304	86	111
Yorks & Humber	110	153	17
East Midlands	105	115	51
West Midlands	205	152	94
Eastern	31	385	691
South East	103	114	331
South West	495	79	191
Wales	272	88	110
Total	**1645**	**110**	**126**

Source: Morris et al. (2005)104

From this analysis, it appears there is no likely downward trend in livestock numbers in the UK. However, there will potentially be a withdrawal of livestock production from some northern regions, reallocating to lowland regions.

Facilitators of reductions in livestock production

There are several agricultural trends that could support the replacement of meat with plant based commodities. The strengthening of crop prices, especially for cereals and oilseeds and the curtailment of the

[104] Morris, J., Audsley, E., Wright, I.A., McLeod, J., Pearn, K., Angus, A., Rickard, S. (2005). *Agricultural Futures and Implications for the Environment.* Defra Research Project IS0209. Cranfield University, Bedford.

set-aside programme that took cereal land temporarily out of production, have led to an increase in the arable area. By comparison, sugar beet plantings have declined in response to falling sugar support prices, while relatively low livestock prices and high feed prices have reduced the profitability of grassland farming.

An important assumption in this analysis is that livestock farmers will be able to switch to viable production alternatives as demand for meat and meat products declines in the scenarios. This is likely to make the production of bioenergy crops an important market for farmers switching to cropping activities. The EU and the US have targets for a minimum proportion of conventional road transport fuel to be met by renewable sources (Koh and Ghazoul, 2008)[105]. Upham et al. (2009)[106] estimated that to supply 10 per cent of UK road fuel supply from biofuel would require 600,000ha of current agricultural land and an additional 840,000 ha of land which is now unused, growing oilseed rape. To meet these targets from a sugar beet feedstock would require 10 per cent of UK arable land and from straw would require 45 per cent of UK arable land.

It is likely that attention will switch from growing conventional biofuel crops, such as wheat and oilseed, to second generation biomass crops such as miscanthus and willow, much of which can be grown on poorer wetter land, found in traditional grassland areas (Sherrington et al., 2008).[107] These requirements both in the EU and UK present clear market opportunities for UK farmers. Fisher et al. (2010)[110] estimated that by 2030, 44-53 million ha of EU land could be used for growing biofuel crops, this compares with the current arable land area of approximately 82 million ha. In addition, this form of land management is associated with carbon sequestration in soil.

As a result of increasing biofuel and food demand the international price of all the UK's major agricultural products is predicted to remain about 25-30% higher by 2017 in relation to 2003-2006 levels (see Figure 17 (FAO and OECD (2008)).[108] Therefore, it is reasonable to predict a future where there is strong demand for plant based commodities, supporting development of cropping activities in the UK.

[105] Koh, L. and Ghazoul, J. (2008). Biofuels, biodiversity, and people: understanding the conflicts and finding opportunities. *Biological Conservation*, 141, 2450-2460.

[106] Upham, P., Thornley. P., Tomei, J. and Boucher, P. (2009). Substitutable biodiesel feedstocks for the UK: a review of sustainability issues with reference to the UK RTFO. *Journal of Cleaner Production*, 17, S37-S45

[107] Sherrington, C., Bartley, J. and Moran, D. (2008). Farm-level constraints on the domestic supply of perennial crops in the UK. *Energy Policy*, 36, 2504-2512.

[108] FAO, OECD (2008). Agricultural Outlook 2008-2017. http://www.fao.org/es/ESC/common/ecg/550/en/AgOut2017E.pdf Accessed 17/06/2009

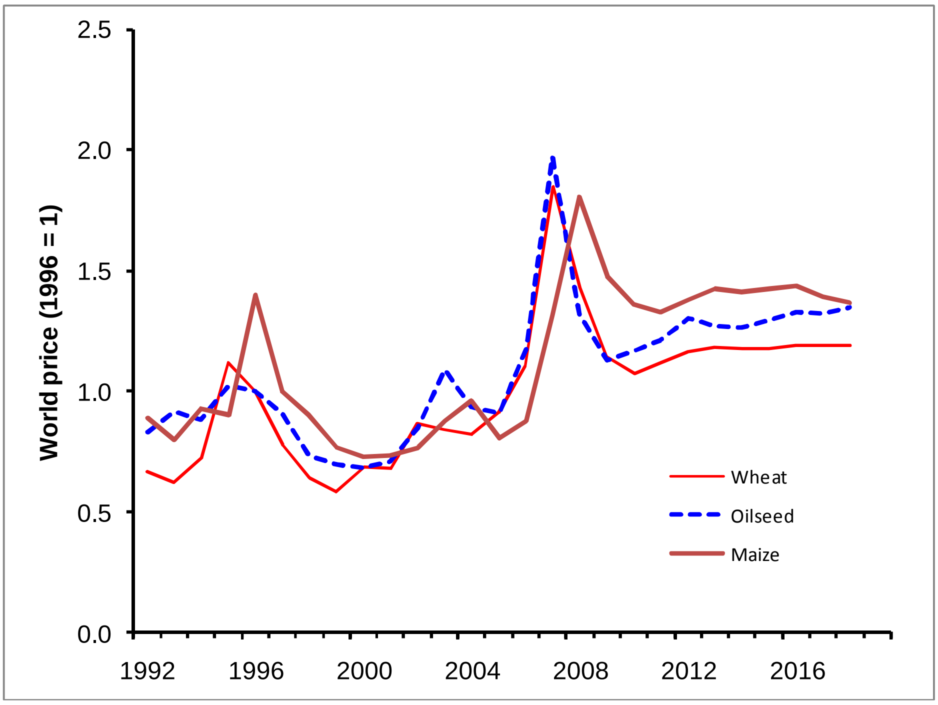

Figure 17 World price (per US tonne), oilseed, and butter as recorded from 1992 to 2008 by OECD-FAO, and for 2009 to 2018 as predicted by OECD-FAO in January 2009 (OECD, 2009)[109]

The global demand for meat and meat products has been predicted to increase in the coming decades (this is discussed further in the next section). A growing global demand for meat has implications for the grain and protein feed markets. Trostle (2008)[116] suggests that producing 1 kg of chicken, pork and beef requires to 2.6, 6.5 and 7.0 kg of maize feed respectively. Thus the increase in demand for meat will have far-reaching consequences for the demand for cereals and coarse grains for animal feeds. Strong international prices for commodities could maintain a high demand for crop commodities in the UK.

There have also been large fluctuations in the type of meat bought because of health concerns, such as BSE, but in general meat consumption has remained relatively steady in the UK. The major change has been the increase in poultry consumption (Figure 18) which has surpassed consumption of other meats in the UK since 2000 (Foster and Lunn, 2007).[110] Recent concerns about the growing incidence of obesity have prompted calls for healthier eating, with implications for the balance of livestock, fruit and vegetables products in the national diet (Foresight, 2007).[111]

[109] OECD (2009). OECD-FAO Agricultural Outlook 2009-2018. OECD Publishing. France

[110] Fisher, G., Prieler, S., Velthuizen, H., Berndes, G., Faaij, A., Londo, M. and de Wit, M. (2010). Biofuel production potentials in Europe: sustainable use of cultivated land and pastures: Part II: land use scenarios. *Biomass and Bioenergy*, 34, 173-187.

[111] Foresight (2007). Tackling obesities: future choices.

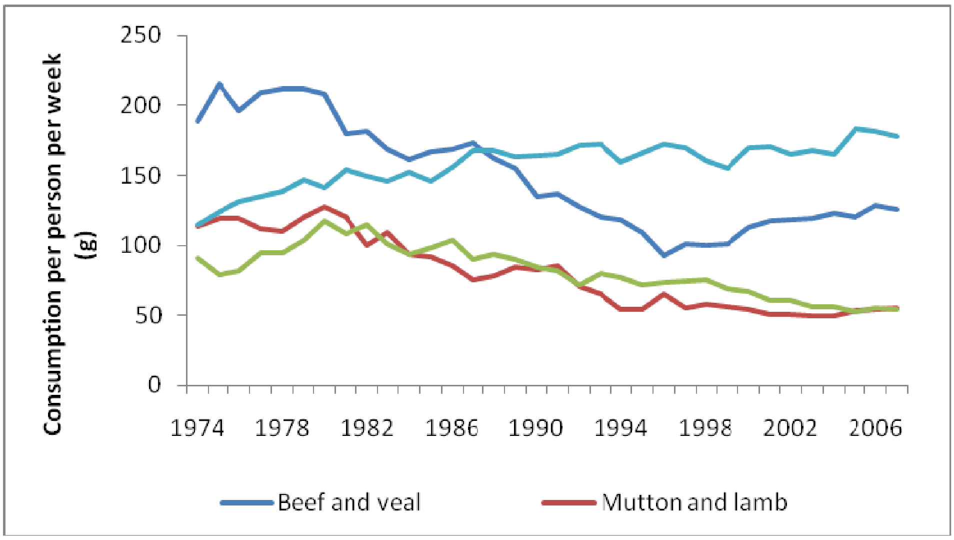

Figure 18 UK household consumption of different meats (grams per person per week) (Source: Defra, 2008b)[112]

Barriers to the change to reductions in livestock production

In general farmers are responsive to upward movement of prices and changes in relative commodity prices. However, they are far less reactive to price falls, as in the short term, agricultural land and other agricultural assets, including famer skills, have limited alternative uses. This results in supply-side inertia whereby farmers continue to operate unprofitable businesses because economic adjustment is painful and resource specificities prevent movement to non-agricultural uses (Angus et al., 2009).[113] Therefore, any adjustment to new farming activities would likely to be slow and gradual.

Further, any adjustments would be limited by the quality of the soil, climate and other environmental factors. Following the logic of Table 45, the most valuable activities will take place on the best land. For instance, horticulture, including the production of high-value vegetable and salad crops, is mainly concentrated in areas of peat or light mineral soils. These areas are mainly in East Anglia, the West Midlands, South West Lancashire, and South Yorkshire. Therefore, the ability for farms in the north and west of the UK to convert from grassland to high value horticultural activities is very limited. Instead, the available activities would be more likely to arise from bioenergy cropping, or diversified activities, such as bed and breakfast provision.

There are several global socio-economic trends that present potential barriers to the attainment of a low meat economy. At the global scale, demand for food is closely linked to increases in the economic prosperity of populations. Between 2004 and 2006, 22 of the world's 34 most food-insecure countries experienced gross domestic product increases of 5-16 per cent (IFPRI, 2007)[114], with a resulting shift from basic staples such as cereals to more varied, protein-rich diets, especially vegetables, fruits, meat, dairy and fish. Between 1964-1966 and 1997-1999, consumption of meat per capita in developing countries increased by 150%, and milk and dairy products by 60% (FAO 2005).[115] Milk and dairy consumption is expected to rise

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[112] Defra (2008b). Food statistics pocketbook 2008. https://statistics.defra.gov.uk/esg/publications/pocketstats/foodpocketstats/default.asp Accessed 18/06/2009.

[113] Angus, A., Burgess, P., Morris, J. and Lingard, J. (2009). Agriculture and land use: demand for and supply of agricultural commodities, characteristics of the farming and food industries, and implications for land use in the UK. *Land Use Policy*, 26, S230-S242.

[114] IFPRI (2007). The world food situation: new driving forces and required action. International Food Policy Research Institute, http://www.ifpri.org/pubs/fpr/pr18.asp Accessed 27/07/2009.

[115] FAO 2005. The implications of supermarket development for horticultural farmers and traditional marketing systems in Asia

by 1% per year through to 2019 (Trostle, 2008).[116] By 2030, it is forecast that per capita consumption of livestock products could rise by a further 44 per cent from current levels (WHO, 2003).[117]

In the UK, demand for food has particular characteristics that mean a reduction in meat consumption of the order required in the scenarios seems unlikely. Demand for food is relatively constant and does not change readily with changes in prices or income, relative to other products. For instance, the latest estimates of UK elasticities of demand for food by Lechene (1999)[118] suggest that a 1% increase in average income will increase total food demand by 0.2 per cent. But any increase in demand for food as income changes will not be uniform across all categories of foods and all income levels (Defra, 2008b).[119] Low-income households tend to buy more bread and cereals, milk, cheese and eggs, sugar and confectionery but less meat, vegetables, fruit and other foods than more affluent families. Similarly, fresh red meat sales have fallen by 40 per cent over the past 30 years, but have remained steady over the past decade. This reflects the impact of changing food tastes and lifestyles. Thus, as UK incomes rise, all things being equal, these trends should continue, with increasing consumption of fresh meat and vegetables.

Although income elasticity is low for raw, unprocessed food, it is much higher for total food expenditure including the convenience and recreational components provided by the food processing and catering sectors. Farmers can offset the disadvantages of the market place for raw, farm-gate food by adding value by moving up the supply chain, by undertaking processing or direct sales themselves, or by focusing on niche, quality produce rather than bulk produce. Renewed 'connectedness' between people and food has increased interest in local foods, encouraging farmers' markets, would provide new opportunities for high value agricultural produce.

10. Implications of consumption change for fisheries and related impacts

The scenarios examined here did not consider changes in the consumption of fish e.g. fish consumption was held constant in developing the scenarios. However, the potential of fish to replace meat and the consequences need consideration.

Fish and seafood account for just over 1% of food energy and fat supplies, and 5% of protein supplies at the commodity level in the UK. This level of fish consumption is modest by European and US standards, but is about 50% higher than the global average (excluding China). The UK Food Standards Agency advises Britons to increase consumption to an average of two 140g portions of fish per week. Current consumption is 165g per week. This means that fish consumption needs to increase by 70% to mean these guidelines. The consumption of oily fish needs to more than double. Current consumption equates to 21kg per person per year so alignment with current dietary guidelines would increase the demand for fish and seafood to 36 kg per person per year.

Murphy-Bokern[120] provides an assessment of the link between UK fish consumption and environmental impacts and impacts on resources, especially in the North-east Atlantic. UK consumers' preferences are conditioned by a plentiful supply in the past of piscivorous fish and herring from the North-east Atlantic. This is manifest in the resilient demand for demersal white fish, salmon and tuna today (about 64% of consumption). In ecological terms, UK consumers' preference for top-predator fish has implications for the impact of consumption on marine ecosystems. Moreover, the demand for demersal fish is met largely by bottom trawling in the North-east Atlantic, and the 'top-predator' consumption includes 100,000 tonnes of tuna. The decline of these fish species at the top of the marine ecosystem food chain caused by over-fishing often causes a deceptive increase in other fish due to the lack of prey. This boost to other species signals a

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[116] Trostle, R. 2008. Global agricultural supply and demand: factors contributing to the recent increase in food commodity prices. USDA economic research service. http://www.ers.usda.gov/Publications/WRS0801/ Accessed 27/05/2010.

[117] WHO (2003). Diet, nutrition and the prevention of chronic diseases. WHO technical report series 916. Report of a joint WHO/FAO expert consultation. http://www.fao.org/docrep/005/AC911E/ac911e00.htm#Contents Accessed 27/05/2010

[118] Lechene, V. (1999). National Food Survey, Section 6. pp. 89–108. Institute of Fiscal Studies Working Papers. London.

[119] Defra (2008b). *Food statistics pocketbook 2008*. https://statistics.defra.gov.uk/esg/publications/pocketstats/foodpocketstats/default.asp Accessed 18/06/2009.

[120] Murphy-Bokern, D. 2010. Environmental impacts of the UK food economy with particular reference to WWF Priority Places and the North-east Atlantic. WWF UK and the FCRN.

collapse in the fishery ecosystem.[121] Arising from efforts to supply European markets, the North-east Atlantic is over-exploited with respect to most popular food species. In addition, species that are currently relatively plentiful have suffered crashes and local extinctions in the past. Reflecting this, UK seafood production is declining and imports are increasing. This pattern is reflected across the EU with EU fish production declining and imports from third countries increasing. The raises the question of the knock-on effects of UK and EU consumption for world fisheries.

Watson and Pauly[122] drew attention to uncertainties in FAO production data and they concluded that world catch fishery production has declined since the 1980s at a rate of about 360,000 tonnes per year due to stock depletion. If present fishing pressures continue, many of the world's commercial fisheries will be wiped out within two to three decades. Already about 75% of fisheries are fished either at or above capacity or are in some other way over-exploited. This mean that there is little scope for expanding catch fishery output and that conservation of stock and a reduction in fishing pressure is part of a strategy to increase fishery output in the longer term.

In addition to the depletion of stock, the energy requirements of fishing need consideration. In contrast to most forms of agricultural production, fishing is an energy intensive activity and CO_2 is the main GHG emission arising. On average, fishing consumes 620 l of diesel per tonne of marine fish caught[123]. This equates to about 1.8 tonnes of CO_2 per tonne of fish caught. This fuel use amounts to 1.2% of mineral oil use in the world. Despite the high energy inputs, the resulting greenhouse gas emissions are low compared with meats from agriculture.

The current advice to eat more fish arises from benefits associated with what fish bring to the diet (beneficial fatty acids) with benefits arising from what fish displace in typical diets (saturated fat). The latter in particular seems to be the driver behind the including white fish in the recommendation to eat 280g of fish per week. White fish fisheries in particular are in a depleted state so these recommendations are coming under scrutiny from a sustainable development viewpoint.

Mirroring a global trend, the demand for fish in the UK is increasingly being met by aquaculture, particularly salmon production reflecting the UK consumers' preference for species native to the North Atlantic. This supply is dominated by salmon from Scotland, Ireland and Norway. Salmon have the added advantage of being oily fish but this characteristic has profound implications for the effect of aquaculture on wild fisheries through the need to use large quantities of wild fish in salmon diets. The Scottish salmon farming sector produces about 127,000 tonnes of salmon per year[124] representing about 10% of the total quantity of fish supply. The production of one kg salmon requires about 5 kg of industrial fish for the production of the fishmeal and fish oil used. [125] As a result, about 45% of the commodity fish consumed by the UK food economy is used for aquaculture. This includes industrial fishing in European waters, e.g. for sand eel as well as fisheries world-wide, e.g. the Peruvian anchovy fishery. The eco-system impact of this industrial fishing is poorly understood. Particularly for sand eel which is food for a wide range of marine animals including fish for wild fisheries such as cod, it remains unclear if current industrial fishing is having significant ecosystem effects.[126] However, there is consensus that blue whiting stocks are already over-exploited. From ecological principles it is reasonable to assume that reduced take of industrial fish would benefit the other fisheries. This is particularly relevant given the large quantities of by-catch in most forms of industrial fishing. In addition to the caught fish used in aquaculture, the non-fish component of the salmon diet is dominated by high quality arable crop products such as soy and cereals.

The feed conversion efficiency of UK salmon production is 1.2 – 1.5:1. About half the content of salmon food is of vegetable origin so it every kg of farmed salmon requires 0.6 – 0.8kg of high quality plant based food as well as about 5kg of caught fish. World-wide, only about a quarter of fish used for feeding fish is derived from by-products of fish processing.

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[121] Pauly, D., V. Christensen, J. Dalgaard, R. Froese and F.C. Torres Jr. 1998. **Fishing down marine food webs**. Science 279: 860-863.

[122] Watson, R. and D. Pauly. 2001. Systematic distortions in world fisheries catch trends. **Nature** 414: 534-536.

[123] Tyedmers, P.H., Watson, R and Pauly, D. 2005. Fuelling global fishing fleets. Ambio 34(8): 635-838.

[124] http://www.scotland.gov.uk/Topics/marine/Fish-Shellfish

[125] Tacon, A.G.T and Metian, M. 2008. Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects.. Aquaculture 285: 146-158.

[126] Huntington, T.C. 2004. Feeding the fish: Report to the Joint Marine Programme Scottish Wildlife Trust, WWF Scotland, RSPB Scotland.

Aquaculture has impacts other than those due to the fish food production.[127] Stocks of farmed fish affect wild stocks of the same and related species through biological pollution. There are about 50 farmed salmon for every wild salmon returning to British rivers.[128] Escaped fish pose a risk to wild fish stocks through hybridisation adding to pressures causing the decline of wild stocks. There are also disease risks. The effluent water is laden with nutrients and uneaten food leading to local enrichment, although on a life-cycle basis these emissions are significantly lower in total than emissions from poultry production.[129] Closed recirculating systems can be used even for marine fish.[130] This is a high cost approach to fish production, but is now being commercialised in way analogous to the development of intensive pig and poultry production, for example by the Big Dutchman Group which is a world leader in providing pig and poultry production facilities.[131]

Farmed fish currently used in the UK has significant resource impacts, particularly arising from the dependence on caught fish in the diet of salmon. Despite the constraints, it is acknowledged that all forms of aquaculture are a very efficient way of producing livestock products. Bellona, a NGO based in Norway, sets this out clearly.[132] Compared with other feed concentrate-based livestock production, even salmon farming is extremely efficient in terms of the utilisation of energy and protein in the feed. Salmon production results in the emission of 2.3 kg CO_2e per kilogram salmon carcase[133] compared with 4.6 for poultry and 16 for beef.[134]

Murphy-Bokern outlines approaches to conserving resources by moving from piscivorous farmed fish consumption to more sustainable fish lower down the food chain.[135] This can be achieved in a number of ways. Consumption could switch from farmed piscivorous fish to direct consumption of the industrial fish fed that are now fed to salmon. The Norwegian fishing industry is already looking at harvesting blue whiting for direct human consumption thereby gaining a premium over blue whiting for fishmeal production. Such a shift could displace the consumption of farm piscivorous fish such as salmon and increase the overall yield of sea fish for human consumption.

Other piscivorous species are being developed as an alternative to salmon, such as the European wels catfish. However, the clearest form of 'eating lower down the food chain' would be a switch to omnivorous farmed fish such as carp and tilapia. Tilapia is an herbivorous freshwater fish produced in warmer climates. Inclusion of fishmeal in tilapia diets is less than 1% and the fish has gained a significant market share in some countries, notably the USA.

Another approach is to make current farmed species such as salmon more herbivorous reducing the inclusion of fishmeal and increasing the proportion of cereals, soy and oilseed meal etc in the diet. There are currently constraints to this because of the role of marine algae in delivering essential omega 3 fatty acids to the marine food chains through the pelagic fish in fishmeal. Salmon need these fatty acids. Moreover, a significant part of the value of farmed salmon in the human diet arises from the link with marine algae that the pelagic fishmeal provides. Recent research is seeking to transfer the genes in marine algae

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127 Naylor, R.L., Goldburg, R.J., Primavera, J.h., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Ludchenco, J., Mooney, H and Troell, M. 2000. Effect of aquaculture on world fish supplies. Nature 405: 1017-1024.

128 Walker, A. M., Beveridge, M. C. M., Crozier, W., O ´ Maoile´idigh, N., and Milner, N. 2006. Monitoring the incidence of escaped farmed Atlantic salmon, Salmo salar L., in rivers and fisheries of the United Kingdom and Ireland: current progress and recommendations for future programmes. e ICES Journal of Marine Science, 63: 1201-1210.

129 Grönroos, J. Seppälla, J., Silvenius, F and Mäkinen, T. 2006. Life cycle assessment of Finnish cultivated rainbow trout. Boreal Environmental Research 11:401-414.

130 Blancheton, J.P. 2000. Developments in recirculation systems for Mediterranean fish species. Aquaculture Engineering 22:17-31.

131 http://www.bd-fish.de/

132 http://www.bellona.org/aquaculture/artikler/Feed_accounts

133 Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope for reduction by 2050. How low can we go? WWF UK and the Food Climate Research Network.

134 Williams, A., Audsley, E. and Sandars, D. 2006. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Defra project report IS0205.

135 Murphy-Bokern, D. 2010. Environmental impacts of the UK food economy with particular reference to WWF Priority Places and the North-east Atlantic. WWF UK and the FCRN.

responsible for the omega 3 fatty acids in seafood to oilseed crops such as linseed thereby opening up the opportunity of further reducing the inclusion of fishmeal and fish oil (Personal communication, Jonathan Napier at Rothamsted).

An assessment of potential role of aquaculture in providing an alternative to agricultural livestock must consider a wide range of complex issues. If it is simply a matter of replacing meat with fish in the diet, then aquaculture has the potential to provide fish with lower resource use and emissions compared with meat. This is particularly the case if meat is replaced with herbivorous fish such as carp and tilapia. This will also reduce saturated fat in the diet. However such an approach will not contribute significantly to increasing the consumption of oily marine species that are rich in essential omega 3 fatty acids. Farmed salmon remains the main alternative to wild oily fish.

11. Opportunities

Alternative uses for released land

There exists a variety of possible uses for land released in the scenarios. Current arable land could be used for other arable crops with relatively little difficulty, although local conditions could limit what is grown. These could include annual crops used for biofuels (e.g. wheat) or annual crops that could be grown for export. Arable land could also be converted to grow perennial bioenergy crops, such as miscanthus, or converted to orchards or forestry. It could also be converted to grassland for agriculture or recreation.

The grassland released in our scenarios exists in a range of qualities. Grassland that is tillable could be converted to arable and so support a range of crops, but these may be more limited in scope than much existing arable land. Tillable grassland will generally support annual crops that could be used for food crops or biofuels or perennial energy crops, such as miscanthus or willow. This latter option may be increasingly the preferred option as the quality of tillable grassland decreases. Tillable grass could be converted to conventional woodland and some could be to orchards (depending on the soil and climate).

The potential suitability of land for forestry and the Agricultural Land Class were compared in Scotland by intersecting the digital maps of agricultural and forestry land capability and applying scaling factors to the forest suitability descriptions. The results (Table 46) show that the agricultural land class is highly correlated with the forestry potential. Although these were derived in Scotland, there is no reason to suppose that the general relationship would apply elsewhere in the UK.

Table 46 Comparison of Scottish Agricultural Land Classes with suitability for forestry

Agricultural Land Class	Forestry suitability Score
1	10.0
2	9.9
3.1	8.3
3.2	7.5
4.1	6.7
4.2	5.5
5.1	5.0
5.2	4.2
5.3	3.2
6.1	3.6
6.2	2.1
6.3	1.4
7	0.0

Some “non-tillable” grassland could be converted to forestry (i.e. requiring one-off cultivation and subsequent management), but this would be the minority of land. All grassland could, in theory, continue in animal production for export, depending on market and political forces. The main alternatives, however, would be re-wilding to natural vegetation (including woodland) or more actively managed conversion for recreation or biodiversity.

Any decisions over what land is best suited (beyond the technical capacity) to what purpose will depend on prevailing political and economic drivers.

12. General discussion

Effects of reducing livestock product consumption

This study has clearly shown that UK land can support consumption change that reduces greenhouse gas emissions from the food system. A 50% reduction in livestock product consumption reduces the arable and especially grassland land area in the UK needed to supply the UK with no effect on the need for overseas arable land. These benefits come with other environmental benefits (dominated by near halving of a wide range of emissions from the agricultural phase of food production) and opportunities to deliver other products from UK agricultural land. All consumption change scenarios reduce greenhouse gas emissions and the total economic value of the food produced for UK consumption. This presents significant economic challenges for the farming and food sector. The response of the food industry and the retail and food service sectors has not been explored in this study, but the balance of economic power between agriculture and these players will change. The study shows clearly that consumption change to reduce greenhouse gas emissions would have profound implications for UK agriculture. A major result of this study is to bring into sharp relief the profound implications consumption change could have.

A 50% reduction in livestock product consumption scenario is the most significant in policy terms of the three consumption scenarios studied – it is central to the general purpose of the study. The quantity and quality of land released based on today's pattern of land use will reduce UK arable and potentially tillable land needs by about 2.7 million ha and non-arable grassland needs by 4.6 million ha. Our estimate that the release of UK arable land currently used for animal feed more than off-sets the extra land needed for crops for direct human consumption is an important result. It means this consumption change releases arable as well as grassland resources. This scenario also reduces the need for overseas grassland by 1.3 million ha. In summary, a 50% reduction in livestock product consumption opens up the opportunity to release about half of UK land currently used for agriculture with two-thirds of this release on land not suited to arable production and a further third comprising grassland with some arable potential. So almost all of the land released is land currently used for grass. There would be with higher levels of land release in Scotland, Wales and Northern Ireland than in England. With uniform release, about 40% of the land released is very unproductive in terms of food, but it can be assumed that about 4 million ha of the land released has significant potential for other agricultural uses, for example for the production of livestock for export, restoration of wild vegetation and for forestry.

A 50% reduction in livestock consumption combined with an emphasis on retaining production on high quality land releases all UK land not suited for crop production from agriculture (6.9 million ha) plus 1.7 million ha of tillable land currently used for grassland. Overall, this means the withdrawal of agriculture land not suited to arable crop production. It would mean withdrawal of livestock production for the UK from most of Scotland, Wales and Northern Ireland, and large parts of northern and western England.

The combination of reduced livestock product consumption with production that emphasises the use of lower grade land leaves production on the lowest grade grassland unchanged but releases land from all other categories. Even 0.7 m ha non-arable grassland (15%) is released along with 45% of tillable grassland (3.5 m ha) and 0.3 m ha of arable land. The major effect of this scenario is the release of tillable grassland, e.g. grassland on lowland farms.

Environmental effects of reduced livestock product consumption

Previous work identified the role reductions in livestock product consumption can play in reducing consumption related greenhouse gas emissions.[136] This work, which based it assessments of greenhouse

[136] Audsley, E., Brander, M., Chatterton, J., Murphy-Bokern, D., Webster, C., and Williams, A. (2009). An assessment of greenhouse gas emissions from the UK food system and the scope for reduction by 2050. How low can we go? WWF UK and the Food Climate Research Network.

gas emissions on updates of the same models[137], estimated large reductions in greenhouse gas emissions from reductions in the consumption of livestock products.

These have a direct effect on calculations of consumption related emissions, e.g. personal carbon footprints. However, their translation into effects on the UK greenhouse gas inventory depends on how released land is used for other purposes. Obviously, if the land released for UK consumption is used to supply livestock products for export, the UK greenhouse gas emissions inventory remains unaffected. Such an outcome depends on the competitiveness of UK production, the economic viability of other alternative land uses, land use policies that might intervene in land managers' decisions, and the demand outside the UK for livestock products associated with Britain, for example high quality beef and lamb, or British cheeses.

The same principle applies to other emissions such as ammonia to air and nutrient emissions to water. The reductions in the livestock population supplying UK consumers have a direct effect on ammonia emissions. A direct scaling down of ammonia inventory emissions[138] driven by out 50% reduction scenario reduces total emissions by 54%. It would mean that the UK would meet all existing and foreseeable commitments in this area. The over-proportional reduction in emissions is due to the large proportion of emissions from the beef herd which is reduced by 64%. It is reasonable to speculate that a contraction in the livestock sector would result in additional reductions as the less efficient production from older livestock facilities with relatively high emissions is taken out of production first.

Recent research (Johnes et al.)[139]in the UK indicates that the requirements of the Water Framework Directive with respect to nitrate far exceed those of the Nitrates Directive (which has been a major influence on agriculture), especially in western and northern Britain where shifts from the baseline state of rivers have been particularly large. Key conclusions of that research include the identification of the need to take some sensitive lands out of production, introduce ceilings on fertilizer use and stocking densities, and tight controls on agricultural practice in higher risk areas where intensive and inappropriate agriculture is combined with a low intrinsic nutrient-retention capacity in the landscape[140]. Johnes argues that a major restructuring of UK agriculture is required centred around reductions in livestock production. Re-thinking the role of animal agriculture as part of the wider socio-economic and environmental systems is a first step. In line with our previous work on gaseous emissions[141], Johnes indicates that improving production efficiency and practice will not be sufficient particularly in sensitive and some stock reductions are necessary, particularly in sensitive marginal lands, if degradation of the natural environment is to be halted.

Our analysis of land use statistics reveals the large proportion of land occupied by cattle and beef production. A 2007 report from ADAS for Defra states *'All livestock systems contribute positively to the environment by their addition of nutrients to soils and indeed recycling of manures by well managed land spreading (as opposed to grazing animals) leads to better distribution of nutrients and potentially a lower risk of nutrient leaching'.*[142] This assertion exemplifies the widely held view that livestock, especially grazing livestock, are an environmental good. Moving in the direction of consumption scenario 1 requires reassessment of such positions.

The widespread use of such lower capability land for livestock is a feature of agriculture on the British Isles and the UK is perhaps unusual in how livestock on such land are assumed to deliver environmental goods. ADAS advised Defra that "*Grazing beef cattle and sheep are fundamental to the management of large areas of upland and hill land and contribute significantly to the maintenance and enhancement of biodiversity, provided winter grazing (where practised) is adequately managed*". Behind this is the assumption that biodiversity associated with semi-natural grasslands grazed by farm livestock has a particularly high value.

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[137] Williams, A., Audsley, E. and Sandars, D. 2006. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Defra project report IS0205.

[138] Misselbrook, T., Chadwick, D., Chambers, B.J., Smith, K.A., Williams, J. 2008. Inventory of ammonia emissions from UK agriculture. Defra project AC0112.

[139] Johnes, P.., Foy, R., Butterfield, D. and Haygarth, P.M. 2007. Land use scenarios for England and Wales: evaluation of management options to support 'good ecological status' . Soil use and management 23: 176-194.

[140] Johnes, P.J. 2007. Meeting Ecological Restoration Targets

in European Waters: a Challenge for Animal Agriculture. Chapter 11 in *Redesigning Animal Agriculture* (eds D. Swain, E. Charmley, J. Steel and S. Coffey). CAB International

[141] Defra, 2008. The limits to a sustainable livestock sector in the UK. Defra research project report AC0208.

[142] ADAS 2007: The Environmental Impact of Livestock Production. Report for Defra FFG.

Cattle grazing is important to the optimal management of semi-natural grasslands for biodiversity[143] so a reduction in the suckler herd will have implications for this type of environmental output. However, other forms of land use are claimed to also have biodiversity benefits, for example the production of willow for energy.[144] Our study also shows that the grazing of these lands for biodiversity benefits is not dependent on current high levels of livestock product consumption.

The uplands and hills of Germany and France are typically wooded with forest accounting for 32% and 29% of the land area in these countries respectively compared with 12% in the UK. Woodland is the obvious alternative use for released grassland. Our study has identified very significant benefits for greenhouse gas emissions of both the use of harvested wood and sequestration in soil when grassland is converted to forestry. Valentine et al concluded that willow for energy grown in Wales results a GHG mitigation effect equivalent to 4.6 – 6.5 t C ha^{-1}.

Additional land use effects

Gill *et al*.[145] draw attention to the contribution grasslands make to global food supply through ruminants. Livestock on grassland combined with use of arable crop by-products in livestock feeding contributes to the human food supply. Our results show that focusing a reduced cattle and sheep industry on non-arable land would result in the release substantially more tillable land than if the reduced livestock population is concentrated on higher quality land. In a reduction scenario, maximising the use of lower grade land releases 3.5 million ha of tillable grassland (including 1.3 million ha of good arable land). The opposite approach of withdrawing production from lower grade land releases just 1.4 ha of grassland with arable potential, with almost no release of the grassland well suited for to arable production. The land-use trade-off is therefore clear – 2.1 M ha of tillable grassland is required to compensate for the withdrawal of cattle and sheep production from 6.9 M ha of lower grade, non-arable, land.

This large area of grassland redundant to livestock production, including tillable grassland, opens up the opportunity to extensify production right across agriculture. Such an approach is compliant with improving environmental outcomes from grassland and widespread adoption of less intensive production techniques across all agriculture, including organic production. The environmental effects of extensification will vary depending on the nature of the practices and location. However, it is reasonable to expect that a combination of various degrees of extensification combined with re-wilding of particularly sensitive habitats would bring significant benefits to the rural environment generally, and to air and water quality in particular. Defra research has shown that stocking rates that are optimal for biodiversity in grazed semi-natural grassland are about half those optimised for production.[146] Such habitats are very sensitive to interventions to raise productivity, particularly nutrients.[147] We therefore conclude that a reduction in livestock product consumption is compatible with the optimisation of biodiversity benefits of extensively grazed semi-natural grasslands. This view is reinforced by the observation that livestock production on these lands, despite the very large area involved, is not dependent on current consumption levels. A greatly reduced market for livestock products is still large enough to farm un-tillable grassland.

Resource conservation in production

Our original plan for this study also included a production scenario based around conservation of resources, improved nutrient cycling in 'mixed' farming and the adoption of lower intensity production techniques to reduce production emissions. Our earlier work indicates that reducing the intensity of production has

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[143] Defra 2007. Determining environmentally sustainable and economically viable grazing systems for the restoration and maintenance of heather moorland in England and Wales. Research project report BD1228.

[144] Valentine J, Duller C J, Hinton-Jones M, Tubby I, Fry D A, Slater F M, Sherborne A, Jones E, Heaton R, Farrell J, Horne B, Green C G, Powell H, 2009. The development of sustainable heat and power fuelled by biomass from short rotation coppice in Wales. Aberystwyth University Report of the Helyg i Gymru / Willow for Wales 2004-2008 project. 92pp

[145] Gill, M., Smith, P. and Wilkinson, J.M. (2009). Mitigating climate change: the role of domestic livestock. Animal 1-11.

[146] IGER, 2005. Ecologically sustainable grazing management of lowland unimproved neutral grassland and its effect on livestock performance. Defra research project report BD1440

[147] Kirkham, F.W. 2006. The potential effects of nutrient enrichment in semi-natural lowland grasslands through mixed habitat grazing or supplementary feeding. Scottish Natural Heritage Commissioned Report No. 192

relatively little effect on emissions per unit output in general[148], although we have concluded in a Defra study that there is some scope for savings through improved use of co-products etc, for example the increased use of dairy calves in beef production.[149] That Defra study examined the scope for reducing greenhouse gas and ammonia emissions from livestock production and concluded that the scope for reductions of greenhouse gas emission through better use of animal manures is limited. Overall, it showed that reconfiguration of the sectors to optimize the existing production systems with the gaseous emissions (both GHGs and NH_3) reduced by 20% would only enable production at between 80.7% (poultrymeat) and 86.4% (pigs and sheep) of current amounts. Johnes also concludes that improvements to production have limited scope to address emissions to water.[150]

Our consideration of a resource conserving or extensification production option was complicated by interactions between the consumption and production scenarios. For example, our previous work[149] identified that the integration of beef and dairy production through the increased use of dairy calves for beef production has potential to reduce emissions where the balance between beef and dairy production is as it is today. However, in our 50% reduction in consumption scenario, beef consumption drops by 64% and dairy consumption by only 40%. This results in the dairy sector playing a greater role in the beef supplied with consequences for carcase conformation quality. .

Another consideration is the reality that these resource efficiency measures, including the use of culled dairy cows and male calves for beef, are already part of production. Similarly, pre-consumer food 'waste' is already recycled in the livestock sector (through both cattle and pigs) and crop by-products are a major feed ingredient. Returning to swill feeding requires a change in the law and it seems more likely that food waste will increasingly be treated by anaerobic digestion. Anaerobic digestion of food waste reduces net GHG emissions, but does not directly affect land use. However, we do acknowledge that the reduction in production intensity opens up opportunities to more easily adopt emission reduction approaches in specific situations. We estimate that the increased use of rapeseed meal in animal feeds could reduce total food production emissions by about 1% and save about 120,000 ha of land (overseas). The reduction in demand for grassland output opens up the opportunity to reduce the intensity of grassland production with the adoption of grass/clover based systems. These have the potential to almost eliminate the need for synthetic fertiliser nitrogen on grassland with significant reductions in CO_2 and N_2O emissions while maintaining animal performance. We have estimated that the adoption of grass clover grassland under the 50% reduction scenario can reduce emissions by 1.7 million t CO_2e but requires an additional 0.3 million ha.

The consumption and production scenarios have relatively little effect on the land currently used for arable production, but the prospect of large areas of tillable grassland being released open up opportunities in both arable and grassland based farming, including closer integration between them, or the use of more diverse rotation, for example including the production of protein crops such as peas and beans. More complex rotations may reduce fertiliser inputs and the need for pesticides, but the effects on greenhouse gas emissions overall may be positive or negative. The risk of emissions of nitrate to water may increase.

Economic considerations

The reduction in the amount of land needed to supply the UK goes hand-in-hand with a reduction in the value added by agriculture supplying UK consumed food. The value added in the production of major agricultural commodities is about £5.5 billion. Livestock commodities account for 50% of this. A 50% reduction in livestock product consumption (scenario 1) reduces the farm-gate value of livestock products from £7.6 to 3.5 million. Beyond the farm-gate, it is reasonable to assume that livestock products account for at least half of the total value of the £80 billion post-farm agri-food sector. The livestock sector from farm to fork is ca. 3.3% of the economy[151]. A reduction in livestock product consumption will result in increased demand for other foods, but it is reasonable to expect that such changes will result in a net reduction in the total value of the UK food market to UK agriculture. The increased demand for cereals, potatoes, fruit and vegetables for human consumption translates into an increase of ca. £0.6 billion, but this is off-set by the reduction in use of cereals in animal feeds resulting in little change in the value of the output of crops.

[148] Williams, A., Audsley, E. and Sandars, D. 2006. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Defra project report IS0205.

[149] Defra, 2008. The limits to a sustainable livestock sector in the UK. Defra research project report AC0208.

[150] Johnes, P.J. 2007. Meeting Ecological Restoration Targets in European Waters: a Challenge for Animal Agriculture. Chapter 11 in *Redesigning Animal Agriculture* (eds)

[151] UK Government 2010. Agriculture in the United Kingdom 2009.

Relating this to the release of land (4.5 – 8.3 million ha, depending on the type of land released), the current value of the output of this released land is on average £494-911. The value of output in any situation will vary greatly from high levels on intensively managed lowland grassland to the very low output of the lowest grade rough grazing land.

The farm-level economic impact of a change along these lines will depend crucially on what replacement output is found for the land released and market effects that are beyond the scope of this study. It is clear that finding replacement outputs that match the values given above is a challenge. One economic response scenario is that the land resource released remains in agriculture serving export markets. Under these circumstances, effects at farm level would be minor – output and much of the post-farm processing effort would remain in place. The main economic effect of such a scenario is that the UK net trade deficit in food would decline. However, it is unlikely that a change in consumption would be unique to the UK and that such a scenario would be realised with similar changes in other European countries and/or the developed world. Another strategy is to use the land for non-food purposes. Using biomass energy cropping as a benchmark and assuming a price of £40/tonne biomass wood, we estimate that replacing the value of the food output of released land will be challenging, although it is reported as an economically viable alternative to sheep production on uplands.[152]

The data on land release indicate two broad categories of land where change is greatest: the uplands and hills, and tillable grassland. Reed et al.[153] provide a review of the challenges facing upland and hill rural communities. They emphasise the wide range of services provided by these areas and the external nature of many benefits. This means that other communities benefit but the costs are over-proportionally borne by those who own or manage uplands. This provides a rationale for policy intervention. They point out that the multiplicity of ecosystem services provided means there is much competition for land. Therefore, upland rural economies are increasing less dependent on primary production, particularly food production. The economy of these communities has gradually switched from production to consumption. The economic consequences of change will depend on the combination, and interaction between, new provisioning, regulating and cultural service outputs. As a major upland and hill landowner, the National Trust for Wales has addressed the consequences of consumption change[154] recognising that the need to shift towards a low-carbon diet is a challenge, both in terms of consumer behaviour change and the reliance of Welsh upland agriculture on meat production. Recognising the risk to farm incomes, the Trust points out that there are opportunities for Welsh agriculture in a low-carbon society. Increased use of bioenergy heating will result in increased demand for wood-fuel.

Effects of switching from red to white meat, and of reducing white meat consumption

Since red meat (ruminant) production is responsible for the majority of methane emissions and is intrinsically inefficient in the use of land resources because of the high resource cost of breeding, replacing red with white meat is an obvious option. Gill et al.[155] provide a discussion of the consequences for food security on a global scale drawing attention to the role cattle and sheep have in supplying human food from non-arable land.

Our scenario assumed a reduction of 75% leaving 25% as a market for culled dairy cows and male dairy calves. This scenario would practically eliminate the market for sheepmeat as the dairy beef would supply most of the red meat required. This switch reduces greenhouse gas emissions from production by 9% (7.3 million t CO_2e/year).

The main effect is the increased need for overseas arable land, increasing the use of overseas arable land by 0.5 million ha, with a slight increase in UK arable land needs. This scenario has the potential to release 7.3 million ha of grassland if production is concentrated on high quality land. This represents the withdrawal of food production from 77% of UK grassland.

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[152] Heaton, R.J., Randerson, P.F., Slater, F.M. 1999. The economics of growing short rotation coppice in the uplands of mid-Wales and an economic comparison with sheep production. Biomass and Bioenergy 17: 59-71.

[153] Reed MS, Bonn A, Slee W, Beharry-Borg N, Birch J, Brown I, Burt TP, Chapman D, Chapman PJ, Clay G, Cornell SJ, Fraser EDG, Holden J, Hodgson JA, Hubacek K, Irvine B, Jin N, Kirkby MJ, Kunin WE, Moore O, Moseley D, Prell C, Quinn C, Redpath S, Reid C, Stagl S, Stringer LC, Termansen M, Thorp S, Towers W, Worrall F (2010) Future of the uplands. **Land Use Policy.** Vol 2. 26/1: 204-216

[154] The National Trust for Wales. Inquiry into the future of the uplands in Wales. http://www.assemblywales.org/1_national_trust_formatted.pdf

[155] Gill, M., Smith, P. and Wilkinson, J.M. (2009). Mitigating climate change: the role of domestic livestock. Animal 1-11.

The importance of this part of the study is the quantification of the effect on the overseas arable land. The additional land required is dominated by the need to produce soy. If this scenario was widely adopted across Europe, the global market for soy would increase significantly. Other effects depend on the success in controlling emissions from intensive livestock production. Overall, due to the import of and concentration of nutrients in intensive pig and poultry production, this change increases the risk of excess nutrient excesses and emissions at a range of scales.

A 50% reduction in white meat consumption reduces production greenhouse gas emissions by only 5%, but releases 0.4 million ha of overseas arable land 0.2 million ha of UK arable land.

Potential risks and unintended consequences

The general effects of these scenarios have been discussed. This section provides an overview more specific effects.

Livestock breeding

These scenarios examine extremes. Some of the scenarios would make the maintenance of adequate stocks of high quality breeding animals difficult and many native breeds might disappear, at least from commercial production. In reality, to preserve the genetic viability of the UK's native rare and endangered breeds, commercially viable production systems need to remain to a certain extent in all the habitats. Additionally, grazing livestock are a natural management tool for the preservation of flora and fauna of semi-natural grassland.

Horticulture

The general conclusion that a reduction in livestock production consumption will have little effect in total arable land requirements masks some important local effects. In general, this scenario will reduce arable production for livestock feed to arable production for direct human consumption, including a 50% increase in fruit and vegetables. The increase of 0.5 million ha of UK crops for human consumption includes an increase of about 0.2 million ha in potatoes, field vegetables and fruit. Research indicates that agricultural change driven by healthy eating recommendations will result in expansion of production of these crops in the south-east.[156] Many of these crops are irrigated and some are protected using for example poly-tunnels. While the change in land use is small in absolute terms, the effect locally on water resources and landscape will be significant.

Previous assessments have drawn attention to the consequences of weaknesses in the UK horticulture sector.[157] The full effect of the 50% expansion in fruit and vegetable consumption will depend on the type of produce favoured, the effect of retailers on influencing demand and supply chains, and the ability of the UK growers to respond. The near collapse of the British orchard fruit sector over the last twenty years has consequences for the effect of demand on overseas land.

A reduction in demand for livestock products could affect rotations by reducing the demand for peas and beans for livestock feed, and increase the demand for high quality bread wheat. The overall effect could be a simplification in arable rotations and an increased demand for the best arable land.

Seasonality of lamb production

The production scenarios (with varying emphasises on production from different types of grassland etc) have implications for the seasonality of sheepmeat production where the relationship between upland and lowland production is affected.

The majority of lamb is finished is the second 6 months of the year, with a peak around September – October and the rest carried over to be finished in the early part of the following year. Some flocks target finishing lamb for the very early market (April-May) by lambing indoors over winter, but the majority lamb in March-April. Lowland lambs are usually then finishing in the summer-autumn, whereas hill lambs are finishing much later, often as stores on the lowland over winter. Thus the phased availability of finished lamb is to a substantial extent currently the product of the structured hill to lowland industry.

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[156] Jones, P.J. and Tranter, R.B. 2007. Modelling the impact of different policy scenarios on farm business management, land use and rural employment Project Document No. 13. Implications of a nutrition driven food policy for land use and the Rural Environment. Workpackage No. 5, Report No. 02

[157] Murphy-Bokern, D. (2010). Environmental impacts of the UK food economy with particular reference to WWF Priority Places and the North-east Atlantic. WWF UK.

Under production scenario 2, lamb production is dominated by lowland flocks which are currently finished by the end of the year. It is possible in the lowland case for producers to choose to lamb later in the spring so that their lambs finish later, and hence supply the winter market, but of course this will lose the advantage held by the lowland flocks of using plentiful grazing and would thus increase the GWP of the flock.

Uneven distribution of economic effects

Related to the changes in crop production, the effect of a contraction in the valuable of farm output discussed above will be unevenly distributed. There will be many losers, but also some winners. Put bluntly almost all Welsh, Scottish and Northern Irish farmers will be losers counterbalanced by a fewer number of winners in the south-east of England. Jones and Tranter[156] discuss the need to manage the consequences of this in some detail, especially the social consequences in the hills and uplands.

Effects on overseas land use

The reduction in livestock product consumption will have little effect overall on overseas land needs. The release of land used for livestock feed is approximately equal to the extra land needed for more imported fruit, vegetables, specialised cereals etc. Overall, release of land in South America and the USA used for animal feed, especially soy, will be counter-balanced by increases in a wide range of crops elsewhere. Some of the expansion may take place in areas already stressed by food production: the expansion of fruit and vegetable production in the Mediterranean basin and South Africa increases the use of scarce irrigation water. However these risks can be managed, especially by UK supply chains which are vertically integrated. The effect is that reductions in commodity soy production in South America are largely off-set by much more traceable horticultural and oil crop production elsewhere. Consumer policy has much more influence over this production compared with the production of soy displaced. Furthermore, consumers can opt to buy UK fruit and vegetables or more UK grown cereals but have little control over soy needs of the livestock sector. There may be a case for addressing the decline in UK field crop horticultural production in particular to reverse the trend away from the staples of UK field horticulture. The UK horticultural sector is not growing in line with the increase in UK fruit and vegetable consumption.

The consumption changes also reduce the need for overseas grassland. This affects three countries in particular: Ireland (dairy products, beef), New Zealand (butter and lamb), and Brazil (beef). The effect on Brazil is now small as imports have dwindled in recent years but the change would close off the UK as a growth market for Brazilian beef in the longer term. The effects on Ireland are particularly significant because of the limited range of alternatives for Irish grassland.

13. Conclusion

This study has clearly shown that UK land can support consumption change that reduces greenhouse gas emissions from the food system. The reduction in land needed to supply the UK that comes with a reduction in livestock product consumption comes with environmental benefits and opportunities to deliver other products, including other ecosystem services, from UK agricultural land. The potential of the options that consumption change provides in terms of land use and greenhouse gas emissions and sequestration effects is clearly estimated. A major outcome of this study is the very clear and quantified elucidation of the profound implications that consumption change could have for UK land use.

Annex 1 Annex1: participants in the workshop on the land use & GHG implications of consumption change

Friday 29 January 2010, 4th Floor, Manning House, 22 Carlisle Place, London

Experts & Stakeholders

Alison Spalding	Food Standards Agency
Andrew Kuyk	Food and Drink Federation
Andrew McWhir	Defra
Ian Crute	Agriculture and Horticultural Development Board
Jeff Allder	Food Standards Agency
Joe Millward	University of Surrey
Jonathan Scurlock	National Farmer's Union
Joyce D'Silva	Compassion in World Farming
Maggie Gill	Scottish Government
Mario Deconti	Defra
Mark Driscoll	WWF-UK
Mary Vickers	EBLEX
Peter Bradnock	British Poultry Council
Peter Morris	National Sheep Association
Philip Jones	University of Reading, Centre for Agricultural Strategy
Richard Bradbury	RSPB
Tara Garnett	Food Climate Research Network
Tim Lang	Sustainable Development Commission

Cranfield University Team

Adrian Williams

Daniel Sandars

Donal Murphy-Bokern

Committee on Climate Change

David Kennedy	Chief Executive
Adrian Gault	Chief Economist
Mike Thompson	
Kavita Srinivasan	

Annex 2 Agricultural land classification of England and Wales[158]

A. Description of the grades and sub-grades

The agricultural land is graded according to the degree to which its physical characteristics impose long-term limitations on agricultural use. The limitations operate in one or more of four principal ways: they may affect the range of crops which can be grown, and the level of yield, the consistency of yield and the cost of obtaining it. Ability to grow a wide range of crops (including grass) whether actual or potential, is given considerable weight but it does not outweigh the ability to produce consistently high yields of a somewhat narrower range of crops.

The main physical factors which have been taken into account are climate (particularly rainfall, transpiration, temperature and exposure), relief (particularly slope) and soil (particularly wetness, depth, texture, structure, stoniness and available water capacity). The grading of agricultural land is on the basis of physical quality alone. Other less permanent factors such as the standard and adequacy of fixed equipment, the level of management, farm structure and accessibility have not been taken into account. It follows that the grades give no indication of the relative values of farms located on them, either as a source of income or capital, since these values will usually depend largely on such shorter term factors.

The most productive and flexible land falls into Grades 1 and 2 and Sub-grade 3a and collectively comprises about one-third of the agricultural land in England and Wales. About half the land is of moderate quality in Sub-grade 3b or poor quality in Grade 4. Although less significant on a national scale such land can be locally valuable to agriculture and the rural economy where poorer farmland predominates. The remainder is very poor quality land in Grade 5, which mostly occurs in the uplands.

i. Grade 1 - excellent quality agricultural land

Land with no or very minor limitations to agricultural use. A very wide range of agricultural and horticultural crops can be grown and commonly includes top fruit, soft fruit, salad crops and winter harvested vegetables. Yields are high and less variable than on land of lower quality.

ii. Grade 2 - very good quality agricultural land

Land with minor limitations which affect crop yield, cultivations or harvesting. A wide range of agricultural and horticultural crops can usually be grown but on some land in the grade there may be reduced flexibility due to difficulties with the production of the more demanding crops such as winter harvested vegetables and arable root crops. The level of yield is generally high but may be lower or more variable than Grade 1.

iii. Grade 3 - good to moderate quality agricultural land

Land with moderate limitations which affect the choice of crops, timing and type of cultivation, harvesting or the level of yield. Where more demanding crops are grown yields are generally lower or more variable than on land in Grades 1 and 2.

Sub-grade 3a - good quality agricultural land

Land capable of consistently producing moderate to high yields of a narrow range of arable crops, especially cereals, or moderate yields of a wide range of crops including cereals, grass, oilseed rape, potatoes, sugar beet and the less demanding horticultural crops.

Sub-grade 3b - moderate quality agricultural land

Land capable of producing moderate yields of a narrow range of crops, principally cereals and grass or lower yields of a wider range of crops or high yields of grass which can be grazed or harvested over most of the year.

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[158] MAFF 1988. Agricultural land classification of England and Wales.
http://www.defra.gov.uk/foodfarm/landmanage/land-use/documents/alc-guidelines-1988.pdf

iv. Grade 4 - poor quality agricultural land

Land with severe limitations which significantly restrict the range of crops and/or level of yields. It is mainly suited to grass with occasional arable crops (e.g. cereals and forage crops) the yields of which are variable. In moist climates, yields of grass may be moderate to high but there may be difficulties in utilisation. The grade also includes very droughty arable land.

v. Grade 5 - very poor quality agricultural land

Land with very severe limitations which restrict use to permanent pasture or rough grazing, except for occasional pioneer forage crops.

Annex 3 The Scottish system of land capability for agriculture classification

B. Class 1 land capable of producing a very wide range of crops

Cropping is highly flexible and includes the more exacting crops such as winter harvested vegetables (cauliflowers, Brussels sprouts, leeks), The level of yield is consistently high. Soils are usually well-drained deep loams, sandy loams, silty loams, or their related humic variants, with good reserves of moisture. Sites are level or gently sloping and the climate is favourable. There are no or only very minor physical limitations affecting agricultural use.

C. Class 2 land capable of producing a wide range of crops

Cropping is very flexible and a wide range of crops can be grown though some root and winter harvested crops may not be ideal choices because of difficulties in harvesting. The level of yield is high but less consistently obtained than on Class I land due to the effects of minor limitations affecting cultivation, crop growth or harvesting. The limitations include, either singly or in combination, slight workability or wetness problems, slightly unfavourable soil structure or texture, moderate slopes or slightly unfavourable climate. The limitations are always minor in their effect however and land in the class is highly productive.

D. Class 3 land capable of producing a moderate range of crops

Land in this class is capable of producing good yields of a narrow range of crops, principally cereals and grass, and/or moderate yields of a wider range including potatoes, some vegetable crops (e.g. field beans and summer harvested brassicae) and oil-seed rape. The degree of variability between years will be greater than is the case for Classes I and 2, mainly due to interactions between climate, soil and management factors affecting the timing and type of cultivations, sowing and harvesting. The moderate limitations require careful management and include wetness, restrictions to rooting depth, unfavourable structure or texture, strongly sloping ground, slight erosion or a variable climate. The range of soil types within the class is greater than for previous classes.

E. Class 4 land capable of producing a narrow range of crops

The land is suitable for enterprises based primarily on grassland with short arable breaks (e.g. barley, oats, and forage crops). Yields of arable crops are variable due to soil, wetness or climatic factors. Yields of grass are often high but difficulties of production or utilisation may be encountered. The moderately severe levels of limitation restrict the choice of crops and demand careful management. The limitations may include moderately severe wetness, occasional damaging floods, shallow or very stony soils, moderately steep gradients, erosion, moderately severe climate or interactions of these which increase the level of farming risk.

F. Class 5 land suited only to improved grassland and rough grazing

Land capable of use as improved grassland. The agricultural use of land in Class 5 is restricted to grass production but such land frequently plays an important role in the economy of British hill lands. Mechanised surface treatments to improve the grassland, ranging from ploughing through rotation to surface seeding and improvement by non-disruptive techniques are all possible. Although an occasional pioneer forage crop may be grown, one or more severe limitations render the land unsuited to arable cropping. These include adverse climate, wetness, frequent damaging floods, steep slopes, soil defects or erosion risk. Grass yields within the class can be variable and difficulties in production, and particularly utilisation, are common.

G. Class 6 land capable only of use as rough grazing

The land has very severe site, soil or wetness limitations which generally prevent the use of tractor-operated machinery for improvement. Some reclamation of small patches to encourage stock to range is often possible. Climate is often a very significant limiting factor. A range of widely different qualities of grazing is included, from very steep land with significant grazing value in the lowland situation to moorland with a low but sustained production in the uplands. Grazing is usually insignificant in the arctic zones of the mountain lands but below this level grazing which can be utilised for five months or longer in any year are included in the class. Land affected by severe industrial pollution or dereliction may be included if the effects of the pollution are non-toxic.

H. Class 7 land of very limited agricultural value

Land with extremely severe limitations that cannot be rectified. The limitations may result from one or more of the following conditions: extremely severe wetness, extremely stony, rocky land, bare soils, scree or beach sand and gravels, toxic waste tips and dereliction, very steep gradients, severe erosion including intensively hagged peat lands and extremely severe climates (exposed situations, protracted snow-cover and short growing season). Agricultural use is restricted to very poor rough grazing.

I. The divisions

A division is a ranking within a class; the approach to it however needs to be selective. Because the requirements of the crops suited to Classes 1 and 2 are fairly stringent, land in these classes has inherently low degrees of internal variability. The requirements of crops grown in the remaining classes are less rigorous, consequently land included is more variable in character and covers larger areas. For purposes of strategic and regional planning, it is quite clear that some further guidance is necessary in these areas, although for detailed planning the variability of the class dictates that on-site inspections must always be made. Classes 3 and 4 each have two divisions based on increasing restrictions to arable cropping. These are principally climate, in particular the reliability of suitable weather conditions and interactions between soil properties and climatic features. Qualities of land such as workability and droughtiness are particularly affected. Relatively small amounts of rain upon clayey topsoils may equal or exceed in their effect upon farming (e.g., that of large amounts upon coarser topsoil textures). Site criteria and erosion play relatively small parts. Class 5 land has three divisions based on potential for successful reclamation and Class 6 three based upon the value of the existing vegetation for grazing purposes.

vi. The divisions of class 3

The definition of Class 3 incorporates land which has a good capability for the production of a moderate range of crops, that part of the British farmscape which is usually regarded as 'average arable land'. For economic reasons it is devoted principally to cereal and grass farming, but the land is often capable of producing in addition, potatoes, oilseed rape, field beans or some vegetables. The picture throughout the class is one of variability so that it is possible that, in anyone year, the situation may differ drastically from the mean. It is against this background that farmers have to plan the long-term investment and decide the kinds of enterprise to practise and thus the actual farming patterns found reflect social as much as physical conditions. In dividing any class, the choice of limits is difficult and their significance to agricultural operations more tenuous. This is particularly so in Class 3 and for this reason only two divisions are proposed.

Division 1

Land in this division is capable of producing consistently high yields of a narrow range of crops (principally cereals and grass) and/or moderate yields of a wider range (including potatoes, field beans and other vegetables, and root crops). Short grass leys are common.

Division 2

This land is capable of average production but high yields of grass, barley and oats are often obtained. Other crops are limited to potatoes and forage crops. Grass leys are common and reflect the increasing growth limitations for arable crops and degree of risk involved in their production.

vii. The divisions of class 4

The class comprises land marginal for the economic production of crops and usually confined to types suitable for winter feeding to livestock. Farming enterprises on this land are based primarily on livestock production, as with Class 3, year to year variability in crop yield is large, but the risks of crop failure or poor weather interfering with harvests are higher. Class 4 land is principally found where the deleterious effects of many types of limitation combine. Foremost among these are high rainfall causing wetness limitations, particularly in central and western Scotland. In southern and eastern Scotland, however, shallow or sandy soils and low rainfall are responsible for some areas being included in the class because of drought limitations. As with Class 3, the critical parameters are climate, wetness and doughtiness.

Division 1

Land in this division is suited to rotations which, although primarily based on long ley grassland, include forage crops and cereals for stock feed. Yields of grass are high but difficulties of utilisation or conservation may be encountered. Other crop yields are very variable and usually below the national average.

Division 2

The land is primarily grassland with some limited potential for other crops. Grass yields can be high but the difficulties of conservation or utilisation may be severe, especially in areas of poor climate or on very wet soils. Some forage cropping is possible and, when the extra risks involved can be accepted, an occasional cereal crop.

viii. The divisions of class 5

By definition, land included in Class 5 is suited to use as grassland and to improvement by mechanised means. Improvement may take the form of regeneration (reseeding of previously sown swards which have deteriorated in quality through time) or reclamation (the production of new grasslands from previously uncultivated natural or semi-natural vegetation). By 'mechanised means' is understood all techniques for the production of grassland from full ploughing to surface seeding without the disruption of soil. Class 5 land is broadly constrained by climate limitations to hill areas where risks are too great for arable cropping. Other limitations are usually subsidiary in determining the overall pattern of class distribution but become important in intra-class ranking and in determining the boundary between Classes 5 and 6. The assumption regarding level of management is significant in determining what land is to be considered improvable, since it involves a favourable balance in input output relationships. This latter criterion should not be carried too far however, for it is the physical qualities of the land which are diagnostic. Many other characters, such as the pattern of land ownership, farm structure, availability of roads and the farmer's preference may determine the actual areas selected for improvement within the class. The allocation of land to Class 5 only indicates a potential for some improvement, which is attainable within a very short time scale compared with the slower improvements which result from careful grazing management within Class 6. It is useful, therefore, to know whether the improvement results in valuable grassland with long term potential or grassland with only short term potential and requiring constant maintenance. Sward quality of improved grasslands and their levels of production are always high compared with the semi-natural grasslands found in hill areas. The important factors to be considered in improvement are (a) the ease or otherwise of establishment of the sward, (b) the persistence of the sown species, (c) the costs of maintenance and (d) whether the resultant sward can be used for grass conservation or whether it must be grazed.

Division 1

Land well suited to reclamation and to use as improved grassland Establishment of a grass sward and its maintenance present few problems and potential yields are high with ample growth throughout the season. Patterns of soil, slope or wetness may be slightly restricting but the land has few poaching problems. High stocking rates are possible.

Division 2

Land moderately suited to reclamation and use as improved grassland Sward establishment presents no difficulties but moderate or low trafficability, patterned land and/or strong slopes cause maintenance problems. Growth rates are high and despite some problems of poaching, satisfactory stocking rates are achievable. Division 3 Land marginally suited to reclamation and use as improved grassland Land in this division has properties which lead to serious trafficability and poaching difficulties and although sward establishment may be easy, deterioration in quality is often rapid. Patterns of soil, slope or wetness may seriously interfere with establishment and maintenance. The land cannot support high stock densities without damage and this may be serious after heavy rain, even in summer.

ix. The divisions of class 6

Land included in Class 6 is unsuited to improvement by mechanised means but has some sustained grazing value. The grazings must be available for five months or more in any year. Improvements to sward quality and quantity have been practised in these areas for many years and include stock control by fencing, encouragement to the grazing animal to range (mosaic improvements of small areas « 40%) by limited mechanical means) and by burning. In general, such improvement techniques are slow compared with those available on Class 5 land and often achieve their more striking successes only on the best land of the class. With such a wide range of sward quality included, attention has been given to developing a technique of assessing relative grazing values of different swards. In this, the use of adequately described and defined plant communities (e.g. Birse and Robertson 1976) was invaluable. The number and type of plant communities in any area can be determined and the value of each to the grazing animal assessed. Communities dominated by grasses are usually of high relative value; those by dwarf shrubs and mosses of low value. Management of hill and mountain areas has often resulted in the modification of the original plant communities, sometimes fairly substantially. The resultant replacement communities have a relationship with the original communities and, if the particular form of management ceases, will revert to them within a short period. In the broad sense there is a relationship between the semi-natural and replacement communities and the underlying soil types, and both are related to climatic zones in mountainous areas which allow useful suitability groups to be identified. It must be stressed that rarely does one plant community cover a large enough area to map individually, but mosaics of plant communities are found which are averaged to give values for the area.

Division 1 High grazing value

The dominant plant communities contain high proportions of palatable herbage, principally the better grasses, e.g. bent-fescue or meadowgrass-bent pasture.

Division 2 Moderate grazing value

Moderate quality herbage such as white and flying bent grasslands, rush pastures and herb-rich moorlands, or a mosaic of high and low grazing values characterises land in the division.

Division 3 Low grazing value

The vegetation is dominated by plant communities with low grazing values, particularly heather moor, bog heather moor and blanket bog.

Annex 4 Disaggregation of forage land areas to NUTS 1 and NUTS 2 level

The disaggregated results for the baseline case (

Table 47) and land release under Scenarios 1 and 2 (Table 48 and Table 49) are presented without further comment. The disaggregated results for NUT2 follow.

Table 47 Baseline use of land for forage broken down to NUTS1 level. All values are in kha.

NUTS 1 area code	NUTS 1 area description	Arable land used for forage maize	Potentially tillable grassland	Non-tillable grassland
UKC	North East	0.2	102	171
UKD	North West	9.2	217	351
UKE	Yorkshire	2.7	196	146
UKF	East Midlands	7.9	257	53
UKG	West Midlands	14.5	371	51
UKH	East Anglia	6.3	175	8
UKI	London	0.2	6	0
UKJ	South East	18.0	400	15
UKK	South West	47.4	867	158
UKL	Wales	6.8	409	718
UKM	Scotland	0.0	681	3,587
UKN	N. Ireland	0.0	512	466

Table 48 Release of land under Scenario 1 (50% reduction in livestock product consumption). All values are in kha.

Production scenario	NUTS 1 area code	NUTS 1 area description (England is implied)	Arable land used for forage maize	Potentially tillable grassland	Non-tillable grassland
Uniform land release	UKC	North East	0.1	64	113
	UKD	North West	3.7	110	209
	UKE	Yorkshire	1.1	114	91
	UKF	East Midlands	3.2	152	32
	UKG	West Midlands	5.8	213	31
	UKH	East Anglia	2.8	107	6
	UKI	London	0.1	3	0
	UKJ	South East	7.5	238	10
	UKK	South West	19.0	474	99
	UKL	Wales	2.7	243	456
	UKM	Scotland	0.0	417	2,421
	UKN	N. Ireland	0.0	288	303
Grass release maximised	UKC	North East	0.0	47	171
	UKD	North West	0.0	108	351
	UKE	Yorkshire	0.2	61	146
	UKF	East Midlands	0.3	33	53
	UKG	West Midlands	0.2	40	51
	UKH	East Anglia	0.9	43	8
	UKI	London	0.0	1	0
	UKJ	South East	1.0	32	15
	UKK	South West	0.2	306	158
	UKL	Wales	0.0	192	718
	UKM	Scotland	0.0	315	3,587
	UKN	N. Ireland	0.0	208	466
Tillable land release maximised	UKC	North East	0.2	90	50
	UKD	North West	9.2	120	74
	UKE	Yorkshire	2.7	159	20
	UKF	East Midlands	7.9	231	5
	UKG	West Midlands	14.5	324	3
	UKH	East Anglia	6.3	158	0
	UKI	London	0.2	5	0
	UKJ	South East	18.0	375	1
	UKK	South West	47.4	612	26
	UKL	Wales	6.8	315	188
	UKM	Scotland	0.0	0	0
	UKN	N. Ireland	0.0	372	65

Table 49 Release of land under Scenario 2 (red to white meat). All values are in kha.

Production scenario	NUTS 1 area code	NUTS 1 area description (England is implied)	Arable land used for forage maize	Potentially tillable grassland	Non-tillable grassland
Uniform land release	UKC	North East	0.0	69	128
	UKD	North West	0.0	70	197
	UKE	Yorkshire	0.2	108	91
	UKF	East Midlands	0.3	146	30
	UKG	West Midlands	0.2	189	29
	UKH	East Anglia	1.0	111	6
	UKI	London	0.0	3	0
	UKJ	South East	1.1	229	11
	UKK	South West	0.2	382	104
	UKL	Wales	0.0	229	473
	UKM	Scotland	0.0	432	2,764
	UKN	N. Ireland		255	353
Grass release maximised	UKC	North East	0.0	66	165
	UKD	North West	0.0	73	255
	UKE	Yorkshire	0.0	66	118
	UKF	East Midlands	0.0	54	39
	UKG	West Midlands	0.0	62	37
	UKH	East Anglia	0.0	65	8
	UKI	London	0.0	2	0
	UKJ	South East	0.0	65	14
	UKK	South West	0.0	328	134
	UKL	Wales	0.0	222	611
	UKM	Scotland	0.0	401	3,565
	UKN	N. Ireland	0.0	333	466
Tillable land release maximised	UKC	North East	0.0	90	83
	UKD	North West	0.0	92	124
	UKE	Yorkshire	0.2	142	46
	UKF	East Midlands	0.4	192	11
	UKG	West Midlands	0.3	247	10
	UKH	East Anglia	1.3	146	0
	UKI	London	0.0	4	0
	UKJ	South East	1.4	301	2
	UKK	South West	0.3	504	47
	UKL	Wales	0.0	299	315
	UKM	Scotland	0.0	570	517
	UKN	N. Ireland	0.0	351	110

J. Disaggregation of forage land areas to NUTS 2 level

Please note that the NUTS2 areas for N. Ireland could not be analysed separately, but the six counties are shown instead.

Table 50 Baseline use of land for forage. All values are in kha.

NUTS 2 area code	NUTS 1 area description	Arable land used for forage maize	Potentially tillable grassland	Non-tillable grassland
UKC1	Tees Valley & Durham	2.2	59	23
UKC2	Northumberland And Tyne & Wear	2.3	141	46
UKD1	Cumbria	0.0	247	64
UKD2	Cheshire	19.8	66	7
UKD3	Greater Manchester	0.5	14	5
UKD4	Lancashire	2.1	105	32
UKD5	Merseyside	1.4	3	0
UKE1	East Riding & North Lincolnshire	27.5	6	1
UKE2	North Yorkshire	31.3	140	73
UKE3	South Yorkshire	6.5	7	7
UKE4	West Yorkshire	2.6	27	13
UKF1	Derbyshire & Nottinghamshire	31.1	67	33
UKF2	Leicestershire Rutland & Northants	81.4	42	2
UKF3	Lincolnshire	27.9	24	2
UKG1	Herefordshire Worcestershire & Warks	132.2	41	5
UKG2	Shropshire & Staffordshire	74.4	133	28
UKG3	West Midlands	3.5	5	0
UKH1	East Anglia	38.1	69	6
UKH2	Bedfordshire & Hertfordshire	21.0	13	1
UKH3	Essex	4.3	30	1
UKI1	Inner London	0.0	0	0
UKI2	Outer London	2.4	3	0
UKJ1	Berkshire Bucks & Oxfordshire	97.4	30	2
UKJ2	Surrey East & West Sussex	72.9	64	4
UKJ3	Hampshire & Isle Of Wight	36.8	30	3
UKJ4	Kent	52.1	20	2
UKK1	Gloucestershire Wiltshire & North Somerset	76.6	158	9
UKK2	Dorset & Somerset	42.5	212	22
UKK3	Cornwall & Isles Of Scilly	5.3	171	9
UKK4	Devon	2.5	288	31
UKL1	West Wales & The Valleys	8.2	529	178
UKL2	East Wales	26.5	238	147
UKM1	North East Scotland	14.8	148	163
UKM2	Eastern Scotland	47.1	258	645
UKM3	South Western Scotland	30.5	295	401
UKM4	Highlands And Islands	9.8	203	2,051
	Antrim	0	103	116
	Armagh	0	68	19
	Down	0	98	60
	Fermanagh	0	57	52
	Londonderry	0	71	92
	Tyrone	0	115	126

Table 51 Release of land under Scenario 1 (50% reduction in livestock product consumption), with uniform release of land. All values are in kha.

NUTS 2 area code	NUTS 1 area description	Arable land used for forage maize	Potentially tillable grassland	Non-tillable grassland
UKC1	Tees Valley & Durham	1.3	37	15
UKC2	Northumberland And Tyne & Wear	1.5	91	32
UKD1	Cumbria	0.0	140	43
UKD2	Cheshire	9.1	31	5
UKD3	Greater Manchester	0.3	7	3
UKD4	Lancashire	1.2	54	21
UKD5	Merseyside	0.8	2	0
UKE1	East Riding & North Lincolnshire	16.9	3	1
UKE2	North Yorkshire	19.1	79	49
UKE3	South Yorkshire	3.8	4	5
UKE4	West Yorkshire	1.6	15	9
UKF1	Derbyshire & Nottinghamshire	17.9	36	20
UKF2	Leicestershire Rutland & Northants	48.9	26	1
UKF3	Lincolnshire	17.6	14	1
UKG1	Herefordshire Worcestershire & Warks	80.1	25	4
UKG2	Shropshire & Staffordshire	41.5	70	18
UKG3	West Midlands	2.1	3	0
UKH1	East Anglia	23.6	42	4
UKH2	Bedfordshire & Hertfordshire	12.9	8	1
UKH3	Essex	2.6	18	1
UKI1	Inner London	0.0	0	0
UKI2	Outer London	1.4	2	0
UKJ1	Berkshire Bucks & Oxfordshire	58.0	18	2
UKJ2	Surrey East & West Sussex	43.6	37	3
UKJ3	Hampshire & Isle Of Wight	20.8	17	2
UKJ4	Kent	32.7	12	2
UKK1	Gloucestershire Wiltshire & North Somerset	43.7	86	6
UKK2	Dorset & Somerset	22.3	111	14
UKK3	Cornwall & Isles Of Scilly	2.7	96	6
UKK4	Devon	1.5	163	21
UKL1	West Wales & The Valleys	4.9	310	122
UKL2	East Wales	15.5	148	99
UKM1	North East Scotland	8.9	94	110
UKM2	Eastern Scotland	29.5	167	438
UKM3	South Western Scotland	15.8	175	267
UKM4	Highlands And Islands	6.2	130	1,394
	Antrim	0	57	76
	Armagh	0	39	12
	Down	0	54	39
	Fermanagh	0	33	34
	Londonderry	0	41	60
	Tyrone	0	64	82

Table 52 Release of land under Scenario 1 (50% reduction in livestock product consumption), with grassland release maximised. All values are in kha.

NUTS 2 area code	NUTS 1 area description	Arable land used for forage maize	Potentially tillable grassland	Non-tillable grassland
UKC1	Tees Valley & Durham	0.0	40	23
UKC2	Northumberland And Tyne & Wear	0.0	109	46
UKD1	Cumbria	0.0	223	64
UKD2	Cheshire	0.0	17	7
UKD3	Greater Manchester	0.0	13	5
UKD4	Lancashire	0.0	96	32
UKD5	Merseyside	0.0	2	0
UKE1	East Riding & North Lincolnshire	0.0	2	1
UKE2	North Yorkshire	0.0	88	73
UKE3	South Yorkshire	0.0	3	7
UKE4	West Yorkshire	0.0	19	13
UKF1	Derbyshire & Nottinghamshire	0.0	34	33
UKF2	Leicestershire Rutland & Northants	0.0	9	2
UKF3	Lincolnshire	0.0	7	2
UKG1	Herefordshire Worcestershire & Warks	0.0	9	5
UKG2	Shropshire & Staffordshire	0.0	48	28
UKG3	West Midlands	0.0	1	0
UKH1	East Anglia	0.0	30	6
UKH2	Bedfordshire & Hertfordshire	0.0	3	1
UKH3	Essex	0.0	9	1
UKI1	Inner London	0.0	0	0
UKI2	Outer London	0.0	1	0
UKJ1	Berkshire Bucks & Oxfordshire	0.0	7	2
UKJ2	Surrey East & West Sussex	0.0	15	4
UKJ3	Hampshire & Isle Of Wight	0.0	10	3
UKJ4	Kent	0.0	3	2
UKK1	Gloucestershire Wiltshire & North Somerset	0.0	36	9
UKK2	Dorset & Somerset	0.0	78	22
UKK3	Cornwall & Isles Of Scilly	0.0	101	9
UKK4	Devon	0.0	179	31
UKL1	West Wales & The Valleys	0.0	435	178
UKL2	East Wales	0.0	149	147
UKM1	North East Scotland	0.0	83	163
UKM2	Eastern Scotland	0.0	174	645
UKM3	South Western Scotland	0.0	213	401
UKM4	Highlands And Islands	0.0	169	2,051
	Antrim	0	52	116
	Armagh	0	26	19
	Down	0	25	60
	Fermanagh	0	29	52
	Londonderry	0	27	92
	Tyrone	0	47	126

Table 53 Release of land under Scenario 1 (50% reduction in livestock product consumption), with tillable land release maximised. All values are in kha.

NUTS 2 area code	NUTS 1 area description	Arable land used for forage maize	Potentially tillable grassland	Non-tillable grassland
UKC1	Tees Valley & Durham	2.2	36	2
UKC2	Northumberland And Tyne & Wear	2.3	90	7
UKD1	Cumbria	0.0	94	8
UKD2	Cheshire	19.8	31	1
UKD3	Greater Manchester	0.5	4	0
UKD4	Lancashire	2.1	26	4
UKD5	Merseyside	1.4	3	0
UKE1	East Riding & North Lincolnshire	27.5	5	0
UKE2	North Yorkshire	31.3	78	9
UKE3	South Yorkshire	6.5	4	0
UKE4	West Yorkshire	2.6	13	1
UKF1	Derbyshire & Nottinghamshire	31.1	36	2
UKF2	Leicestershire Rutland & Northants	81.4	36	0
UKF3	Lincolnshire	27.9	21	0
UKG1	Herefordshire Worcestershire & Warks	132.2	35	0
UKG2	Shropshire & Staffordshire	74.4	76	2
UKG3	West Midlands	3.5	4	0
UKH1	East Anglia	38.1	57	0
UKH2	Bedfordshire & Hertfordshire	21.0	11	0
UKH3	Essex	4.3	26	0
UKI1	Inner London	0.0	0	0
UKI2	Outer London	2.4	3	0
UKJ1	Berkshire Bucks & Oxfordshire	97.4	26	0
UKJ2	Surrey East & West Sussex	72.9	52	0
UKJ3	Hampshire & Isle Of Wight	36.8	22	0
UKJ4	Kent	52.1	17	0
UKK1	Gloucestershire Wiltshire & North Somerset	76.6	112	0
UKK2	Dorset & Somerset	42.5	123	2
UKK3	Cornwall & Isles Of Scilly	5.3	97	1
UKK4	Devon	2.5	175	2
UKL1	West Wales & The Valleys	8.2	254	21
UKL2	East Wales	26.5	171	22
UKM1	North East Scotland	14.8	113	4
UKM2	Eastern Scotland	47.1	190	35
UKM3	South Western Scotland	30.5	166	22
UKM4	Highlands And Islands	9.8	109	59
	Antrim	0	67	14
	Armagh	0	54	5
	Down	0	73	10
	Fermanagh	0	39	12
	Londonderry	0	54	9
	Tyrone	0	86	14

Table 54 Release of land under Scenario 2 (red to white meat), with uniform land release. All values are in kha.

NUTS 2 area code	NUTS 1 area description	Arable land used for forage maize	Potentially tillable grassland	Non-tillable grassland
UKC1	Tees Valley & Durham	1.2	38	17
UKC2	Northumberland And Tyne & Wear	1.5	102	36
UKD1	Cumbria	0.0	121	49
UKD2	Cheshire	3.8	14	5
UKD3	Greater Manchester	0.2	6	4
UKD4	Lancashire	1.2	36	23
UKD5	Merseyside	0.7	2	0
UKE1	East Riding & North Lincolnshire	17.6	4	1
UKE2	North Yorkshire	19.8	69	53
UKE3	South Yorkshire	3.6	3	5
UKE4	West Yorkshire	1.6	12	10
UKF1	Derbyshire & Nottinghamshire	16.5	29	19
UKF2	Leicestershire Rutland & Northants	48.2	26	1
UKF3	Lincolnshire	19.4	15	1
UKG1	Herefordshire Worcestershire & Warks	79.4	25	4
UKG2	Shropshire & Staffordshire	34.8	51	19
UKG3	West Midlands	2.1	2	0
UKH1	East Anglia	25.1	43	5
UKH2	Bedfordshire & Hertfordshire	13.5	8	1
UKH3	Essex	2.7	19	1
UKI1	Inner London	0.0	0	0
UKI2	Outer London	1.2	2	0
UKJ1	Berkshire Bucks & Oxfordshire	56.8	19	2
UKJ2	Surrey East & West Sussex	42.2	35	3
UKJ3	Hampshire & Isle Of Wight	18.1	15	2
UKJ4	Kent	34.0	12	2
UKK1	Gloucestershire Wiltshire & North Somerset	39.3	69	7
UKK2	Dorset & Somerset	15.9	78	16
UKK3	Cornwall & Isles Of Scilly	1.8	83	7
UKK4	Devon	1.5	144	24
UKL1	West Wales & The Valleys	4.5	285	137
UKL2	East Wales	14.3	150	112
UKM1	North East Scotland	9.0	106	126
UKM2	Eastern Scotland	31.8	186	500
UKM3	South Western Scotland	11.0	173	306
UKM4	Highlands And Islands	6.8	146	1,592
	Antrim	0	49	88
	Armagh	0	36	15
	Down	0	47	46
	Fermanagh	0	30	39
	Londonderry	0	37	70
	Tyrone	0	56	95

Table 55 Release of land under Scenario 2 (red to white meat), with grassland release maximised. All values are in kha.

NUTS 2 area code	NUTS 1 area description	Arable land used for forage maize	Potentially tillable grassland	Non-tillable grassland
UKC1	Tees Valley & Durham	0.0	43	22
UKC2	Northumberland And Tyne & Wear	0.0	120	46
UKD1	Cumbria	0.0	153	62
UKD2	Cheshire	0.0	15	7
UKD3	Greater Manchester	0.0	8	5
UKD4	Lancashire	0.0	46	30
UKD5	Merseyside	0.0	2	0
UKE1	East Riding & North Lincolnshire	0.0	3	1
UKE2	North Yorkshire	0.0	75	68
UKE3	South Yorkshire	0.0	3	7
UKE4	West Yorkshire	0.0	15	13
UKF1	Derbyshire & Nottinghamshire	0.0	32	25
UKF2	Leicestershire Rutland & Northants	0.0	20	2
UKF3	Lincolnshire	0.0	13	2
UKG1	Herefordshire Worcestershire & Warks	0.0	19	5
UKG2	Shropshire & Staffordshire	0.0	48	25
UKG3	West Midlands	0.0	2	0
UKH1	East Anglia	0.0	41	6
UKH2	Bedfordshire & Hertfordshire	0.0	7	1
UKH3	Essex	0.0	17	1
UKI1	Inner London	0.0	0	0
UKI2	Outer London	0.0	2	0
UKJ1	Berkshire Bucks & Oxfordshire	0.0	15	2
UKJ2	Surrey East & West Sussex	0.0	30	4
UKJ3	Hampshire & Isle Of Wight	0.0	15	3
UKJ4	Kent	0.0	8	2
UKK1	Gloucestershire Wiltshire & North Somerset	0.0	62	9
UKK2	Dorset & Somerset	0.0	78	21
UKK3	Cornwall & Isles Of Scilly	0.0	93	9
UKK4	Devon	0.0	159	30
UKL1	West Wales & The Valleys	0.0	346	175
UKL2	East Wales	0.0	168	144
UKM1	North East Scotland	0.0	114	163
UKM2	Eastern Scotland	0.0	210	644
UKM3	South Western Scotland	0.0	209	397
UKM4	Highlands And Islands	0.0	180	2,046
	Antrim	0	43	116
	Armagh	0	30	19
	Down	0	20	60
	Fermanagh	0	28	52
	Londonderry	0	30	92
	Tyrone	0	48	126

Table 56 Release of land under Scenario 2 (red to white meat), with tillable land release maximised. All values are in kha.

NUTS 2 area code	NUTS 1 area description	Arable land used for forage maize	Potentially tillable grassland	Non-tillable grassland
UKC1	Tees Valley & Durham	1.6	39	7
UKC2	Northumberland And Tyne & Wear	2.0	104	20
UKD1	Cumbria	0.0	113	23
UKD2	Cheshire	5.0	18	2
UKD3	Greater Manchester	0.3	6	1
UKD4	Lancashire	1.6	32	12
UKD5	Merseyside	1.0	2	0
UKE1	East Riding & North Lincolnshire	23.3	5	0
UKE2	North Yorkshire	26.1	79	27
UKE3	South Yorkshire	4.8	3	0
UKE4	West Yorkshire	2.1	14	3
UKF1	Derbyshire & Nottinghamshire	21.8	33	7
UKF2	Leicestershire Rutland & Northants	63.2	34	0
UKF3	Lincolnshire	25.6	19	0
UKG1	Herefordshire Worcestershire & Warks	103.7	32	0
UKG2	Shropshire & Staffordshire	45.7	63	7
UKG3	West Midlands	2.8	3	0
UKH1	East Anglia	33.3	57	0
UKH2	Bedfordshire & Hertfordshire	17.8	11	0
UKH3	Essex	3.5	25	0
UKI1	Inner London	0.0	0	0
UKI2	Outer London	1.6	2	0
UKJ1	Berkshire Bucks & Oxfordshire	74.8	24	0
UKJ2	Surrey East & West Sussex	55.2	46	0
UKJ3	Hampshire & Isle Of Wight	23.8	19	0
UKJ4	Kent	44.2	16	1
UKK1	Gloucestershire Wiltshire & North Somerset	51.9	91	1
UKK2	Dorset & Somerset	21.0	99	6
UKK3	Cornwall & Isles Of Scilly	2.4	96	2
UKK4	Devon	2.0	176	5
UKL1	West Wales & The Valleys	5.9	287	64
UKL2	East Wales	18.6	173	65
UKM1	North East Scotland	12.0	121	11
UKM2	Eastern Scotland	41.8	209	105
UKM3	South Western Scotland	14.5	184	66
UKM4	Highlands And Islands	9.0	137	176
	Antrim	0	60	24
	Armagh	0	47	9
	Down	0	59	17
	Fermanagh	0	36	22
	Londonderry	0	47	15
	Tyrone	0	70	24

Annex 5 Worked example of allocation of grassland

England & Wales

This illustrates the application of the allocation of grassland to all the 5km^2 cells in England. The same procedure is applied to every grid.

Example 1

The census data on the 5km^2 (2500ha) grids shows for this example grid:

ha	Arable	Temporary grass	Permanent grass	Rough grazing	Woodland	Total	Forage maize
Census	1462	214	1020	333	27	3362	130

Note that the census will not include non-agricultural areas and urban land. In this example the area is greater than the total possible due to the location of the farmsteads.

The Land Cover 200 data indicates the use of the grid:

Arable	Temporary grass	Permanent grass	Rough grazing	Urban	Other	Total
44.1%	36.6%		3.0%	13.0%	3.3%	100.0%

There are 18 land classes in total. Grass is identified as managed grass but not identified as temporary or permanent. Grass shrub heath, heath grass, marsh rough grass and shrub heath are classified as rough grazing.

The Soils database indicates the soils have the following possible uses:

	AR	LE	PG	OT	
Soil	82.4%	0.0%	0.0%	0.0%	82.4%

Note that soils which are classified as AR can also be used for LE, PG and OT. LE soils can also be used for PG and OT and soils which are PG can also be used for OT.

In this case all soils are suitable for arable crops. The suitability analysis shows that the soils are *well suited* to arable crops.

Clearly the data from different sources do not exactly agree although they do not totally disagree. Thus 48% of the census area is arable versus the 44.1 in the land cover. The most difficult choice is rough grazing. In this case the census number is higher, though in many cases the reverse is true. We choose to standardise on accepting the Land Cover proportion and define the balance of the census rough grazing as permanent grass.

Using the soils data we determine the proportion of the permanent grass which is suitable for arable – in this case all of the soil.

The census data indicates the number of dairy beef and sheep animals in this grid, which are converted to Livestock Units(LU). This amounts to 1.41 LU/ha. Allocating sheep first to rough grazing and then the next quality of land until consumed, then beef to the next best land and finally the cows, all the grassland is allocated.

Finally applying the scenario of a 31% of the sheep, 36% of the beef and 60% of the dairy, we can calculate the land which is no longer required. This amounts to 52ha forage maize and 638 grassland which is well suited to arable plus 83ha of rough grazing,

	DairyLU	BeefLU	SheepLU	Fmaize	Suitable	Permanent Grass	Rough Grazing
Census	1898	293	77	130	1449	0	120
1.41 LU/ha	1342	207	54	130	1449	0	24
Sheep			**54**		**30**	**0**	**24**
Beef		**207**			**207**		
Dairy	**1342**			**131**	**1211**		
	Scenario				Released land, ha		
Sheep	31%			0	21	0	17
Beef	36%			0	133	0	0
Dairy	60%			52	485	0	0
				52	**638**	**0**	**83**

Example 2:

ha	Arable	Temporary Grass	Permanent Grass	Rough Grazing	Woodland	Total
Census	255	159	977	289	122	1692

Arable	Temporary Grass	Permanent Grass	Rough Grazing	Urban	Other	Total
8.6%	57.4%		19.1%	2.0%	12.9%	100.0%

This illustrates that whilst the data do not agree exactly, the general orders of magnitude do agree. Thus the arable is around 10% rather than the 45% of the previous example.

	AR	LE	PG	OT	
Soil	35.5%	4.0%	41.5%	0.0%	81.0%

In this case the soil which is capable of arable production is only marginally suited to arable cropping. There are 18 soils in the grid:

Soil name	% of grid	Use
ONECOTE	13.4316	PG
ESCRICK	8.172	AR
WILCOCKS	8.0588	PG
BROMYARD	6.5484	AR
ANGLEZARKE	5.99	PG
IPSTONES	5.3716	PG
MALVERN	4.67	PG
VERNOLDS	4.4544	AR
REVIDGE	3.9924	PG
EARDISTON	3.9072	AR
MIDDLETON	3.868	AR
NUPEND	3.764	AR
DAVIDSTOW	3.1132	LE
MORETONHAMPSTEAD	3.1132	AR
HOLLINGTON	0.9044	LE
HODNET	0.6884	AR
BROMSGROVE	0.5544	AR
NETCHWOOD	0.4592	AR

Applying the procedure we find that 27.4% of the 57.4% is suitable for arable crops (marginally) and 30% can only be grassland.

	DairyLU	BeefLU	SheepLU	Marginally Suitable	Permanent Grass	Rough Grazing
Census	44	497	840	511	557	355
1.21 LU/ha	36	411	694	511	557	71
Sheep			**694**	**66**	**557**	**71**
Beef		**411**		**411**		
Dairy	**36**			**36**		
	Scenario			Released land, ha		
Sheep	31%			46	384	49
Beef	36%			263	0	0
Dairy	60%			14	0	0
				323	**384**	**245**

Thus the land released is a combination of marginally suitable arable land, permanent grassland and rough grazing.

Scotland

The census data provides similar data on the area of cropping and the numbers of livestock which are converted to Livestock Units.

The soil data in Scotland is described in Annex 3. Classes 1 to 3 are suitable for arable cropping, and 4.1 is marginally suited (the equivalent of AR). Above this and is only suitable for grassland (PG) and rough grazing (OT).

As before land is progressively applied to arable, dairy, beef and sheep to determine the class of land currently being used by livestock.

Then as land is released by the scenarios, the quality of the land is determined.

Northern Ireland

Census data is known by district within region. Thus the area of arable crops, grassland, rough grazing and livestock units can be calculated.

However soils data for Northern Ireland relate to counties, but uses a similar grade system to England. Thus grades 1 to 3b are suitable for arable whilst grades 4 and 5 are only suitable for grassland. They applied pro rata to the district within the counties.

The soils are then as before applied progressively to arable, dairy, beef and sheep to determine the current allocation of soil to livestock. Then as land is released by the scenarios, the quality of the land is determined.

Beef sheep order of allocation

The grassland for beef and sheep can be allocated to the animals in a number of ways. Clearly sheep only are grazed on land which is unsuitable for other livestock such as high moorland and steeply sloping fields. Equally however sheep and beef cattle are often, but not always, grazed together on lowland farms. Grids may contain mainly or even only sheep, or mainly beef cattle. Some grids contain mainly rough grazing and others only arable quality grassland. Generally grids with mainly poor grass contain a higher proportion of sheep and vice-versa.

The worst grassland can be allocated to the sheep first, then the next to the beef, or the grassland can be allocated in proportion to the beef and sheep livestock units in the grid, or an in between system of sheep to rough grazing then the remainder in proportion.

To estimate the effect of these assumptions, the Scottish data was analysed by the two extreme methods of sheep first versus equal proportion.. The effect as expected is that only 80 kha of the worst grassland is allocated to beef compared to 400 kha respectively. The scenario of reduction in red meat was then applied and the result is shown below. The effect is very small (21 kha out of a total of 1400 kha) and confined to grass which is not suitable for arable cropping.

	Good for arable	Moderate for arable	Marginal for arable	Grass not for arable	Poor Grass	Very Poor grass	Grass sum
Sheep to poorest land first	43	135	91	115	278	745	1,407
Beef and sheep in census proportion to all grassland	43	133	91	116	289	767	1,438

This is partly due to the fact that changes to beef and sheep are similar in the scenarios. It would be of more importance where significantly different changes were made to beef and sheep. However it seems unreasonable to assume that large amounts of beef are found on rough grazing.

Annex 6 Agricultural land management practices

Dairy production

The UK is self-sufficient in milk for direct consumption, and about 90% self-sufficient for milk and milk products in terms of milk commodity. Net imports of butter and cheese are partially off-set by net exports of cream and milk powder. Dairy farming is the largest single sector of agriculture in the UK, representing about 22% of UK agricultural production by value. There are approximately 30,000 dairy farmers in the UK and the main milk producing regions are Cumbria, Cheshire and Devon in England.

The number of dairy farms in England has fallen dramatically in the last twelve years from 22,000 dairy farms in England in 1996 to just over 10,000 dairy farms in February 2008. However, changes in breeding and animal management have increased the annual milk production from 4,998 litres per cow in 1989 to 6,916 litres per cow in 2007, and since farmers now require fewer cows to produce the same amount of milk, numbers have fallen by 20% since 1996. About a quarter of the calves are required for replacement of the cow and most dairy farms sell the surplus calves for beef production or breeding purposes. Geographically, dairy farms are frequently found in areas such as the western UK where grass production is favoured by higher rainfall and a milder climate[159].

Milk production is generally associated with intensive grassland management with higher rates of nitrogen fertiliser applied compared with that for other uses of grassland[160]. However about 25% of milk produced in England and Wales comes from the Less Favoured Areas[161]. The general trend within the UK dairy industry in recent years has been towards fewer, larger dairy farms with increasing herd sizes dominated by Friesian/Holstein cows. Dairy farms in the LFA tend to be smaller than the UK average but have adopted similar farming practices to non-LFA farms, improving grassland management and seeking to increase milk yields.

The industry is based on the delivery of 13,208 million litres of milk from 1.8 million cows[162] (in 2009). Output is capped by the quota system (14446 million litres in 2002/3) but has been below this level for many years. Due to low milk prices, output has dropped by about 1,000 million litres over the last 10 years (7%). Year-on-year trends are characterised by a decreasing number of cattle, on fewer farms, producing a roughly equivalent output of milk. The distribution of the herd in 2006, including heifers was set out by Foster et al.[163].

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[159] The Dairy Supply Chain Forum 2008. The Milk Roadmap.

[160] Defra 2007. British Survey of Fertiliser Practice. Fertiliser use on farm crops for crop year 2006. Defra, York, UK.

[161] Defra 2004. An assessment of the impacts of hill farming in England on the economic, environmental and social sustainability of the uplands and more widely. A study for Defra by the Institute for European Environmental Policy, Land Use Consultants and GHK Consulting.

[162] Defra 2010. Agriculture in the United Kingdom 2009.

[163] Foster, C., Audsley, E., Williams, A., Webster, S., Dewick, P. and Green, K. 2007. The environmental, social and economic impacts associated with liquid milk consumption in the UK and its production. A review of literature and evidence.

Table 57 The distribution of the herd in 2006,

	Cows	In-calf heifers	Not in-calf heifers
England	1,290,230	278,571	246,669
Wales	280,968	62,269	56,143
Scotland	198,940	44,160	38,130
Northern Ireland	295,951	63,475	No data

The dairy cow population have dropped from 2.4 million to 1.8 million over the same period (ca. 25%). This is part of a trend that goes back to the early 1980 when 3.3 million dairy cows with an average annual yield of 4,793 litres produced 15,974 million litres. The increase in milk yield per cow is largely due to the adoption of Holstein breeding stock combined with the more intensive feeding that these animals respond to. Holsteins are larger animals than the traditional British Friesian producing more milk but the breed is less suited to beef production. The switch to Holstein Friesians was also associated with a decline in the longevity of cows in the herd with lactation number declined from about 5 in 1980 to 3.5 today. This means a higher turnover of cows which requires a larger number of heifers to replace the herd. It also means a greater output of beef from cull cows per milking cow. However, across the industry there is a widespread variation in culling with between 18-35% of the cows being removed per year[164]. Current dairy herd planning assumptions are an average herd life of 3.5 lactations with 50% of the matings to a dairy sire and 50% to a beef sire[165].

Dairy cattle typically enter the milking herd at about two years of age, having been mated at about 14 months. In LCA terms, the rearing of dairy heifers is similar to that of the raising of other stock derived from the dairy herd. Within the milking herd, cows receive 1 to 2 tonnes of concentrate feedstuffs per year and otherwise feed mainly on grass and grass silage. Maize silage makes up 20 – 25% of forage intake of high yielding herds with the higher proportions used for higher yielding autumn calving cows. Concentrate feeds include soy for high quality protein, cereals and a wide range of co-products of crops such as rapeseed meal, citrus pulp, brewers' grains and wheatfeed.

The dairy sector is closely linked to the beef sector with the about half of the animals in the rest of UK cattle herd originating from the dairy sector. Previous work[166] estimated that the annual output of calves per 1000 high yielding dairy cows with longevity of 3 lactations is as follows: female dairy 307; male dairy, 320; female beef cross, 111; male beef cross, 116.

Even though 25% of production comes from Less Favoured Areas (LFA), dairy farming is generally associated with intensive production on good quality grassland. The use of nitrogen fertiliser is significantly higher than for other types of grassland farming. The dairy herd is responsible for 34% of ammonia emissions from livestock[167].

Beef production

The Red Meat Industry Forum provides an overview of beef production in the UK.[168] The UK cattle herd of about 10.1 million produces about 850,000 tonnes of beef per year. About half of this is derived from calves reared for beef from the dairy herd, with some from culled dairy cows. The other half originates from calves

[164] http://www.dairyco.org.uk/farming-info-centre/health--welfare/cow-culling.aspx, accessed 27/07/2010

[165] Agro Business Consultants (2010) The Agricultural Budgeting and Costing Book, 70th Edn., May 2010, Agro Business Consultants: Melton Mowbray,474pp, see page 65,

[166] Williams, A., Audsley, E. and Sandars, D. 2006. Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Defra project report IS0205.

[167] Misselbrook, T., Chadwick, D., Chambers, B.J., Smith, K.A., Williams, J. 2008. Inventory of ammonia emissions from UK agriculture. Defra project AC0112

[168] http://www.redmeatindustryforum.org.uk/supplychain/BeefProduction.htm

reared for beef from 1.6 million beef suckler cows. Suckler cows are animals that are kept specifically for the purpose of breeding and rearing cattle for beef production (as opposed to producing milk/dairy products). Suckler cows range from traditional British breeds well adapted to UK conditions (and renowned for high quality beef) to heavy fast growing, slow maturing animals derived from continental Europe. The combination of fast growth and late maturity of Continental breeds such as the Charolais result in heavy lean animals, with high yields of beef (per tonne carcase).

Dairy cows are crossed with dairy bulls to produce replacement heifers for the dairy herd. Half of the calves born are male and can be used for beef production. These represent an extreme type for beef production having a dairy genetic background. These animals are poorly conformed for beef production. This means the meat yield per tonne carcase is relatively low but this is not detrimental to eating quality. With a replacement rate of 18-35%, between half and two thirds of matings must be to dairy bulls (See subsection 0 Dairy production). The remaining half to a third is to beef bulls producing 'dairy x' calves.

About half of the calves reared for beef originate from the dedicated 'suckler' beef herd. While the dairy herd is fairly uniform in terms of genetics and management, the beef herd is very diverse. It ranges from specialised continental beef breeds on lowland farms with calves reared to heavy weights on grass and cereals, to upland based herds whose calves are sold on to lowland farms for finishing. Calves are weaned at 6 – 10 months and reared on in a wide range of systems.

Production in all cases is based on cows producing one calf per year. Twins occur occasionally. Dairy calves are usually withdrawn from the mother within 2 to 3 days of birth. The calf is then either adopted by a multiple suckler cow, or fed artificially. Artificially fed animals are transferred to other feed early – at about 12 weeks, while calves reared by suckling are weaned at 6 – 10 months when their digestive tracks are fully mature.

In all cases, finishing can be grass/silage or cereal based, or a mixture of these. Grass based diets are the most common in the UK. Summer grazing cattle on grass pasture often supplies all of the needs of the growing animal. Cereal based concentrate rations are used to supplement grass particularly in winter and/or to supplement forage in the finishing phase. Various co-products of the food industry are used, including bakery waste and food that has exceeded its sell-by date. Concentrate feeding is required more for the successful finishing of cattle derived from the dairy herd, especially pure-bred Holstein Friesian males, or Holstein x Continental males.

Cereal based feeding systems are used for bull beef production or where a rapid turnover finishing of stock is required. Cereals include barley, wheat and oats supplemented by soy. Some forage is required to prevent digestive disorders hindering production. This is often supplied in the form of cereal straw.

Table 58 Summary of UK beef production systems

Diet type	Breed type/sex	Age of slaughter
Intensive cereal beef	Continental and dairy breeds/bulls	12 months
Intensive grass silage beef	Dairy cross and beef breeds/bulls & steers	16 months
Mixed grass/concentrate fed beef	Dairy cross / Steers & Heifer	18-20 months
Mixed grass/concentrate fed beef	Dairy cross & beef / Steer	22-26 months
Forage based suckler beef	Beef breeds / Steers and Heifers	18-20 months

So the beef industry is complex rearing a wide range of animals on different feeding systems in a wide range of environments. To model resource use and emissions, we have developed a model of UK beef production. The withdrawal of the 30 month scheme allowed animals over 30 months to be re-admitted to the food chain. This boosted beef supplies in 2005 – 2006. Beef production capacity is now declining. The National Beef Association has drawn attention to recent trends in dairy cow matings that signal a decline in UK beef production capacity[169].

[169] National Beef Association 2009. Substantial drop in dairy beef production inevitable. Factsheet NBA002.

Sheep production

The sheep sector produced 314,000 tonnes of carcase meat in 2009 from a production base of 15 million ewes. This carcase meat output came from the slaughter of 14 million lambs and 2 million other sheep, mainly culled ewes.

The UK sheep sector is structured to exploit the range of UK land resources on hills, uplands and lowlands. This stratification is an adaptation to UK land that has evolved over centuries. It is based on a network of pure and cross-bred flocks. Defra[170] provides a summary of the system. Ewes of pure-bred hill breeds well adapted to hill conditions are bred with pure-bred hill rams to produce hill-based lambs. These lambs are transferred to lowland farms in autumn for finishing, when they reach about 25 kg. After three or four crops of lambs, the breeding ewes move down to the uplands and are mated to the Blue-faced Leicester rams to produce the prolific crossbred mule ewes for lowland farms. These female progeny are transferred to lowland where they are mated with Suffolk/Texel and similar type rams for prime lamb production. This unique UK system of breeding ewes for lowland production being produced in the upland areas from hill bred stock allows the lowlands to be used only to produce the maximum amount of prime lamb.

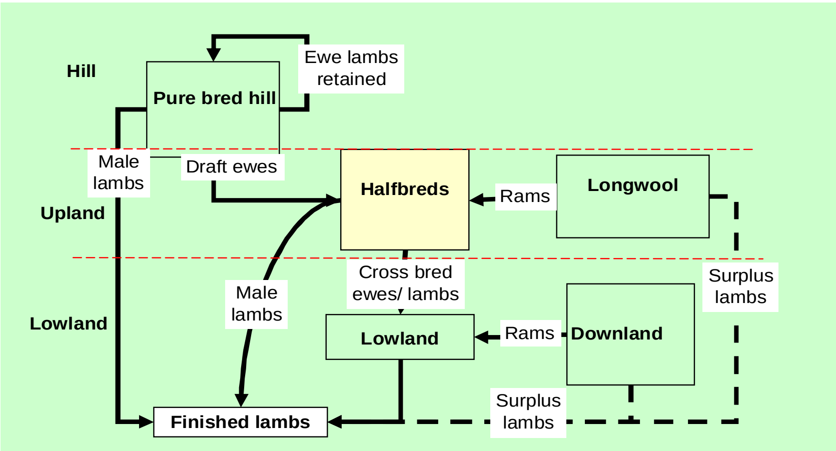

Figure 19. The breeding structure off the UK sheep industry in relation to altitude of land used.

Sheep production peaked in 1993 at just over 400,000 tonnes and has since declined by 22%. The breeding flock declined by about 18% over the same period (based on data provided by Pollott and Stone[171]).

The Red Meat Industry Forum provides a good overview of sheep production in the UK[172]. The following is a summary of that document.

There are approximately 7900 holdings with breeding ewes applying different systems of production to suit the local geography and climate. The breeds used and their position in the stratified breeding system are set out in Table 59**Fehler! Verweisquelle konnte nicht gefunden werden.**. There are about 70 recorded pure-breeds and more than 300 cross-bred types, most of which are named by their regional origin. Eight pure-breeds account for about half the total breeding flock, and cross breeds from these account for a further quarter. The oestrus of the ewe is regulated by changes in day length and ewes are mated during the autumn, with a gestation period of 21 weeks. Lambing therefore coincides with the growth of new grass during the spring. However, to meet demand for the earlier Easter market some producers choose to lamb during December/January by bringing the mating period forward to July/August.

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[170] Defra 2004. An assessment of the impacts of hill farming in England on the economic, environmental and social sustainability of the uplands and more widely. A study for Defra by the Institute for European Environmental Policy, Land Use Consultants and GHK Consulting.

[171] Pollott, G.E. and Stone, D.G. 2004. The breeding structure of the British sheep industry. Defra.

[172] The Red Meat Industry Forum. Introduction to sheep production in UK. http://www.redmeatindustryforum.org.uk (accessed 19 May 2010).

Table 59 Stratified sheep breeding system in Britain

<table>
<tr><td colspan="5">GB Integrated sheep breeding system</td></tr>
<tr><td>Hill flocks</td><td>Upland flocks</td><td colspan="3">Lowland flocks</td></tr>
<tr><td>Purebred ewes from hill flocks</td><td>X Purebred longwool rams</td><td>= Cross bred ewes</td><td>X Purebred lowland rams (terminal sires)</td><td>= End product</td></tr>
<tr><td>Cheviot</td><td>Border Leicester</td><td>Scottish half bred</td><td rowspan="5">Suffolk, Charolais, Texel, or other terminal sire</td><td rowspan="5">Finished lambs</td></tr>
<tr><td>Scottish Blackface</td><td rowspan="2">Border Leicester/ Bluefaced Leicester</td><td>Mule</td></tr>
<tr><td>Welsh Mountain</td><td>Greyface</td></tr>
<tr><td rowspan="2">Swaledale</td><td>Teeswater</td><td>Welsh Half-Bred</td></tr>
<tr><td>Bluefaced Leicester</td><td>Mule</td></tr>
</table>

Most flocks are brought indoors or to some sheltered fields close to lambing for management, monitoring and postnatal care. If lambing takes place later in the spring, ewes and lambs are then turned out to grass within a day or two if weather conditions are favourable. Lactating ewes, especially ewes with twins, require either a good supply of grass or supplementary feeding to ensure lambs grow well. On average a ewe raises 1.1 lambs each year. Most male lambs are castrated.

From about 3-4 weeks old lambs supplement their milk diet with either grass or concentrates. About 50 per cent of lamb production is from lowland flocks born in early spring which are finished and sold from the ewe. Strong single lambs from early lambing flocks can be weaned from two months, fed supplementary feed and finished for market at between 10 and 12 weeks old.

In an integrated system a farm will have a breeding flock, and rear the lambs for slaughter. In integrated lowland systems lambs are usually weaned at three to four months old and finished primarily on grass. Lambs in upland flocks tend to be weaned later, from five months, and tend to be sold as 'store' lambs. These lambs are then usually kept on lowland farms over the autumn and winter months and finished on grass, arable stubble, kale and feed. When they reach an appropriate weight they are sold at auction or directly to an abattoir. UK lamb is available throughout the year as follows:

- Easter lamb: Born in December/January on lowland farms, reared intensively for 10-16 weeks (including using concentrate feeds), sold in March to May.
- Summer lamb: Born in spring on lowland farms, ewes and lambs grass-fed, sold in June/October.
- Autumn lamb: Born in spring on upland and hill farms, sold in November/December following intensive feeding on concentrates or lowland grass.
- Hoggets: Generally from hill or upland flocks, over-wintered on lowland farms on grass, forage and concentrates.

Pigmeat production

UK pig production declined by about one third between 2000 and 2005. Production has now stabilised at 700,000 tonnes per annum. 400,000 sows are the basis of this production. The Red Meat Industry Forum summarises how pigs are produced[173]

[173] The Red Meat Industry Forum. Introduction to pig production in UK. (accessed 19 May 2010) http://www.redmeatindustryforum.org.uk

Pig production in the United Kingdom is concentrated in large herds with around 80 per cent of pigs kept in herd sizes of over 1000 animals. The national breeding herd has contracted over the last 10 years but output has declined to a lesser extent as the number of pigs finished per sow and the daily liveweight gain have both improved with genetics and improved production techniques.

Pigs tend to be kept in units which specialise in one particular aspect of the pig production system i.e. breeding, rearing, growing or finishing units. In 1999, a ban on sow stalls and tethers in response to demands from consumers insisting on higher levels of animal welfare was introduced in the UK in advance of any other EU country. Breeding stock and technology have been developed for systems that allow for loose housing of groups of sows in straw yards. The introduction of new welfare legislation also led to an increase in the number of outdoor breeding units which had a reduced capital investment requirement.

There are 13 established pedigree pig breeds within the UK herd. The most popular are British Landrace and Large White. Hybrid vigour is achieved when a Landrace/Large White crossed female is bred with either a purebred Landrace or Large White, resulting in an increased number of stronger faster-growing piglets. A Large White sire produces fast growing lean carcases for fresh pork production whilst the demand for bacon carcases has led to the development of terminal sire Landrace lines. Duroc crosses are used extensively in outdoor pig breeding units producing offspring better able to handle UK weather conditions, winter and summer.

Replacement females to the breeding herd can either be home bred, bought as weaner gilts at 30kg (or 70 days old) or bought at 150 days old (or 100kg). Throughout her useful productive life a sow will typically produce 6 litters in total. The gestation period is 115 days (3 months, 3 weeks and 3 days).

The average litter size is 11.9 piglets, the average number reared per litter is 9.8 piglets. Sows rear 21 piglets per year on average. A sow in full milk production requires 8 to 10 kg of an energy and protein rich diet. Younger pigs (weaners) are traded between breeding units and finishing units. This would normally take place when they are around 7 kg or 35 kg liveweight. The majority of male pigs produced in Britain for meat production are not castrated.

Feed costs make up 70 per cent of the production costs within the growing and finishing stage of pig production. Normally pig rations comprise cereals, protein, minerals and vitamins in a compound form. Various co-products of the food industry are used, including bakery waste and food that has exceeded its sell-by date. The target is to achieve 100 kg liveweight at 140 days old at a food conversion ratio of 2.4 kg feed intake to 1 kg liveweight gain.

The majority of commercially produced pigs sold directly to abattoirs are valued on a deadweight basis when they have reached a specific weight. The exceptions to this are cull sows and boars (breeding animals that are no longer commercially viable).

Poultrymeat production

The UK is a major producer of poultrymeat and this sector expanded rapidly during the 1990s in response to increasing demand. This production is dominated by 800 million chickens, each producing on average a 2.2 kg carcase at about 43 days of age. Apart from free-range production which accounts for less than 1%, production is highly specialised in large production units with highly regulated housing environments and feeding regimes. Three generations of breeding stock are required to produce the final generation. One breeding hen produces about 345 eggs per year so the resource cost of this breeding is very low.

Poultrymeat production is very efficient. Poultry have a feed conversion efficient of about 2:1. This means only about 2 kg of feed are required for each kg liveweight gain. The feed is made up mainly of cereals and a relatively large supplement of soy meal (about 25%).

Egg production

Like poultrymeat, there are three generations of breeding stock. The UK egg industry is based on about 27 million hens producing 9.4 billion eggs. The egg industry also produces about 55,000 tonnes of spent hen poultrymeat. There are three production systems used: free-range, barns and caged flocks. Caged hens produce more eggs per kg feed compared with free-range and barn housed hens. It takes about 150g of a feed based on wheat and soy to produce one egg.

Cereal production

Crop production in the UK is dominated by cereal crops: wheat, barley and oats. Cereal crops are well adapted to the UK climate and soils. UK yields are very high by world standards. The UK produced 21 M t in 2009 and is more than self-sufficient. Exports exceed imports. The 21 M t produced comprises: wheat, 14.9 M t from 1.8 million ha; 5.5 M t of barley from 1 million ha; and 0.5 M t of oats from 91,000 ha.

About half of the wheat crop is used for animal feed, the other half for flour (41%), seed (2%) and other uses such as distilling. Almost two thirds of the barley crop is used for animal feed, the balance is mostly used for beer and distilling. Two thirds of the oat crop is used for human consumption.

Most cereal crops are sown in September and October using a range of cultivation techniques. Rotations vary, but typically winter wheat and barley are rotated with autumn sown oilseed rape giving a system dominated by high yielding autumn sown arable crops. Specialisation has reduced the use of temporary grass leys in the rotation as well as spring sown crops. Spring sown sugar beet and potatoes are exceptions to this.

The use of fertiliser nitrogen is the most important issue from a resource use and emissions viewpoint. About 180 kg N/ha is applied to winter wheat for feed purposes with an additional 40 kg applied to winter wheat for bread-making. Protein concentration and quality are important determinants of the quality of the flour and so this additional nitrogen is used to support higher protein levels in the grain destined for bread-making. About 150 kg N are applied to winter barley for feed purposes. About 20 kg less is applied to malting barley to keep help reduce protein levels in the grain, which is a malting quality criterion. About 100 kg N are applied to spring sown barley.

In addition to these fertiliser applications, like all crops, cereals must be supplied with adequate potassium and phosphorus. Sulphur is also increasingly applied. Cereals are also treated with pesticides. Molluscicides are used in wet in some years to control slugs in autumn, at least one herbicide is used (usually in autumn), one or two insecticide applications, and one to three fungicide applications.

Oilseed rape

The UK produces 1.9 M t from about 0.75 million ha. The average yield is 3.4 tonnes of rapeseed per ha. From a resource use and LCA viewpoint, the production of oilseed rape is similar to winter wheat. About 200 kg N [Fertiliser]/ha is applied. The levels of pesticide use are similar to winter wheat. The recovery of nitrogen in the harvested seed is much lower than for cereals and much of the crop nitrogen is returned to the soil. This leads to losses and also, along with the reduction of cereal diseases, to increases in the yield of subsequent cereal crops, usually winter wheat.

Sugar beet

The UK is about two-thirds self-sufficient in sugar. UK sugar is provided by 120 ha of sugar beet yielding about 10 tonnes refined sugar per ha (70 tonnes of sugar beet/ha). Sugar beet is therefore a very productive crop. It is grown in the eastern side of England only on good arable soils. Sugar beet is harvested in September to November and usually followed by winter wheat or spring barley, depending on the opportunity to sow winter wheat after harvest.

Potatoes

6.4 M t potatoes were produced on 149,000 ha in 2009. This production makes the UK 84% self-sufficient in potatoes. As with sugar beet, production is concentrated on the best soils. The position in the rotation is similar to sugar beet. Cultivation is intensive. Pesticides are also intensively used, mainly against fungal diseases and slugs.

Peas and beans

These are pulse crops harvested dry using combine harvesters, i.e. as with cereals. In 2009, they comprised 190,000 ha beans that produced 722,000 tonnes and 28,000 ha peas that produced 141,000 tonnes. Beans are sown in autumn and spring while peas are spring sown only. These legume crops are significant in resource terms in a number of respects: they fix nitrogen and so require no fertiliser nitrogen. They supply nitrogen to subsequent crops and are also a ‘break’ crop providing a disease free entry for cereals. Peas are used for human consumption and animal feed, while beans are largely used for animal feed. As protein rich pulses, they substitute partly imported soy. Pesticide use is generally low.

Field fruit

UK fruit production is based on 18,000 ha of orchards and 10,000 ha of soft fruit (e.g. strawberries). Orchard production dropped from about 28,000 ha in the mid 1990s to about 18,000 in 2005. All these fruit crops are perennial and management varies greatly. Scotland is renowned for raspberry and black current production.

Most of the remaining fruit is in England. The UK is only 12% self-sufficient in fruit. UK production was 415,000 tonnes in 2009, out of a total consumption of 3.5 million tonnes.

Field vegetables

This category of produce covers a wide range of crops including root vegetables, cabbage, broccoli, cauliflowers, lettuce, onions and leeks. The UK is 59% self-sufficient in vegetables producing 2.6 M t from 123,000 ha. This includes 1,000 ha of protected crops, for example tomatoes and mushrooms. Production practices are diverse but generally characterised by the use of the highest quality land, high rates of nitrogen application and some irrigation.

Annex 7 Detailed tables of land use for each scenario

Table 60 Land requirements for food consumption in the UK under Scenario 1: 50% reduction in livestock product consumption with Uniform Land Release (in kha)

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor grass	Very poor grass	All qualities
Arable crops	2,310	981	3,292						2,310	981				
Paddy rice		173	173							173				
Horticultural crops	121	68	189						121	68				
Orchards	29	1,481	1,510						29	1,481				
Plantations		739	739							739				
Dairy				212	55	313	371	144	1,040	55	163	23	1	
Beef				104	58	207	395	174	879	58	265	248	259	639
Sheep				17	6	71	104	62	254	6	123	229	1,009	61
Poultrymeat				150	246				150	246				
Pigs				95	235				95	235				
Eggs				71	75				71	75				
Totals	2,460	3,442	5,902	649	674	591	870	380	4,949	4,116	551	500	1,269	700

OS = Overseas

Table 61 Land requirements for food consumption in the UK under Scenario 1: 50% reduction in livestock product consumption with maximum release of low quality land (mainly grassland) (in kha)

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor grass	Very poor grass	All qualities
Arable crops	2,310	981	3,292						2,310	981				
Paddy rice		173	173							173				
Horticultural crops	121	68	189						121	68				
Orchards	29	1,481	1,510						29	1,481				
Plantations		739	739							739				
Dairy				212	55	485	562	0	1,259	55	0	0	0	
Beef				104	58	573	668	0	1,345	58	0	0	0	639
Sheep				17	6	233	324	60	634	6	0	0	0	61
Poultrymeat				150	246				150	246				
Pigs				95	235				95	235				
Eggs				71	75				71	75				
Totals	2,460	3,442	5,902	649	674	1,291	1,554	60	6,014	4,116	0	0	0	700

OS = Overseas

Table 62 Land requirements for food consumption in the UK under Scenario 1: 50% reduction in livestock product consumption with maximum release of tillable land (in kha)

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor grass	Very poor grass	All qualities
Arable crops	2,310	981	3,292						2,310	981				
Paddy rice	0	173	173							173				
Horticultural crops	121	68	189						121	68				
Orchards	29	1,481	1,510						29	1,481				
Plantations	0	739	739							739				
Dairy				206	55	71	421	240	938	55	272	38	2	
Beef				101	56	0	0	116	217	56	685	692	722	639
Sheep				16	5	0	0	4	20	5	11	528	3,301	61
Poultrymeat				150	246				150	246				
Pigs				95	234				95	234				
Eggs				71	75				71	75				
Totals	2,460	3,442	5,902	639	671	71	421	360	3,951	4,113	968	1,257	4,025	700

OS = Overseas

Table 63 Land requirements for food consumption in the UK under Scenario 2: Red to white Meat with uniform land release (in kha)

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor Grass	Very Poor grass	All qualities
Arable crops	1,756	722	2,478						1,756	722				
Paddy rice		130	130							130				
Horticultural crops	102	47	148						102	47				
Orchards	19	1,050	1,069						19	1,050				
Plantations		739	739							739				
Dairy				343	92	521	618	240	1,723	92	272	38	2	
Beef				70	39	144	275	121	610	39	184	173	180	1,291
Sheep				11	3	49	72	43	176	3	85	159	701	
Poultrymeat				604	991				604	991				604
Pigs				382	945				382	945				382
Eggs				118	125				118	125				
Totals	1,876	2,688	4,565	1,528	2,196	715	965	404	5,488	4,884	542	370	883	2,277

OS = Overseas

Table 64 Land requirements for food consumption in the UK under Scenario 2: Red to white meat with maximum release of low quality land (mainly grassland) (in kha)

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor Grass	Very Poor grass	All qualities
Arable crops	1,756	722	2,478						1,756	722				
Paddy rice		130	130							130				
Horticultural crops	102	47	148						102	47				
Orchards	19	1,050	1,069						19	1,050				
Plantations		739	739							739				
Dairy				342	91	521	584	240	1,688	91	272	38	2	
Beef				71	40	575	235	0	881	40	0	0	0	444
Sheep				11	4	233	208	0	452	4	0	0	0	42
Poultrymeat				604	991				604	991				
Pigs				382	945				382	945				
Eggs				118	125				118	125				
Totals	1,876	2,688	4,565	1,528	2,196	1,330	1,027	240	6,001	4,885	272	38	2	486

OS = Overseas

Table 65 Land requirements for food consumption in the UK under Scenario 2: Red to white meat with maximum release of tillable land (in kha)

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor grass	Very poor grass	All qualities
Arable crops	1,756	722	2,478						1,756	722				
Paddy rice		130	130							130				
Horticultural crops	102	47	148						102	47				
Orchards	19	1,050	1,069						19	1,050				
Plantations		739	739							739				
Dairy				343	92	521	584	240	1,689	92	272	38	2	
Beef				70	39	0	0	18	88	39	440	692	722	444
Sheep				11	3	0	0	2	13	3	5	110	3,301	42
Poultrymeat				604	991				604	991				
Pigs				382	945				382	945				
Eggs				118	125				118	125				
Totals	1,876	2,688	4,565	1,528	2,196	521	584	260	4,770	4,884	717	840	4,025	486

OS = Overseas

Table 66 Land requirements for food consumption in the UK under scenario 3: 50% Reduction in white meat consumption with uniform land release (in kha)

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor grass	Very poor grass	All qualities
Arable crops	1,897	794	2,691						1,897	794				
Paddy rice		143	143							143				
Horticultural crops	112	51	163						112	51				
Orchards	21	1,136	1,157						21	1,136				
Plantations		734	734							734				
Dairy				354	92	521	618	240	1,734	92	272	38	2	
Beef				288	160	575	1,101	484	2,448	160	738	692	722	1,776
Sheep				47	15	233	339	202	821	15	401	749	3,301	168
Poultrymeat				208	342				208	342				
Pigs				132	119				132	119				
Eggs				118	125				118	125				
Totals	2,030	2,858	4,888	1,147	852	1,330	2,057	926	7,489	3,711	1,412	1,478	4,025	1,944

OS = Overseas

Table 67 Changes in land use requirements for food consumption in the UK under Scenario 1: 50% reduction in livestock product consumption with uniform land release (in kha). Note that positive values indicate land released and negative values an increased demand.

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor grass	Very poor grass	All qualities
Arable crops	-555	-259	-814						**-555**	**-259**				
Paddy rice	0	-43	-43						**0**	**-43**				
Horticultural crops	-19	-21	-40						**-19**	**-21**				
Orchards	-10	-430	-441						**-10**	**-430**				
Plantations	0	1	1						**0**	**1**				
Dairy				142	37	209	247	96	**693**	**37**	109	15	1	0
Beef				184	103	369	705	310	**1,568**	**103**	473	443	463	1,137
Sheep				30	11	162	235	140	**568**	**11**	279	520	2,292	108
Poultrymeat				266	438	0	0	0	**266**	**438**	0	0	0	0
Pigs				170	417	0	0	0	**170**	**417**	0	0	0	0
Eggs				47	50	0	0	0	**47**	**50**	0	0	0	0
Totals	-584	-753	-1,337	839	1,054	739	1,188	546	**2,729**	**301**	861	978	2,755	1,244
OS = Overseas														

Table 68 Changes in land use requirements for food consumption in the UK under Scenario 1: 50% reduction in livestock product consumption with maximum release of low quality land (mainly grassland) (in kha). Note that positive values indicate land released and negative values an increased demand.

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor grass	Very poor grass	All qualities
Arable crops	-555	-259	-814						**-555**	**-259**				
Paddy rice	0	-43	-43						**0**	**-43**				
Horticultural crops	-19	-21	-40						**-19**	**-21**				
Orchards	-10	-430	-441						**-10**	**-430**				
Plantations	0	1	1						**0**	**1**				
Dairy				142	37	36	57	240	**474**	**37**	272	38	2	0
Beef				184	103	3	432	484	**1,103**	**103**	738	692	722	1,137
Sheep				30	11	0	15	142	**187**	**11**	401	749	3,301	108
Poultrymeat				266	438	0	0	0	**266**	**438**	0	0	0	0
Pigs				170	417	0	0	0	**170**	**417**	0	0	0	0
Eggs				47	50	0	0	0	**47**	**50**	0	0	0	0
Totals	-584	-753	-1,337	839	1,054	39	504	866	**1,664**	**301**	1,412	1,478	4,025	1,244
OS = Overseas														

Table 69 Changes in land use requirements for food consumption in the UK under scenario 1: 50% reduction in livestock product consumption with maximum release of tillable land (in kha). Note that positive values indicate land released and negative values an increased demand.

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor grass	Very poor grass	All qualities
Arable crops	-555	-259	-814						**-555**	**-259**				
Paddy rice	0	-43	-43						**0**	**-43**				
Horticultural crops	-19	-21	-40						**-19**	**-21**				
Orchards	-10	-430	-441						**-10**	**-430**				
Plantations	0	1	1						**0**	**1**				
Dairy				148	36	450	197	0	**795**	**36**	0	0	0	0
Beef				187	104	575	1,101	368	**2,231**	**104**	53	0	0	1,137
Sheep				31	12	233	339	199	**801**	**12**	391	221	0	108
Poultrymeat				266	438	0	0	0	**266**	**438**	0	0	0	0
Pigs				170	418	0	0	0	**170**	**418**	0	0	0	0
Eggs				47	50	0	0	0	**47**	**50**	0	0	0	0
Totals	-584	-753	-1,337	850	1,057	1,259	1,636	566	**3,727**	**304**	444	221	0	1,244
OS = Overseas														

Table 70 Changes in land use requirements for food consumption in the UK under scenario 2: red to white meat with uniform land release (in kha). Note that positive values indicate land released and negative values an increased demand.

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor grass	Very poor grass	All qualities
Arable crops	0	0	0						**0**	**0**				
Paddy rice	0	0	0						**0**	**0**				
Horticultural crops	0	0	0						**0**	**0**				
Orchards	0	0	0						**0**	**0**				
Plantations	0	0	0						**0**	**0**				
Dairy				11	-1	0	0	0	**11**	**-1**	0	0	0	0
Beef				218	121	432	826	363	**1,838**	**121**	554	519	541	485
Sheep				36	13	184	267	159	**646**	**13**	316	590	2,600	168
Poultrymeat				-187	-308	0	0	0	**-187**	**-308**	0	0	0	-604
Pigs				-117	-293	0	0	0	**-117**	**-293**	0	0	0	-382
Eggs				0	0	0	0	0	**0**	**0**	0	0	0	0
Totals	0	0	0	-39	-467	615	1,092	522	**2,190**	**-467**	870	1,109	3,141	-333
OS = Overseas														

Table 71 Changes in land use requirements for food consumption in the UK under Scenario 2: red to white meat with maximum release of low quality land (mainly grassland) (in kha). Note that positive values indicate land released and negative values an increased demand.

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor grass	Very poor grass	All qualities
Arable crops	0	0	0						**0**	**0**				
Paddy rice	0	0	0						**0**	**0**				
Horticultural crops	0	0	0						**0**	**0**				
Orchards	0	0	0						**0**	**0**				
Plantations	0	0	0						**0**	**0**				
Dairy				12	0	0	34	0	**45**	**0**	0	0	0	0
Beef				217	120	0	866	484	**1,566**	**120**	738	692	722	1,332
Sheep				36	13	0	131	202	**369**	**13**	401	749	3,301	126
Poultrymeat				-187	-308	0	0	0	**-187**	**-308**	0	0	0	0
Pigs				-117	-293	0	0	0	**-117**	**-293**	0	0	0	0
Eggs				0	0	0	0	0	**0**	**0**	0	0	0	0
Totals	0	0	0	-40	-468	0	1,031	686	**1,676**	**-468**	1,140	1,441	4,022	1,458
OS = Overseas														

Table 72 Changes in land use requirements for food consumption in the UK under Scenario 2: red to white meat with red to white meat with maximum release of tillable land (in kha). Note that positive values indicate land released and negative values an increased demand.

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor grass	Very poor grass	All qualities
Arable crops	0	0	0						**0**	**0**				
Paddy rice	0	0	0						**0**	**0**				
Horticultural crops	0	0	0						**0**	**0**				
Orchards	0	0	0						**0**	**0**				
Plantations	0	0	0						**0**	**0**				
Dairy				11	-1	0	34	0	**45**	**-1**	0	0	0	0
Beef				218	121	575	1,101	465	**2,359**	**121**	299	0	0	1,332
Sheep				36	13	233	339	201	**808**	**13**	396	639	0	126
Poultrymeat				-187	-308	0	0	0	**-187**	**-308**	0	0	0	0
Pigs				-117	-293	0	0	0	**-117**	**-293**	0	0	0	0
Eggs				0	0	0	0	0	**0**	**0**	0	0	0	0
Totals	0	0	0	-39	-467	808	1,473	666	**2,908**	**-467**	695	639	0	1,458
OS = Overseas														

Table 73 Changes in land use requirements for food consumption in the UK under Scenario 3: 50% reduction in white meat consumption with uniform land release (in kha). Note that positive values indicate land released and negative values an increased demand.

Item	Crops eaten by humans			Arable land used for concentrate feed production		UK land used for grass and forage production with some arable potential			**Total potentially and actually tillable land of all qualities (NB: equally weighted)**		UK non-arable grassland			Overseas grassland
	UK	OS	Total	UK	OS	Good for arable	Moderate for arable	Marginal for arable	**UK**	**OS**	Grass not fit for arable	Poor grass	Very poor grass	All qualities
Arable crops	-141	-72	-213						**-141**	**-72**				
Paddy rice	0	-13	-13						**0**	**-13**				
Horticultural crops	-10	-4	-14						**-10**	**-4**				
Orchards	-2	-86	-88						**-2**	**-86**				
Plantations	0	5	5						**0**	**5**				
Dairy				0	0	0	0	0	**0**	**0**	0	0	0	0
Beef				0	0	0	0	0	**0**	**0**	0	0	0	0
Sheep				0	2	0	0	0	**0**	**2**	0	0	0	0
Poultrymeat				208	342	0	0	0	**208**	**342**	0	0	0	0
Pigs				133	533	0	0	0	**133**	**533**	0	0	0	0
Eggs				0	0	0	0	0	**0**	**0**	0	0	0	0
Totals	-153	-170	-323	342	876	0	0	0	**188**	**706**	0	0	0	0
OS = Overseas														

Table 74 Breakdown of direct greenhouse gas emissions from primary production for all scenarios. Locations are the sources of GHG emissions, e.g. feed crops grown overseas for UK consumption are included in the overseas columns. All values are in kt CO_2e/year

	Arable crops			Horticultural crops			Milk		
Scenario	**UK**	**OS**	**Total**	**UK**	**OS**	**Total**	**UK**	**OS**	**Total**
Baseline	11,886	5,414	17,300	1,632	13,785	15,417	17,322	361	17,684
50% reduction in livestock with land release									
Uniform	15,843	7,330	23,173	2,267	18,192	20,459	10,393	217	10,610
Maximise release of grassland	15,843	7,330	23,173	2,267	18,192	20,459	10,407	218	10,625
Maximise release of tillable land	15,843	7,330	23,173	2,267	18,192	20,459	10,385	216	10,602
Red to white meat with land release									
Uniform	11,886	5,414	17,300	1,632	13,785	15,417	17,322	361	17,684
Maximise release of grassland	11,886	5,414	17,300	1,632	13,785	15,417	17,360	364	17,724
Maximise release of tillable land	11,886	5,414	17,300	1,632	13,785	15,417	17,309	361	17,670
50% reduction in white meat consumption with land release						13,026	5,952	18,978	1,759
Uniform	11,886	5,414	17,300	1,632	13,785	15,417	17,322	361	17,684
	Beef			**Sheepmeat**			**Pig meat**		
Scenario	**UK**	**OS**	**Total**	**UK**	**OS**	**Total**	**UK**	**OS**	**Total**
Baseline	7,920	4,936	12,856	4,018	465	4,483	2,685	2,469	5,155
50% reduction in livestock with land release									
Uniform	2,851	1,777	4,628	1,447	168	1,614	967	977	1,944
Maximise release of grassland	2,806	1,773	4,579	1,549	165	1,715	860	977	1,837
Maximise release of tillable land	2,879	1,778	4,658	1,533	168	1,700	860	977	1,837
Red to white meat with land release									
Uniform	1,980	1,234	3,214	1,005	116	1,121	3,464	3,934	7,398
Maximise release of grassland	1,926	1,230	3,156	1,076	115	1,191	3,464	3,934	7,398
Maximise release of tillable land	1,999	1,235	3,235	1,065	116	1,181	3,464	3,934	7,398
50% reduction in white meat consumption with land release									
Uniform	7,920	4,936	12,856	4,018	465	4,483	2,685	2,469	5,155
	Poultry			**Eggs**			**Total**		
Scenario	**UK**	**OS**	**Total**	**UK**	**OS**	**Total**	**UK**	**OS**	**Total**
Baseline	5,098	1,232	6,330	1,132	337	1,468	51,693	29,001	80,694
50% reduction in livestock with land release									
Uniform	1,835	594	2,429	679	202	881	36,282	29,456	65,738
Maximise release of grassland	1,835	594	2,429	679	202	881	36,246	29,451	65,697
Maximise release of tillable land	1,835	594	2,429	679	202	881	36,282	29,457	65,739
Red to white meat with land release									
Uniform	7,392	2,393	9,785	1,132	337	1,468	45,812	27,575	73,387
Maximise release of grassland	7,392	2,393	9,785	1,132	337	1,468	45,867	27,572	73,439
Maximise release of tillable land	7,392	2,393	9,785	1,132	337	1,468	45,878	27,575	73,453
50% reduction in white meat consumption with land release									
Uniform	2,549	744	2,544	1,132	307	1,247	51,693	29,001	80,694

Annex 8 Glossary

C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent (a measure of global warming potential)
GHG	Greenhouse Gas
GWP	Global Warming Potential
kcal	kilo calorie (known by dieters as a calorie)
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LFA	Less Favoured Area
LU	Livestock Unit (dairy cow = ca. 1)
LUC	Land Use Change
N	Nitrogen
N_2O	Nitrous Oxide
NH_3	Ammonia
NO	Nitrogen Monoxide
NO_3	Nitrate (more formally: NO_3^-)
PO_4	Phosphate (more formally: PO_4^{3-})