HOW LOW CAN WE GO?

An assessment of greenhouse gas emissions from the UK food system and the scope for reduction by 2050

Prepared by: Eric Audsley, Cranfield University, UK | Matthew Brander, Ecometrica, UK | Julia Chatterton, Cranfield University, UK
Donal Murphy-Bokern, independent researcher, Germany | Catriona Webster, Ecometrica, UK | Adrian Williams, Cranfield University, UK
January 2010

Cranfield University
Cranfield
Bedford MK43 0AL
UK

Murphy-Bokern Konzepte
Lindenweg 12
49393 Lohne
Germany

Ecometrica
Kittle Yards
Edinburgh EH9 1PJ
UK

Acknowledgements

This study was conducted for the WWF- UK and the Food Climate Research Network. We thank Mr Richard Perkins of WWF- UK and Ms Tara Garnett of the University of Surrey (FCRN) who initiated the work and provided valuable support. We also thank participants of in the project's conference on 22 June 2009 to who discussed preliminary results. In particular we want to acknowledge the following for written comments: Dr Havard Prosser, Welsh National Assembly Governmentfor Wales; Dorian Wynne Davies, Welsh National Assembly Governmentfor Wales; Ian Smith, the Royal Agricultural Society of England; Dr Doug Parr, Greenpeace UK; Mike Thompson, Secretariat to the Committee on Climate Change; Keith James, WRAP; and Dr Jeremy Wiltshire, ADAS.

Disclaimer

Copyright

Citation

Please cite this report as follows:

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

Correspondence

To correspond with the research team, please contact Dr Donal Murphy-Bokern (donal@murphy-bokern.com) who serves as corresponding author.

To correspond with the commissioning organisations, please contact Ms Tara Garnett of the FCRN (taragarnett@blueyonder.co.uk) or Mark Driscoll of WWF- UK (MDriscoll@wwf.org.uk).

Contents

Foreword

In 2008, the Food Climate Research Network (FCRN) published a report[1] which estimated that our consumption of food in the UK, from agriculture through to consumption, accounts for 19% of all the greenhouse gas (GHG) emissions generated through the goods and services we consume. It also argued that a reduction of up to 70% should be possible if we deployed a mix of technological improvements and changes in consumption. The report recommended that government should commit to reducing emissions by this amount, by 2050, and should set out a road map for how it intends to do so, stating what proportion would be achieved through technological and managerial improvements; and what from changes in the balance of what people eat.

This recommendation and WWF-UK's desire to understand what approaches are needed to reduce GHG emissions from food by 70% provided the impetus for WWF-UK and the FCRN to join forces in commissioning a piece of work that would: first, re-examine total food chain emissions taking into account emissions arising from agriculturally induced land use change; and, second, would investigate *whether* and if so *how* a 70% reduction in GHG emissions might be achieved.[2]. This report, undertaken by a team of researchers from Cranfield University, Ecometrica and Murphy-Bokern Konzepte, is the result.

We welcome it. This is an innovative piece of work. It has gone a considerable way towards expanding our understanding of the food chain and its impacts, and of highlighting the actions that may be needed both pre and post farm gate, both technological and behavioural, if we are to reduce emissions. By making, as it has had to, a great many fairly major assumptions as to both impacts (particularly with respect to land use) and as to what solutions might be possible in the coming years, it has also underlined how much we still don't know, and need to know.

We would like to draw attention to what we feel are the most striking aspects of this work.

A first key finding of the report is that a focus on one solution only will not lead to the reductions that are needed. Single measures, such as the elimination of meat and dairy products from our diet, or the decarbonisation of the supply chain, or the development of technologies to eliminate enteric methane emissions will not by themselves cut emissions by 70%. If the UK food chain is to make a proportionate contribution to the UK's target of reducing its overall emissions by 80% by 2050, then policy makers will need to put in place a combination of measures that change not only how we produce and consume food, but also what it is we consume.

A second important finding is that the report corroborates previous estimates, both by both the FCRN and Defra[3], of the contribution that food chain emissions (excluding land use change) makes to UK GHG emissions. They all fall between 152- and 159 MtT CO_2 eq - and put the food chain's contribution to overall UK consumption related emissions at approximately 20%.

Third is the striking and disturbing finding of this report with respect to land use. This, to our knowledge, is the first report that actually links changes in land use overseas to the food consumption patterns of one country. It finds that the inclusion of CO_2 emissions resulting from UK food-consumption induced land use change increases food's footprint by 50% and increases the contribution made by the food system to overall UK consumption related GHG impacts to 30%.

---

[1] Garnett, T. (2008). *Cooking up a Storm: Food, greenhouse gas emissions and our changing climate*. The Food and Climate Research Network, Centre for Environmental Strategy, University of Surrey.

[2] The full terms of reference for this research are provided in an appendix.

[3] Defra., 2008. *The environment in your pocket*, 2008.

The fourth striking conclusion, again, one that previous studies have also drawn, is the important contribution that meat and dairy products make to the overall footprint of the food chain. Emissions from livestock rearing alone account for over 57% of agricultural emissions. However, the inclusion of the land use change dimension – livestock are also responsible for more than three quarters of land use change emissions – adds even more emphasis to this conclusion.

Now that this report has been published, what next? We very much hope that others will use this report as a starting point for further exploration. The report has highlighted the important contribution played by land use change but clearly much more work needs to be done to increase our understanding of how these impacts play out both by commodity type and by agricultural system, as well as what we might need to do about them.

More work needs to be done to examine the trade offs and synergies with other social and environmental goals, notably with animal welfare and biodiversity. The report suggests that a lower-meat diet may, for example, have nutritional benefits, and it also looks at the potential knock-on effects of reduced livestock production from an industrial perspective. In the next phase of this work, WWF-UK and the FCRN intend to explore the broader social, ethical and environmental implications of different mitigation scenarios more closely.

Finally, we need to do more work to make change happen. We know enough now to conclude that the food system contributes very substantially to the problem of climate change. We also know enough about where and how the impacts arise to start doing something about them. Business-as-usual, and indeed even business-as-usual *lite*, are no longer options. We urge decision makers, in Ggovernment, the food industry and in the civil society sector to read this report, and to start thinking urgently about what they intend to do now to create a low GHG, sustainable food system for ourselves and for our children.

Summary

The overall aim of this study was to develop a set of scenarios that explore how greenhouse gas emissions from the UK food system may be reduced by 70% by the year 2050. The work is focused on all emissions from the supply chains and systems, not just the emissions from the UK food chain that arise in the UK. The study comprises an audit of the greenhouse gas emissions arising from the UK food economy and an examination of the scope for substantial reductions of these emissions.

The aim of this short and preliminary study conducted over a few months in 2009 is to stimulate debate about the full GHG impact of the UK food chain and the scope and options for reducing GHG emissions in line with wider climate change policy. The study is theoretical, in effect a thought experiment based on detailed inventories of emissions and the use of life cycle assessment (LCA) to examine the effects of measures. As far as we are aware, this is the first study to identify systematically the proportion of global land use change attributable to commercial agriculture linked to international trade. From this its estimates a proportion of global land use change emissions attributable to the UK food supply chain.

In considering this report, especially the scenarios for reductions, it is important to appreciate that we are not presenting a model or components of a model for working out the full effect of policy choices. This report identifies the size and sources of present emissions and identifies scenarios from these for reductions. Our scenarios set out possible directions of travel but we emphasise that the full real-world effect of greenhouse gas mitigation strategies will depend on the consequences of complex interactions that cannot be predicted here. Measures may open up opportunities for synergies in specific circumstances that will be revealed in the path to a low carbon food system giving additional benefits. Similarly, there are also risks that some measures may trigger economic responses with unintended consequences – for example a reduction in demand for ruminant products may cause the wide-spread abandonment of UK grazing land leading to increased imports from sources closer to active land use change.

Our estimates are based on the current UK population. This is expected to increase substantially by 2050. There will be a corresponding increase in food system emissions as the food economy grows. But from a global perspective, this is a growth in GHG emissions that will occur somewhere as the global population expands. By working on the basis of food system emissions in 2005, we have avoided confusion between the effectiveness of measures and trends in population. We also want to emphasise that our study is about the food system and therefore does not consider other agricultural land uses – for example for biofuels. However, our findings are applicable to the assessment of other uses of agricultural products.

Our main results are as follows:
Using a detailed inventory of emissions developed from LCA of a wide range of foods and processes, we estimate that the supply of food and drink for the UK results in a direct emission equivalent of 152 Mt CO_2. A further 101 Mt CO_2e from land use change is attributable to UK food. Total UK consumption emissions are estimated to be about 748 Mt CO_2e (excluding land use change).[4]. This means that direct emissions from the UK food system are about 20% of the currently estimated consumption emissions. When our estimate of land use change emissions is added to these, this rises to 30%.

In our work, we refer to direct emissions (excluding land use change emissions) as 'supply chain emissions'. Of these, about 58% arise from animal products which account for just over 30% of consumer energy intake. Two- thirds of food production emissions arise in the UK, 16%

[4] Garnett, T. (2008). *Cooking up a storm. Food, greenhouse gas emissions and our changing climate*. The Food and Climate Research Network.

arise outside Europe. Overall, about one fifth of direct UK food chain emissions occur outside the UK. If land use change emissions are taken into account, then about a half of total food system emissions arise outside the UK. So our results indicate that the food system in particular presents special challenges for climate change policy focused on domestic emissions and targets.

Taking the food chain as a whole, the supply chain emissions comprise (on a CO_2 equivalent basis) CO_2 – 102 Mt, CH_4 – 23 Mt, N_2O -– 21 Mt and refrigerants -– 6 Mt. 56%Fifty-six per cent of emissions arise from primary production (mainly farming) with CH_4 and N_2O accounting for more than half of these.

Land use change (mainly deforestation) driven by agricultural expansion is a hugely important source of emissions attributable to the global food system. The UK food system is part of the global food system contributing to the underlying forces. We estimate that global land use change emissions account for 40% of the emissions embedded in UK consumed food and 12% of emissions embedded in all UK consumption overall. This is based on the allocation of 2.1% of global land use change emissions to the UK food supply chain. This estimate is based on global average yields and land use. Managed and native grassland covers more land than arable crops. As a result, a large proportion (arounda three quarters) of LUC emissions is allocated to ruminant meat. We used alternative ways of allocating emissions which increase allocations to crops and reduce allocations to pasture, for example by allocating according to the economic value of crop and livestock farm outputs. This reduced emissions from beef and sheep/goat meat production from 77 Mt CO_2e to 42 Mt CO_2e out of a total of 102 and 86 Mt CO_2e respectively. So while allocation on economic value reduces the emissions attributable to beef and sheep meat, we are confident that the broad conclusions remain across the various allocation methods that could be used.

By assessing and attributing a proportion of land use change emissions to agricultural land use generally, our analysis draws attention to how consumers share responsibility directly or indirectly for the drivers behind land use change. We work on the premise that commodity markets are highly connected. Our analysis could lead to the conclusion that transferring consumption away from products directly linked to land use change to products from established farmland through product certification may displace rather than reduce the underlying pressures. This highlights the need for demand/market based approaches (e.g. product certification and moratoria) that counter the economic forces driving land use change, complementing ‘top-down’ government measures that seek to stop deforestation directly.

The supply chain measures we examined to achieve a 70% reduction in supply chain emissions range from the decarbonisation of energy carriers used in food production, and measures to increase farm efficiency, to technologies to reduce emissions of methane. Our results confirm that significant reductions will involve radical structural change throughout the supply chain from the generation of electricity through to the preparation of food. No single measure or the combination of similar measures is capable of reducing emissions by more than about half. The decarbonisation of the wider economy sought now by government policy by 2050 will reduce food supply chain emissions by about 50%.

A vegetarian diet (with dairy and eggs), a 66% reduction in livestock product consumption, and the adoption of technology to reduce nitrous oxide emissions from soils and methane from ruminants are measures that each haves the potential to reduce direct supply chain emissions by 15 - 20%. Modifying consumption has a particularly important role to play and consumption measures offer opportunities for reductions that could be implemented in the near future. In addition, consumption measures align with other public policies, particularly health. A switch from red to white meat will reduce supply chain emissions by 9% but this would increase our reliance on imported soy meal substantially. Our analysis indicates that the effect of a reduction in livestock product consumption on arable land use (which is a critical component of the link with deforestation) will depend on how consumers compensate for lower intakes of meat, eggs and dairy products. A switch from beef and milk to highly refined livestock product analogues such as tofu and *Quorn* could actually increase the quantity of arable land needed to supply the UK. In contrast, a broad-based switch to plant based products through simply increasing the intake of cereals and vegetables is more sustainable. We estimate that a 50% reduction in livestock production consumption would release about 1.6 Mha of arable land (based on the yield of crops supplying the UK) used for livestock feed production. This would be off-set by an increase of about 1.0 M ha in arable land needed for direct crop consumption (based on UK yields). In addition to the release of arable land, between 5 and 10 Mha of permanent grassland would be available for extensification, other uses, or re-wilding. Such changes would open up 'game-changing' opportunities but there needs to be careful assessment made in the development policy if unintended consequences are to be avoided. A contraction in the livestock sector that might follow a significant change in consumption could trigger a collapse of livestock production in the UK. The consequences for the emissions from the UK food chain would then depend on developments elsewhere. Completely unregulated, such a collapse could reinforce expansion in low cost exporting countries, even adding to forces driving land use change.

Our examination of measures that raise production and nitrogen use efficiency indicates that this approach has the potential for savings that are less than consumption based measures. This is supported by the scientific literature. However we acknowledge and set out evidence from elsewhere that this too has an important role to play. We anticipate too that there are potential synergies between production efficiency measures and consumption measures that we have not been able to simulate – for example a reduction in livestock product consumption may synergise with efforts to raise the efficiency of nitrogen use in the food system. There are also possible synergies between efforts to raise production efficiency and the use of technologies to reduce emissions directly. Consumption based measures would mean a significant contraction in livestock production for UK consumption and this opens up opportunities to restructure agriculture in a way that enhances the benefits of production efficiency measures. In addition, from a global perspective, reductions in livestock consumption and measures to increase production efficiency synergise with efforts to eliminate deforestation. Improving production efficiency and reducing production emissions directly will mean embracing new technologies. These need to be carefully applied to whole systems to raise system eco-efficiency. Our analysis indicates there is little scope for emission reductions through the exclusion of production technologies – for example through the widespread adoption of organic farming. We estimate from analysis of recently published work that a complete conversion to organic farming in the UK with corresponding changes in diet would reduce supply chain emissions by about 5%.

Emissions from fish consumption were quantified, but expansion in fish production to replace other livestock products was not considered owing to concerns about the sustainability of wild fish stocks. This though has significant potential depending on the success of developing new aquaculture systems.

Very significant change in the food system is required to achieve a 70% reduction in supply chain emissions. The consumption and farm technology changes align with other policy objectives, for example public health, nitrate emissions, ammonia emissions and biodiversity. The scenarios set out here do not have definitive implications for animal welfare outcomes in one direction or another. The reduction in animal products consumption generally as set out in consumption measures opens up opportunities to improve welfare. However, measures to increase production efficiency at the animal level raise questions about the welfare consequences. This underscores the importance of whole system analyses and an emphasis on whole system solutions rather than just on interventions at the individual animal level.

Our results also show that a 70% reduction in supply chain emissions (i.e. excluding land use impact) may be possible without significant changes in consumption. However, if repeated across the developed and developing world, such a high level of livestock product consumption would require a large expansion in global agriculture and would make contraction and convergence of emissions difficult. Per-capita UK meat consumption is more than twice the world average, and nearly three times that of developing countries. As the global food system becomes more resource constrained and developing countries lift themselves out of poverty, consumption based measures will acquire relevance beyond just the UK's greenhouse gas emissions.

Introduction

This study examines the feasibility of achieving a significant reduction (possibly 70%) in greenhouse gas (GHG) emissions from the UK food system by 2050. The work is consumption based. It relates UK consumption to all direct and indirect emissions from the supply of food for UK consumption, both in the UK and overseas. The study comprises an audit of the greenhouse gas emissions arising from the UK food economy and an examination of the scope for substantial reductions of these emissions in this timeframe. The overall aim was to develop a set of scenarios that explore how greenhouse gas emissions from the UK food system may be reduced by 70% by the year 2050.

To achieve this, two broad objectives were addressed:

1. To compile a complete inventory of all UK food consumption from domestic production and imports, distribution and consumption, including direct greenhouse gas (GHG) emissions related to primary and post-primary production and indirect emissions resulting from Land Use and Land Use Change (LULUC) associated with this production.
2. To develop and assess a set of scenarios to reduce these emissions by 70% based on measures from both production and consumption systems by 2050.

The work was prompted by the suggestion from the FCRN that the UK Ggovernment should commit to achieving a 70% or more absolute reduction in food-related GHG emissions by 2050.[5]. Since then, the UK Climate Change Act 2008 which aims to improve carbon management and support the transition towards a low carbon economy in the UK has been enforced. It seeks to demonstrate strong UK leadership internationally, with a commitment to share of responsibility for reducing global emissions globally. Targets include an 80% reduction in UK greenhouse gas emissions through action in the UK and abroad by 2050, and reductions in CO_2 emissions of at least 26% by 2020, against a 1990 baseline. The 80% target translates into a 77% reduction in relation to 2005. This research examines in outline if and how changes to the UK food system can make a significant contribution to this target. It also identifies the relevance of this domestic target focused on emissions from the UK to the emissions arising from the wider UK food system.

GREENHOUSE GAS EMISSIONS AND THE FOOD ECONOMY – CURRENT ESTIMATES

World wide, agriculture, and related up-stream activities such as fertiliser manufacture plus land use change are responsible for about a third of the world's greenhouse gas emissions (Figure 1). In primary agricultural production, the profile and underlying causes of GHG emissions is different to most other sectors. N_2O from the nitrogen cycle dominates direct greenhouse gas emissions from crops in terms of global warming potential, accounting for about 70% of the GHG emission from wheat production for example. In addition, methane from livestock production, particularly from cattle and sheep, is a potent global warming gas emission. Methane and nitrous oxide emissions have risen in a pattern similar to CO_2. Agriculture's role in carbon dioxide emissions arises mainly from land use change rather than fossil fuel use.

UK greenhouse gas inventories indicate that 7% of UK emissions are attributable to UK agriculture[6] made up of the equivalent of 51 Mt of CO_2e as carbon dioxide (11%), methane (37%) and nitrous oxide (53%). This is only a small proportion of total emissions attributable to the food system. There are also emissions from the manufacture of farm inputs, food processing, distribution, retailing and preparation. The manufacture of nitrogen fertilisers

[5] Garnett, T. (2008.) *Cooking up a storm. Food, greenhouse gas emissions and our changing climate*. The Food and Climate Research Network.

[6] HM Government,. 2006. *Climate change, the UK programme*.

(registered in GHG inventories as an industrial emission) is the most important cause of direct emissions upstream of agriculture. About 900,000 tonnes of nitrogen as fertiliser is used in UK agriculture each year. Assuming 80% is ammonium nitrate and 20% is urea[7], the manufacture of this fertiliser emits the equivalent of 6 Mt of carbon dioxide, the equivalent of about 1% of the GHG emissions in the UK.

The UK is a net importer of many foods and emissions from the production of imports are not reflected in UK inventories. Previous analyses indicate that overall, UK agriculture, fertiliser production, and livestock agriculture in near-neighbouring countries for export to the UK is responsible for the emission of about 62 Mt carbon dioxide per year, equivalent of 10% of emissions attributed to the UK in inventories. Livestock products represent the majority of imports from these nearby counties. Their production, especially of poultry and pig meat, is similar in LCA terms to that of the UK. So drawing on UK LCA data[8], it is estimated that the production of these imported livestock commodities emits the equivalent of about 3.7 Mt carbon dioxide on a life- cycle basis up to the farm- gate. Land use change in other countries is also excluded from national emissions inventories. So it can be concluded that the role of the UK food system in global greenhouse gas emissions is far greater than that indicated by UK emissions attributable to UK agriculture.

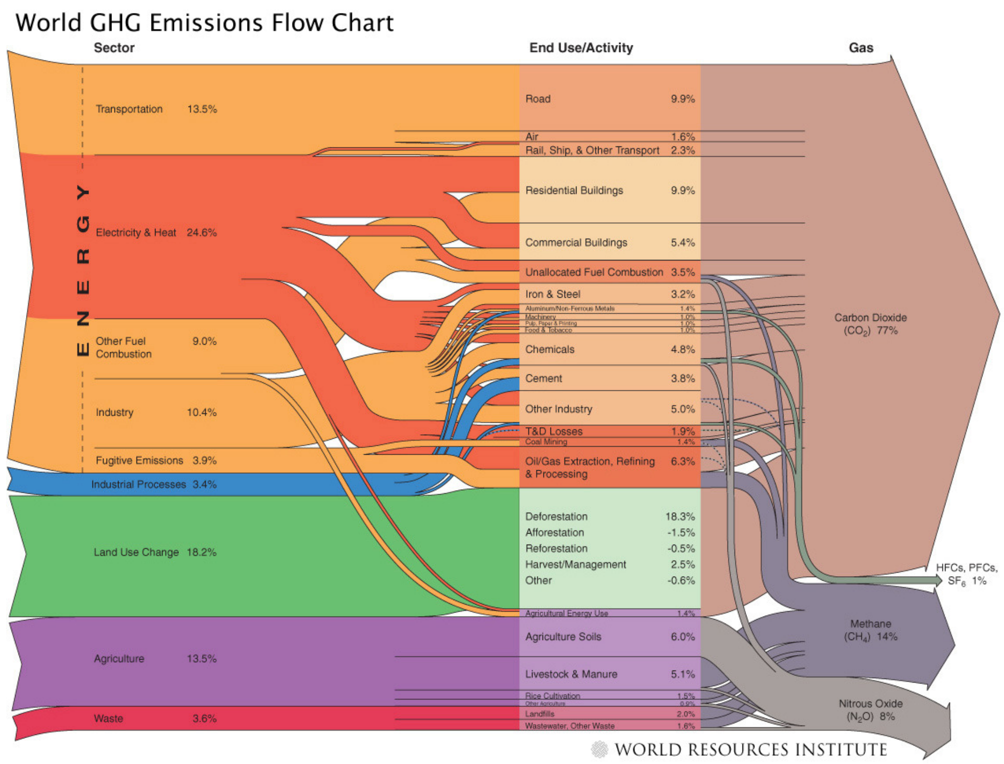

Figure 1. Flow of global greenhouse gas emissions

A number of studies have made estimates of the wider emissions from the food system. The University of Surrey based Food Climate Research Network reports that the UK food chain

---

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

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

(production, processing and retail) accounts for 19% of UK consumption GHG emissions, i.e. the equivalent of 159 Mt of carbon dioxide[9].

The UK Cabinet Office[10] reports 18% with just under half attributed to UK farming and fishing. For Western Europe as a whole, the EU Environmental Impact of Products (EIPRO) study[11] identified food as responsible for 20--30% for most categories of environmental burdens, including greenhouse gas emissions. For greenhouse gas emissions, this 20--30% attributable to food comprises 4 - 12% for meat, 2--4% for dairy products, and about 1% for cereal products. So livestock products account for 6--16% of greenhouse emissions attributable to Europe. An equivalent estimate for the world is 18%.[12].

In addition to direct emissions from the food chain, there is also the UK's share of indirect emissions due to land use change, e.g. deforestation, which in total are estimated to account for 18% of global emissions. Land use change emissions attributable to the UK food economy have not been estimated prior to this study, but even 1% (reflecting the UK population as a proportion of the global population) of the 7,300 Mt of CO_2e due to deforestation globally is very significant (73 Mt CO_2e). Overall, it is clear that the delivery of food up to the point of consumption is significant: food is comparable to transport and domestic energy consumption in terms of its role in personal carbon footprints.

TRENDS IN UK FOOD CHAIN EMISSIONS AND THE SCOPE FOR REDUCTIONS

Greenhouse gas emissions from UK agricultural production have fallen since 1990.[13]. It is difficult to assess trends in greenhouse gas emissions for the food economy as a whole as they are the result of a number of counteracting and poorly understood activities – for example rising commodity consumption is counteracted by increased production efficiency in Europe, and increased energy efficiency in manufacturing is counteracted by increased car use in shopping. Overall, further but modest reductions in emissions from primary production are expected up until 2010.[14] [15]. Due to the intrinsic connection with biological processes causing emissions of nitrous oxide and methane, step- changes in emissions are more difficult to achieve compared with, for example, the electricity sector. Against this background, Defra expects UK agricultural emissions to rise by 6.5% between 2010 and 2020 although the government's low carbon transition plan anticipates a 6% reduction in agricultural emissions on 2008 levels by 2050.

Life- cycle assessments such as those set out in the Cranfield study[16] consistently reveal the large burdens associated with the production of livestock commodities. Livestock are estimated to account for 70% of agricultural land use worldwide (30% of the Earth's land surface), and more than half of the greenhouse gas emissions attributable to agriculture.[17]. Reducing livestock production would reduce emissions directly through reductions in methane from ruminants and waste management, and nitrous oxide from forage and feed production. Indirect reductions would result from reduced nitrogen related enrichment of habitats, from nitrate leaching and ammonia emissions. The biggest effect for the environment may be through the indirect effects

[9] Garnett, T. (2008.) *Cooking up a storm. Food, greenhouse gas emissions and our changing climate*. The Food and Climate Research Network.

[10] Cabinet Office. (2008). *Food matters. Towards a strategy for the 21 st century*. The Cabinet Office Strategy Unit, UK.

[11] Tukker, A., Huppes, G., Guinée, J., Heijungs, R., de Koning, A., van Oers, L., and Suh, S,. Geerken, T., Van Holderbeke, M., and Jansen,, B., and P Nielsen, P. (2006). *Environmental Impact of Products (EIPRO). Analysis of the life cycle environmental impacts related to the final consumption of the EU-25.* Main report IPTS/ESTO project.

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

[13]HM Government., 2006. *Climate change, the UK programme*.

[14] Defra. 2008. *The UK Cclimate Cchange Pprogramme*. 2008)

[15] HM Government. 2009. *The UK Llow Ccarbon Ttransition Pplan*.

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

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

of livestock on land use change where the production of crops for the livestock sector is a factor driving deforestation.

CARBON DIOXIDE EMISSIONS FROM LAND USE CHANGE

An estimated 18% of global GHG emissions arise from land use change and forestry (Figure 1). These estimates are uncertain and emission estimates range from 2,899 Mt of carbon dioxide to 8,601 Mt (20% of carbon dioxide emissions).[18]. Deforestation is by far the largest component of land use change emissions (Figure 2). Drawing on FAO statistics[19], 58% of the deforestation is driven by commercial agriculture. The role of agriculture as a driver can be complex with interaction with other drivers such as road building, logging and population growth. Accepting the uncertainty in estimates and drivers, it remains clear that land use change is connected to agriculture and this is a significant cause of emissions attributable to the global food economy. It is worth noting, for course, that deforestation of the UK to supply agricultural land has taken place over millennia and much reforestation occurred in the 20th century. The associated CO_2 emissions from this historical deforestation have long been assimilated into the eEarth's atmosphere.

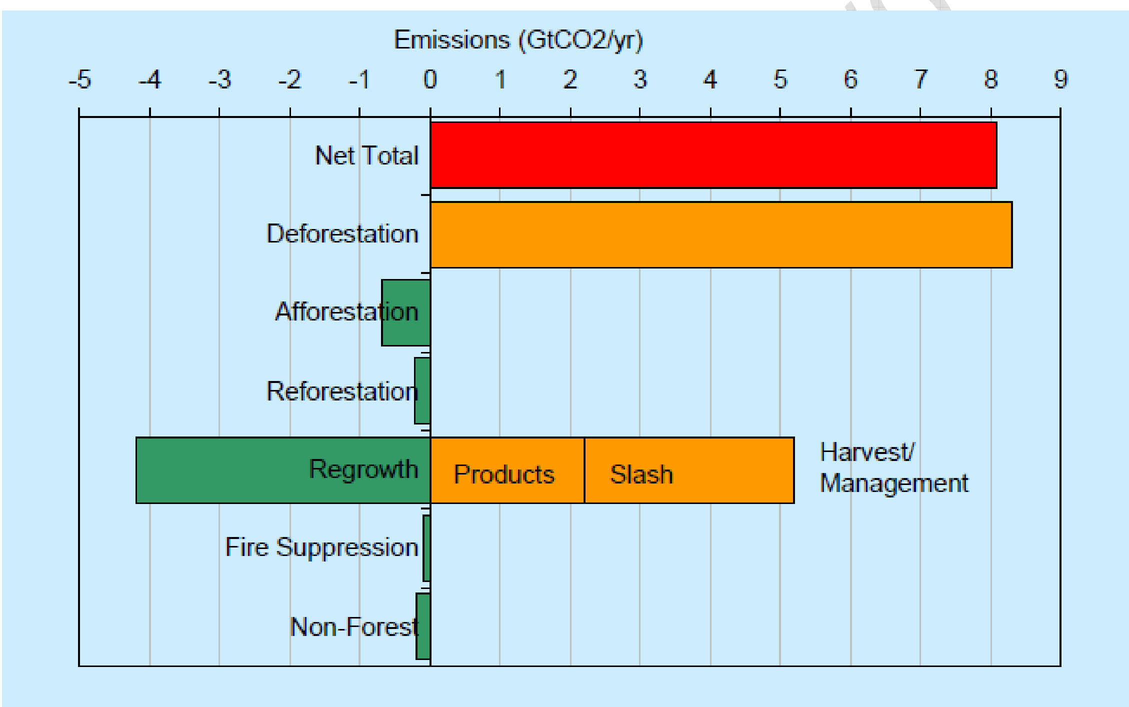

Figure 2. Sources of emissions from global land use change 2000[20]

Most public debate about food and deforestation is focused in direct links between land use change and the UK food system. Considering the dominance of the tropics in land use change (Figure 3), this focuses attention on produce from these regions, particularly soy and beef from South America and palm oil from South-east Asia. This approach to the problem regards deforestation as attributable to UK food consumption when UK consumed food is grown on recently converted land. For example, if the UK consumes palm oil and a proportion of this demand is met by converting forest to palm oil plantations, the emissions from the conversion of

---

[18] Ramankutty, N., Gibbs H.K., Achard, F., Defries, R., Foley, J.A. and RA Houghton, R.A.. (2007). Challenges to estimating carbon emissions from tropical deforestation. *Global Change Biology*, 13, 51-–66.

[19] FAO. 2007. *State of the Wworld's Fforests*.

[20] Baumert, K.A., Herzog, T., and J Pershing, J. (2005). *Navigating the numbers: Greenhouse gas data and international climate change policy*. World Resources Institute.

forest land to plantation are allocated to the palm oil produced on that land. However, it is possible that switching consumption to foods which are grown on existing agricultural land (to reduce direct land use change) will displace the production on that land to other areas, some of which will be converted from other land use types (causing indirect land use change). Therefore there are direct connections to land use change, and there are indirect connections via global commodity trading.

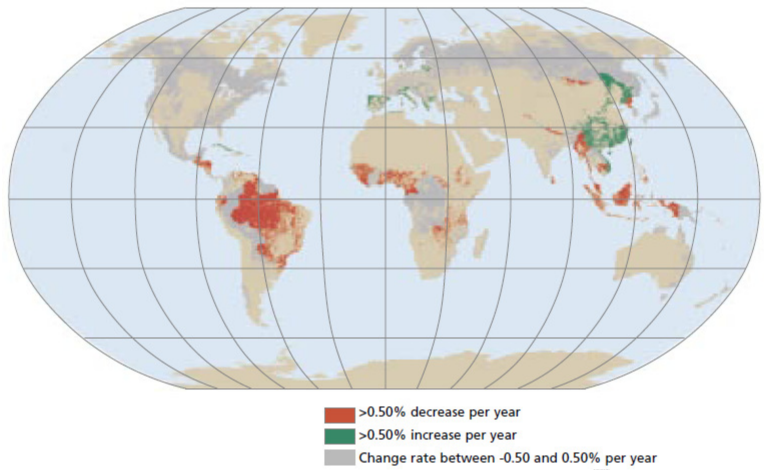

Figure 3. Locations of net deforestation[21]

This study accepts that the global food system is highly connected and indirect effects must be considered. In this, the boundary between agricultural land and other land use can be regarded as a frontier. As the global demand for food or other agricultural products increases, global agricultural output expands. Over the last 50 years, much of this production expansion has been achieved through increases in yield rather than area. However, the relative growth in yields has declined steadily and is now lower than the growth in population. This is a strong pointer towards increased pressure on land use change.

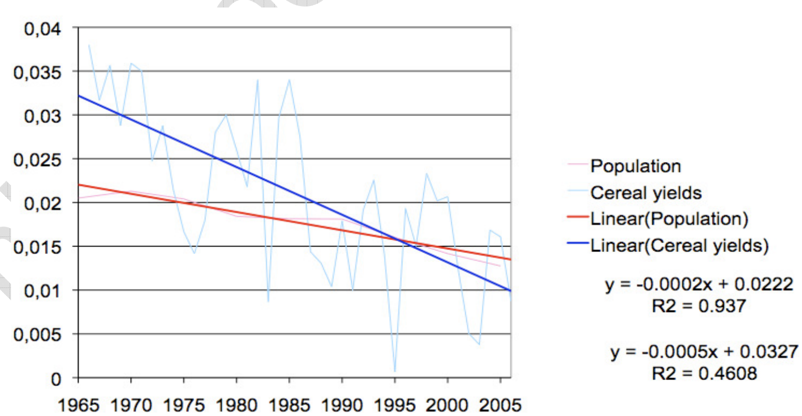

Figure 4. The rate of growth in the world's population is now greater than the rate of growth in crop yields (FAOSTATata by Dr Stephan Bringezu (Wuppertal Institute, Germany)) [22].

[21] FAO. 2005. *Global forest resources assessment: progress towards sustainable forest management.*

[22] Compiled from FAOSTAT data by Dr Stephan Bringezu. (Wuppertal Institute, Germany). http://www.bren.ucsb.edu/events/documents/bringezu_biofuels.pdf

STUDY OUTLINE

Based on an analysis of an inventory of greenhouse gas emissions attributable to the UK food system on a life- cycle basis (including emissions from land use and land use change), this research developed food system scenarios integrating production and consumption mitigation options.

Research on mitigation necessarily examines component emissions in detail leading to identification of individual opportunities for change and incremental progress. This work takes a radical approach in focusing on the effects of a combination of step-changes to reduce greenhouse gas emissions attributable to the UK food system in line with the target for the UK as a whole. It does this by looking at combinations of step-changes in the consumption, trade, processing and production of food.

The study comprised three phases integrated as shown in Figure 5. Phase 1 addressed the question of the size and sources of emissions from the UK food system currently. These comprise emissions from four categories: the production of the food commodities (primary production), emissions from processing, distribution, retail and preparation (post farm- gate emissions), land use emissions, and land use change emissions. Phase 2 looked at the mitigation potential of specific production and consumption measures. Phase 3 of the study examined how these may be radically reduced over the next 40 years in line with current targets for the UK as a whole.

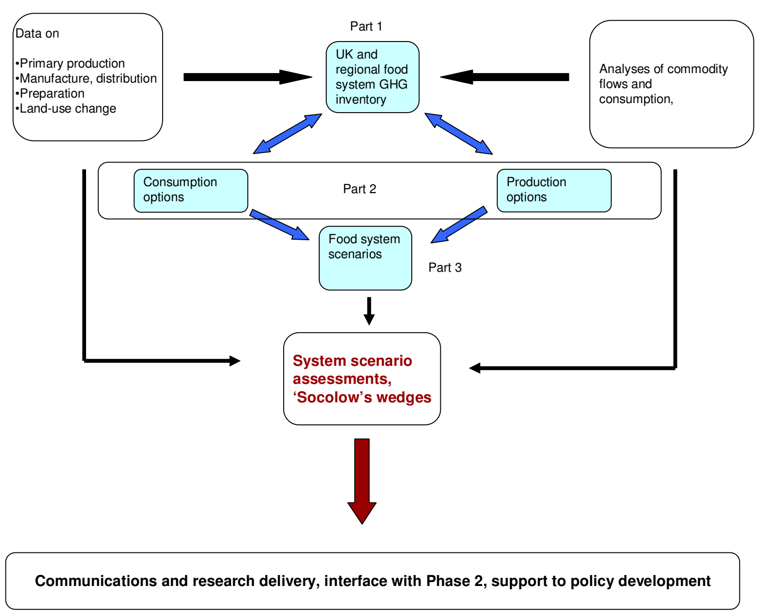

Figure 5. Project overview.

The research took an LCA based approach to estimate direct emissions from the food chain. This was augmented by estimates of emissions arising from land use change to provide estimates of all emissions attributable to the UK food system, including emissions arising from imports, net of exports. The allocation of global land use change emissions to the UK food economy was a particular focus.

METHODOLOGY – INVENTORIES, MEASURES AND SCENARIOS

The foundation of our work is an inventory of emissions from the supply of food for UK consumption. This comprises emissions from primary production (farming and fishing), processing, distribution and retail, consumption, and land use change attributable to the UK food system. We have based our analysis on data for UK food commodity consumption. We were unable to find reliable data for palm oil used in food, so we have included palm oil used for the oleochemical industry drawing on trade data. In addition, there are well developed synergies between a range of non-food industries, pet food and human food production. There are also about 300,000 horses in the UK, of which a good proportion will receive some concentrates that may not have been accounted for. So while we have used data on food consumption, there may have been some over-accounting of items in the food sector as a result of connections with non-food uses, but we are confident that this is small compared with food.

Population

The work conducted here is based on the 2005 population of 60.5 Mmillion. It will undoubtedly have changed by 2050, but no one can say exactly by how much. The current UK forecast from the ONS[23] is for the population to increase to 77 Mmillion, an increase of 27%. Population forecasting is difficult because of immigration and emigration. The analyses were all calculated on the basis of a constant population. We felt that this gives a sufficient clarity in understanding the directions needed to achieve major reductions in emissions.

Methodology for the inventory of emissions from primary agricultural production

The work was based on a detailed analysis of commodity consumption, production and trade data from the UK Department for Environment, Food and Rural Affairs (Defra), the United States Department of Agriculture (USDA) and the United Nations Food and Agriculture Organisation (FAO). Unless otherwise stated, all data on commodity flows come from the FAOSTAT data for 2005, accessed in early 2008. This provided a full list of crop and animal commodities and their quantities entering the UK food system for final consumption. It includes food and drink. Table 1 presents the full list of data for food commodities entering the UK food system in 2005.

These data were used to compile an inventory of emissions from primary production – agriculture, fishing and fish farming. They were also used for the calculation of LULUC emissions. A separate source of data was used for the processing and distribution phases. UK imports of major temperate arable crop and livestock commodities are dominated by supplies from near neighbours. The data relate to primary commodities, that is, products such as olive oil are set out in terms of tonnes of olives, beer and whiskey as barley, wine as grapes etc.

Table 1. Net UK imports, production and consumption of food commodities (2005). Consumption is human consumption only – excluding crop commodities used for animal feed. Data on consumption are independent of data on production and imports and so do not align arithmetically. Data is per thousand tonnes

Commodity	Net Import	UK Production	UK Consumption	Commodity	Net Import	UK Production	UK Consumption
Almonds	27	0	27	Misc. meat	8	6	21
Anise, badian, fennel etc.	8	0	7	Milk	2013	14577	14441
Apples	754	219	1026	Millet	17	0	0
Apricots	70	0	65	Mushrooms and truffles	131	74	199
Artichokes	1	0	1	Natural honey	27	5	32
Asparagus	7	2	8	Nutmeg, mace etc.	1	0	1
Avocados	40	0	28	Misc. nuts	23	0	22
Bananas	702	0	658	Oats	-28	532	106
Barley	-1176	5495	708	Misc. oilseeds	43	0	23
Green beans	6	21	40	Olives	438	0	406

[23] www.statistics.gov.uk/populationestimates/svg_pyramid/default.htm

Dried beans, cow peas	123	0	55	Onions (inc. shallots)	322	405	621
Bird eggs	76	615	559	Oranges	1018	0	1178
Bovine meat	260	762	1041	Other melons	158	0	145
Broad and horse beans	-160	130	0	Palm oil[24]	706	0	706
Brassicas	49	308	268	Papayas	8	0	11
Carrots and turnips	52	833	537	Peaches and nectarines	197	0	145
Cashew nuts	28	0	29	Pears and quinces	238	24	205
Cassava (fresh and dried)	19	0	0	Peas, dry	2	161	169
Cauliflowers and broccoli	124	219	252	Peas, green	10	133	226
Misc. cereals	302	68	237	Pepper (Piper spp.)	6	0	6
Cherries	26	1	23	Pig meat	554	706	1228
Chestnuts	2	0	2	Pineapples	361	0	353
Chick peas	18	0	0	Pistachios	6	0	5
Chillies and peppers, dry	8	0	6	Plantains	16	0	17
Chillies and peppers	139	14	123	Plums and sloes	116	15	135
Cinnamon (canella)	1	0	1	Potatoes	973	5961	6843
Misc. citrus fruit	39	0	46	Chicken meat	317	1360	1598
Cocoa beans	363	0	123	Misc. pulses	-133	500	0
Coconuts (incl. copra)	154	0	69	Pumpkins, squashes	36	0	29
Coffee, green	135	0	120	Rabbit meat	0	0	0
Cottonseed	10	0	2	Rape- and mustard seed	-205	1902	1345
Cranberries, blueberries	5	0	4	Raspberries etc.	8	10	18
Cucumbers and gherkins	123	59	161	Rice, paddy	602	0	531
Currants, gooseberries	12	22	23	Rye	-1	40	19
Dates	17	0	12	Sesame seed	14	0	10
Duck, goose, guinea fowl	4	45	49	Sheep and goat meat	34	331	351
Edible offal	64	115	180	Sorghum	6	0	0
Eggplants (aubergines)	16	0	13	Misc. spices	9	2	9
Figs	11	0	7	Spinach	8	0	6
Misc. fruit	63	0	46	Misc. starchy roots	15	0	0
Garlic	11	0	6	Strawberries	51	63	85
Ginger	13	0	12	Sugar beet	-2075	8687	4901
Grapefruit and pomelo	170	0	174	Sugar cane	8532	0	8066
Grapes[25]	3817	1	3623	Sunflower seed	382	0	284
Groundnuts	253	0	247	Sweet potatoes	20	0	0
Guavas, mangoes etc.	62	0	47	Tangerines etc.	348	0	312
Hazelnuts	9	0	9	Tea and Maté	125	0	129
Kiwi fruit	35	0	22	Tomatoes	1305	80	1441
Leeks etc.	15	50	44	Turkey meat	-17	211	207
Misc. leguminous veg.	0	9	11	Misc. vegetables	3188	339	3370
Lemons and limes	136	0	118	Walnuts	13	0	13
Lentils	18	0	18	Watermelons	40	0	33
Lettuce and chicory	167	140	300	Wheat	-1049	14863	6073
Linseed	-34	89	0	Yams	6	0	6
Maize	1336	0	606	Soy oil***			252

[24] Based on FAOSTAT trade data received in January 2008 including palm oil for non-food uses.

[25] Includes grapes as wine.

Table 2. Commodities and countries of production included in the Defra-funded project FO0103 ("Comparative LCA") [26]

Commodity	Alternative Country to the UK
Beef	Brazil
Chicken meat	Brazil
Lamb	New Zealand
Strawberries	Spain
Tomatoes	Spain
Potatoes	Israel
Apples	New Zealand

Results of the research at Cranfield[26] [27] were used to estimate emissions from the production of major commodities, including the production of animal feedstuffs. The Cranfield data resource[25] includes ten main commodities: bread wheat, potatoes, oilseed rape, beef, pig meat, lamb, poultry meat, eggs, milk, tomatoes. Use of these results also avoided double counting, as emissions relating to livestock feed production (feed wheat, barley, beans, maize, soya, forage maize and grassland) are included in the livestock LCA figures. Further results for domestic and overseas production (and delivery to the RDC) were obtained from the Defra-funded project FO0103.[26]. This included comparative burdens of seven food commodities (Table 2). This was supplemented by reports from the literature[28] for other commodities that are not included in the Cranfield work. Where no data were found, proxy values were used and rational adaptations were made to the model. For example, all tree fruits, except for oranges, were assumed to be apples. Transport adjustments were made when needed to allow for imports.

Regional consumption data was also obtained, and the UK inventory was divided into datasets for each individual country, to enable analysis of regional differences to be considered.

Primary production is defined as all activities and emissions arising from commodity production up to and including arrival at the regional distribution centre (RDC). For most items, this was as raw commodities, although some processing was included for a few items and is discussed later. Post-primary production includes activities such as processing, distribution to retail, retail itself, cooking and waste disposal. The parallel systems in the food service sector were also quantified.

Further data were obtained from the Defra-funded project FO0404[29] that was led by ADAS and assessed the applicability of PAS 2050 for agriculture and food. It provided data on apples, onions, pineapples, tea, coffee and cocoa. The scientific literature was also searched and other sources were identified and used. Care was needed in using other data, e.g. Carlsson-Kanyama[30] included a value for rice, which was strikingly high, but this was partly because she used a 20 year horizon for the GWP of methane, which is a large emitting term. Converting this to a 100 year time horizon reduced this portion of the burden about threefold (Table 3), although the value per tonne of rice is still appreciably higher than other cereals.

[26] Williams, A., Audsley, E. and D Sandars, D. 2006. *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities*. Defra project report IS0205, as further developed under Defra project IS0222.

[27] Williams, A.G,.; Pell, E,.; Webb, J.;, Tribe, E.;, Evans, D.;, Moorhouse, E.; and P Watkiss, P. (2009). *Comparative* Llife Ccycle Aa*ssessment of fFood Ccommodities Pprocured for UK Cconsumption through a Ddiversity of Ssupply Cchains*. Final Report to Defra on Project FO0103.

[28] See reference list at end of this report for full list.

[29] Defra project FO0404. *Scenario building to test and inform the development of a BSI method for assessing GHG emissions from food.*

[30] Carlsson-Kanyama, A. (1998). Climate change and dietary choices — how can emissions of greenhouse gases from food consumption be reduced? *Food Policy*, 23, ((3/4)), 277–293.

Due to the varied nature and detail of results, values were adjusted to fit the context of the study so that they were comparable with other values in the inventory in terms of scope, boundary conditions and functional units. For example, all values were adjusted to include transport up to the Regional Distribution Centre (RDC). Data were adjusted too so that the functional unit was a tonne of commodity production in most cases.

Furthermore, for some commodities there were no complete Life Cycle Assessment (LCA) studies. Appropriate proxy values were chosen and adapted. For example pineapples were used as a substitute for most other exotic fruit including bananas;. Ooats were taken as an average of spring and winter barley;. sStrawberries used for other soft fruits etc. All values were converted into Global Warming Potential (GWP) on a 100 year time horizon, kg CO_2 equivalent (CO_2e) per tonne of commodity production, using the IPCC conversion factors.

Table 3. Global warming potentials of gases over 20, 100 and 500 year timescales[31]

Gas, kg	GWP$_{20}$, kg CO_2e.	GWP$_{100}$, kg CO_2e.	GWP$_{500}$, kg CO_2e.
Carbon dioxide, (CO_2)	1	1	1
Methane (CH_4)	72	25	7.6
Nitrous oxide (N_2O)	289	298	153

Total UK primary production emissions were obtained by multiplying the total consumption of each raw commodity by its burdens per tonne of production including the transport to the RDC.

Methodology for the inventory of emissions from fishing and fish farming

Fish may be caught or farmed and vertebrates or invertebrates (shellfish). Vertebrates are divided mainly into demersal (bottom feeders) and pelagic. Our wild fish consumption is still dominated by demersal white fish like cod, and haddock as well as tuna (pelagic). Vertebrate fish farming is dominated by salmon and trout and invertebrates by mussels, with some production of langoustines. Shellfish are also imported from overseas (as far away as the Far East).

For caught fish, the main burden is the energy used in fishing, including refrigeration. [32] [33] [34]. The feeding stage dominates farmed fish production. [35]. While energy consumption and GHG emissions are closely related to each other, it must be noted that the environmental impacts of fishing and fish farming are more diverse and complex than these alone.[36]. Apart from resource use and emissions to the environment, there are major problems about fish stocks, wastage from the returns to sea of undersized fish etc. Most UK fish farming includes fish meal from wild caught fish, so that expansion of domestic production is limited by the availability of the wild fish supply. For these reasons, we did not include any scenarios about increasing fish consumption.

[31] Forster, P., and Ramaswamy, V. (2007.) Changes in aAtmospheric Cconstituents and in Rradiative Fforcing, in: IPCC AR4 WG1, *Report cClimate Cchange 2007, The pPhysical Sscience Bbasis*. Page 212 http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Ch02.pdf (overall web address http://ipcc-wg1.ucar.edu/wg1/wg1-report.html)

[32] Tyedmers,; P.H.;, Watson, R.; and D Pauly, D. (2005.) Fueling Gglobal Ffishing Ffleets. *Ambio*, 34 (8), 635-–638.

[33] Thrane, M. (2006). Energy Cconsumption in the Danish Ffishery. Identification of Kkey Ffactors. *Journal of Industrial Ecology*, 8, (1–2), 223-–239.

[34]Ellingsen, H; and Aanondsen, A. (2006). Environmental impacts of wild caught cod and farmed salmon - A comparison with chicken. *International Journal of Life Cycle Assessment*, 11, 60-–65.

[35] Papatryphon, E., Petit, J., Van der Werf, H. M. G. and SJ Kaushik, S. J. (2007.) Life Ccycle Aassessment of trout farming in France: aA farm level approach. *Proceedings 5th international conference on LCA in foods*, April 25-–26 April 2007, 71–77,, pp. 71-77. Gothenburg, Sweden.

[36] Cappell, R,.; Wright, S.; and F Nimmo, F. (2007). *Sustainable Pproduction and Cconsumption of fish and shellfish. Environmental Iimpact Aanalysis.* Final rReport to Defra from Royal Haskoning. Project Ccode 9S6182.

Fish production and consumption are not as well defined in data as other foods are.[36] We simplified the data on consumption to allow us to use what data there are from fishing and fish farming. Data resources are dominated by results from Scandinavian research. Part of the problem is the yield is not always clear whether weights refer to gross weight orf net weight after filleting or removing shells etc. The best LCA studies include all stages through to the retail, but these do not cover all fish types. The simplified consumption data set that we derived is provided in Table 4). It should be noted that these data relate to fish as purchased by consumers. Weight loss in the fish supply chain is high and so the quantities of commodity fish used are higher than the quantities shown here.

Table 4. Simplified data for UK fish consumption and specific emissions of GHG.

				LCI kg CO_2e/kg		
Fish type	**Gross wt, kt**	**Wastage rates before consumption**	**Net wt, kt**	**Gross**	**Net**	**Total emissions kt CO_2e**
Farmed						
Salmon	163	25%	122		3.0	366
Trout	9	25%	6		4.5	29
Imports – long distance						
Tuna	98	30%	73	1.9	2.6	194
Shellfish	111	25%	83	5.7	7.6	633
UK and imports from EU						
Wet fish (by difference) as cod	276	25%	207		6.6	1370
Shellfish	37	25%	28	5.1	6.9	190
Total fish	692		519		5.4	2781

Data sources: [37] [38] [39] [40] [41]

Methodology for the inventory of emissions from processing, distribution, retailing and preparation

The RDC (Regional Distribution Centre) is a nominal boundary in our reporting. We adopted this boundary because of data sources vary in detail about end points and because of the imprecision in judging where primary production ends and processing begins. In some cases, the manufacturing, processing and packaging has been included in the pre-RDC side, e.g. liquid

[37] Ellingsen, H, .;Olaussen, J.O. and IB Utne, I.B.. (2009). *Environmental analysis of the Norwegian fishery*

[38] Papatryphon, E., Petit, J., Van der Werf, H. M. G. and SJ Kaushik, S. J. (2007). Life Ccycle Aassessment of trout farming in France: aA farm level approach. *Proceedings 5th international conference on LCA in foods*, April 25-–26 April 2007, pp. 71-–77. Gothenburg, Sweden.

[39] Hospido, A.; and Tyedmers., P. (2005). Life cycle environmental impacts of Spanish tuna fisheries. *Fisheries Research*, 76, 174–186.

[40] Baruthio, A.;, Aubin, J,.; Mungkung, R.,; Lazard, J. and HM Van der Werf H.M. (2008). Environmental assessment of Filipino fish/prawn polyculture using Life Cycle Assessment, . *6th International Conference on LCA in the Agri-Food Sector*, Zurich, 12–14 November 12–14, 2008, Zurich.

[41] Ziegler, F,.; Nilsson, P,.; Mattsson, B,.; and Y Wahher, Y. (2003.) Life Cycle Assessment of Ffrozen Ccod Ffillets Iincluding Ffishery-Sspecific eEnvironmental Iimpacts. *Int J LCA*, 8 (1), 39– - 47.

milk. Milling wheat, however, is processed into bread, biscuits etc. and this is all included in the post RDC data. Secondary processing of meat etc. into sausages, pies, pizzas etc. is included post RDC.

We expected that it would not be possible to examine the post-farm gate part of the food system along commodity lines but that the combination of the pre-farm gate along commodity lines and the post farm gate analyses of food types (e.g. bakery and fresh, preserved or frozen) would deliver an adequate basis for scenario building and assessment. Food product consumption data were obtained from Defra's Family Food Datasets[42]. These include values for home and eating out consumption. These data were supplemented by calculating energy use in distribution, purchasing, processing, refrigeration and cooking using the models of Mila i Canals.[43]. In addition, wastage rates were taken from the Family Food Survey, together with the original source in WRAP's food waste study.[44]. The main data inputs for each activity were taken mainly from Mila i Canals, which includes much from a Swedish study.[45]. Detailed manufacturing energy was mainly taken from data compiled by Carlson-Kanyama and Faist[46], with milk processing data taken from Foster *et al*.[47] [48] and other specific processes from Hanssen *et al*.[49], Jungbluth[50], Braschkat *et al*.[51]; Koroneos *et al*.[52]; Cordella *et al*[53]; Hospido *et al*.[54]; Berlin[55], and Hospido *et al*.[56]. The food and drink consumption data do not conveniently account for all commodities produced and some simplifications were needed in estimating the processing energies and associated GHG emissions. For example, soft drink production was

---

[42] https://statistics.defra.gov.uk/esg/publications/efs/datasets/default.

[43] Milà i Canals, L;., Muñoz, I.,, McLaren, S. and M Brandão, M. (2007*). LCA methodology and modelling considerations for vegetable production and consumption*. CES Working Paper 02/07, University of Surrey. ISSN: 1464-8083. This paper is a result of the Rural Economy and Land Use (RELU) programme. funded project RES-224-25-0044 (http://www.bangor.ac.uk/relu).

[44] WRAP. 2008. *The food we waste*.

[45] Sonesson, U,.;. Janestad, H. and B Raaholt, B. (2003.) Energy for Ppreparation and Sstoring of Ffood -– Models for calculation of energy use for cooking and cold storage in households. SIK-Rapport, 709 2003, 1–-56. Gothenburg, Sweden, SIK. SIK-Rapport.

[46] Carlsson-Kanyama, A. and Faist, M. (2000). *Energy Uuse in the Ffood Ssector: aA data survey*. AFN report 291, Swedish Environmental Protection Agency, Stockholm, Sweden.

[47] Foster, C, Green, K, Bleda, M, Dewick, P, Evans, B, Flynn A, and J Mylan J. (2006.) *Environmental iImpacts of Ffood Pproduction and cConsumption: A report to the Department of Environment, Food and Rural Affairs*. Manchester Business School. Defra, London.

[48] Foster, C.;, Audsley, E.;, Williams, A.G.;, Webster, S.;, Dewick, P.; and K Green, K. (2007). *The eEnvironmental, Ssocial and Eeconomic Iimpacts aAssociated with Lliquid Mmilk Cconsumption in the UK and its Pproduction. A Rreview of Lliterature and Eevidence*. Report to Defra under pProject EVO 2067 for the Milk Roadmap Team. http://www.defra.gov.uk/foodrin/milk/documents/milk-envsocecon-impacts.pdf

[49]Hanssen, O.J.;, Rukke, E-O,.; Saugen, B,.; Kolstad, J.;, Hafrom, P,.; von Krogh, L.;, Raadal, HL,.; Rønning, A and.; KS Wigum, K.S.. (2007).: The eEnvironmental Eeffectiveness of the Bbeverage Ssector in Norway in a Ffactor 10 Pperspective. *Int J LCA*, 12 (4), 257–265.

[50] Jungbluth, N. (2005). *Comparison of the eEnvironmental Iimpact of Ddrinking Wwater vs. Bbottled Mmineral Wwater*. Manuscript for the SGWA information bulletin and GWA (Gas Water Sewage). Commissioned by Swiss Gas and Water Association (SVGW). ESU services, Uster, Switzerland.

[51]Braschkat, J,.; Patyk, A,. Quirin, M; and GA Reinhardt, G.A.; (2003). Life cycle analysis of bread production – a comparison of eight different options. *4th International Conference: Life Cycle Assessment in the Agri-food sector*. 6–8 October, 9–16. Horsens, Denmark (DK) from 6. – 8. October 2003. pp9-16.

[52]Koroneos, C,.; Roumbas, G,.; Gabari, Z,.; Papagiannidou, E. and; N Moussiopoulos, N. (2005.) Life cycle assessment of beer production in Greece. *Journal of Cleaner Production*, 13, 433-–439.

[53]Cordella, M, Tugnoli, A, Spadoni, G, Santarelli, F, and T Zangrando T. (2008).: LCA of an Italian Lager Beer*. Int J LCA*, 13 (2), 133–139.

[54]Hospido, A,.; Moreira, M.T.; and G Feijoo, G. (2005). Environmental analysis of beer production. *Int. J. Agricultural Resources Governance and Ecology*,, Vol. 4,, No. 2., 2005

[55] Berlin, J. (2002.) Environmental life cycle assessment (LCA) of Swedish semi-hard cheese*. International Dairy Journal*, 12, 939–953.

[56] Hospido, A,.; Vazquez, M.E.;, Cuevasc, A,.; Feijoo, G and MT.; Moreira, M.T. (2006) Environmental assessment of canned tuna manufacture with a life-cycle perspective. *Resources, Conservation and Recycling*, 47, 56–72.

based on that of sparkling bottled water [57] with additional sugar and some extra processing energy.

The individual values were summed and cross-checked against top level data for energy use and refrigerant leakage for manufacturing, domestic food related energy consumption, service sector and retail.[58] [59] [60], Utley and Shorrock[61]; James *et al*[62]; LACORSacors.[63]. The cross-checking suggested that the sum of individual cooking energies was about half that surveyed, suggesting a substantial inefficiency in cooking activities. Refrigerant emissions from road transport and retail were taken from a recent study by Brunel University[64] plus corporate social responsibility reports from supermarkets and food processors (e.g. Co-op, Sainsbury's, Morrisons, ASDA, M&S, Waitrose, Tesco, United Biscuits, Unilever, Northern Foods, Weetabix, SAB Miller, Premier Foods, Adnams, Brake Bros). These varied widely in value, with one from Tesco being particularly useful on refrigerant leakage.[65]. One area for which we could find no data was refrigerants from shipping. These, like some large industrial facilities may well be based on low GHG refrigerants anyway.

Alcoholic drinks

One area of consumption data in which the Family Food Survey data clearly under-reported consumption was alcoholic drinks, which are dominated by beer, wine and cider. Sources included the Office of National Statistics (ONS) PRODCOM reports — PRODucts of the European COMmunity, and which is a European Union (EU)- wide scheme[66] [67] [68], the British Beer & Pub Association, UK Quarterly Beer Barometer, the ONS survey on drinking and health, and the Revenue & Customs reporting on alcohol "clearances", presumably after duty has been paid[69], and the Wine and Spirit Trade Association.[70]. These sources indicated a difficulty in obtaining reliable statistics in this area. This difficulty is widely acknowledged and actually caused the part of ONS responsible for the beer PRODCOM report to test the reliability of their survey data.

Food services

[57] Jungbluth, N. (2005). *Comparison of the Eenvironmental Iimpact of Ddrinking Wwater vs. Bbottled Mmineral Wwater.* Manuscript for the SGWA information bulletin and GWA (Gas Water Sewage). Commissioned by Swiss Gas and Water Association (SVGW). ESU services, Uster, Switzerland.

[58] DECC. (2008) Energy Consumption in the UK, Industrial data tables, 2008 update. www.berr.gov.uk/files/file47215.xls

[59] BERR. (2009a). Carbon dioxide emissions estimates and fuel used in electricity generation 1990 to 2007. www.berr.gov.uk/files/file47216.xls

[60] BERR. (2009b). Energy Consumption in the UK, service sector data tables, 2008 update. www.berr.gov.uk/files/file47217.xls

[61]Utley, J.I. and Shorrock, L.D. (2006). *Domestic Eenergy Ffact Ffile* (2006). Report for Defra by BRE. http://projects.bre.co.uk/factfile/TenureFactFile2006.pdf

[62] James, S.J,.; Swain, M.J,.; Brown, T,.; Evans, J.A,.; Tassou, S.A,.; Ge, Y.T,.; Eames, I,.; Missenden, J,.; Maidment, G. and D Baglee, D. (2009.) *Improving the Eenergy Eefficiency of Ffood Rrefrigeration Ooperations.* Presented at The Institute of Refrigeration, 5th February 2009.

[63] LACORSacors. (2007.) UK implementation of fluorinated greenhouse gases and ozone-depleting substances regulations. Market iIntelligence and Rrisk-Bbased Implementation Mmodel. From: http://www.defra.gov.uk/environment/air-atmos/fgas/pdf/fgas-report-1107.pdf

[64] Tassou, S,. ; Hadawey,. A,;, Ge, Y.; and D Marriot, D. (2009). *Presentation on "Greenhouse gas impacts of food retailing".* Defra-funded project FO0405.

[65] Tesco. (2009.) Measuring Oour Ccarbon Ffootprint. http://www.tesco.com/climatechange/carbonFootprint.asp

[66] ONS. (2007a.) ProductRODUCT salesSALES and tradeTRADE. PRA 15960, Beer. 2007. www.statistics.gov.uk/downloads/theme_commerce/PRA-20070/PRA15960_20070.pdf

[67]ONS. (2007b.) ProductRODUCT salesSALES and TRADEtrade. PRA 15940. Cider & Other Fruit Wines. 2007. www.statistics.gov.uk/downloads/theme_commerce/PRA-20070/PRA15940_20070.pdf

[68] ONS. (2007c.) ProductRODUCT salesSALES and tradeTRADE. PRA 15930. Wines. 2007. www.statistics.gov.uk/downloads/theme_commerce/PRA-20070/PRA15930_20070.pdf

[69] Revenue & Customs. (2009). https://www.uktradeinfo.com/index.cfm?task=factalcohol

[70] WSTA. (2005.) Wine and data sheet -– December 2005. http://www.wsta.co.uk/Statistics/Wine-and-Spirit-data-sheet-December-2005.html

The data on impacts of eating out and obtaining food and drink from the service sector are much more uncertain than those for domestic consumption. There is work under way for WRAP and Defra on quantifying these environmental impacts, but results are not available (the Defra-funded study was only due to start in the summer 2009). There are some top level indications of energy consumption in the BERR data, but these are incomplete or may overlap functions, e.g. general hotel operation plus cooking. In the service sector, practices and serving environments will vary considerably (e.g. chip shop to *haute cuisine* restaurant). Additional energy is often used for heating plates, keeping prepared food hot (or cold) and ambience. Wastage rates can be very high, but are not quantified. After due consideration, it was decided to assume that all cooking, cooling and "presentation" energies were twice that of domestic food preparation and that the wastage rate for all food and drink was fixed at 30%.

Substitutes

Our analyses include consideration of the use of plant-based livestock product analogues and other direct 'like-for-like' substitutes. Direct substitutes to animal products were estimated on the basis of soya milk replacing dairy milk, margarine replacing butter and soya cheese replacing dairy cheese. No LCA studies have apparently been performed on soya milk or cheese, so estimates were made on the basis of the mixtures of soya meal, soya oil and sugar needed to produce the gross compositions cited on product labels and/or the composition tables provided by the Food Standards Agency[71], together with some processing energy. Meat substitution was by replacement of the dry weight of all meats by the dry weight of a mixture of alternatives. These were 20% (by protein content) of the textured fungal food, *Quorn*, 20% (by protein content) of tofu and 60% (by protein content) of a mixture of pulses (soya, chickpea, kidney beans, dried peas, green beans and green peas) consumed directly. The substitution reduces protein intake and energy from meat by 33% and 45% respectively (note this is not a change in the whole diet, just this part). All other aspects of diet were assumed to remain the same. Other approaches are possible, but this provided a convenient substitution for intake. An earlier approach of substituting on the basis of the same energy and protein would have led to an untenably high dry matter intake of the alternatives.

There were no complete LCA reports on *Quorn*, but Nonhebel and Raats[72] calculated energy use and material flows in *Quorn* production. We derived the GWP from this source. The main microbial energy substrate in *Quorn* production is molasses, but the large increase in production that would be needed to support a meat-free diet would mean that the amount of molasses currently available as a by-product would be greatly exceeded. Much is currently used in animal feed. So, a main effect would be growing more sugar from domestic beet or overseas cane.

We initially calculated a value for tofu production based on the gross composition and an estimate of manufacturing energy, although other studies subsequently came to light.[73 74]. The study by Muroyama *et al.*[72] is more detailed and process based than that of Håkansson *et al.*[73], which seems to give a very high value, but much is based on the cost of energy and an estimated conversion factor. We cannot say if one is undoubtedly more reliable than the other, but the results of Muroyama *et al.* seem more plausible (and were much closer to ours) and were subsequently used.

---

[71] Food Standards Agency. (2002.) *McCance and Widdowson's The composition of foods*. 6th Summary Edition. Cambridge, Royal Society of Chemistry.

[72] Nonhebel, S.; and Raats, J. (2007.) Environmental impacts of meat substitutes: comparison between *Quorn* and pork. *Proceedings 5th international conference on LCA in foods*, 25–26 April 25-26 2007, pp,. 73-–75. Gothenburg, Sweden.

[73]Muroyama, K,.; Hayashi, T,., Ooguchi, M and J Hayashi, J. (2003.) Evaluation of Eenvironmental Iimpact for Ttofu Pproduction on the Bbasis of cCumulative CO_2 Eemission Uunit. *Environmental Science*, 16 (1), : 25-–32.

[74] Håkansson, S,.; Gavrilita, P. and X Bengoa, X. (2005). Comparative Life Cycle Assessment pPork vs Ttofu. *Life Cycle Assessment*, 1N1800, Group 5 Stockholm.

Egg substitution is very speculative and is based on a hypothetical alternative derived from soya protein.

Vitamin B_{12}, iron and calcium dietary requirements were taken from Salmon[75] and related to the animal-based and vegetable-–based alternatives to estimate supplementation requirements. Vitamin B_{12}, production was assumed to be the same as the synthetic production of the amino acid, lysine and existing inventory values were used for iron and calcium. It is worth noting immediately that the quantities of B_{12} needed are very small, because the amounts in any foodstuff are only a few µg per 100 g, compared with several g of fat, protein or carbohydrate, so that the unit burdens of producing B_{12} would need to be extraordinarily high to have any substantial effect on the overall impacts of a supplemented food.

GHG emissions from the 'Regional Distribution Centre (RDC) to retail

The energy used to deliver food from the RDC to retail stores and during retail itself (including refrigeration, heating, lighting and ventilation) varies according to storage temperatures and throughput, as well as distance. Additional emissions of GHG also occur from mobile chillers and those used in retail outlets as well as land-filling wasted food. The GHG emissions of different foods were estimated from Tassou *et al*.[76] and based on the storage temperatures in the RDC and retail stores (Table 5). The landfill emissions assume a relatively low wastage rate from RDC to retail of 1% over all food types. This is an area still being researched in Defra and WRAP funded studies so is an arbitrary estimate based on informed opinion. The same wastage rate was assumed in service sector supply chain.

Table 5. Estimates of GHG emission for different food types depending on the temperature of storage and delivery, kg CO_2e/kg. The letters have these meanings, with the 1st first applying to the RDC and the second to retail: A = Ambient, R = Refrigerated, F = Frozen, M = Milk (fresh)

Source of emissions	AA	RA	RR	FF	MM
Electricity	0.001	0.008	0.50	0.61	0.036
Refrigerants	0.000	0.000	0.59	0.38	0.044
Road fuel & Oil	0.052	0.018	0.026	0.017	0.016
Landfill	0.012	0.012	0.015	0.012	0.012
Total	**0.065**	**0.038**	**1.1**	**1.0**	**0.11**

Shopping transport energy

Much food is currently bought by using cars or buses, which use petrol or diesel. The energy used in shopping came from Pretty *et al*. (2005).[77]. They calculated that the average shopping basket weighs 28 kg and the mean distance travelled is 6.4 km. Assuming a set of ways of travelling to shops, the GHG emitted per kg is 0.034 kg CO_2e/[kg shopping] (Table 6).

Table 6. Energy used and GHG emitted during the average shopping trip (based on Pretty *et al*. 2005)

Transport modes	Proportion	Fuel, litres/km	Occupancy rate	MJ/kg	kg CO_2e/kg
Car	59%	0.081	1	0.80	0.057
Bus	8%	0.40	30	0.13	0.009
Walking	30%				
Cycling	3%				

[75] Salmon, J. (1991.) *Dietary reference values: aA guide*. HMSO.

[76] Tassou, S,. ; Hadawey,. A,;, Ge, Y.; and D Marriot, D. (2009). *Presentation on "Greenhouse gas impacts of food retailing"*. Defra-funded project FO0405

[77] Pretty, J. N, Ball, A.S, Lang, T, and JIL Morison J. I. L. (2005). Farm costs and food miles: An assessment of the full cost of the UK weekly food basket. *Food Policy*, 30, 1–19.

Total	100%				
Weighted mean				**0.48**	**0.034**

Cold storage in homes and food service sector

Once food and drink are taken home or delivered to a food service sector outlet, some is stored in refrigerators or deep freezes. In the service sector, open top devices are also used (e.g. for salad bars) and drinks may be stored in cellars, behind-bar cabinets and trays and served through chilled pipes. Fridges and freezers are typically the most power consuming item in the home as the top level BRE data shows. The energy use in domestic households was estimated from typical appliance energy usage and the throughput of food and drink in households. It was then allocated to each refrigerated or frozen item by weight (Table 7). Energy use in the service sector was derived from BERR's top level data. It was applied at the sectoral level and the best estimate of the value per kg food or drink is also given.

Table 7. GHG emissions data for cold storage in home and the food service sector used in this study

Domestic		Service sector
Chilled	Frozen	Refrigerated and frozen
0.25 kgCO_2e/kg product	3.5 kgCO_2e/kg product	24 kgCO_2e per person per year

Cooking energy

The cooking energy data originate from the formulae of Sonesson *et al.*[78] (with later interpretations from Carlsson-Kanyama & Faist[79]). Sonesson *et al.*'s formulae seem to be based on best practice. Work at Campden BRI has shown that cooking energies can vary widely for the same food type by using different equipment and cooking methods (e.g. stir fry, roast, boiling or frying. The variation of individuals is also considerable, e.g. observe the amount water boiled to make 1one cup of coffee, let alone the effects of portion size on cooking energy (in which smaller portions are more energy intensive in most cases). We started by quantifying a range of foods using most likely methods and applying Sonesson *et al.*'s formulae, which generated a range of cooking intensities with a maximum of 10 MJ/kg. Using an equal mixture of electricity and gas as energy carriers (i.e. 5 MJ delivered electrical energy and 5 MJ delivered net energy from natural gas) causes the emission of 1.3 kg CO_2e/kg, which was reduced to 0.09 with low CO_2 energy supplies. The food types given in the Family Food Survey were ranked by expert opinion. Small allocations were included for take-away items that were consumed in the home to allow for some re-heating. This bottom-up modelling approach was found to underestimate the energy used in cooking from the BRE top- down survey data[80] by about 50% Given that the scaling applied was relatively coarse and without being able to obtain more detailed activity data, all individual values were then doubled and were used in the subsequent analysis.

Wasted food management

It was assumed that most food waste currently goes to landfill with very limited energy recovery, 0.49 kg CO_2e/kg waste. The improved method is based on data from the Holsworthy centralised anaerobic digester in Devon, in which food wastes and manure are co-digested. The results of

[78] Sonesson, U,.;. Janestad, H. and B Raaholt, B. (2003.) Energy for pPreparation and Sstoring of Ffood -– Models for calculation of energy use for cooking and cold storage in households. SIK-Rapport, 709 2003, 1-–56. Gothenburg, Sweden, SIK. SIK-Rapport.

[79] Carlsson-Kanyama, A. and Faist, M, M. (2000). *Energy Uuse in the Ffood Ssector: a data survey*. AFN report 291, Swedish Environmental Protection Agency, Stockholm, Sweden.

[80] Utley, J.I. and Shorrock, L.D. (2006.) Domestic eEnergy Ffact Ffile (2006). Report for Defra by BRE. http://projects.bre.co.uk/factfile/TenureFactFile2006.pdf

Cumby *et al*[81] were analysed and used to calculate a net credit from electricity generation 0.031 kg CO_2e/kg waste. This allows for the extra fuel of collection etc.

Enteric and sewage emissions

These were omitted from the study owing to lack of resources and the expectation that the effects of dietary change would have relatively small effect on these. Furthermore, while the change in available energy mixture would have some effects on reducing the impact of wastewater and sewage sludge management, the overall range of possibilities really deserves a separate study in the its own right. Also, the focus iof the study was on production, distribution and consumption.

The 'top-down' method of calculating land use change emissions attributable to agricultural production.

This approach involves estimating total observed land use changce (LUC) emissions caused by commercial food production, and allocating that total "pool" of emissions to different food-types consumed in the UK based on their global average land-area requirements per unit of production. It should be noted that this approach does not divide emissions into emissions arising from LUC directly connected to crop consumed (direct emissions) and indirect emissions arising from the effect of land use for consumed crops displacing other crops to agricultural land obtained by LUC (indirect emissions). This is based on a methodology published by Ecometrica.[82]. Central to the approach is the consideration that agricultural commodity markets are global and interconnected, and all demand for agricultural land contributes to commodity and land prices, and therefore contributes to land use change. The steps are set out in Table 8.

There are a number of advantages to this approach. Firstly, the emissions allocated to different food-types will not sum to a figure which is greater than actual observed LUC emissions. This is important to maintain the integrity of a consumption-based emissions accounting approach (i.e. total emissions allocated should not exceed total emissions, also known as the "100% rule"). Secondly, food-types which have high land use requirements (e.g. beef) are allocated higher LUC emissions, and switching to food-types with lower land use requirements will show a reduction in LUC emissions. In addition, measures such as a reduction in total food consumption will show a reduction in LUC emissions. Thirdly, the method recognises that all demand for agricultural land contributes to LUC pressures (either directly or indirectly), and therefore all demand for agricultural land (via the consumption of agricultural commodities) should be allocated a share of LUC emissions.

Table 8. Steps in conducting the 'top-down' method to estimate land use change greenhouse gas emissions attributable to UK food consumption.

Step 1. Estimate total LUC emissions per year (GtCO_2e/yr)
Step 2. Estimate the proportion of total LUC caused by commercial agriculture, including ranching (% of LUC)
Step 3. Divide LUC emissions attributable to agriculture (derived from Steps 1 and 2) by total commercial agricultural land area to derive LUC emissions per hectare (tCO_2e/hectare)
Step 4. Calculate land requirement for each food commodity consumed (hectares/tonne of commodity)
Step 5. Multiply LUC emissions factor (from Step 3.) by commodity land requirement (from Step 4.) to derive LUC emissions per tonne of commodity (tCO_2e/tonne)
Step 6. Multiply LUC factor per tonne of commodity (from Step 5.) by total quantity of each commodity consumed in the UK (tCO_2e/yr)

[81] Cumby, T.R,.; Sandars, D.L.; and E Nigro, E. (2004). Physical assessment of the environmental impacts of centralised anaerobic digestion – Defra-funded project CC0240.
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=9206&FromSearch=Y&Status=3&Publisher=1&SearchText=centralised&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description

[82] Tipper, R., Hutchison, C and M Brander, M. 2009. *A practical approach for policies to address GHG emissions from indirect land use change associated with biofuels*. Ecometrica, UK.

Step 7. Sum the LUC emissions calculated for each commodity (from Step 6.) to derive total LUC emissions associated with UK food consumption.

One of the disadvantages of this method is it does not pick out the possible differences between food-types which happen to have the same land-area requirements per unit of output. For example, if palm oil and rape seed oil had similar land-area requirements per unit of output then they would be allocated the same LUC emissions (although the actual total (direct and indirect) LUC impacts may be different – e.g. palm oil may cause higher total emissions thatn rapeseed oil). This limitation in the accounting method may have the perverse effect of directing consumption towards commodities that have higher LUC impacts. One possible solution to this issue is to implement a decision-rule when considering mitigation options, e.g. if switching from a high land-requirement food to a low land-requirement food, the low land-requirement food should not be associated with direct LUC.

Details of the use of the 'top-down' method as applied to this study.
Global average yields for crops and livestock land requirements were used in the analysis, rather than the yields of crops and the land requirements of livestock directly consumed by the UK. This approach was adopted to reflect the integration of world commodity markets. The UK's demand for commodities contributes to world prices generally, rather than to prices for commodities with a specific land requirement, and therefore world average yields are considered appropriate. This approach also avoids the possibility of "playing" the accounting system by consuming commodities from higher yield regions, and leaving lower yield production for others to consume (with total emissions remaining the same).

Quantifying land use for animal production presented a special challenge, particularly for grassland. We used estimates of total arable crop use in livestock production in 2002[83] to estimate arable crop use in livestock production in 2005 by adjusting the 2002 figures to account for changes in livestock production between 2002 and 2005. Total livestock production in 2005 and associated permanent grassland was screened to identify the world's 'commercial' livestock production and associated pasture. This was done in order to exclude large areas of extensively grazed pasture which are not connected to global commodity markets. FAO country level livestock production, import, export and land use data sets were synchronised with each other to allow screening using all parameters. A country was defined as having a commercial livestock industry connected to world trade if its exports or imports were greater than 0.5% of world imports or exports *and* production iwas greater than 0.5% of world production in 2005. We examined several screens against countries most would regard as connected and not connected to world trade and this screen proved most efficient against these sense checks. Agricultural production on native wild grassland is not connected to land use change. Our screen had the merit of excluding most of the world's native grassland – e.g. the Savannahs of Africa and the native grasslands of Mongolia.

The totals for arable crops used in livestock production were allocated to world livestock production using the rates of feed use for livestock products as identified in the Cranfield model.[84]. From this, the inputs of the major feed commodities per tonne of output were identified. The land area required was calculated as for crops for direct human consumption using average global yields.

The allocation of pasture was done in a slightly different way. The starting point was the assumption that commercial pasture use is dominated by cattle for milk and beef, and sheep and goats for meat. The screen described above was used to identify the area of permanent pasture and the corresponding meat and milk production connected to world trade. The

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

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

cultivated pasture (i.e. pasture sown on arable or potentially arable land) was added to this resulting in an estimate of the total grassland area used to support commercial livestock production connected to world trade. Due to the practice of multiple or combined grazing it was not possible to calculate land requirements for specific commodity types, e.g. bovine meat, sheep meat and milk. Therefore the use of pasture land was treated as a single process and the associated emissions were allocated by economic output value. To avoid using values influenced by local subsidies and markets, representative world prices were derived from average producer prices in Australia and New Zealand in 2005. Total emissions from cultivated pasture were allocated between beef, sheep/goat meat and milk. All the emissions from permanent pasture on land not suitable for arable crops were allocated to the meats. The work therefore considers dairying as based on cultivated pasture, based on an assumption that commercial dairying world-wide is generally conducted on cultivated pasture while commercial permanent grassland is generally used for meat production. The analysis is based on the IPCC estimate of land use change emissions[85] and data on the primary drivers of land use change[86] (Table 9). This identified the total global land use change emissions arising from agriculture.

Table 9. Basis for identifying the proportion of deforestation attributable to commercial agriculture as a basis for partitioning land use change emissions.

Annual average forest loss between 2000 and 2005 - Africa:	4 million ha
Annual average forest loss between 2000 and 2005 - Asia/Pacific:	3.7 million ha
Annual average forest loss between 2000 and 2005 - Latin America:	4.4 million ha
Total	**12.1 million ha**
% of deforestation due to large scale agriculture - Africa:	12%
% of deforestation due to large scale agriculture - Asia/Pacific:	29%
% of deforestation due to large scale agriculture - Latin America:	47%
% of deforestation due to small scale permanent agriculture – Africa:	59%
% of deforestation due to small scale permanent agriculture - Asia/Pacific:	13%
% of deforestation due to small scale permanent agriculture - Latin America:	13%
Proportion of total LUC emissions attributable to commercial agriculture:	**58.1%**

The estimates of LUC emissions associated with UK food consumption resulting from this methodology should be interpreted with care, especially when considering mitigation options. The method is based on an attributional approach which allocates LUC emissions based on the average land area requirements of the foods consumed in the UK. Attributional LCA (ALCA) is useful for allocating "responsibility" for emissions, based as closely as possible on the causal relationship between the emissions and the entity to which they are allocated. It is also the appropriate approach for consumption-based carbon accounting as it avoids double-counting emissions. However, it does not capture all the complexities and consequences of specific mitigation actions or policies.

In order to quantify the full GHG consequences of an action, consequential LCA (CLCA) is required. CLCA looks at marginal changes arising from actions and quantifies all the consequences which flow from this. The attributional approach is therefore useful for estimating the size of LUC emissions attributable to UK food consumption, and it can indicate possible mitigation options, but it does not accurately quantify the actual emissions reductions achieved

[85] IPCC. (2007). *Climate Cchange 2007*:. Synthesis Report.

[86] FAO. 2007. *State of the Wworld's Fforests*.

by different mitigation options. For example, attributional LCA may show that in the current agricultural system, beef has more embedded emissions than poultry meat. The attributional approach is essentially a system of accounting emissions and attributing them to commodities as currently produced and consumed. However, it does not say what the full consequences of a significant shift from beef to poultry would be. For example, a reduction in beef consumption may increase reliance on male calves from the dairy herd reducing the burdens from beef production. It should be noted that this limitation with attributional analysis arises for most emissions sources across the economy. For example, a grid average emissions factor is used when allocating emissions from electricity consumption (within an ALCA)., hHowever, when quantifying the actual emissions reductions from reducing electricity consumption the grid margin should be used, and other consequences from the action should also be taken into account. The relationship between the attributional figures for LUC and the emissions reductions achieved by specific mitigation options is likely to be less close than for other emissions sources, given the complexity of the causal interactions between demand for a food commodity and LUC (particularly indirect land use change). Attributional figures help to indicate possible mitigation options, such as switching from foods which have high land area requirements to those that have lower land area requirements. However, such options should be investigated in greater detail using consequential analysis, in order to accurately assess the emissions reductions achieved.

Uncertainties arising from the 'top-down' method

Estimates of land use change emissions have high uncertainty[87], and perhaps the highest uncertainty of any emissions source. There is therefore high uncertainty associated with the estimate of total LUC emissions used in this study (the 8.5 $GtCO_2e$ figure derived from the IPCC's Fourth Assessment Report[88]). There is also high uncertainty associated with the estimate of the proportion of total LUC emissions attributable to commercial agriculture, which is based on the FAO's *State of the World's Forests Report 2009.*[89]*.* Land use change is driven by the interaction of numerous proximate and underlying causes, and attributing a proportion to a single cause will be approximate.

A further source of uncertainty in the calculations relates to the allocation of emissions associated with pasture use. Data were not available for the average pasture land area requirements for livestock commodities and therefore the LUC emissions associated with the use of pasture land were allocated between beef, sheep and goat meat, and milk products on the basis of economic value (and other underlying assumptions). There are a number of further steps in the methodology which could be performed in different ways, for example, the allocation of emissions could be undertaken on the basis of economic value rather than land area requirement per unit of commodity. This approach would reduce the allocation of LUC emissions to high land requirement commodities such as beef and sheep meat, but the LUC emissions associated with these commodities would remain relatively high due to their high economic value.

Differentiated emissions value for pasture land/credit for increased carbon sequestration in pasture land

[87] Ramankutty, N., Gibbs, H.K., Achard, F., Defries, R., Foley, J.A. and RA Houghton, R.A. (2007). Challenges to estimating carbon emissions from tropical deforestation. *Global Change Biology*, 13, 51-–66.

[88] Barker T., I,. Bashmakov, IL,. Bernstein, LJ. E,. Bogner, JEP. R., Bosch, RP,. Dave, O. R,. Davidson, OB. S,. Fisher, BS,. Gupta, SK,. Halsnæs, KG.J., Heij, BJS,. Kahn Ribeiro, S,. Kobayashi, SM. D,. Levine, MD. L,. Martino, DLO,. Masera, OB,. Metz, BL. A,. Meyer, LG.-J,. Nabuurs, , G-JA,. Najam, AN,. Nakicenovic, NH. -H,. Rogner, H-H J,. Roy, J,. Sathaye, JR,. Schock, RP,. Shukla, PR. E. H,. Sims, REHP,. Smith, PD. A,. Tirpak, DA., Urge-Vorsatz, D. and D Zhou., 2007: Technical Ssummary. In: *Climate Cchange 2007: Mitigation. Ccontribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, and L. A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[89] FAO. 2009. *State of the Wworld's Fforests* Rreport http://www.fao.org/docrep/011/i0350e/i0350e00.HTM

The method for estimating LUC emissions attributable to UK food consumption uses a single emissions factor for agricultural land, i.e. 1.43 tCO_2e/hectare of agricultural land used. There is a case for using different emissions factors for pasture land and cropland, as grassland generally has higher carbon stocks than cropland. In order to apply this approach average carbon stock figures for pasture and cropland are required. The average baseline carbon stock of land converted to agriculture and a method for calculating emissions factors to reflect the relative contribution of pasture or cropland to LUC emissions would also be required. It is also necessary to ensure that when the calculated emissions factors are multiplied by the total area of each land use type, the total emissions figure equals the total LUC emissions associated with agriculture (to avoid over or under allocating emissions). Further complexities may arise if the categories of pasture land and cropland are considered too broad, and differences within these categories are accounted for, such as the variation in carbon stocks depending on crop type, land management practices, and soil type.[90] [91]. The possibility of using different emissions factors for different land use types should be the subject of further research. An alternative approach may be to apply a single emissions factor for agricultural land, but to introduce a "credit" or derogation for commodities which are from agricultural systems which can be shown to avoid direct and indirect land use change. For example, if commodities are produced on marginal or degraded land, which would not have been used for any other purpose, they may have neutral or even positive effects on direct carbon stocks (e.g. on the degraded land), and will not displace other agricultural activities (and therefore avoid indirect land use change).

Land use emissions, soil carbon changes

The world's soils are estimated to contain 1,500 Gt of organic carbon which is roughly twice that in the atmosphere.[92]. Oxidation of soil organic matter accounts for a natural flux of about 75 Gt per year through which carbon entering the soil from plants is returned to the atmosphere.

The UK has a net emission of 2 Mt CO_2 from land according to the UK GHG inventory.[93]. Grassland absorbs 8 Mt, and crop land releases 15 Mt. Losses from arable soils include the oxidation of fenland peat, which is an irreversible loss. The uptake of carbon by grassland includes increased storage in temporary grassland which is partly offset by emissions from the arable phase land in these mixed-farming rotations. Climate change rather than land use is implicated in long-term reductions.[94]. This has not been formally introduced into the UK GHG inventory, but the possibility is being considered.[95].

In the UK context, these fluxes from soil are reversible and not intrinsically linked to agriculture on stable soils such as those in northern Europe. However, we recognise that expansion of agricultural land on a global scale, especially the expansion of arable land, would increase soil carbon losses.

Regional emissions

[90] Wang, Z.,, Han, X., and L Li, L. (2008). Effects of grassland conversion to croplands on soil organic carbon in the temperate Inner Mongolia. *Journal of Environmental Management* 86, (2008) 529–534.

[91] Kim, H., Kim, S., and B Dale, B. (2009). Biofuels, Lland uUse Cchange, and Ggreenhouse Ggas Eemissions: Some Uunexplored Vvariables. *Environmental Science and Technology***.** 2009**,** 43*,* 961–967.

[92] Schlesinger, W.H. and Andrews, J.A. 2000. Soil respiration and the global carbon cycle. *Biogeochemistry* 48,: 7-–20.

[93] NAEI. 2005. *UK emissions of air pollutants 1970 to 2005.*

[94] Bellamy, P.H., Loveland, P.J., Bradley, R.I., Lark, R.M. &and GJD Kirk G.J.D. (2005). Carbon losses from all soils across England and Wales 1978–2003. *Nature*, 437, 245–248.

[95] Thomson, A.M. (2008). *Inventory and projections of UK emissions by sources and removals by sinks due to land use, land use change and forestry*. Annual Report, July 2008. Defra Contract GA01088, CEH No. C03116. (http://www.edinburgh.ceh.ac.uk/ukcarbon/docs/2008/Defra_Report_2008.pdf)

The study examined differences in consumption between the UK regions and the implications for emissions. The consumption of commodities by the English, Welsh, Scottish and Northern Irish was derived from the Family Food Survey consumption data. The commodity contents of all product categories from milk to various types of ready meals and food service products were estimated from the commodity composition of each. The total commodity values consumed were then summed and compared with the pre-RDC FAO data. Agreement was reasonably good (70% to 110% for most commodities). The FAO data were then scaled by the population of each part of the UK and the per capita consumption of commodities wasere obtained.

Mitigation measures

The main aim of the study was to consider potential scenarios for reducing human-induced GHG emissions attributable to the UK food system by 70% by 2050. To examine reductions in the region of 70%, scenarios require several mitigation measures to be implemented together.

The research first examined the effect of individual mitigation measures on the emissions inventory. The first stage was to be a free-thinking listing of all possible measures (e.g. change from red meat to white meat; reduce GHG emissions form livestock waste). We identified 7 consumption and 23 production measures (Table 10).

Production measures

A series of production measures was drawn up and a model developed to test the overall impact of these when applied to all commodities. The majority of GWP values for these measures were derived using the Cranfield model and values for other commodities scaled or inferred from proxy values.

Zero electricity from fossil fuels

This measure assumed that all electricity could be produced from non-fossil fuel based sources. Electricity burdens within the Cranfield model were adjusted to reflect this and other commodity values were scaled in proportion to the reduction achieved.

Zero enteric emissions

This highly speculative measure assumed the development of technology or feed to completely remove or perfectly capture enteric emissions from ruminants. The Cranfield model is structured such that it was possible to set enteric methane emission factors for beef, dairy cattle and sheep to zero. Using data from the comparative LCA study[96], GWP values for commonly imported livestock commodities such as Brazilian Bbeef and New Zealand lamb were scaled appropriately based on results for UK livestock.

N_2O release inhibitor with fertiliser

This measure assumed that fertiliser could be produced such that N_2O emissions from soils could be completely prevented. To simulate this, the IPCC emission factor EF1 (emission factor for N_2O emissions from N inputs[97] was set to zero. This assumes that a nitrification and denitrification inhibitor can stop N_2O emissions from synthetic N fertiliser.

Anaerobic digestion (AD) of manure (no stored manure emissions)

This was applied to manure from all non-grazing stock and it was assumed that the emissions of methane from the point of manure capture were zero. The benefits of anaerobic digestion were quantified as credits from removing methane emission from managed manure and credits for

[96] Defra project FO0103. *Comparative life-cycle assessment of food commodities procured for UK consumption through a diversity of supply chains.*

[97] IPCC. 2006. *IPCC Guidelines for Nnational Ggreenhouse Ggas Iinventories*. (2006 Guidelines) http://www.ipcc-nggip.iges.or.jp/

generating electricity. The electricity generated was taken from Parsons[98] [99] and the benefits are summarised in Table 11.

50% yield increase
This measure assumed that with no increase in fertiliser application rates or change to land requirements it would be possible to increase crop yields by 50%.

Zero N_2O from nitrate fertiliser production
This is a specific emission from one stage in fertiliser manufacture that relates only to nitrate production and is associated with N_2O emissions that can be abated already to some degree.

Improved Feed Conversion Ratio
Without reference to method, this measure assumed that it would be possible to improve the feed conversion ratio (FCR) of livestock by 25% over the next 40 years, that is, the ratio of mass of all food eaten to body mass gain over a specified period of time. If body mass gain is greater, or food consumption reduced this reduces the ratio. Thus the Cranfield model was used and the FCR reduced by 25% for pig meat, poultry and eggs. For beef, dairy cattle and lamb, the efficiency of fattening was increased by 25% to give an equivalent effect.

Table10. Details of mitigation measures

Production	
Zero fossil fuels (electricity and other energy carriers)	Very low carbon fuels (1% of standard) – including diesel
No enteric methane emissions from ruminants	No enteric methane emissions from ruminants
N_2O inhibitor with fertiliser (no N_2O from soils)	No N_2O from fertiliser applied to soils
Anaerobic digestion (AD) of manure (no stored manure emissions)	No methane from manure and all used in AD to produce bio-energy
50% yield increase	Crops having 50% increase in yield with associated increase in inputs
Zero N_2O from nitrate fertiliser production	No N_2O from fertiliser production through perfect filtration
25% improvement in feed conversion efficiency	Improved feed conversion ratio (FCR) for finishing meat animals and in egg and milk production
N use efficiency in crop production increased by 50%	Reduce losses of nitrogen by denitrification, volatilisation or leaching by 50%
Livestock production based on by-products (grass still used for ruminants)	Concentrates produced only using by-products plus beans and wheat where necessary
Minimum tillage (where possible)	Reduce tillage energy to levels of minimum tillage for all crops.
Organic production	Commodity production using organic methods rather than the non-organic assumed elsewhere
Energy, processing, distribution, retail and preparation (post RDC)	
Low carbon energy for cooking	Reduced emissions from cooking by using very low carbon fuels (7% of standard), but the same amount of process energy in the home and service sector
Low carbon energy for supply chain chilling	Reduced emissions from refrigeration and freezing by using very low carbon fuels (1.25% of standard), but the same amount of process energy.

[98] Parsons, DJ. (1984.) *A survey of literature relevant to the economics of anaerobic digestion of farm animal waste*. Divisional Note DN. 1225, National Institute of Agricultural Engineering, Silsoe, UK., 1984

[99] Parsons, DJ. (1986). The economics of the treatment of dairy-cow slurry by anaerobic-digestion. *Journal of Agricultural Engineering Research*, 35 (4), 259-–276.

	Refrigerant emissions still the same.
50% saving in energy inputs into processing	Assumed more efficient food industry using 50% of energy in embedded materials and process energy
Low GWP potential refrigerants	Low GWP potential refrigerants used in transport and retail cold shelves
Low carbon transport in processing and distribution	Very low carbon fuels (1.25% of standard) used in the RDC and retail stores
Energy recovery from food waste using AD	No reduction in waste arisings, but better management with energy recovery
Low energy use in consumer transport	10% of current energy used by shoppers and in transport to service outlets
95% reduction in GWP of packaging	Reduced GWP from packaging in the supply chain (5% of standard), e.g. much lower wastage, less material &/or fuel efficient recycling
75% reduction in GWP from shopping bags	25% of current GWP by more re-use of shopping bags from retail and take-away service sector outlets etc.
Low GWP home refrigerants	Low GWP potential refrigerants in homes and service sector outlets
Consumption	
No meat	Meat is replaced by fungal protein, tofu and pulses
66% reduction in livestock products	Livestock products are reduced and other food increased by 29%
50% reduction in livestock products	Livestock products are reduced and other food increased by 21%
Red to white meat	Red meat is replaced by white meat with an increase in vegetables (NB there is still some shortage of vitamins, but these have small burdens of production)
No dairy milk	Dairy milk and products are replaced by soy based milk products
No rice	Rice is replaced by wheat and potatoes
No eggs	Eggs are replaced by "soy synthetic egg"
All avoidable food waste avoided	Unavoidable waste (WRAP definition) still to landfill etc., but less production needed

Table 11. Manure dry matter (DM) outputs and GHG emissions credits from using anaerobic digestion.

	Manure DM output per t commodity	Electricity generated, kWh/t manure DM	kWh/t commodity	GHG Credit, kg CO_2e, electricity/t commodity	Credit from stopping CH_4 emissions, kg CO_2e /t commodity	Total GHG Credit t CO_2e /t commodity
Pig	1.9	196	373	250	398	0.65
Poultry	0.7	420	273	183	8	0.19
Beef	8.0	155	1,243	831	1,135	2.00
Milk	0.4	155	55	36	47	0.08
Eggs	1.1	420	448	299	17	0.32

N use efficiency in crop production increased by 50%

This assumed that N losses by denitrification, volatilisation and leaching were all reduced, thus requiring lower N supplies for the same yield.

Livestock from by-products

The concentrates were re-formulated to use by-products (rapemeal, brewer's grains and wheatfeed) as protein sources replacing imported soya and maize by-products. The aim was to maintain the same metabolisable energy and digestible crude protein content. Where necessary UK feed peas/beans were increased to balance the diet. Although by-products are fully used at present, increasing amounts will become available with increased biodiesel and bioethanol production and similarly in a scenario with refined cereal based products replacing meat.

Minimum tillage

This assumes reduced energy consumption for cultivation, equivalent to the energy required for minimum tillage. The Cranfield model allows most crop commodities to be modelled at this reduced energy input level, and burdens for other crops were scaled according to the proportional reduction in appropriate proxy crops.

Zero fossil fuels
Further to the zero electricity from fossil fuels measure, this assumes that all other energy requirements could be produced from renewable sources. To model this it was assumed that all pre-RDC carbon dioxide (CO_2) emissions arose from combustion, and thus were subtracted from GWP values for each commodity. This was applied both using both the Cranfield model and various studies from the literature search which produced sources that gave a breakdown of GWP into component gases. With post RDC cooking, a slightly less effective change was assumed, given that some gas or solid fuels would always be needed.

100% organic production
This measure assumed that all commodities would be produced using organic production. This presents some difficulties because the production of all commodities currently consumed is unlikely to be possible using an all organic scenario (e.g. less poultry and pig production seems inevitable, while beef and sheep would increase). Estimating possible production levels is not without difficulty and a recent study for the Soil Association by a team from Reading University[100] illustrated this well, with extensive discussion of their findings in the FCRN. They did not have the resources to model all land use and production thoroughly but used statistical data from the Farm Business Survey on yields and farm types around England and Wales to estimate production from yields or farm types. These produced quite disparate results for good reasons, e.g. wheat production going down by about 35% or 65%. Crops like oilseed rape and sugar beet are rarely (if at all) grown in the UK, because there is currently apparently no UK organic market. We would still need oil and sugar in our diets (although not necessarily as much as we have now) and these would need to be sourced from somewhere. It is inconceivable that a market would not develop and that some domestic sugar and oil would be produced, although overseas production might dominate an open market. Another aspect of this is what that wider context is. In a 100% organic world, global land use would be very different and the ability to import would change too, so adding further to speculation. The range of commodities actually consumed would be determined by market forces (it is reasonable to assume). So, with barley production falling by about 50% [96], the amounts of poultry and pig products would be in direct competition with barley for malting. Factors like this add to the complexity of any forecasting.

We, like the Reading University team, did not have the resources to model an all organic future as well as could be wished for. The main comparison simply considers the substitution of current consumption by the same amount of commodities produced organically. This is unlikely, but it provides some quantification of the differences in GHG emissions between the production systems. While some commodities have been analysed with the Cranfield model, it does not address all commodities, especially those produced overseas nor any fruit or field vegetables (except potatoes). There are some other LCA studies that study organic production, but the picture is incomplete. Where there were gaps in the data, (e.g. fruits) missing values were assumed to be no different from non-organic production.

Some explorations of alternative production scenarios based on Jones & Crane were also explored, but they are limited in what they can offer.

It should be noted that post- farm gate, it can only be assumed that distribution and cooking are essentially the same. Critical comment is inevitable and to avoid re-runs of well worn arguments about the Cranfield model, we present results from four independently conducted studies on

[100] Jones, P.; and Crane, R. (2009). *England and Wales under organic agriculture: how much food could be produced? CAS Report 18, Centre for Agricultural Strategy*, University of Reading. ISBN 978 0 7049 9802 5.

one the biggest single terms – milk. All the results are broadly similar, without any systematic differences between non-organic and organic milk production (Table 12).

The systems approach of the Cranfield LCA model enabled the main commodities to be modelled with the N_2O-N portion of the GWP attributable to fertiliser manufacture removed and other commodity values scaled from this.

Table 12. Comparisons of GHG emissions from milk production by organic and non-organic production to the farm gate per m^3

Study	Non-organic	Organic
Williams *et al.*, 2006[101]	1.10	1.20
Cederberg & Mattsson (2000) [102]	1.10	0.95
Thomassen *et al.* (2008) (on farm)[103]	0.70	0.90
Wiltshire *et al.* (2009)[104]	1.2 (high yield), 1.4 (low yield)	1.30

The results of the organic scenarios stand apart somewhat from the main body results of results and are in a separate section. Note that the implications for LUC emissions which are not included are enormous.

Post RDC measures

Cooking

The same amount of process energy is used for cooking, but with very low carbon electricity and some gas. This would reduce emissions to 7% of standard.

Chilling energy

The same amount of process energy is used for refrigeration and freezing in homes and service sector outlets, but using very low carbon electricity, i.e. 1.25% of standard emissions. Refrigerant emissions are assumed not to change.

Food processing

A more efficient food processing industry is assumed that reduces external energy input to 50% of current levels using a combination of embedded energy in materials and more efficient use of process energy.

Distribution chain refrigerants

The current generation of chiller units used in transport and retail cold shelves mainly use high GWP potential refrigerants. This assumes that low GWP ones can be used. In general, larger static plants already tend to use lower GWP refrigerants and /or leak less.

Distribution chain fuels

This assumes that in the RDC and retail outlets, very low carbon fuels electricity (1.25% of standard) is used.

All current food waste to AD

---

[101] Williams, A., Audsley, E. and D Sandars, D. 2006. *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities*. Defra project report IS0205, as further developed under Defra project IS0222.

[102] Cederberg, C, and Mattsson, B. (2000): Life cycle assessment of milk production — a comparison of conventional and organic farming. *Journal of Cleaner Production*, 8(1), 49-–60.

[103] Thomassen, M.A,.; van Calker, K.J,.; Smits, M.C.J., Iepema, G.L.; and IJM de Boer, I.J.M. 2008. Life cycle assessment of conventional and organic milk production in the Netherlands. *Agricultural Systems* 96, 95–107.

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

It is assumed that the current level of food waste arisings is maintained, but it is managed better. Instead of going to landfill, food waste is co-digested with energy recovery as electricity.

Distribution chain delivery energy
Very low carbon fuels (1.25% of standard) are used for transport between the RDC and, retail stores and food service outlets.

Shopping transport
It is assumed that 10% of current energy (and hence GHG emissions) is used by shoppers and in transport to service outlets.

Packaging
Reduced GWP from packaging in the supply chain (5% of standard), e.g. much lower wastage, less material &and/or fuel efficient recycling

Shopping bags
More re-use of shopping bags from retail and take- away service sector outlets etc. is assumed , so resulting in GHG emissions falling to 25% of the current level.

Refrigerants (end users)
Current units use high GWP refrigerants in homes and service sector outlets, although leak much less thant mobile or retail units. It is assumed thatn low leakage and low GWP potential refrigerants are used.

Consumption measures
There is now consensus that consumption based mitigation will have changes to livestock consumption as a major element. Specifying relevant changes in diet presents a special challenge. We adopted an open approach to developing consumption (diet) measures which are not be constrained by fixed approaches such as 'vegetarian' or 'vegan', or by a % percentage of the population adopting such approaches. The important thing for the research question is commodity consumption at the population level rather than the proportion of the population adopting a particular diet. It is not sufficient to change one dietary component, for example to reduce beef consumption. The change must be made to the entire diet to reflect increases in some components in response to decreases in others.

Measures examined include the direct substitution of livestock products using plant based alternatives. However, we also consider more comprehensive whole diet changes that are not anchored by efforts to match nutrient profiles, for example protein intake. To guide us, we examined consumption profiles across the world – first by examining the FAO country profiles of agriculture and diet[105] seeking examples of consumption patterns at the population level that show how food systems may change in relation to diet. Throughout most of the world, significant deviations from the commodity consumption characteristic of the UK are associated with greater incidence of under-nutrition, so most countries with low livestock product intakes cannot be used as examples. Japan is an example of a country with a combination of lower calorie intake, and lower intakes of animal products (54% that of the UK). The consumption of meat and especially dairy products is low. However fish consumption is high and individual calorie intake is low. Turkey was identified as a country with low incidences of under-nutrition with calorie intakes similar to the UK even though the intake of animal products is only 36% that of the UK. Total apparent (i.e. all commodity entering the food system including food that is wasted) daily calorie intake is 3,340 per day compared with 3,440 in the UK. Of key importance is that this is achieved with daily calorie intake in livestock products being just 385 (12%) compared with 1056 (31%) in the UK. These significant reductions in livestock production consumption are

[105] FAO. 2004. Country profiles. Statistical Yearbook 2004. http://www.fao.org/ES/ESS/yearbook/vol_1_2/site_en.asp?page=cp

dominated by very significant reductions in meat intake with more moderate reductions in dairy and especially egg consumption. Increased cereal intake compensates in terms of calories. This pattern of commodity consumption was used as a template for identifying realistic dietary measures involving significant reductions in livestock products. This was used to formulate measures resulting in a 50% and 66% reduction in the consumption of livestock products. The 66% reduction option was chosen because the pattern of commodity use in Turkey can be used to identify possible consequences. The 50% reduction measure was derived from this to examine the consequences of halving livestock product calorie intake.

This gives the following changes:

UK diet with a 50% reduction in livestock product intake:

% consumption compared to current diet	
Ruminant meat	30%
Milk	60
Butter	60
Cheese	60
Eggs	90
Demersal fish	27
Poultry	40
Pig meat	40
Other animal fats	30

This gives a total livestock product calorie intake of 526 compared with 1,056. This is compensated by increasing cereal, fruit, pulse, potato, vegetable and vegetable oil consumption by 21%.

UK diet with a c.a 66% reduction in livestock product intake compared with current diet:

% consumption compared to current diet	
Ruminant meat	20%
Milk	50
Butter	33
Cheese	20
Eggs	66
Demersal fish	9
Poultry	33
Pig meat	20
Other animal fats	20
Offal	33

This gives a total livestock product daily calorie intake of 359 compared with 1,056, compensated for by a 29% increase in crop production consumption.

Scenario generation

Scenarios examined the effects of combinations of production and consumption measures. This presented a complex challenge in trying to simulate significant interactions between measures, particularly with respect to the nitrogen cycle. In delivering insight into the scope for reductions, we opted for intermediate scenarios comprising combinations of measures around particular themes. These are as follows:

- "**Non-mobile energy**" – reducing GWP from the fuel input to non-mobile equipment that typically use electricity or gas, such as ventilation and cooking. Typically this would comprise use of renewable energy for electricity or nuclear power, with a shift from gas to electricity in food preparation;.
- "**Mobile energy**" – reducing GWP from the fuel input to mobile equipment that typically use diesel and also GWP from fertiliser production from gas. Typically this would involve replacing diesel with hydrogen or electric engines in vehicles and a new method of fertiliser production using electricity not gas;.
- "**Direct GHG emissions**" – directly reducing direct emissions of GHGs to the atmosphere: refrigerants, methane, nitrous oxide. Typically this would be non GHG refrigerant gas and techniques for reducing methane emitted by ruminants;.
- "**Production efficiency**" – reducing GWP by reducing waste, increasing food conversion efficiency and crop yields, and reducing the energy required in the production processes of food;.
- "**Consumption**" – changing consumption;.
- "**Conservation**" – recycling and avoiding wasteful use.

Combining measures

The general procedure was applied when quantifying the emissions reductions in themes (i.e. a set of measures). The theme was determined, e.g. non-mobile energy. The primary measures associated with it were identified. The potential for emissions reduction with the primary measures were estimated using expert judgement. This included an assessment of technical feasibility, cost and societal acceptance. These were made over time up to 2100 and quantified on the basis of the percentage of the total possible reduction achieved over time. The secondary measures were similarly quantified, but with a lower rate of uptake to reflect the higher importance of the primary measures. Interactions between measures were carefully scrutinised to avoid any double counting. Thus if the consumption of livestock products was reduced, then the potential for savings from methane emissions was also reduced.

The scenarios indicate potential tracks which would result in an eventual 70% saving in emissions. There are an infinity of possible combinations of themes which can be constructed to achieve 70%, but equally there is no single theme which can.

Our consumption based scenario focuses on livestock products. In addition to reducing emissions directly, less meat consumption and production could mean reduced emissions of GHG from arable land as more land would be available for crops for human consumption which could then be grown with less fertiliser-N giving further reductions in N_2O emissions. However, complete removal of livestock products is an extreme option which is not realistic and presents very significant nutritional challenges. So, consumption options other than vegetarianism or veganism were considered in developing the consumption based scenario. The role of meat, dairy, eggs and fish, out-of-season and refrigerated products was examined. This included for example examination of the effect of replacing one type of meat with another. A simple scenario analysis indicated that the substitution of beef and lamb through increasing poultry and pigmeat consumption would lead to a reduction in the direct GHG emissions from primary production of about 6 Mt CO_2e. However, such a simple analysis based only on our existing LCA results is inadequate in estimating the full effects of such a change. To more fully quantify rigorously the potential impacts of such a change, the emissions from changing land use, e.g. tilling grasslands to produce cereals for pig and poultry feeds, need to be estimated as well as the effects of increased soy consumption. In addition, long-term changes to N inputs also need to be taken into account and a proper net GHG budget prepared. For example, while CO_2 emissions from soil will increase following conversion of grassland to arable, the availability of N from soil organic matter will lead to reduced emissions of N_2O from N fertiliser application.

The land resource based food chain was one approach used to configure a scenario that viewed livestock as a means to utilise resources not suitable or needed for the production of plant products. Ruminants are fed only on the grass grown on the land not suitable for crops, while no crops are grown solely for consumption by pigs and poultry. In this scenario, land currently used directly or indirectly for livestock farming could be freed up for other purposes, such as carbon sequestration. This is a complex scenario requiring detailed study to elicit an accurate assessment of potential reduction in GHG emissions.

RESULTS

Current emissions from primary production – up to the Regional Distribution Centre (RDC)

LCI values for commodities to the RDC used in this study. The descriptions are those used by the FAO. Note that feed crops such as feed wheat are not shown. These have already been used in the calculation of the LCI of animal products. Results for all commodities are provided in Table 13. These are condensed to commodity categories in Table 14.

Table 13. Greenhouse gas emissions (CO_2e/kg) from the production of commodities in the UK, the rest of Europe (RoE) and the rest of the world (RoW) for direct UK consumption

Commodity	kg CO_2e/kg commodity		
	UK	RoE	RoW
Almonds			0.88
Anise, badian, fennel etc.			1.41
Apples	0.32	0.43	0.88
Apricots		0.43	
Artichokes		0.48	
Asparagus	1.94	2.22	2.39
Avocados		0.43	0.88
Bananas			1.33
Barley	3.24	3.35	
Beans (incl. cow peas), dry		0.61	
Beans, green	1.55		10.70
Beef	12.14	12.26	32.00
Cabbages, other brassicas	0.22	0.48	0.64
Carrots and turnips	0.35	0.46	
Cashew nuts			1.06
Cauliflowers and broccoli	1.94	2.22	2.39
Misc. cereals	0.37	0.49	
Cherries	0.32	0.43	0.88
Chestnuts		0.43	
Chick peas		0.77	0.80
Chicken meat	2.84	2.95	2.60
Chillies and peppers, dry		1.30	
Chillies and peppers, green	5.88	3.12	
Cinnamon (canella)			0.87
Citrus fruit, misc.		0.51	
Cocoa beans			0.74
Coconuts (incl. copra)			1.78
Coffee, green			8.10
Cranberries, blueberries			1.39
Cucumbers and gherkins	3.79	1.30	
Currants and gooseberries	0.84		
Dates	0.32		0.88
Eggplants (aubergines)		1.30	

Eggs	2.94	3.04	
Figs		0.43	
Fish [1]	5.36		
Misc. fruit		0.43	0.88
Garlic	0.57	0.68	
Ginger			0.88
Grapefruit and pomelo		0.51	0.70
Grapes		0.42	0.75
Grapes as wine		0.65	1.08
Groundnuts			0.65
Guavas, mangoes etc.			1.78
Hazelnuts		0.43	0.88
Kiwi fruit		0.43	0.88
Misc. leguminous veg.	1.55		
Lemons and limes		0.51	
Lentils			1.06
Lettuce and chicory	1.15	1.00	10.00
Maize		0.45	
Milk, whole, fresh	1.19		
Millet			0.47
Mushrooms and truffles	1.00	1.11	
Natural honey	1.00	1.00	1.00
Nutmeg, mace and cardamoms			0.87
Misc. nuts			0.88
Oats	0.38	0.12	
Misc. oilseeds		2.20	
Olives		3.66	
Onions (inc. shallots)	0.37	0.48	
Oranges		0.51	
Other melons, (incl. cantaloupes)		1.55	1.74
Palm nuts-kernels (nut equiv.) /Oil			2.23
Papayas			0.88
Peaches and nectarines		0.43	0.88
Pears and quinces	0.32	0.43	0.88
Peas, dry	0.51	0.62	0.15
Peas, green	0.29	0.40	
Pepper (Piper spp.)			0.87
Pig meat	4.45	4.56	
Pineapples			1.78
Pistachios			0.88
Plantains			1.33
Plums and sloes	0.32	0.43	0.88
Potatoes	0.26	0.51	
Pumpkins, squash and gourds		2.22	
Rapeseed and mustard seed	2.09		

Raspberries and other berries	0.84	0.95	1.41
Rice, paddy			3.50
Rye	0.38	0.49	
Sesame seed		1.05	
Sheep and goat meat	14.61		12.00
Sorghum			0.47
Soy oil		0.77	0.80
Spices			0.87
Spinach		2.22	
Strawberries	0.84	1.06	1.39
Sugar beet	0.10		
Sugar cane and misc. sugar crops			0.09
Sunflower seed		2.20	
Tangerines, mandarins etc.		0.51	
Tea and Maté			0.87
Tomatoes	3.79	1.30	
Turkey meat	3.76	3.87	
Walnuts			0.88
Watermelons		1.33	1.33
Wheat – Milling	0.52	0.63	0.66
Yams			0.88

Notes

1 One composite number for fish

2 Values for a few commodities, such as milk, actually extend to retail.

Table 14. Greenhouse gas emissions from the primary production of food for consumption in the UK – up to the RDC.

Food category	**kt CO_2e**
Red meat	19,400
Milk	17,200
White meat	10,900
Cereals, including for brewing and distilling.	9,750
Vegetables & legumes	5,380
Oil-based crops	4,060
Salad Ccrops	3,580
Fish	2,780
Grapes & wine	2,610
Temperate & Mediterranean fruit	2,220
Rice	1,860
Exotic fruit	1,780
Eggs	1,650
Sugar	1,200
Beverages	1,180
Nuts	254
Misc. including spices	79
Total	85,883

Gas emitted (% of total GWP from primary production)	
Carbon dioxide CO_2	(54%)
Nitrous oxide N_2O	(24%)
Methane CH_4	(22%)

Livestock product components account for 61% of direct primary production emissions while serving about one third of calorie intake.

Table 15. Location of GHG emissions from the primary production of commodities for UK consumption.

	UK	**RoE**	**RoW**	**Total**
GHG for all commodities (kt CO_2e)	56,400	15,500	13,600	85,500
Proportion from regions	66%	18%	16%	100%

Current emissions from processing, distribution, retail and food preparation (post regional distribution centre)

A summary of the inventory of emissions from the processing, distribution, retail and preparation of food for UK consumption is provided in Table 16.

Table 16.
Greenhouse gas emissions from processing, distribution and retail for consumption in the UK – after the regional distribution centre.

	Home consumption, kt CO_2e / year	**Eating out, kt CO_2e / year**	**Total, kt CO_2e / year**
Cooking	11,100	4,410	15,510
Manufacturing	12,200	2,720	14,920
Food storage energy	11,200	2,170	13,370
Refrigerants	4,630	1,270	5,900
Electricity	4,530	1,090	5,620
Landfill of food waste	2,550	928	3,478
Washing-up	1,970	257	2,227
Road fuel & oil	1,380	271	1,651
Travel to outlet	1,330	113	1,443
Packaging	719	136	855
Landfill	488	155	643
Carrier bags and take- away containers	391	51	441
Food storage refrigerants	61	180	241
Total	**52,549**	**13,751**	**66,300**
Gas emitted as % of total GWP			
Carbon dioxide CO_2			85%
Nitrous oxide N_2O			0%
Methane CH_4			6%
Refrigerants			9%

Land use change emissions

Land use change emissions - background data

Table 17. Summary of global land use and LUC data used

Total world agricultural area (for comparison)	4,946 Mha
Total world arable and permanent crop area	1,244 Mha
Total pasture area connected to world trade	2,232 Mha*
Total agricultural land area -– excluding non-commercial pasture	3.475 Mha*
Total world area used for commercially traded livestock (pasture and crops)	2,710 Mha*
Total world area used for directly consumed crops	765 Mha
Total UK land requirements for directly consumed crops (food only)	7.469 Mha
UK land requirement for directly consumed crops as % of total food crop land	0.98%
UK population as % of world population	0.9%
Total LUC emissions attributable to commercial agriculture	5 $GtCO_2e$/yr
% of LUC emissions attributable to UK food consumption	2.1%

*See Table 19.

Screened as set out in methods – production from countries accounting for more than 0.5% of world trade AND production

Land use change emissions attributable to crops for direct human consumption

Table 18. Arable land and crop (directly consumed by humans) commodity consumption data in emission calculations and the associated estimated LUC emissions.

Commodity	Land requirement per tonne of food commodity (hectare/t)	Emissions per tonne of food commodity (tCO_2e/t)	UK consumption of food commodity (t/yr)	LUC emissions associated with UK consumption (tCO_2e/yr)	Total land area required (hectares)
Almonds	1.00	1.43	26,700	38,202	26,791
Anise, badian, fennel etc.	1.53	2.18	7,450	16,228	11,381
Apples	0.08	0.11	1,026,460	113,142	79,346
Apricots	0.14	0.19	65,240	12,562	8,810
Artichokes	0.10	0.14	810	114	80
Asparagus	0.20	0.28	7,570	2,109	1,479
Avocados	0.12	0.17	27,510	4,714	3,306
Bananas	0.06	0.09	658,030	56,390	39,546
Barley*	0.40	0.57	707,720	404,942	283,985
Green beans	0.14	0.20	39,970	8,077	5,664
Dried beans, cow peas	1.40	2.00	55,040	110,074	77,195
Cabbages and other brassicas	0.05	0.07	268,340	17,711	12,421
Carrots and turnips	0.05	0.06	536,690	34,461	24,167
Cauliflowers and broccoli	0.06	0.08	251,830	20,654	14,484
Misc. cereals	0.96	1.37	236,840	323,886	227,141
Cherries	0.19	0.27	22,740	6,086	4,268
Chestnuts	0.27	0.38	2,210	843	591
Chillies and peppers, dry	0.66	0.95	5,870	5,555	3,895
Chillies and peppers, green	0.07	0.10	123,060	12,100	8,486
Cinnamon (canella)	1.31	1.87	1,130	2,114	1,483

Misc. citrus fruit	0.15	0.22	45,960	9,941	6,972
Cloves	4.45	6.34	240	1,522	1,068
Cocoa beans	1.89	2.69	123,410	332,214	232,981
Coconuts (incl. copra)	0.19	0.27	68,850	18,267	12,811
Coffee, green	1.43	2.04	119,550	244,471	171,447
Cranberries, blueberries	0.12	0.17	4,130	693	486
Cucumbers and gherkins	0.06	0.08	161,150	13,220	9,272
Currants and gooseberries	0.20	0.28	23,110	6,488	4,550
Dates	0.17	0.24	12,150	2,974	2,085
Eggplants (aubergines)	0.06	0.08	12,970	1,061	744
Figs	0.38	0.54	7,200	3,866	2,711
Misc. fruit	0.15	0.22	46,270	10,203	7,155
Garlic	0.08	0.11	6,140	694	487
Ginger	0.29	0.42	12,170	5,107	3,582
Grapefruit and pomelo	0.07	0.09	173,520	16,190	11,354
Grapes**	0.11	0.16	3,623,380	564,084	395,591
Groundnuts	0.62	0.88	247,150	218,459	153,205
Guavas, mangoes, mangosteens	0.15	0.21	46,600	9,658	6,773
Hazelnuts	0.73	1.05	9,360	9,800	6,873
Kiwi fruit	0.06	0.08	22,180	1,870	1,312
Misc. Legume vegetables	0.17	0.24	11,230	2,665	1,869
Lemons and limes	0.06	0.09	117,680	10,379	7,278
Lentils	1.01	1.44	17,820	25,716	18,035
Lettuce and chicory	0.05	0.06	300,210	19,490	13,669
Linseed	1.03	1.47	0	0	0
Maize	0.21	0.29	606,170	178,423	125,128
Millet	1.15	1.64	0	0	0
Mushrooms and truffles	0.00	0.01	199,140	1,142	801
Nutmeg, mace and cardamoms	3.38	4.82	750	3,615	2,535
Misc. nuts	0.79	1.12	22,450	25,171	17,652
Oats	0.48	0.68	106,130	72,523	50,860
Misc. oilseeds	0.73	1.03	23,370	24,160	16,943
Olives	0.58	0.82	405,730	334,088	234,296
Onions (inc. shallots)	0.05	0.08	620,690	47,574	33,363
Oranges	0.06	0.09	1,177,690	102,460	71,855
Other melons (incl. cantaloupes)	0.05	0.07	145,290	9,733	6,826
Papayas	0.06	0.08	10,560	871	611
Peaches and nectarines	0.08	0.12	145,110	17,444	12,233
Pears and quinces	0.08	0.12	204,640	24,527	17,201
Dry peas	0.57	0.82	169,330	138,265	96,965
Green peas	0.14	0.20	225,750	45,091	31,623
Pepper (Piper spp.)	1.16	1.66	5,640	9,349	6,557
Pineapples	0.05	0.07	353,190	24,769	17,371
Pistachios	1.23	1.75	4,710	8,232	5,773
Plantains	0.16	0.23	16,790	3,846	2,697
Plums and sloes	0.25	0.36	135,350	48,716	34,165
Potatoes	0.06	0.08	6,842,620	576,932	404,601
Misc. pulses	1.35	1.93	0	0	0
Pumpkins, squash and gourds	0.08	0.11	29,370	3,159	2,215
Rapeseed and mustard seed	0.55	0.79	1,344,730	1,060,732	743,890
Raspberries and other berries	0.19	0.27	18,300	5,025	3,524
Rice, paddy	0.24	0.35	531,320	185,492	130,085

Rye	0.44	0.63	18,620	11,809	8,282
Sesame seed	2.22	3.17	10,270	32,557	22,832
Sorghum	0.73	1.04	0	0	0
Spices, misc.	0.50	0.71	9,250	6,552	4,595
Spinach	0.06	0.09	5,540	504	354
Strawberries	0.07	0.10	85,220	8,364	5,865
Sugar beet	0.02	0.03	4,900,830	150,156	105,304
Sugar cane etc.	0.02	0.02	8,066,360	174,853	122,624
Sunflower seed	0.76	1.09	284,160	308,482	216,338
Sweet potatoes	0.07	0.10	0	0	0
Tangerines, mandarins etc.	0.08	0.12	311,830	36,172	25,367
Tea and Maté	0.75	1.07	128,790	137,469	96,407
Tomatoes	0.04	0.05	1,441,180	73,291	51,399
Vanilla	9.62	13.71	30	411	288
Misc. vegetables	0.07	0.10	3,370,170	348,771	244,593
Walnuts	0.38	0.55	13,060	7,155	5,018
Watermelons	0.04	0.05	33,370	1,709	1,198
Wheat	0.35	0.50	6,072,710	3,043,560	2,134,445
Yams	0.09	0.13	6,270	828	581
Palm oil	0.33	0.47	706	333,711	234,031
Soy oil	0.85	1.21	251,695	304,804	213,759
				10,651,494	**7,469,880**
* includes barley for alcohol	** includes grapes for alcohol				

Land use change emissions attributable to livestock

Table 19. Countries and land areas included in estimates of commercial permanent pasture use connected to world trade

Countries with pasture based agriculture connected to world trade	Total land area (hectares)	Total agricultural land area (hectares)	Total arable crop land (hectares)	Total permanent pastures (hectares)
Algeria	238,174	41,211	8,363	32,848
Argentina	273,669	131,350	31,500	99,850
Australia	768,230	445,149	49,742	395,407
Brazil	845,942	264,000	67,000	197,000
Canada	909,351	67,569	52,139	15,430
China	932,749	547,340	147,339	400,000
Egypt	99,545	3,523	3,523	4,990
Ethiopia	100,000	33,691	13,691	20,000
France	54,766	29,550	19,643	9,907
Germany	34,877	17,031	12,102	4,929
Greece	12,890	8,334	3,734	4,600
India	297,319	179,858	169,443	10,415
Ireland	6,889	4,302	1,187	3,115
Italy	29,414	14,736	10,334	4,402
Japan	36,450	4,692	4,692	229
Mexico	194,395	107,300	27,400	79,900
Netherlands	3,376	1,921	941	980
New Zealand	26,771	12,641	1,047	11,594
Russian Federation	1,638,139	215,680	123,581	92,099

Saudi Arabia	214,969	173,717	3,717	170,000
South Africa	121,447	99,578	15,650	83,928
Spain	49,909	29,164	17,844	11,320
Ukraine	57,938	41,304	33,353	7,951
United Kingdom	24,193	16,956	5,776	11,180
USA	916,192	412,878	175,178	237,700
Uruguay	17,502	14,740	1,340	13,400
	7,906	**2,918**	**1,000**	**1,923**
% of world total				**57%**

57% Fifty-seven per cent of the world's permanent pasture is in countries connected to the world trade in beef, sheep or goat meat.

Table 20. Land and livestock commodity use data used in emission calculations and the associated estimated LUC emissions attributable to livestock. The LUC emissions attributed to permanent pasture use have been allocated to beef and sheep/goat meat on the basis of the economic value of outputs of beef and sheep/goat meat at world market prices

Commodity	Land requirement per tonne of food commodity (hectare/t) Derived from FAO world average yield figures (for year 2005)	Emissions per tonne of food commodity (tCO2e/t)	UK consumption of food commodity (t/yr) Derived from FAOstat for year 2005	LUC emissions associated with UK consumption (tCO2e/yr)
Pig meat	2.4	3.35	1,228	4,119,240
Poultry	1.8	2.56	1,805	4,629,632
Beef		52.69	1,041	54,847,431
Sheep and goat meat		50.26	351	17,641,150
Milk		0.65	14,442	9,416,080
Eggs	1.4	1.97	559	1,102,888
Total for livestock commodities				**91,756,421**

Table 21. Greenhouse gas emissions from the supply of food for the UK (kt CO_2e) – emissions from primary production attributed land use change emissions and post RDC emissions.

Activity	Direct emissions	Attributed LUC emissions	Total
Primary production of			
Red meat	19,400	76,607	96,007
Milk	17,200	9,416	26,616
White meat	10,900	4,629	15,529
Cereals including brewing and distilling.	9,750	3,711	13,461
Vegetables & legumes	5,380	1,682	7,062
Oil-based crops	4,060	2,365	6,425
Salad Ccrops	3,580	126	3,706
Fish	2,780	-	2,780
Grapes & wine	2,610	564	3,174
Temperate & Mediterranean fruit	2,220	450	2,670
Rice	1,860	185	2,045
Exotic fruit	1,780	102	1,882

Eggs	1,650	113	1,763
Sugar	1,200	325	1,525
Beverages	1,180	714	1,894
Nuts	254	326	580
Misc. including spices	79	93	172
Sub-total for primary food production	**85,883**	**101,408**	**187,291**
Post 'RDC' – processing distribution retail preparation.	**66,300**	**0**	**66,300**
Totals	**152,183**	**101,408**	**253 ,591**

For comparison (kt CO_2e):

Total emissions from the UK (greenhouse gas inventory emissions): 652,000
Total UK consumption emissions: 748,000[106]
Direct emissions from UK agriculture: 51,000

[106] Estimated by Garnett 2008 http://www.fcrn.org.uk/frcnPubs/publications/Overall%20food%20GHGs.doc

Regional differences in consumption based emissions

The research included an assessment of emissions as affected by regional differences in consumption. UK emissions are dominated by England. Regional differences in the resulting emissions (Table 22) and commodity sources (Table 23) are relatively small. Considering the uncertainties in the data, they are not the subject of further assessment in this research.

Table 22. Regional differences within the parts of the UK in annual per capita emissions

		Annual emissions per capita in regions kg CO_2e			
Area	Population, M	Pre-RDC	Post-RDC	LUC	Total
England	50.7	1,430	1,090	1,690	4,200
Scotland	5.1	1,330	1,060	1,600	3,980
Wales	3.0	1,500	1,120	1,850	4,460
Northern Ireland	1.7	1,290	1,020	1,670	3,970
All UK	60.5	1,420	1,100	1,690	4,200

Table 23. Pre-RDC emissions by broad food group per capita in the UK and its areas, ordered by magnitude.

	Emissions per head, kg CO_2e/annum				
Food type	**UK**	**England**	**Scotland**	**Wales**	**N Ireland**
Red meat	320	322	305	352	319
Milk	284	283	271	292	256
White meat	179	178	154	221	202
Cereals	161	158	163	191	132
Vegetables & legumes	89	91	83	96	88
Oil-based crops	67	68	68	62	58
Salad Ccrops	59	61	55	54	42
Fish	46	48	43	42	33
Grapes & wine	43	45	41	45	34
Rice	31	35	23	23	22
Exotic fruit	29	31	29	30	22
Eggs	27	28	13	14	14
Mediterranean fruit	23	25	23	22	19
Misc. (inc. tea, coffee)	21	20	22	21	14
Sugar	20	20	19	20	19
Temperate fruit	14	15	13	13	13
Nuts	4	5	3	3	3
Total	1420	1430	1330	1500	1290

Effects of measures

Measures were blocked into categories across the supply chain.

Table 24. Effect of measures on supply chain emissions (excluding LUC emissions).

Total supply chain emissions (excluding land use change), kt CO_2e	**152,000**	
Energy generation measures	**Benefit of measure**	
Zero fossil fuels (electricity and other energy carriers)	24,100	15.8%
Zero electricity from fossil fuels	4,400	2.8%
Zero N_2O from nitrate fertiliser production	9,100	5.9%
Low carbon energy for cooking	16,300	10.7%
Low carbon energy in supply chain chilling	13,400	8.8%
Zero fossil fuels in distribution system electricity	5,600	3.6%
Zero fossil fuels in distribution transport energy	1,500	0.9%
Resource conservation - Lots of recycling, co-product feeding, AD of food waste etc.		
Anaerobic digestion (AD) of manure (no stored manure emissions)	4,585	3.0%
Energy recovery from food waste using AD	3,561	2.3%
Low energy use in consumer transport	1,163	0.7%
Improved waste management in distribution and retail	464	0.3%
75% reduction in GWP from shopping bags	322	0.2%
Production efficiency Increased efficiency through the supply chain		
No enteric methane emissions from ruminants	15,800	10.3%
N_2O inhibitor with fertiliser (no N_2O from soils)	9,700	6.3%
Manufacturing	7,800	5.1%
Low GWP refrigerants in the supply chain	5,900	3.8%
50% yield increase	4,300	2.8%
Zero N_2O from fertiliser production	3,400	2.2%
Improved FCR/efficiency of finishing	2,700	1.7%
N use efficiency increased by 50%	1,800	1.1%
By-product based livestock production	1,600	1.0%
Minimum tillage (where possible)	1,100	0.7%
Packaging	700	0.5%
Refrigerants (End users)	100	0.1%
Reduced and changed consumption		
No meat	30,000	19.7%
66% reduction in livestock products	22,100	14.9%
50% reduction in livestock products	19,300	12.6%
Avoidable food waste avoided	16,200	10.6%
Red to white meat	14,000	9.2%
No dairy milk	10,900	7.1%
No rice	3,000	1.9%
No eggs	1,400	0.9%

Table 25. Supply chain emissions, including emissions attributed to LUC, as affected by consumption based mitigation measures.

Consumption Scenario in all UK	**Total w/o**	**LUC, kt**	**Total**	**Benefit of**	**Change**

	LUC	CO_2e		a change	
Base consumption	152,183	101,408	253,591		
66% redn. in livestock products	129,900	23,200	153,100	100,900	39.7%
No meat	122,000	31,300	153,300	100,700	39.6%
Red to white meat	138,000	23,400	161,400	92,614	36.4%
50% redn. in livestock products	132,700	31,900	164,600	89,414	35.2%
No avoidable food waste	135,800	80,200	216,000	38,014	14.9%
No dairy milk	141,100	93,700	234,800	19,214	7.5%
No rice	149,000	91,800	240,800	13,214	5.2%
No eggs	150,600	90,700	241,300	12,714	5.0%

SCENARIOS TO ACHIEVE A 70% REDUCTION

Scenarios examined the effects of combinations of production and consumption measures. In delivering insight into the scope for reductions, we opted for theme based combinations of measures. These are as follows:

- "**Non-mobile energy**" – reducing GWP from the fuel input to non-mobile equipment that typically use electricity or gas, such as ventilation and cooking. Typically this would comprise use of renewable energy for electricity or nuclear power, with a shift from gas to electricity in food preparation;.
- "**Mobile energy**" – reducing GWP from the fuel input to mobile equipment that typically use diesel and also GWP from fertiliser production from gas. Typically this would involve replacing diesel with hydrogen or electric engines in vehicles and a new method of fertiliser production using electricity not gas;.
- "**Direct GHG emissions**" – directly reducing direct emissions of GHGs to the atmosphere: refrigerants, methane, nitrous oxide. Typically this would be non GHG refrigerant gas and techniques for reducing methane emitted by ruminants;.
- "**Production efficiency**" – reducing GWP by reducing waste, increasing food conversion efficiency and crop yields, and reducing the energy required in the production processes of food.;
- "**Consumption**" – changing consumption;.
- "**Conservation**" – recycling and avoiding wasteful use.

Reduction potential of individual categories (themes) of measures

Figure 6 shows that even a 100% reduction in any one category of measures (highlighted) cannot achieve the required 70% savings (excluding LUC) overall and thus wider combinations of mitigation measures are needed. Our scenario approach here examines the extent to which emphasis on one theme will require the implementation of other mitigation measures to reach the levels of overall reduction sought. Thus there could be a major emphasis on reducing fossil fuel use in the power and transport sectors with major government investment in hydrogen powered vehicles. This is an energy led scenario. Alternatively the emphasis could be on changes to diet (consumption led scenario) or on research to reduce the agricultural emissions of methane and nitrous oxide (emission scenario). The mitigation measure theme implemented at 100% is marked by a black (or grey) outline. The six scenarios illustrated comprise the extent of reduction in other mitigation themes that plausibly would accompany the implementation of one theme at 100%.

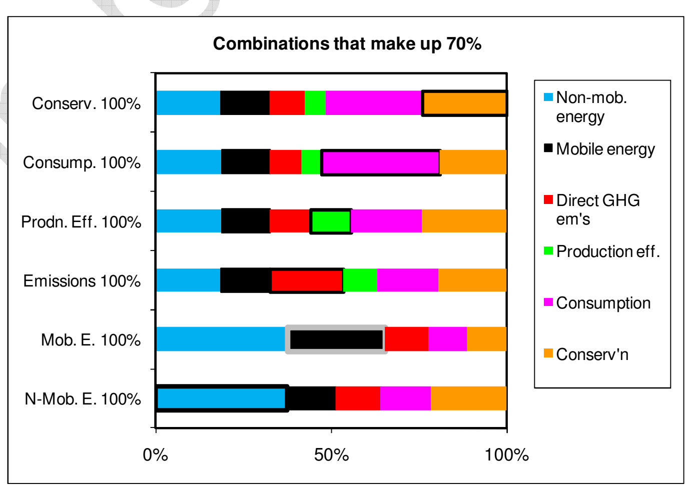

Figure 6. The effect of the 100% implementation of themes of mitigation measures to deliver a 70% reduction overall.

A 100% decarbonisation of energy carriers (non-mobile and mobile) would result in a 66% reduction in emissions from the supply chain (excluding land use change). The UK government seeks an 80% reduction in these energy emissions by 2050 which would translate into a 53% reduction across the food chain.

These themes are not independent. Figure 7 shows the impact of reducing all of these mitigation themes by the same amount. Thus if all were reduced by 40% there would be an overall saving of 45%. The achievement of 45% from the 40% implementation of the combination of measures reflects synergies between measures. Conversely, as some measures are implemented, e.g. reductions in livestock product consumption, the effect of other related measures is reduced (in this case, the reduction of production emissions as a separate measure).

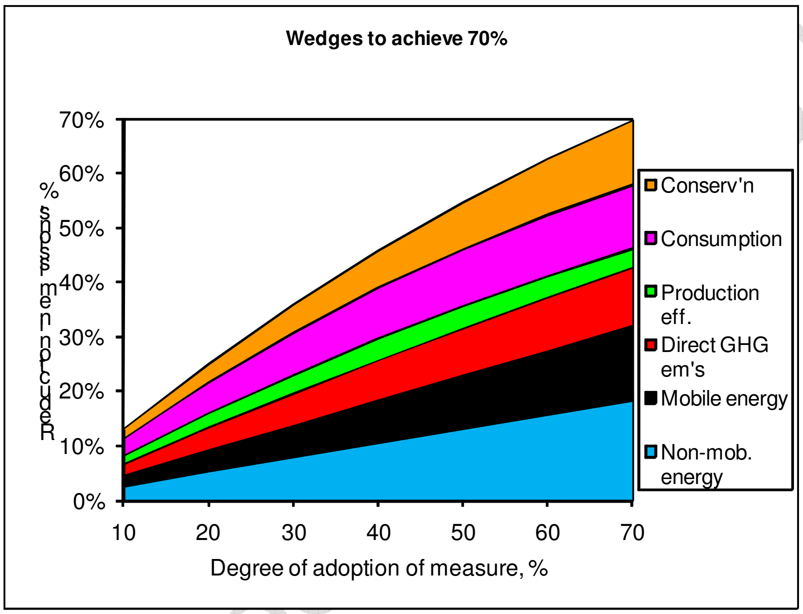

Figure 7. The combined mitigation effect of implementing the seven mitigation themes.

These results should not be seen as a league table of mitigation options as the rate and extent of implementation would vary in the real world. Some savings are easy to make and could be achieved quite quickly. Others are difficult to achieve, are dependent on the structure of the wider economy and/or need considerable research. Others are technically possible today but will take considerable time – for example replacing all power stations with non-fossil sources is possible and is likely to be largely achieved by 2050, if for no other reason than the current generation will most likely have been replaced through normal wear and tear. Reducing field nitrous oxide emissions and enteric methane emissions are particularly speculative and their full elimination may not be technically possible. A substantial reduction in methane emissions from managed manure and food wastes is technically more achievable, although widespread implementation depends on economic conditions and behavioural change is needed for improved food waste management. Implementation over a significant proportion of production is likely to present considerable challenges. The production mitigation options are largely based on increases in production efficiency that are plausible in 10-–20 years.

The energy based scenario

Figure 8 shows a possible time course for a scenario based on energy savings aiming to achieve an overall saving of nearly 60% by 2050 (Figure 9). This scenario assumes that by

2050 we will have achieved the following reductions in emissions for each measure, where each is shown as the percentage of what is possible for that measure.

- 90% of potential reduction possible from changes in non-mobile energy;.
- 80% of potential reduction possible from conservation – waste reduction and recycling.;
- 60% of potential reduction possible from increased production efficiency;
- 40% of potential reduction possible from changes in mobile energy;.
- 25% of potential reduction possible from consumption changes, for example by eliminating red meat consumption or through an overall 40% reduction in livestock products;.
- 25% of potential reduction possible from direct emissions – methane, nitrous oxide and refrigerants.

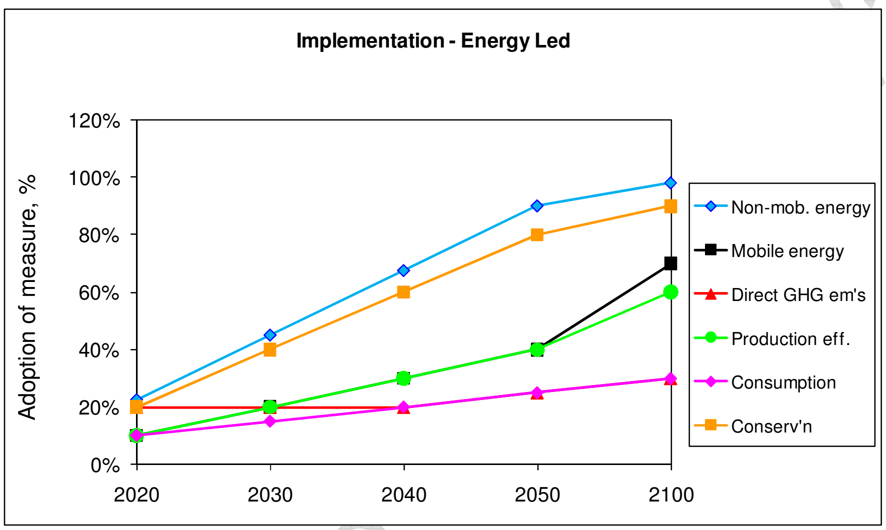

Figure 8. The adoption of measures over time in an energy led scenario.

This results in a saving of 57% by 2050 (Figure 9). This would increase to a 65% reduction by 2100, with 98% electricity from non-fossil fuels (and other improvements), and so come close to the overall goal. Note that although times are associated with each level of emissions reduction, these are our estimates and could be achieved earlier or later in reality. While we have specific targets for 2020 and 2050, they are based on annual emission rates. If these can be achieved earlier, the cumulative emissions to the atmosphere will be reduced so achieving a greater overall benefit. And vice-versa!

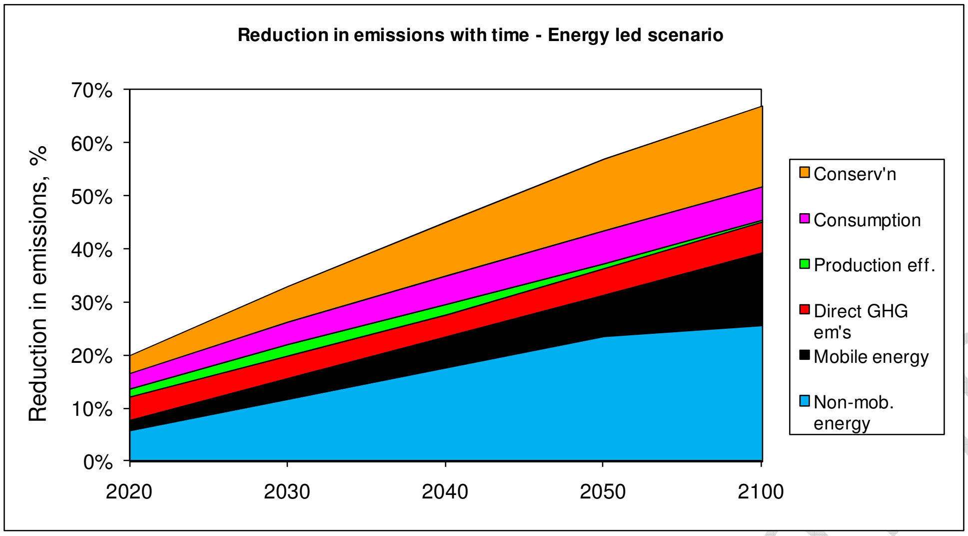

Figure 9. Reductions in emission over time in an energy led scenario.

Consumption based scenario

Figure 10 shows a similar scenario, but led by changes in consumption, so depending on a variety of motivations to achieve this, such as health concerns, idealism or price adjustments through government intervention. This assumes that by 2050, 80% of the emissions from livestock products and rice will have been saved through switching consumption from livestock products and to rice alternatives. This requires the elimination of most meat, rice and milk consumption. In addition the scenario assumes that by 2050 we will have achieved the following reductions in emissions for each measure, where each is shown as the percentage of what is possible for that measure.

- 78% of potential reduction possible from conservation – waste reduction and recycling;.
- 42% of potential reduction possible from increased production efficiency;
- 40% of potential reduction possible from changes in non-mobile energy;
- 20% of potential reduction possible from changes in mobile energy;
- 80% of potential reduction possible from consumption changes, for example by eliminating red meat consumption or through an overall 40% reduction in livestock products;.
- 20% of potential reduction possible from direct emissions – methane, nitrous oxide and refrigerants.

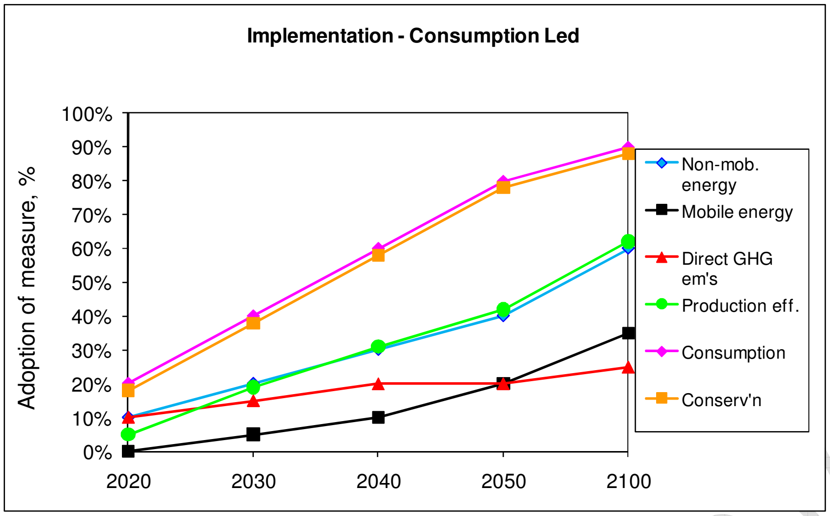

Figure 10. The adoption of measures over time in a consumption led scenario.

The consequences of the consumption- led scenario are to achieve a reduction in emissions of nearly 60% by 2050, 15% by 2020 (Figure 11).

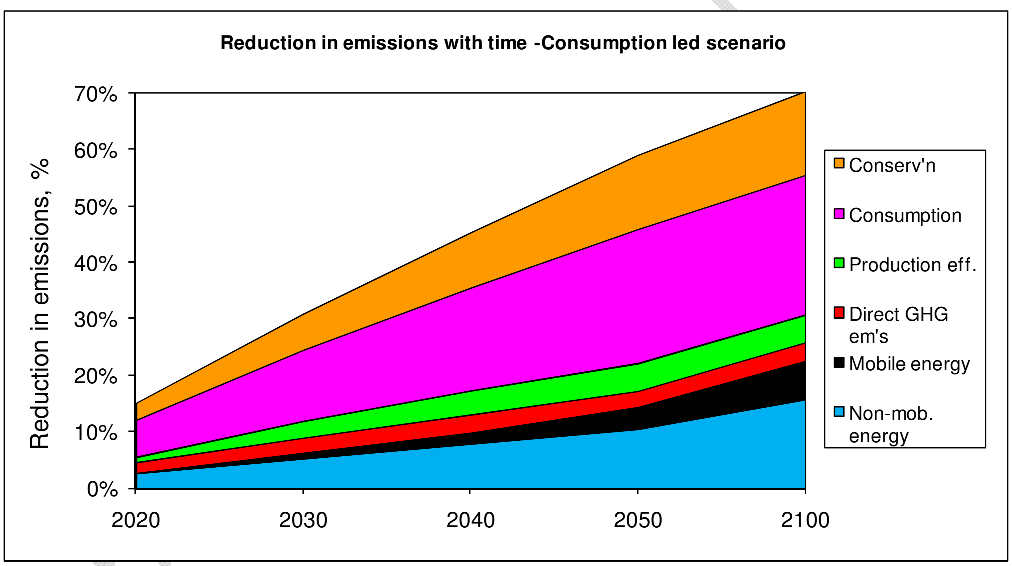

Figure 11. Reduction in emissions over time in a consumption led scenario

Emission based scenario

This scenario is highly dependent on technological fixes to fixed point and diffuse pollution. The main targets are reducing methane emissions from enteric activity and manure, plus the elimination of refrigerant losses (whether by better sealing or very low GWP refrigerants) together with some savings in nitrous oxide. Given its strong technological outlook, other technological solutions also have fairly high implementation rates (Figure 12). By 2050 this scenario will comprise:

- 80% of potential reduction possible from conservation – waste reduction and recycling;.
- 25% of potential reduction possible from increased production efficiency;
- 70% of potential reduction possible from changes in non-mobile energy;
- 20% of potential reduction possible from changes in mobile energy;

- 40% of potential reduction possible from consumption changes, for example by eliminating red meat consumption or through an overall 40% reduction in livestock products.;
- 20% of potential reduction possible from direct emissions – methane, nitrous oxide and refrigerants.

The results (Figure 13) show that a 55% reduction is possible by 2050 (15% in 2020).

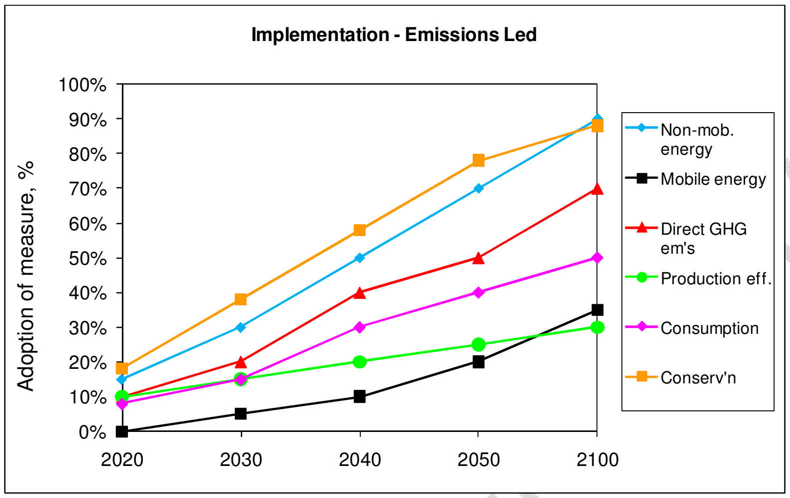

Figure 12. The rate of adoption of measures in an emissions led scenario

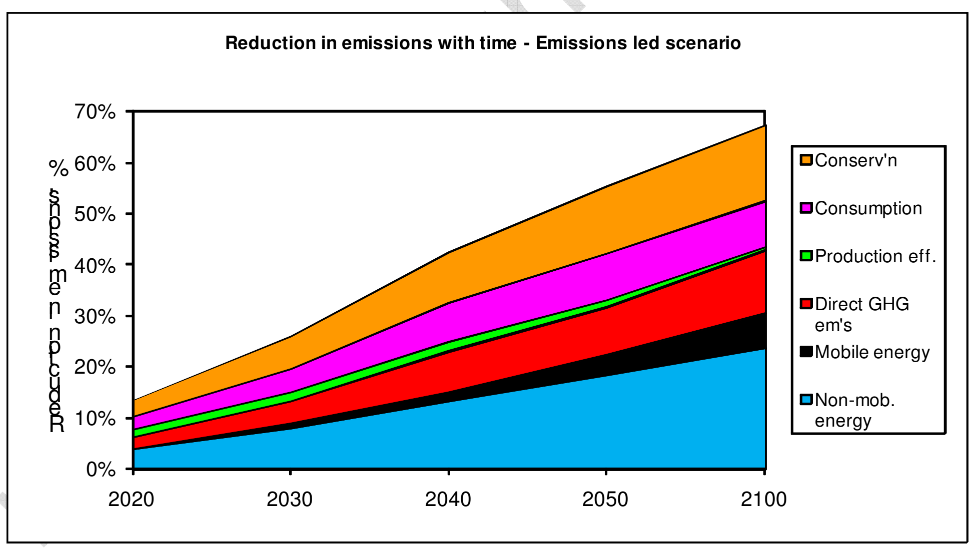

Figure 13. Reductions in emissions over time in an emissions led scenario

The all-themes scenario

Given that none of the previous scenarios achieved a 70% reduction in GHG emissions by 2050, a combined approach with a wider spread of progress in technology and behaviour was examined (Figure 14). The results (Figure 15) shows that combined implementation of measures as shown succeeds in achieving the desired 70% emissions reduction in the food supply chain by 2050 (22% by 2020). The main deduction from this is that progress is needed across all fronts to achieve success. While improving the nation's energy supply will achieve much, it does not achieve all. Changes are still needed in production efficiency, resource conservation and consumption. There is also a clear need to overcome some substantial technical obstacles and to maintain a successful economy that enables improvements rather than hinders them.

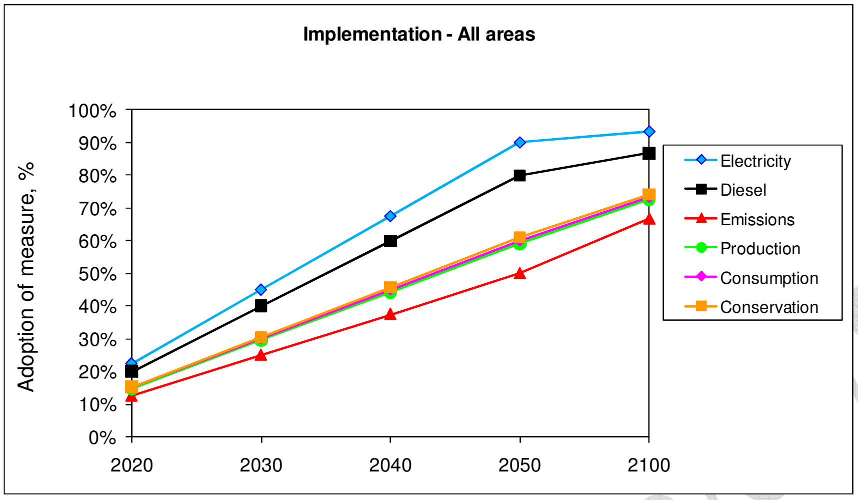

Figure 14. Rate of implementation of measures over time in an ‘all-themes’ scenario.

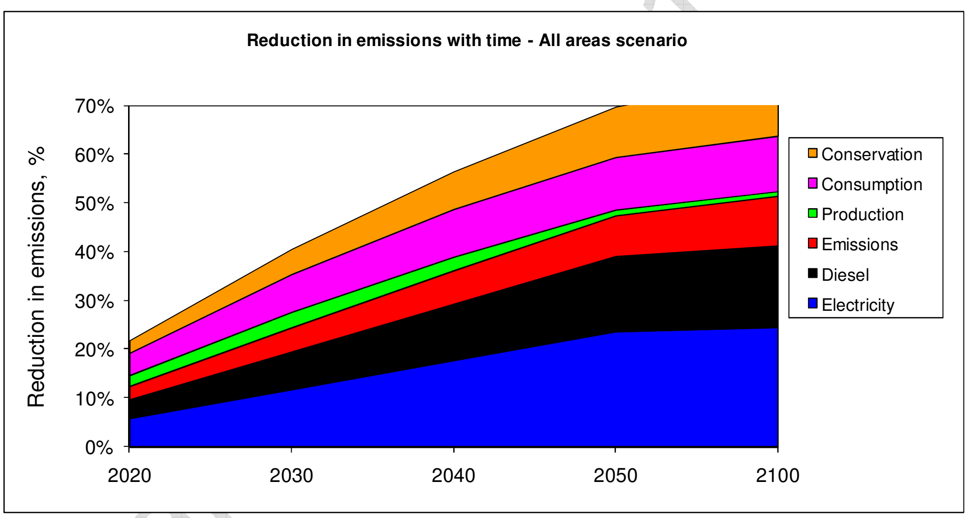

Figure 15. Emission reductions over time as affected by the rate of implementation of all categories of measures

THE POTENTIAL OF ORGANIC FARMING IN DELIVERING REDUCTIONS

Given that organic farming is based on the exclusion of many external inputs into the farm system, it is an obvious option for consideration in the delivery of production based measures. The complexities of a switch to organic methods of production are such that it is beyond the scope of this research to present results for an organic measure in the same way as other production measures. However, consideration of land resources available, outputs and the life-cycle data available from previous research at Cranfield allow some assessment of the potential of a switch to organic food in terms of GHG mitigation across the economy.

A recent study by Jones and Crane[107] suggests estimates of organic production as a proportion of current conventional production in England and Wales, based on weighting by reduced yields and farm type. We have built on that study making estimates of the potential emissions for the 3three organic scenarios based on their work, t. The first incorporating organic meat and egg production, the second building on this but including organic milk, sugar beet and potatoes and a third based on the first two, but also including cereals (Table 26). We assumed that oilseed rape and sugar beet would be grown, even though there is currently no market for these.

Table 26. Rates of UK self-sufficiency in three organic farming scenarios, based on proportions derived in the Jones and Crane study.

	Organic 1	Organic 2	Organic 3
Wheat	100%	100%	76%
Barley	100%	100%	50%
Oats	100%	100%	100%
Oilseed rape	100%	100%	50%
Potatoes	100%	100%	100%
Sugar beet	100%	50%	50%
Milk	100%	70%	70%
Beef	168%	168%	168%
Sheep	155%	155%	155%
Pigs	30%	30%	30%
Poultry	30%	30%	30%
Eggs	73%	73%	73%

The Cranfield LCA model was used to examine the greenhouse gas emissions of primary production for the UK if these scenarios for organic farming were implemented (Table 27).

Table 27. Total UK consumption and emissions from production for 3three organic production scenarios, compared with the non-organic base case (production for the current UK food system).

	Non-Organic Base		Organic 1	
	Consumption, kt	**Emissions, kt CO2e**	**Consumption, kt**	**Emissions, kt CO2e**
Wheat	6,070	3,290	6,070	2,980
Barley	1,940	6,300	1,940	6,490
Oats	106	40	106	50
Oilseed rape	538	1,130	538	1,140
Potatoes	6,840	2,030	6,840	1,980
Sugar beet	4,900	496	4,900	496

[107] Jones, P and Crane, R. 2009. *England and Wales Uunder organic agriculture: how much food could be produced?* CAS Report 18. University of Reading.

Milk	14,400	17,200	14,400	16,100
Beef	1,040	14,300	1,750	23,000
Sheep	351	5,040	544	6,780
Pigs	1,230	5,520	368	1,430
Poultry	1,600	4,550	479	1,870
Eggs	559	1,650	408	1,340
Sub-total		**61,500**		**63,700**
Others		24,383		24,600
Overall total		**85,883**		**88,300**
	Organic 2		**Organic 3**	
	Consumption, kt	**Emissions, kt CO2e**	**Consumption, kt**	**Emissions, kt CO2e**
Wheat	6,070	2,980	4,620	2,260
Barley	1,940	6,490	970	3,240
Oats	106	50	106	50
Oilseed rape	538	1,140	269	570
Potatoes	6,840	1,980	6,840	1,980
Sugar beet	2,450	248	2,450	248
Milk	10,100	11,300	10,100	11,300
Beef	1,750	23,000	1,750	23,000
Sheep	544	6,780	544	6,780
Pigs	368	1,430	368	1,430
Poultry	479	1,870	479	1,870
Eggs	408	1,340	408	1,340
Sub-total		**58,600**		**54,100**
Others		24,600		24,600
Overall total		**83,200**		**78,700**

A food system built on UK organic farming would reduce the overall meat supply to about 75% of current. There would be a very significant contraction in the production of pigs and poultry. This would be partly compensated by an increase in the supply of beef. Overall, production emissions in scenario 3 would reduce food production emissions by about 8%. This translates into a supply chain reduction of about 5%.

EFFECTS OF LIVESTOCK PRODUCT SUBSTITION ON LAND USE

In scenarios in which the UK consumption of livestock products is reduced, substitute crop commodities would be required. This analysis examines the scenario in which livestock products would be substituted by plant based analogues such as *Quorn*, tofu and pulse based products. These substitutes require land for their production. Reducing, or cutting out, the production of livestock would release a significant quantity of land (both arable and grassland) that could potentially be available for crop production and balance this requirement. The question addressed here is what would be the overall effect on land use and supply chain greenhouse emissions.

UK agricultural land is graded in terms of quality according to guidelines and criteria provided in the Agricultural Land Classification of England and Wales (MAFF, 1988).[108]. Land is classified into one of five grades, with "Grade 1 being land of excellent quality and Grade 5 land of very poor quality". Almost half the agricultural land in the UK is classified as Grade 3, which is further divided into 3a – good quality agricultural land, capable of producing moderate to high yields of

[108] MAFF., 1988. *Agricultural Lland Cclassification of England and Wales.* Revised guidelines and criteria for grading the quality of agricultural land.

a wide range of crops, particularly cereals, and 3b – moderate quality agricultural land. Grades 4 and 5 are described as having "severe limitations" as regards the range and yield of crops, except grass and rough grazing, and thus land is normally grazed extensively by livestock.

We investigated whether the arable land currently used to produce crops for feeding livestock and arable quality land used for grazing that would be released would be sufficient to support the increase in crop based alternatives required. The Cranfield LCA model was used to derive the total land requirements for the current UK production of consumption of ruminant commodities. The model provides a breakdown into the land classifications described above according to material flow through the production system. The grade 3a land used was thus divided into the production of concentrates and straw, maize silage and that used for grazing and grass silage.

Proportions were allocated to each grade to give the quantity of each that could potentially be used for arable crop production. Quantities of land attributable to each ruminant commodity were then derived, giving totals for arable land used as arable, arable land use for grass/forage and land suitable for grass only.

When multiplied by the total UK production (for UK consumption as per data from FAOSTAT), this gave the total land area in the UK that would be available for growing substitute crops (Tables 28 and 29).

A total for beef and sheep is provided separately as the potential for dairy substitutes to be produced in the UK is currently very low because the current alternatives are predominantly soy-based and thus grown overseas.

It was assumed that currently 70% of ruminant livestock concentrates are produced in the UK, thus providing the majority of grade 3a land that would become available (Table 29).

Table 28. Current land use for UK-based livestock production as estimated by the Cranfield LCA model.

		Land needed (ha) per t or 1 m^3			**Land used, kha**		
	UK Production, kt	**Arable quality used as arable in UK and overseas, ha**	**Arable quality land used for grass / forage, ha**	**Grass only, ha**	**Arable quality land used for arable crops**	**Arable quality land used for grass/ forage**	**Grassland quality only**
Beef	762	0.50	0.75	1.25	382	574	956
Lamb	317	0.21	0.83	9.34	66	263	2,960
Pig meat	554	0.71			872		
Poultry meat	304	0.65			1,205		
Eggs	76	0.56			313		
Milk	14,442	0.022	0.088	0.011	318	1,271	159
Total ruminant meat					448	837	3,916
Total ruminant meat + milk					766	2,108	4,075
Total for all commodities					3,156	2,108	4,075

Table 29. Land needed in the UK and overseas for arable crops to support UK-based livestock production.

Commodity	UK, kha	Overseas, kha	Total area, kha
Beef	268	115	382
Lamb	46	20	66
Total ruminant meat	**314**	**135**	**448**
Pig meat	479	393	872
Poultry	630	575	1,205
Eggs	168	145	313
Milk	223	95	318
Total	**1,814**	**1,343**	**3,156**

Substituting meat

An estimate was made of the quantity of substitutes (microbial protein, based on *Quorn*, dried fresh peas and beans, and tofu) and sugar crops needed. This was based on the supply of protein from *Quorn*, pulses and tofu being 20%, 60% and 20% respectively. This mixture was then equated to the average composition of meat in order to supply the same amount dry matter. It was considered that equating the current supply of protein and energy from the substitutes was not realistic owing to lower energy density and protein concentrations, which would require an unreasonably high dry matter intake.

The quantities of meat consumed and gross nutrient content are given in Table 30. The quantities of substitutes required are provided in Table 31.

Table 30. Protein, fat and total energy in UK consumed livestock products

Commodity	Beef	Lamb	Pork	Chicken	Turkey	Total, kt	Energy, TJ
Commodity consumption, kt	1041	351	1228	1598	207	4425	35,546
Protein consumption, kt	178	58	199	310	41	786	18,868
Fat consumption, kt	147	41	232	29	3	451	16,678

Table 31. Quantities of *Quorn*, pulses and tofu needed to substitute current meat consumption in the UK, together with gross nutrient intakes.

	Quorn	Peas and beans	Tofu	Total
Fresh weight consumption, kt	613	9,152	1,060	10,825
Dry weight consumption, kt	158	1,115	181	1,454
Protein consumption, kt	86	259	86	432
Fat consumption, kt	20	53	54	127
Carbohydrate consumption, kt	12	476	22	510
Energy consumption, TJ	2,994	16,190	4,458	23,642

The actual commodities needed to substitute meat in this way are provided in Table 32.

Quorn is based on microbial protein and requires a nitrogen source, energy for aeration, temperature control and mixing, and a substrate. The substrate currently used is molasses, but with a large increase in demand, the amount of molasses currently used in animal feeds would be inadequate to supply all needs, so sugar would be needed. It was assumed that this would come equally from cane and beet. 2.9 kg molasses are needed per kg *Quorn*[109], but only about 65% of the weight of sugar is needed as molasses to supply the metabolic energy needed. This leads to the overall substitution rates for meat given in Table 33.

Table 32. Composition of a unit weight of meat alternative on a fresh weight basis.

Substitutions for meat	Fresh weights, kg/kg
Alternatives	
Quorn	0.14
Peas and beans	2.07
Tofu	0.24
Primary commodities	
Soy bean	0.27
Chickp Peas	0.28
Kidney beans	0.27
Lentils	0.25
Fresh peas or beans	0.85
Field Ppeas or beans (dried)	0.27
Sugar from cane	0.06
Sugar from beet	0.06

Table 33. Overall substitution rates for meat (fresh weight substitution).

Commodity	Quantity of meat substituted (kt)	Total quantity of substitute (kt)		
		Quorn	Peas and beans	Tofu
Beef	1,041	144	2,153	249
Lamb	351	49	726	84
Total ruminant meat	**1,392**	**193**	**2,879**	**333**
Pig meat	1,228	170	2,540	294
Poultry	1,805	250	3,733	432
Total meat	**4,425**	**613**	**9,152**	**1,060**

Other meat alternatives

Preliminary work on cyanobacterial based meat substitutes[110] suggests that much less energy-using and CO_2 emitting alternatives may be developed in the future. This work is still at an early stage and factors such as cyclical yields with the annual cycle of temperature and solar are not adequately known and hence the impact on land area required.

One area where we lack data data is nut production (peanuts are leguminous and are thus based on other leguminous field crops). All the nut values we use were based on apples, as being the nearest crop. A major change of diet could increase the demand for nuts as part of the change. This has the potential to stimulate forestation and help reverse global trends.

Substituting milk

[109] Nonhebel, S.; and Raats, J., 2007. Environmental impacts of meat substitutes: comparison between Quorn and pork. *Proceedings 5th international conference on LCA in foods*, 25–26 April 25-26 2007, pp. 73-–75. Gothenburg, Sweden.

[110] Hanna Tuomisto, Pers. Com, 2009. University of Turku, Finland

Table 34. Amounts of milk and milk products substituted by soy based alternatives together with alternative constituents

		Alternative raw materials, kg per kg product					
Milk and milk products	**Quantities of commodity, kt**	**Soy meal**	**Soy oil**	**Rape Ooil**	**Sugar**	**Vitamins**	**Minerals**
Milk	7289	0.050	0.011	0.009	0.007	3.8E-06	0.00057
Yoghurt	589	0.050	0.011	0.009	0.007	3.8E-06	0.00057
Cheese	279	0.078	0.12	0.10	0.0005		
Butter	138			0.82			
Dried milk	100	0.93					
Condensed / evaporated milk	127	0.12	0.026	0.0216	0.0168	9.2E-06	0.001368
Cream	147			0.25			
Sums, kt	**8,670**	**524**	**123**	**251**	**57**	**0.031**	**4.7**

While the milk alternatives currently available are based on soy, there is anm imbalance between meal and oil for this purpose. So, the amount of rape oil was increased to allow the soy meal and oil components to be matched in the whole soy bean. Because the sugar that was cited in soy milk recipes is cane sugar, we used that, but the choice of cane or beet is arbitrary. The raw agricultural commodities required for the whole substitution follow (Table 36).

Table 35. Weights of commodities and land areas needed to replace all milk and milk products.

Commodity	Quantity needed, kt	UK land, kha	Overseas land, kha	Total area, kha
Soy beans	726		313	313
Oil seed rape	618	143		143
Sugar from cane	58		8.7	9
Total		**143**	**322**	**465**

Land use for substitutes

The arable crops and land needed to supply the meat substitutes was calculated (Table 36). The UK land area involved in their production was calculated using the Cranfield model. The area of land used outside the UK was calculated from global average yields. This calculation was also repeated for ruminant only meat (Table 37).

Table 36. Commodity quantities and associated land use for all meat (4,425 kt) being substituted by alternatives.

Commodity	Quantity needed, kt	UK land, kha	Overseas land, kha
Soy bean	1,204		519
Chick peas	1,217		1,478
Kidney beans	1,173		1,645
Lentils	1,089		1,102
Fresh peas or beans	3,757	532	
Field Ppeas or beans (dried)	1,194	398	
Sugar from cane	276		42

Sugar from beet	281	28	
Total		**958**	**4,787**

Table 37. Commodity quantities and associated land use for ruminant-only meat (1,392 kt) being substituted by alternatives.

Commodity	Quantity needed, kt	UK land, kha	Overseas land, kha
Soy bean	517		223
Chickp Peas	290		353
Kidney beans	280		392
Lentils	260		263
Fresh peas or beans	896	127	
Field Ppeas or beans (dried)	285	95	
Sugar from cane	803		121
Sugar from beet	816	81	
Total		**302**	**1,352**

Table 38. Commodity quantities and associated land use for substitutes of pig and poultry meat (3,033 kt).

Commodity	Quantity needed, kt	UK land, kha	Overseas land, kha
Soy bean	1,126		486
Chickp Peas	632		768
Kidney beans	610		855
Lentils	566		573
Fresh peas or beans	1,952	277	
Field Ppeas or beans (dried)	620	207	
Sugar from Ccane	1,749		264
Sugar from bBeet	1,776	175	
Total		**659**	**2,946**

Livestock product substitutes – land use implications

The estimates that follow must be regarded as only 1st first order approximations for guidance and deal with a scenario based on 100% substitution. A full and detailed assessment is not possible. Of the substitute commodities for meat, fresh and dried peas or field beans and sugar beet are the most likely to be produced in the UK and would require about 314 kha land. It thus appears superficially possible to produce these substitute commodities on UK land released if ruminant meat consumption stopped (Table 39). This should, however, be taken with caution as there are uncertainties in the estimates of the distribution of land classes. There is also about 850 kha land released from ruminant production that is tillable, although it would not be the same quality as the mainstream arable land used for concentrate production.

Table 39. Land use effects of substituting ruminant meat with *Quorn*, tofu and pulses.

	UK	Overseas	Total area
Land used for ruminant meat concentrates	314	134	448
Land needed for meat substitutes	302	1,352	1,655
Reduction in arable-only land	11	-1,218	-1,207
Released arable-forage land	837		

Released arable-forage and arable land	848	-1218	-370

Some substitute crops required are currently only grown overseas (e.g. soy, chick pea, lentils). The land required for all these crops to replace beef and lamb is about 1,352 kha, compared with about 135 kha to supply concentrates for ruminant meat now. So, the substitution of beef and sheep meat with Quorn, tofu and pulses clearly demands more overseas land. Part of this is because two major crops selected for substitution are low yielding (lentils and chick peas at <= 1 t/ha). Were higher yielding pulses used, this demand would clearly be reduced.

We modelled milk and most milk products (cheese, yoghurt, dried milk, cream, evaporated milk) as soy-based commercially available alternatives, with marginal extrapolations, (except margarine and spreads from rapeseed oil), thus most land demand is overseas. The UK land requirements would fall by 80 kha, so releasing arable land (Table 40). In contrast, the overseas requirement would increase by some 1,700 kha. There would also be about 1,300 kha potentially arable land available from that currently used for grass-forage production. The overseas land requirement increases, as with ruminant meat, but the increase is smaller at 230 kha.

Table 40. Land use effects of substituting milk with dairy analogues.

	UK	Overseas	Total area
Land used for milk concentrates	223	95	318
Land needed for milk alternatives	143	322	465
Reduction in arable-only land	80	-226	-147
Released arable-forage land	1,272		
Released arable-forage and arable land	1,351	-226	1125

Other land use consequences of the reduced ruminant meat or milk scenarios are possible, e.g. using crops like oats as a basis of a milk substitute, which would help utilise more land in the UK. It may also be associated with reduced protein intake overall which would mean that the ruminant component would be replaced by high yielding crops. In the future, soy production may be enabled in the UK as the climate warms and new varieties are made available. With the protein based substitution approach based on livestock product analogues modelled here, the overall effects of these changes are to:

- increase overseas land requirements substantially (about 1.4 Mha);
- make about 2.2 Mha tillable land that is currently used for grass or maize silage available for arable only use (remembering that is likely to be lower quality for arable than currently dedicated arable land);
- make about 10.0 Mha permanent grassland (including rough grazing) available for other uses.

We have also examined the land use consequences of compensating for a reduction in livestock product intake through a broad-based increase in plant products. This is set out in the Concluding Discussion.

The future uses for grassland could range from simple abandonment and return to the natural ecosystems expected for their location or more active management, e.g. forestry, biofuels. Some forestry could also be for food production, e.g. fruit or nuts.

These speculative land use changes would have mixed effects when considered individually with possible soil and biomass C gains in the UK, but further losses overseas. The top down

LUC model includes most of these effects in an integrated way, except for possible re-afforestation of grassland. This possibility has not been explicitly quantified.

Analysis of error

Errors were examined in the inventories using Monte Carlo simulations. A very detailed examination was not possible, but the following values of the coefficient of variation, CV, (standard deviation / mean) were used as the basis of the assessments: UK population (5%), volume of a traded commodity or food items consumed (55%), GWP of a commodity or food item (35%) and LUC in its entirety (15%). These were applied to the traded volume of each individual commodity (or food item consumed) and to the associated GHG emission of that commodity or food item. The sum of items consumed from the family survey data was also scaled by the UK population. Although the error for each item is quite large, the nature of an inventory is to sum terms, which tends to reduce the overall error. In contrast, errors increase when any terms are multiplied together.

The results were that the CV of the overall estimate of the UK consumption inventory (253 Mt CO_2e) was 7% (Table 41) 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 41. Estimated means and errors of the main UK consumption-oriented food inventory.

	Mean	Std. Dev.	CV	Lower 95% CI	Upper 95% CI
Pre-RDC	86	8	9%	70	102
Post RDC	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.

CONCLUDING DISCUSSION

The size and sources of UK food chain GHG emissions

Food is a very significant source of greenhouse gas emissions, especially when considered on the basis of consumption related emissions. We estimate that the supply of food for the UK results in a direct emission of 152 M t CO_2e with a 95% confidence interval of 217 and 289 M t CO_2e. Total UK consumption emissions are estimated to be about 748 M t CO_2e (excluding land use change).[111]. This means that direct emissions from the UK food system are about 20% of the currently estimated consumption emissions. It is noteworthy that these estimates based on our detailed inventory analysis of the UK food system compare well to previous analyses based on less complete data sets. It also aligns with the results of Tukker *et al*.[112] who concluded that the current European food system was responsible for 27% of environmental impacts in the EU. In agreement with previous work, more than half of direct emissions arise in primary production. Of these, about 58% arise from the production of animal products which account for just over 30% of consumer energy intake. A further 102 M t CO_2e from land use change is attributable to UK food. When our estimate of land use change emissions is considered, food consumption emissions rise to 30% of total consumption emissions.

Taking these estimates as a whole (254 M t CO_2e), they comprise three parts: primary production to the regional distribution centre (RDC) 34%, the RDC to consumption (through retail and cooking) 26% and LUC 40%. They are each thus of a similar order of magnitude.

Emissions arising outside the UK

Our analysis indicates that about one fifth of direct UK food chain emissions occur outside the UK presenting a special challenge for climate policy, which is close to the estimate provided by Garnett[1098]. The Climate Change Act seeks to demonstrate strong UK leadership internationally, with a commitment to share of responsibility for reducing global emissions globally. However, the UK emissions inventory (which misses a large proportion of feed system emissions) is regarded as a leading indicator of progress. So, our results indicate that the food system in particular presents particular challenges for climate change policy focused on domestic emissions and targets.

Land use change (e.g. deforestation)

This study is perhaps the first that estimates the proportion of global land use change emissions (mainly deforestation) attributable to the UK food supply chain. When land use change emissions are considered, about a half of UK food chain emissions arise outside the UK. We conclude that the direct and in-direct effect of the supply of food for the UK as a contributor to global land use change pressures is a significant factor in UK consumption emissions. It accounts for 40% of the emissions embedded in food and 12% of emissions embedded in UK consumption. We recognise that there are significant uncertainties in our estimates. However, there are facts or at least estimates that are accepted across the world underpinning our analysis. Deforestation is a larger source of emissions than agriculture, and expansion of agriculture is the biggest driver. Our estimate of emissions attributed to the UK is broadly in line with the role of the UK in the global food economy and the UK food system is well connected to global markets. Our analysis is based on the proportion of global land use attributable to the supply chain on the basis of average global yields. Since managed and native grassland covers more land than arable crops, this analysis attributes a large proportion (c.a three quarters) of LUC emissions to ruminant meat. We could use other ways of allocating emissions and we examined the effect of allocation of land use on the basis of world-market producer prices. This

[111] Garnett, T. (2008). *Cooking up a storm. Food, greenhouse gas emissions and our changing climate*. The Food and Climate Research Network.

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

reduced emissions from beef and sheep/goat meat production from 77 Mt CO_2e to 42 Mt CO_2e out of a total of 102 and 86 Mt CO_2e respectively. So while allocation on economic value reduces the emissions attributable to beef and sheep meat, we are confident that the broad conclusions remain valid across the various allocation methods that could be used.

Care is needed in interpreting our results on land use change emissions. Our work should not be used to predict the consequences of mitigation strategies based solely on these estimates of emissions sources today. The form of emissions auditing we used does not predict what will happen to these emissions in response to specific changes in the UK food system. This means that switching consumption from for example beef to poultry will not necessarily result in a corresponding change in LUC emissions as estimated here. We must also be mindful that in switching from a commodity with relatively high attributed LUC emissions to one with relatively low attributed LUC emissions we might shift from a commodity such as rapeseed which is only indirectly connected to LUC to one such as palm oil that is directly implicated. The analysis also shows that some commodities that are directly connected to LUC (e.g. palm oil) have lower total LUC emissions than similar commodities that are not grown on recently converted land (e.g. olive oil).

It might be argued that the land use change assessment we have used unjustifiably allocates land use change emissions, most of which occur in the tropics, to land that is long established in agriculture in the UK and other parts of Europe. Our analysis is based on the premise that while expansion of commercial agriculture is currently manifest mostly in a few places in the world driven directly by only a few commodities, the underlying driver is the expansion in demand for agricultural land more generally and all agricultural land use shares responsibility for this. Our analysis is supported however by the direct connections to land use change hot-spots through the consumption of the related commodities, such as beef and palm oil.

Mitigating land use change emissions

A detailed examination of the role of the UK food economy in global land use change is outside the scope of this study as is a detailed debate about international measures addressing land use change more generally. Our analysis presents challenges to some approaches to tackling land use change, particularly with respect to change that reduces agricultural productivity. As the global food system becomes more resource constrained, increasing production efficiency becomes a key part of efforts to reduce deforestation. The reality is deforestation occurs because the forest is worth more dead than alive. Our premise is that commodity markets are highly connected and that transferring consumption away from products directly linked to land use change may displace rather than eliminate pressures. Private- sector mitigation approaches such as product certification and moratoria on crop expansion will be effective if they reduce overall pressures on land use change. The literature on land use change in the Amazon and Cerrado sets out the complex interactions between many different agents of change.[113]. Rural poverty is a major driver in some cases. The individuals clearing land and the ranchers buying it are risk averse.[114]. This risk aversity increases the chances of success of market orientated strategies. However, changing consumer preferences in relation to commodities from particular countries, for example in relation to 'beef from Brazil' or 'palm oil from Indonesia' is a blunt instrument, especially against the background of the production in these countries driven by domestic consumption and global spot markets. Recent reductions in demand for livestock products have already underpinned reductions in deforestation[115] and these support the broad thrust of our analysis. Central government policy is crucial and can be effective, for example

[113] Chomitz, K. (2007). *At loggerheads? Agricultural expansion, poverty reduction, and environment in the tropical forests*. The World Bank.

[114] Nepstad, D.C., Stickler, C.M. and Ol Almeida, O.I. (2006). Globalisation of the Amazon soy and beef industries: opportunities for conservation. *Conservation Biology*, 20,: 1595-–1603.

[115] *Mongabay*. 2009. Amazon deforestation drops 70% for November 2008-–January 200 period. http://news.mongabay.com/2009/0304-brazil.html

recent government policy in Brazil.[116]. Paraguay is an example of a country where a clear central government policy on land use change has been effective.

Land use emissions

Our study does not allocate any direct soil carbon emissions to the UK food supply chain. This is justified by the uncertainty in the cause of the emissions from established European agricultural soils, the off-setting of emissions in the arable part of mixed rotations by periods of sequestration in grassland, and the over-riding role of wider environmental change in determining soil carbon losses.[117]. We are mindful that a large proportion of the potential savings in GHG emissions indicated in our analysis coming from reducing the consumption of meat from ruminants on grassland may be off-set if permanent grassland was converted to arable cropping.

While not allocating soil carbon emissions to the food chain, we emphasise that soil carbon sequestration is an important mitigation opportunity. Interest in soil carbon sequestration has been expressed to us by interested parties and claims for increased carbon sequestration are made for some agricultural practices and systems so a discussion of these is provided here.

Modified soil management, particularly a switch to reduced cultivations, is widely regarded as a means of increasing soil carbon sequestration. Since it is widely believed that soil disturbance by tillage was the cause of the historical loss of soil carbon, it is assumed that soil carbon sequestration can be obtained by replacing intensive plough based cultivations with less intensive methods. For example, Robertson *et al*. (2000)[118] compared management techniques in a three crop rotation over an eight year period in Michigan. The net changes in soil C ($g\ m^{-2}\ year^{-1}$) were: conventional tillage plough- based tillage, 0; organic with legume cover, 8.0; low input with legume, 11 and no till, 30. Some farmers in the US receive payments in return for practiscing reduced or 'conservation' tillage.

However, the consequences of reduced tillage for soil carbon are not straight-forward. More than twenty 20 years ago, David Powlson and John Jenkinson at Rothamsted Research concluded that conservation tillage "has little effect on soil organic matter, other than altering its distribution in the profile".[119]. Although Smith *et al*. (1998) produced estimates of the potential for carbon mitigation in European soils through no-till farming amounting to 23 M t C per year in an analysis of the results of more recent field experiments covering a wide range of soil (including tropical soils), Baker *et al*. (2007)[120] conclude that the widespread belief that reduced tillage favours carbon sequestration may simply be an artefact of sampling methodology with reduced tillage resulting in a concentration of soil organic matter in the upper soil layer rather than a net increase through the soil. They did highlight that there were several good reasons for implementing reduced tillage practices. Dawson and Smith (2007) reviewed this whole subject area and suggested sequestration rates of 0.2 (0–0.2) and 0.39 (0–0.4) t C ha y^{r-1} for reduced tillage and no-till farming respectively.[121]. There is not the opportunity here to revisit this entire body of work, but it indicates that more work is needed to evaluate some potentially helpful possibilities. It should be noted that the Cranfield model used in the present study only

[116] Partlow, J. 2008. Brazil's decision on deforestation draws praise. *Washington Post*, 6 December 6, 2008. http://www.washingtonpost.com/wp-dyn/content/article/2008/12/05/AR2008120503325.html

[117] Bellamy, P.H., Loveland, P.J., Bradley, R.I., Lark, R.M. &and GJD Kirk G.J.D. (2005). Carbon losses from all soils across England and Wales 1978–2003. *Nature*, 437, 245–248.

[118] Robertson, G.P., Eldor, A.P., and RP Harwood, R.P. (2000.) Greenhouse Ggases in Iintensive Aagriculture: Contributions of Iindividual gGases to the Rradiative Fforcing of the Aatmosphere. *Science*, 289 (15 September 2000), 1922-–1925.

[119] Powlson, D.S., and Jenkinson, D.S., 1981. A comparison of the organic matter, biomass, adenosine triphosphate and mineralizable nitrogen contents of ploughed and direct-drilled soils. *J. Agric. Sci*. 97,: 713–721.

[120] Baker, J.M., Ochsner, T.E., Venterea, R.T., and TJ Griffis, T.J. 2007. Tillage and soil carbon sequestration – what do we really know. *Agriculture, Ecosystems and Environment*, 118,: 1-–5.

[121] Dawson, J.J.C. and Smith, P. (2007). Carbon losses from soil and its consequences for land use management. *Science of the Total Environment*, 382, 165–190.

addresses fuel use (lower), herbicide use (higher) and yield (slightly lower) in examining the effect of reduced tillage on GHG emissions.

Ultimately, soil organic matter represents one of several carbon pools maintained by the Net Primary Production (NPP) of an ecosystem, the NPP being the gross primary production through photosynthesis minus respiration. Over time, steady-state equilibria will establish on a site and the carbon content of the soil will remain unchanged as long as carbon inputs and outputs remain unchanged. This applies to organic as well as conventionally managed soils, and to arable as well as grassland. Conversion, especially from ruminants on grassland to annual crop production, is associated with a reduction in carbon inputs in organic matter. This can be reversed. A switch from an agri-ecosystem that supports a low soil carbon content to one that supports high levels of soil carbon, for example a switch from intensive arable cropping with removal of straw to perennial agro-forestry or permanent grassland, will deliver net carbon sequestration in depleted soils until a new steady state is achieved – a process which can last several decades and even centuries. This cannot be viewed in isolation. Changes in soils management practices will also result in changed outputs.

In arable crops, the supply of organic matter to the soil is positively correlated with that crop's growth and yield. Smith *et al*. 2007[122] emphasise the role of improved agronomy in supporting soil carbon storage. They estimate the potential of improved agronomy world-wide to be up to 0.13 - 0.34 tonnes C ha^{-1} per annum depending on the region, with the higher potentials in moister regions. Improved agronomy increases crop growth and carbon returns to soil. This includes using better varieties, nutrition and crop protection, reducing fallowing, and the production of 'catch' and 'green manure' crops that have the double benefit of conserving nitrogen and adding organic matter to the soil.

Mitigating supply chain emissions

In this discussion, we refer to emissions directly attributable to food excluding LUC emissions as 'supply chain emissions'. The maximum possible effect of measures was calculated. Measures were combined in scenarios in which different proportions of measures were combined over time considering the likely degree of implementation up to 2100. These four scenarios were led by energy, consumption and technical measures to reduce emissions and a combination of these.

The reductions that appear possible by 2050 from the four scenarios were energy-led 55%, consumption-led 59%, emissions-led 55%, and all areas 70%. Eliminating avoidable food waste would reduce emissions by about 15%. The energy related emissions savings would come from a combination of a switch to non-carbon fuels and increased energy use efficiency while a cessation in land use change emissions would come from international pressure and local 'top-down' enforcement of bans on negative land use change.

Primary production, i.e. the production of food commodities, accounts for 56% of direct emissions (excluding land use change). Nearly half comprise nitrous oxide from agricultural soils and methane from livestock. Our study also identifies the source of the other half – dominated by CO_2 emissions from energy used in the manufacture of agricultural inputs, energy use in farming, commodity storage and some processing. Beyond primary production, energy use in processing, manufacture, transport, retail and food preparation accounts for 37% of all direct emissions. So we conclude that actions to deliver significant reductions in supply chain emissions must be broad based.

[122] Smith, P., Martino, D., Zucong, CCai, Z., Gwary, D., Janzen, H., Kumar, P., MccCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M., and J Smith, J. (2007). Greenhouse gas mitigation in agriculture. *Phil. Trans. R. Soc. B.*, 363,:789-–813.

This balance of emissions across the whole supply chain means that focus on any one aspect – for example farm emissions or consumption – will not be sufficient to achieve a 70% reduction in supply chain emissions overall.

Decarbonisation in the wider economy

Decarbonisation of energy and energy efficiency offers the single most effective mitigation measure. Current government policy is focused on an 80% reduction in emissions from the wider economy by 2050. The 80% target in the Climate Change Act draws on a detailed evidence base that sets out the challenges.[123] [124]. If delivered, this will result in about a 50% reduction from the supply chain as a whole – excluding land use change. A 100% decarbonisation of energy used in the food system would reduce emissions by about two-thirds. Therefore, achieving a reduction of 70% from the supply chain requires additional changes in either consumption or production (or both).

Mitigation through changes in consumption

Diet provides single measures with big effects. In addition, these measures are technically feasible now. The most effective single measure (meat-free diet) gives a 20% reduction. The benefit of a vegetarian diet increases to about 38% when our estimates of LUC emissions are included, but this excludes the loss of soil carbon if UK grassland was converted to arable cropping. Our analysis of the effects of the production of substitutes leads to the conclusion that a broad reduction in livestock product consumption balanced by broad-based increases in crop product intake is a more feasible measure which avoids the land use burden associated with soy based livestock product analogues. A 66% reduction in livestock products delivers a 15% reduction in supply chain emissions. Moreover, reduction in ruminant production in particular will reduce methane emissions.

The main dietary changes examined would involve substantial social change. This is quite likely to be the largest barrier. Meat, milk and eggs have been part of our diet for centuries. While a substantial minority actively embrace a meat free or vegan diet, most consumers will continue to consume livestock products. The better nutritional properties of the animal products compared with the non-animal alternatives mean that vitamin supplementation is required. However manufacturing vitamin supplementation appears to be trivial in energy and GHG terms owing to the very small quantities needed. Our analysis is not a complete environmental assessment which would be required to test the full effects of elimination of livestock products completely. Eliminating animal production would have wider system effects on other areas of industry, e.g. non-fossil alternatives needed to leather and wool and the use of by-products, e.g. from brewing, which provide protein and fibre for ruminants.

Not only is consumption change technically feasible now, there is consensus that it aligns with health objectives in developed economies. Public health policy generally emphasises a balanced diet, for example as illustrated by the FSA.[125]. The 'five-a-day' policy for fruit and vegetables is well established and has been adopted in other countries. The FSA 8eight tips for healthy eating emphasise reducing salt and fat intake, but put no numbers on how much meat and dairy product intake is desirable. The emphasis is on advising consumers what to eat more of rather than what to reduce. As a result, FSA diet recommendations do not necessarily lead to changes in livestock product consumption. In addition many of the popular fruit and vegetables have large burdens.

However, other independent and authoritative sources of nutritional advice closer to the medical profession do quantify ideal livestock product intakes. The German Society for Nutrition

[123] CCC. 2008. *Building a low carbon economy*. Committee on Climate cChange.

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

[125] http://www.eatwell.gov.uk/healthydiet/eatwellplate/

recommends a weekly intake of meat of 300 – 600 g[126], with zero intake of processed meats. In a study examining the alignment of climate and health policies, McMichael *et al*.[127] conclude that “particular policy attention should be paid to the 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”. They go on to advocate an average intake of 630 g per day, with no more than 300 g from ruminants. This compares with an average intake of 1,200 g per week in the UK. We conclude that there is a striking alignment between healthy eating and the consumption measures we have examined, especially the measures to reduce livestock product intake by between 50 and 66%.

Our analysis shows that direct substitution of livestock products in the diet with analogue products such as *Quorn* and tofu involves increased intake of imported protein crop commodities, particularly soy. Such a strategy is likely to increase the total soy intake of the UK food chain. Modern diets have protein in excess and substitution through a general increase in crop products is a more effective and sustainable strategy.

Mitigation through production measures – raising yields and efficiency.

Our study indicates that a 100% implementation of our measures to increase yield, feed conversion, and nitrogen use efficiency has the potential to reduce supply chain emissions by 12%. This relatively low reduction is however in line with expert opinion. Pollock (2008) estimates a potential to reduce emissions from UK farming by 10–-15% assuming static levels of production.[128]. Considering the longer timescale we are concerned with and the radical nature of other measures, our measures are perhaps more conservative, rooted in the reality that only incremental change can be expected. They include a 50% increase in nitrogen use efficiency. Nitrogen use efficiency within animal production systems is low. For example, for every 100 kg N entering the pig production system it is estimated that only about 17 kg is removed in the carcasse.[129]. The nitrogen efficiency of the animals, i.e. the amount of ingested nitrogen in the product, ranges from as low as 7% for beef cattle and sheep to about 33% for poultry meat.[130]. Overall, only about 4% of reactive nitrogen entering animal production systems is eaten by humans.[131]. The largest proportion of the resulting emissions is from the animal where ammonia emissions occur and where manure applied to crops is poorly utilised. Our analysis indicates that increasing the efficiency of N use by 50% would reduce emissions from primary production by about 2%. Raising the efficiency of nitrogen use through whole systems will depend heavily on long-term changes to livestock production systems that conserve more nutrients. It is reasonable to contend that our nitrogen use efficiency measures are conservative. In the longer term more ambitious improvements in efficiency could be envisaged. We also have not been able to simulate complex interactions between measures to raise nitrogen use efficiency in production systems and the changes in agricultural systems that may come about through consumption changes. Possible synergies, for example include synergies between changes to livestock diets, manure management, crop breeding and crop fertilisation, have not been considered. Defra research led by Del Predo and Scholefield[132] indicates that much more substantial reductions in nitrous oxide emissions can be made through increasing the nitrogen

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

[127] McMichael, A.J., Powles, R.W., Butler, C.D., and R Uauy, R. (2007). Food, livestock production, energy, climate change, and health. *The Lancet* 370 (9549),:1253-–1263.

[128] Pollock, C. 2008. Options for greenhouse gas mitigation in UK farming. http://thecarbonfootprintofbritishagriculture.com/downloads/chris_pollock.pdf

[129] Braun, E. 2007. *Reactive nitrogen in the environment*. UNEP.

[130] Van der Hoek, KW. 1998. Nitrogen efficiency in global animal production. *Environmental Pollution*, 102,: 127-–132.

[131] Galloway, J. 2006. http://www.ametsoc.org/atmospolicy/documents/JamesGalloway_Nitrogen_March_21_2006.pdf

[132] Defra. 2008. *New integrated dairy production systems: specification, practical feasibility and ways of implementation*. Defra project report IS0214.

use efficiency of whole systems – in their case dairy. They estimate that a 10% increase in nitrogen use efficiency reduces N_2O emissions by 6%. Defra research examining the potential for using plant genetic improvement to reduce nitrogen emissions from cereal and oilseed rape based supply chains concluded that genetic improvement that led to a 20% reduction in optimum nitrogen application rates could reduce the GHG emissions from wheat and oilseed rape production by 20%.[133]. Current policy is focused on reducing individual nutrient pollutants in individual environmental media separately e.g. nitrates in water and ammonia in air. The results of Del Predo and Scholefield indicate that approaches focused on entire systems and entire nutrient cycles are required, based on farm and regional nutrient accounting.

Increasing efficiency in livestock production reduces methane emissions principally by reducing the number of animals required to produce a given level of output. Some very significant reductions have been claimed. Garnsworthy reported that restoring the fertility of dairy cows to 1995 levels combined with further increases in yields per cow would reduce methane emissions from milk production by 24% by reducing the number of young female animals raised to replace the dairy herd and the number of lactating cows in the herd.[134]. That analysis did not consider the role of the dairy herd in supporting beef production and also worked on the assumption that lactation length and the pattern of daily milk yield over the lactation is fixed. Using sophisticated modelling approaches, Del Predo and Scholefield estimate that measures to increase the fertility of dairy cows would reduce methane emissions by 3%. The dramatic increases in the lactation or annual yield of dairy cows over the last thirty 30 years, principally through the introduction of the high yielding Holstein Friesian, has led to an apparent reduction in the methane emissions per unit output of milk. However, secondary effects on the wider agricultural system are easily overlooked, for example effects on the supply and quality of calves for beef production. In considering the effect of efficiency increases, care is needed in considering all the outputs of complex interconnected systems, for example meat and milk from the cattle herd.

Basing livestock production on recycling of crop by-products would reduce supply chain emissions by 1%. The small effect is due to the dominance of methane emissions which occur regardless of whether diets are based on fodder and feed crops or on semi-natural grassland, crop by-products and recycled foodstuffs.

One of the benefits of increasing global average yields is the potential to decrease the pressure on LUC. Although the UK already has high yields by world standards, there is still potential to achieve more. Spink *et al*. (2009)[135] suggested that the potential productivities of wheat and oilseed rape are about twice those currently achieved. One obvious area for improvement in the developing world to increase net yields is that post harvest losses are much larger than in the developed world.

Overall, we conclude that raising production efficiency is an important element of reducing emissions overall. There are synergies with technologies to reduce biogenic emissions directly (see below). In particular, we emphasise that raising production efficiency more generally in global agriculture is essential if land use change is to be halted while agricultural output expands to meet the needs of an increasing global population.

Mitigation through technical progress to reduce direct emissions

Using technology to reduce nitrous oxide and methane emissions directly from the food chain has an important role to play with a total potential of about 20% of food chain emissions.

[133] Defra. 2006. *A study of the scope for the application of crop genomics and breeding to improve the N economy within cereals and rapeseed food chains*. Defra research report AR0714.

[134] Garnsworthy, P. C. 2004. The environmental impact of fertility in dairy cows: A modelling approach to predict methane and ammonia emissions. *Animal Feed Science and Technology*, 112,: 211-–223.

[135] Spink,. J., Street, P., Sylvester-Bradley, R., and P Berry, P. (2009) .*The potential to increase productivity of wheat and oilseed rape in the UK*. Report to the Government Chief Scientific Adviser, January 2009.

Inhibitors of the conversion of ammonium to nitrate in soil (nitrification inhibitors) were developed several decades ago but adoption has been hindered by the cost compared with the direct yield benefits. However, there is now renewed interest in their use to obtain the associated reductions in nitrous oxide emissions.[136]. Substantial reductions (in the region of 50%) in nitrous oxide emissions from agricultural soils have been recorded and we estimate their use would reduce emissions from primary production by 11%. Inhibitors may also be bred into plants so the approach is promising in the long- term if the investment in R&D is made. This approach to conserving reactive nitrogen in the soil/plant system is highly complementary with increasing production efficiency.

Technical measures to reduce methane emissions are more problematic. Antibiotic based approaches were commercialised in the 1980s and raised animal performance by altering rumen flora and fauna to produce less methane. Regulations now preclude the use of antibiotics. Feed additives, for example based on garlic, reduce emissions dramatically (+90%) under laboratory conditions but only by c.a 15% in the field due to the resilience of the rumen flora. These studies have not attempted to account for the production of the garlic itself. It is worth noting that kangaroos emit H_2 rather than CH_4 during cellulose digestion. However, it is reasonable to expect that 50% reductions in emissions from the rumen over the next 40 years are possible (and without depending on feeding more concentrates). These measures are highly complementary with production efficiency measures.

Anaerobic digestion technology (biogas) that can generate and capture methane from manure and slurry is now commercially available. Its use to capture the majority of emissions of methane from manure would require restructuring of animal production and very significant capital investment. Recent Defra-funded research has shown that only about a quarter of the theoretical potential is technically available[137] and is accessible only through substantial public investment. Reports emphasise how the technology captures methane from manure but rarely mention the consequences of leaks of the additional methane generated. MAFF research on farm systems concluded that the net effect is a reduction in manure emissions provided biogas systems are well built, maintained and operated.[138]. Like other measures, the anaerobic digestion is highly compatible with production efficiency measures where the by-product (digestate) is used as a high value fertiliser to reduce losses from the nitrogen cycle.

The actual realisation of the benefits of AD may arise through unexpected consequences. One of the authors heard a farmer talk about his experience of involvement in the Holsworthy centralised AD project in Devon.[139]. His initial scepticism was overcome by his experience of having a uniform digestate to apply, rather than heterogeneous manure. Because of the waste management regulations, all loads of digestate arrived with analysis tickets, including NPK. That was the critical factor in enabling the farmer to raise the efficiency of nutrient use.

Consequences

Other studies indicate that a significant proportion of the production and direct emission reduction measures outlined could be implemented at reasonable cost with the potential for long-term economic benefits. Assessments made for the Committee for Climate Change estimate that a feasible investment in mitigation technology would reduce UK agricultural

[136] http://www.maf.govt.nz/mafnet/press/2009/050809-nitrification-inhibitor-research.htm

[137] Defra. 2006. *Assessment of methane management and recovery options for livestock and slurries*. Defra research project AC0402.

[138] MAFF. 2000. *Fugative emissions of methane from anaerobic digestion*. MAFF research project CC0222.

[139] Cumby, T.R.,; Sandars, D.L.; and E Nigro, E. (2004). *Physical assessment of the environmental impacts of centralised anaerobic digestion.* – Defra-funded project CC0240. http://preview.tinyurl.com/oysx2w

emissions by 10.8 M t CO_2e by 2022 (23% of UK farm emissions).[140]. About half of this could be achieved at negative or neutral costs. If this approach was applied to the whole of the UK supply chain production base, it would translate into a 13% reduction of supply chain emissions. If such measures were combined with the 80% decarbonisation of the wider economy that is now the aim of government policy, supply chain emissions would be reduced by 66%. The MAC curve work was done with input from one of us. We stress that these MAC curves were not produced using an LCA perspective. The general magnitudes may be about right, but the error margins are considerable.

Dietary change includes measures with the most far-reaching consequences. The dietary changes we have examined involved very substantial changes. Broadly speaking, changes are in line with diet guidelines such as those published by the German Nutrition Society and that would make a significant contribution to emissions, involvinge halving livestock product consumption. This means a halving of the livestock industry supplying UK consumers.

There are a number of possible consequential scenarios. One is that the UK livestock sector would switch to exports. This would mean that while UK consumption emissions would drop, UK agricultural inventory emissions would remain unchanged by the change in UK consumption. This scenario may seem unlikely now, but Europe is already emerging as a supplier of livestock products to expanding developing country markets. The UK is placed in a highly productive arc of intensive livestock production stretching from Ireland to Denmark, which, depending on the impacts of climate change, may be required to provide crops and livestock for far more people than at present. Compared with livestock production in other north-west European countries, UK agriculture is well placed to develop eco-efficient livestock systems having an agricultural structure in which crop and animal production are spatially integrated facilitating good use of nutrients.

Another scenario is that production will contract to low cost producers in the UK. A large drop in beef and sheep production might virtually eliminate the beef cow herd and most of the sheep flock resulting in extensification or widespread abandonment of the 12.5 Mha of grassland currently used by the livestock sector. If production retreated to lower cost lowland grassland, abandonment would be even greater, possibly including all of the 5.5 Mha of rough grazing and several million hectares of less productive cultivated grassland. The demand for arable feed crops would also fall accordingly releasing a total of about 1.5 Mha of arable land, including about 0.7 Mha under soybean production in South America. Our analyses indicate that if these livestock products were replaced with vegetarian analogues, the overall use of arable land may increase, particularly outside the UK. From an analysis based on average global yields for crops for livestock and human consumption, we expect that the 22% increase in direct crop consumption required to compensate for a 50% reduction in livestock product intake would be accommodated by the arable land previously used for feed crops provided the additional crop consumption is broad based and not focused on livestock product analogues. In this scenario, between 5 and 10 Mha of grassland in the UK would be available for other uses, abandonment, re-wilding (for example wetlands and restoration of peat land), and for woodland providing opportunities for bioenergy.

A contraction in the livestock sector of this magnitude could trigger a collapse of livestock production in the UK. The consequences for the emissions from the UK food chain would then depend on developments elsewhere. Completely unregulated, such a collapse could reinforce expansion in low cost exporting countries such as Brazil, even adding to forces driving land use change.

[140] Moran, D., MacLeod, M., Wall, E., Eory, V., Pajot, G., Matthews, R., McVittie, A., Barnes, A., Rees, B., Moxey, A., Williams, A. and P Smith, P. 2008. *UK marginal abatement cost curves for the agricultural and land use change and forestry sectors out to 2022, with qualitative analysis of options to 2050.* Report to the Committee on Climate Change.

A report from ADAS for Defra said that *'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'*.[141]. This statement exemplifies the view that livestock, especially grazing livestock, represent an environmental good. Without livestock, grassland would revert to the climax vegetation, deciduous woodland in many cases. This is argued to be a form of environmental degradation. A certain intensity grazing of semi-natural grassland is required to achieve a vegetation cover that is more diverse in terms of species numbers than unmanaged vegetation.

A scenario with public intervention may see efforts to retain semi-natural grassland in ruminant production thereby providing food from land that cannot be used for arable food crop production. Defra research has shown that stocking rates that are optimal for biodiversity in grazed semi-natural grassland are about half those optimised for production.[142]. Such habitats are very sensitive to interventions to raise productivity, particularly nutrients.[143]. We therefore conclude that depending on measures to support extensive production on grassland, a reduction in livestock product consumption is compatible with the optimisation of biodiversity benefits of extensively grazed semi-natural grasslands. This is also likely to be compatible with improved animal welfare.

Gill *et al*. (2009)[144] draw attention to the contribution grasslands make to global food supply. The retention of a contracted livestock sector on semi-natural grassland combined with use of arable crop by-products in livestock feeding would release a substantial amount of arable and grassland that could be used for cropping. There are a number of options for this: re-wilding of some arable land, for example fenland, extensification reducing emissions, non-food crop production including bioenergy, and crop production for export.

We have not included scenarios based on an expansion of fish farming. This is because much aquaculture is currently based on diets that have high inclusion rates of fish that is derived from caught fish and there are major concerns about the sustainability of supplies. There was also insufficient LCA data on other fish types that could be fed on more sustainable feeds. So, the future of fish could be larger than may be inferred from this report.

Clearly certain scenarios would have substantial implications for the UK food and farming sectors. It should be stressed that in this and other respects it is not possible to predict reliably the results of research and development that may take place over the next 40 years as this will depend heavily on levels of investment and development incentives.

[141] ADAS. 2007: *The Environmental Iimpact of Llivestock Pproduction*. Report for Defra FFG.

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

[143] 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.

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

ACRONYMS AND ABBREVIATIONS

BRE	Building research establishment
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent (on 100 year timescale)
CFC	Chlorofluorocarbon
CHP	Combined Heat and Power
Defra	Department for Environment, Food and Rural Affairs
EU	European Union
FAO	The Food and Agriculture Organisation of the United Nations
FAOSTAT	The statistical service of the FAO
FCRN	The Food Climate Research Network of the University of Surrey
GHG	Greenhouse gas
GJ	Gigajoule
GW	Gigawatt
GWP	Global warming potential
Ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
LCA	Life- cycle assessment
LUC	Land use change (e.g. deforestation)
LULUC	Land use and land use change
MAFF	The Ministry of Agriculture, Food and Fisheries (now Defra)
Mha	Million hectare
MJ	Megajoule
MW	Megawatt
N_2O	Nitrous oxide
RDC	Regional distribution centre – an arbitrary point in the food chain.
REDD	Reduced emissions from deforestation and degradation
RoE	Rest of Europe
RoW	Rest of World

Appendix 1: Terms of reference

REDUCING GHG EMISSIONS FROM THE FOOD CHAIN: HOW LOW CAN WE GO?
A call for proposals

1. Introduction

A recent Food Climate Research Network report, *Cooking up a Storm*,[145] concluded that it would be possible to reduce greenhouse gas (GHG) emissions from the UK food system by 70% by 2050. The report also recommended that Government should make a commitment to reducing emissions by this degree and should set out how it intends to do so, stating what proportion would be achieved through technological and managerial improvements; and what from changes in the balance of diets, or what people eat.

2. The proposed research

The Food Climate Research Network and WWF-UK are developing a programme of joint work to help foster further action along the path to food GHG reduction. This work comprises two separate but linked stages of research.

The FCRN/WWF-UK proposes initially to commission Stage One of the programme of work and is inviting proposals from interested parties. Further funds, and possibly additional funding partners, will be identified for Stage two.

The successful contractor for Stage one will be invited to make proposals for Stage two, but award of a Stage one contract does not automatically lead to an award of the Stage two contract. Stage one applicants should however, be mindful of the integrated nature of the two stages when developing their proposals. The stages are:

Stage One: Research to examine a range of feasible scenarios for achieving a substantial cut (possibly 70%) in GHG emissions from the food chain by 2050, exploring both technological and behavioural options.

Stage Two: Research identifying in greater detail the barriers to and opportunities for achieving these reductions across the food supply chain, examining what policies and business actions are required so that they are achieved, and highlighting knowledge gaps.
Further details are as follows:

Stage One

Research in this stage should examine a range of feasible scenarios for achieving a substantial cut (e.g. 70%) in GHG emissions from the whole food chain by 2050, both at a UK and regional level (England, Scotland, Wales and Northern Ireland) and with an interim target for 2020. The whole food chain includes foods that are imported and excludes exports – in other words it considers the embedded GHG emissions in all the foods we consume rather than those just associated with UK food production. Food's GHG contribution should be viewed as a proportion of the UK's total consumption-oriented GHG emissions. [146]

The researchers should develop 3 or 4 possible scenarios each of which:

[145] Garnett T. (2008). *Cooking up a Storm: Food, greenhouse gas emissions and our changing climate*. Food Climate Research Network, Centre for Environmental Strategy, University of Surrey.

[146] By this we mean all GHG emissions associated with the UK's consumption of all goods and services. The figure includes imports and excludes exports. See for example Druckman, A., Bradley, P. Papathanasopoulou, E. and Jackson T. (2008). Measuring progress towards carbon reduction in the UK. *Ecological Economics* 66, pp 594-604.

1. Tests the 70% target: the research should investigate in closer detail whether this level of reduction or an alternative figure (higher or lower) would be more realistic.
2. Considers both direct and indirect GHG impacts) and potential reductions at **all** stages in the supply chain from the manufacture of agricultural inputs and the clearing of land for agriculture through agriculture, food manufacture, distribution and consumption to disposal and wastes arising from consumption (see specific note below on land use and land use change).
3. Examines how a maximum level of savings across the whole food production and consumption chain might be achieved, specifically:
   a. What reductions are possible through current and expected technological and managerial improvements
   b. What changes in consumption behaviour are required e.g. in the type and quantities of different foods consumed, and in the way these might be processed, distributed, packaged and prepared
4. Investigates the economic cost implications of these mitigation measures
5. Investigates critical trade-offs – i.e. identifies where specific measures to reduce emissions could impact on other areas of social or environmental concern, such as human health or animal welfare.
6. Identifies major opportunities and barriers to achieving these reductions across the food supply chain.

This course of action should be taken for each scenario. Proposals should specify the methodological approach i.e. LCA, I-O etc. they plan to adopt. In addition to the analysis, findings should be represented in the form of 'Socolow wedges'[147] to enable ready interpretation of the results.

Note that of the total funding available, approximately a quarter (see 6, below) is ringfenced for research into the impacts of UK food consumption on land use change overseas and associated emissions. Specifically, this element of the research should address the following questions:

Of food's total GHG contribution, what proportion is directly and indirectly attributable to emissions arising from changes in land use (land use change and forestry) that in turn result from the production of food for UK consumption? Such foods include (but are not limited to) palm oil, soy and beef. We would like to see:

- *Estimates of total direct and indirect emissions (tonnes CO_2e) attributable to food-related land use change*
- *An assessment of land use change's overall contribution to a. UK food consumption - related and b. UK total consumption-related GHG emissions.*

Process and delivery of Stage One

Researchers will be expected to produce an interim report half way through the research process and to present this at a meeting to the commissioners (Tara Garnett and Richard Perkins) where the progress, direction and content of the research will be discussed, and comments/steerage given. FCRN advisory group members will also be invited to attend, and to provide input to this meeting.

The researchers will then produce a draft final report which will be reviewed both by the steering group and by external invited reviewers; reviewers' comments should be incorporated as appropriate into a final report, to be completed by mid June 2009. Researchers will be asked to

[147] Pacala, S., and R. Socolow, 2004. "Stabilization wedges: Solving the climate problem for the next 50 years with current technologies." *Science* 305: 968-972

present the findings of their report at the Stage one/two linking seminar shortly thereafter. See 7 below for a detailed timetable and schedule of payments.

3. Stage One /Two linking seminar

This event will be attended by key stakeholders drawn from Government, NGOs, research institutions and the food industry. The insights offered by these stakeholders at the seminar, together with the Stage One report will shape and structure the development of Stage Two.

4. Stage Two

To recapitulate, the purpose of *Stage One* described above is to explore the feasibility of achieving a 70% reduction in food consumption related GHG emissions; to develop a range of scenario 'routes' showing how this might be achieved through a differing balance of technological and behaviour change; to identify the economic and social implications of the different scenarios and to highlight potential barriers to and opportunities for action.

Stage Two, which will be the subject of a separate call for proposals, seeks to further the path towards implementation. Work will be undertaken to identify the most acceptable scenario from a social and cost perspective, to explore in more detail the barriers to and opportunities for its implementation and to begin developing a series of policy recommendations aimed at Government and the food sector .

Specifically, it is currently anticipated that Stage Two will examine:

- What policies and measures do Government and the food industry need to adopt to overcome the barriers identified in Stage one and foster the uptake and implementation of technological and managerial improvements across the whole food chain;
- What policies and measures do Government and the food industry need to adopt to overcome behavioural barriers identified in Stage one to achieve changes in the UK's food consumption;
- What are the knowledge gaps and what further research is needed?

Acknowledgements

We extend thanks to all you took part in our workshop around this report and those who contributed feedback towards the document. They offered many helpful insights that helped us in the final draft.

This report was sent out for consultation to a selection of people and organisations. We appreciate all the feedback we received and would like to thank all who did so. Our thanks go to: ADAS, The Committee on Climate Change, Compassion in World Farming, DEFRA, EBLEX, EuGeos, the food and drink federation, the Food Ethics Council, Friends of the Earth, Greenpeace, Peter Harper, RASE, the Soil Association and Tesco.

We had originally intended to include all the feedback in an appendix but many of the comments made were of an informal nature and not intended for formal standalone publication. Instead the comments have been incorporated into the report where possible and relevant, and will also be used to frame and inform the development of the second stage of our work, How Low 2, which is looking at how we might influence policy making in the light of the findings.

About the Food and Climate Research Network (FCRN)

The FCRN's aim is to increase our understanding of how the food system contributes to greenhouse gas emissions and what we could do to reduce them.

Its focus is broad, encompassing technological options, behaviour change and the policy dimension. We look at the role of technology in reducing food-related emissions but also at what changes in our behaviour (in what and how we eat) are also needed - bearing in mind too the complex interactions between technological developments and changing behavioural norms. We explore the role that government, the business community, non-governmental organisations and individuals could play in tackling food related emissions. Finally, we recognise that the climate challenge needs to be seen in a broader social, ethical and environmental context. We look at how actions to reduce GHG emissions might affect other areas of concern such as human food security, animal welfare, and biological diversity.

For more information see here: www.fcrn.org.uk

About WWF – UK

WWF's mission is to stop the degradation of the Earth's natural environment, and to build a future in which humans live in harmony with nature by:

• safeguarding the natural world and conserving biodiversity
• tackling climate change
• ensuring humanity's global footprint stays within the earth's capacity to sustain life

In January 2009, WWF-UK launched the One Planet Food programme, which aims to:

- reduce greenhouse gas emissions from the food economy by 70% by 2050;
- eliminate unsustainable impacts on water;
- change trading patterns and governance structures so that UK food is making a net positive contribution to WWF Priority Places, such as the Amazon.

The One Planet Food programme incorporates the whole food chain, from the production of commodities through processing and on to consumption and disposal. This is a complex task, and since 2008 WWF has been working in collaboration with scientists and key actors in the food system – businesses, policy makers, consumer organisations and other non-governmental organisations – to understand the impacts of the food consumed in the UK, whether grown here or imported from abroad.

Further Information

For Further information on this report contact

Tara Garnett
Food Climate Research Network
Centre for Environmental Strategy
University of Surrey (note this is NOT the postal address)
e: taragarnett@blueyonder.co.uk
t: +44 (0)20 7686 2687

To discuss this report and its relevance to the work of WWF UK's One Planet Food Programme, please contact:

Mark Driscoll (Head of Sustainable Consumption Policy)
WWF-UK
Panda House
Weyside Park
Godalming
GU7 1XR
United Kingdom
e: mdriscoll@wwf.org.uk
t: +44 (0)7909 882892

Anyone with questions as to the content of the report please contact:

Dr Donal Murphy-Bokern
Murphy-Bokern Konzepte
Lindenweg 12
49393 Lohne-Ehrendorf
Germany
e: donal@murphy-bokern.com
t: 0049 (0) 4442 802190

Citation

Please cite this report as follows:

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

The Food Climate Research Network's aim is to increase our understanding of how the food system contributes to greenhouse gas emissions and what we can do to reduce them.

The mission of WWF is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, by
• conserving the world's biological diversity
• ensuring that the use of renewable natural resources is sustainable
• reducing pollution and wasteful consumption

wwf.org.uk

for a living planet®

WWF-UK
Panda House, Weyside Park
Godalming, Surrey GU7 1XR
t: +44 (0)1483 426333
f: +44 (0)1483 426409