MEAT AND DAIRY PRODUCTION & CONSUMPTION

Exploring the livestock sector's contribution to the UK's greenhouse gas emissions and assessing what less greenhouse gas intensive systems of production and consumption might look like

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SUMMARY

Global consumption of livestock products is growing rapidly. At the same time we urgently need to curb the growth in anthropogenically generated greenhouse gas (GHG) emissions. A growing body of research argues that the livestock sector, and in particular the rearing of ruminants,[1] accounts for a significant proportion of these emissions. This paper explores the contribution that our consumption of livestock products in the UK makes to greenhouse gases, the complexities associated with attempts at quantifying these impacts, the options for mitigation and the environmental and welfare challenges these options may present.

The issues are tangled, thanks both to the complexity and variability of what goes into the livestock system: energy, diverse feedstuffs and land; and to the many and diverse products that result from the livestock production process. These include meat, milk and other edible products; leather, manure, and wool; and benefits such as soil quality, species diversity and landscape aesthetics – sometimes described as 'environmental services'. This paper, while reviewing UK and global attempts at quantifying the livestock's contribution to greenhouse gases, deliberately engages with the issues that *confuse* efforts at quantification. Taking a needs- rather than demand-based approach it considers whether our requirement for a range of goods, both edible and inedible, might be met in ways that carry a lower burden of greenhouse gases. We also take a 'what if?' approach to possible alternative land uses (agricultural production for human consumption, biofuels, carbon sequestration) for current areas put to livestock production, and consider what the subsequent greenhouse gas implications might be.

Critically, we identify 'nodal' issues for sustainability: that is, while considering approaches to reducing livestock greenhouse gas emissions we explore the implications from other sustainability objectives, particularly animal welfare and biodiversity. Finally we sketch out a series of scenarios, exploring how and whether greenhouse gases might be reduced under these circumstances and the implications for other social, ethical and environmental concerns, before drawing some conclusions.

Livestock greenhouse gas impacts

We find, drawing upon other studies, that the UK's consumption of meat and dairy products accounts for some 8% of UK consumption related greenhouse gases (including imports), largely due to significant emissions of methane (CH_4) and nitrous oxide (N_2O). European studies find that meat and dairy products contribute about half the food greenhouse gas burden[2] [3] while a report by the Food and Agriculture Organisation puts livestock related greenhouse gases as high as 18% of the world total.[4] Data for impacts associated with leather production and so forth, are not available.

While clearly the impacts are significant, we need also to consider the fact that if we did not eat meat or drink milk we would have to expend energy and emit greenhouse gases to produce substitute foods. If we did not have leather, wool, manure or other

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[1] Ruminants include cows, sheep and goats.

[2] *Environmental impact of products (EIPRO): Analysis of the life cycle environmental impacts related to the total final consumption of the EU25*, European Commission Technical Report EUR 22284 EN, May 2006

[3] Jan Kramer K, Moll H C, Nonhebel S, Wilting H C (1999). *Greenhouse gas emissions related to Dutch food consumption*, Energy Policy 27 203-216

[4] *Livestock's Long Shadow – Environmental Issues and Options*, FAO, December 2006

animal-based products, we would have to grow or manufacture substitutes which again require energy to produce and will inevitably generate greenhouse gases. In addition, livestock utilise waste food and by-products that may be going spare, and graze on land that could not be used productively for any other form of agriculture.

In other words while livestock farming generates considerable volumes of greenhouse gases, it is undoubtedly the case that were livestock *not* being reared, greenhouse gases would still be emitted as we go about producing substitutes for the goods that livestock currently provide, such as food, leather, wool, fertiliser and (by consuming food waste and by-products) waste-disposal services. Thus there is an 'opportunity cost' of securing foods and other products from non-animal sources and it is against these that we should properly measure the greenhouse gas burden of livestock production.

This paper takes a closer look at these points, by examining the nature and role of both the inputs to and the outputs from the livestock system.

The inputs: their impacts and greenhouse gas implications

We examine the three main categories of inputs: direct energy (fuel); feed (cereals, oilseeds/meals, by-products) and land for grazing. We consider the 'what if' consequences of alternative uses for livestock inputs – could these inputs be put to other uses and what might the implications be for greenhouse gas emissions?

Direct energy inputs are in fact low for the livestock sector on average[5] (as is the case for agriculture as a whole) and so we do not discuss the matter in much detail. The situation as regards feed is, however, very different. We argue that, notwithstanding arguments about variations in quality between human and animal grade cereals, much cereal fed to livestock could be eaten directly by humans. Cereals could also be used as a feedstock for biofuel production although concerns are increasingly being voiced as to the environmental impacts of so doing.[6] [7]

Alternatively, instead of growing cereals, the land could be used for other purposes. Oilmeals, a second key element of the diet, are not so much a by-product of the oil production process as a co-product – and in some years oilmeal demand actually drives oilseed cultivation. We make the case for paying more attention to the 'second order' impacts of oilseed cultivation, a factor that is not considered in most life cycle studies. These impacts include deforestation or the clearance of biomass-rich land to make way for grazing or feed cropping, and hence lost carbon sequestration potential. As regards by-products, livestock tend to make good use of these resource streams; equally though they may have alternative potential as feedstocks in anaerobic or other biofuel systems.

For land, the third input, we find that while livestock may be reared on terrains that cannot be used for other agricultural purposes, in some cases this situation reflects the economic status quo rather than actual biological incapacity. Alternative agricultural uses may be possible given the right economic context. Where crop

[5] Although relatively more significant for some livestock types, as we discuss.
[6] Crutzen PJ, Mosier AR, Smith KA, Winiwarter W. (2007). *N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels.* Atmospheric Chemistry *and Physics Discussions* 7, 11191–11205, www.atmos-chem-phys-discuss.net/7/11191/2007/
[7] Doornbosch R and Steeblik R (2007). *Biofuels: Is the cure worse than the disease? Paper prepared by the Roundtable on Sustainable Development for the OECD*, September 2007, Paris

cultivation is not possible, there may be scope to investigate the diversion of some pasture land to forestry or other forms of biomass production. We also note that much pasture land is heavily fertilised, with consequences for soil nitrous oxide emissions.

The outputs: Their impacts and greenhouse gas implications

Outputs include food, leather, manure, and wool as well as benefits such as soil quality, species diversity and landscape aesthetics. We consider how far we need these goods (as opposed to demand them) and whether their production by alternative means might lead to greater or fewer greenhouse gas emissions.

As regards their nutritional contribution to our diets, meat and dairy products are somewhat of a curate's egg. They are rich sources of essential nutrients (iron, calcium and protein) but in many cases we consume livestock-based nutrients to a nutritionally unnecessary (protein) or excessive degree (fat). Note that given the high greenhouse gas burdens of dairy production, a vegetarian diet does not necessarily carry a lower greenhouse gas burden although a vegan diet may. However while a balanced vegan diet is capable of meeting our needs for a full range of amino acids and supplying a nutritionally adequate diet,[8] [9] [10] [11] it can be hard to achieve. Individual preferences will vary, but as a general rule, eating small (and considerably less than currently consumed) quantities of meat and dairy products may be the easiest route to achieving a good, nutritionally balanced diet.

Regarding non-food outputs, we find that for leather we may well produce more than we 'need'. As such, measures to reduce livestock numbers in order to cut greenhouse gas emissions would not necessarily require that we produce more leather substitutes. Hence the argument that leather (and livestock) production helps avoid the generation of greenhouse gases resulting from the production of substitute fabrics cannot be invoked, since some of the leather goods available are not needed and might not end up being produced at all from alternative materials. Wool is a very small player on the international textiles market (2.4%)[12] and therefore massive changes in numbers would be needed to affect the market in any way. As regards rendered products, these, post BSE, are struggling to find a role. Tallow is mainly used to fuel the rendering process while most meat and bone meal is landfilled; other rendered products face competition from plant-based alternatives. Manure is clearly a valuable output but can also pose problems for methane and nitrous oxide emissions in areas of high manure concentration. We also consider the role of grazing livestock on landscape aesthetics, carbon sequestration and biodiversity and find their impacts to be mixed.

Mitigation options

The paper considers the broad range of mitigation options that have been proposed. These in summary are: Changes to husbandry (changing feed, genetic makeup, lifespan); Changes to the management system (organic, extensive, housed); Changing the outputs (manure); and finally, changing the numbers of livestock we rear (reduction). We find that some measures may have damaging consequences for animal welfare and raise the question of what our 'ethical non-negotiables' might be. Other measures may impact on biodiversity. We also note, having reviewed an extensive range of literature, that as often as not study findings are contradictory with

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[8] Appleby P N, Thorogood M, Mann J I, Key T J (1999). The Oxford Vegetarian Study: an overview. *American Journal of Clinical Nutrition*; **70** (3 Suppl): 525S-531S

[9] Key, T J. et al. (1999) Health Benefits of a vegetarian diet. *Proceedings of the Nutrition Society* v.58 p.271-5

[10] Sanders, T.A (1999) The nutritional adequacy of plant-based diets, *Proceedings of the Nutrition Society*, 58,265-269

[11] Millward, D.J. (1999) The nutritional value of plant based diets in relation to human amino acid and protein requirements. *Proceedings of the Nutrition Society*, 58, 249-260

[12] Wool Statistics, British Wool, http://www.britishwool.org.uk/pdf/Factsheet4.pdf

some finding in favour of one approach (organic, say) with others coming to the opposite conclusion.

In addition, tackling one type of greenhouse gas may lead to pollution swapping – either increases in another greenhouse gas or in another kind of environmental pollutant, such as ammonia. Similarly, reductions in one part of the farm ecosystem can prompt increases in another. We note too that the options for mitigation depend not only on what area has the greatest impact, but also on where the greatest scope for achieving savings (economically and practically) might lie. This could of course change in future years as new technologies develop.

A few scenarios

As a starting point for investigating the implications of these mitigation options we sketch out six possible scenarios: *Letting current trends continue*; *Maximising productivity*; *Switching to organic/extensive systems*; *Combining intensive and extensive approaches*; *Livestock switching* (increasing pig and poultry numbers at the expense of ruminants); and finally the *Marginal livestock rearing approach* (rearing only the numbers that marginal land unsuited to other purposes can support). For each we consider the implications for greenhouse gas mitigation as well for other concerns such as human nutrition, animal welfare, biodiversity and the land opportunity cost.

The 'maximising productivity' approach is one that is most consistent with the current approach. We find here that while greenhouse gas emissions may be reduced in the UK, the second order consequences for emissions in the developing world are unclear, and possibly negative. The impacts on animal welfare and biodiversity may also be negative.

Under an organic farming scenario and for the same level of production and consumption, greenhouse gas emissions unlikely to differ much from the 'maximum productivity' approach. However there may be gains for biodiversity and animal welfare.

A mix of intensive and extensive approaches is one where livestock would be reared extensively on an area basis but whose diets would be supplemented with cereals, oilseeds and other feed inputs. This intensive-extensive scenario may have some benefits for greenhouse gas emissions, but again the differences as compared with the 'maximum productivity' approach will be minor at current levels of consumption. There may, however be some benefits for animal welfare and biodiversity, as with the organic scenario.

The 'livestock switching' scenario envisages a decline in ruminant production and consumption (meaning fewer methane emissions) with the shortfall met by more pig and poultry rearing. While conventional life cycle analyses find pig and poultry products to be significantly less greenhouse gas intensive than sheep meat, beef or dairy products, these studies do not, however, take into account the second order impacts and possible losses in carbon sequestration potential in the developing world. Hence the predicted fall in livestock related greenhouse gas emissions can by no means be assumed.

The marginal livestock rearing approach is one that we feel merits some consideration. Under this scenario, the framing challenge would be to determine:

- How much land in the UK is truly unusable for other purposes such as arable farming or biomass production?

- How much land needs to be grazed and at what stocking density in order to promote biodiversity?
- What volume of genuine by-products have we available to use, balancing the advantages of feeding them to livestock against their possible use as a feedstock in anaerobic digestion systems?

This is a demand reduction scenario - our level of dairy and meat consumption would be limited by what we can sustainably manage within the perameters given above. Policy strategies would need to be put in place to influence consumer demand for livestock products, otherwise the shortfall would be met by imports. In this scenario policies would also seek to encourage a shift towards 'nose to tail eating' including the consumption of offal and other edible parts that currently go for rendering.

With the marginal livestock rearing approach, while emissions per quantity of meat or milk produced might increase, the second order impacts would decline since there would be no dependence on overseas farming systems. In addition, land currently used directly or indirectly for livestock farming could be freed up for other purposes, while soil quality and biodiversity would be preserved since these priorities set limits on the amount of livestock that can be reared. The impacts on animal welfare could be positive provided that efforts are made to ensure the animals' diets are adequate.

This scenario, however, would lead to an absolute reduction in greenhouse gas emissions if, and only if, levels of consumption declined to match lowered levels of production - otherwise the shortfall would be met by imports. The impacts on the rural economy could, however, be very negative, given the current prices paid to farmers. Hence such an approach would require a serious reassessment of the main players with interests in the meat and dairy supply chain and the current cost of livestock products.

Discussion and conclusions

Drawing upon these scenarios we consider what course of action UK policy makers might wish to consider. Clearly this very much depends on the policy standpoint. Are current trends in consumption (and hence production) to be assumed as a given and if so, how can greenhouse gas emissions be reduced within the context of that 'given'? Or will policy makers question and perhaps seek to alter the direction of these trends? Additionally, it will be necessary to decide whether to take an atomised or a synthetic approach to the sustainability challenges we face. Do we target individual areas of concern – greenhouse gases, unhealthy eating habits, biodiversity losses – separately? Or do we adopt a more utilitarian 'greatest good for the greatest number' stance? In this case we would explore a range of problems in tandem and try to work out an approach which tackles all of them, accepting that for no one particular area will this represent an optimal approach.

When it comes to mitigation it is important also to think not just one move ahead, but several. Land use provides a salient example. We need to consider not just how to reduce emissions from land associated with livestock production (be it grazing land or land used to grow fodder) but how to do so in such a way that the opportunities for greenhouse gas savings on other areas of land (unrelated to livestock production) are maximised. So, for example, while livestock fed a diet high in concentrates generate less methane (and possibly fewer overall emissions per unit of output) than those left simply to graze on upland areas, animals grazing on the uplands are using land that can be put to no other use apart from woodland planting. The concentrates fed to the other livestock on the other hand, could be used for non-livestock purposes, perhaps as a feedstock for biofuels production (bearing provisos about biofuels in mind) or directly for human consumption. A third possibility might be to

use the upland areas for growing carbon sequestering biomass, to use arable land hitherto used for feed cultivation to grow crops for human consumption, and to abandon livestock farming altogether. In which case we will need to think about how much land might be needed to furnish us with the other outputs of livestock rearing, such as non-food products, soil fertilisation and so forth. And these are just three of a potentially vast range of moves in this rather crucial game of chess.

Our thinking needs to be done too with global population growth in mind. By 2050 the global population is projected to top 9 billion.[13] Demand for land, for food and for energy will grow. If land is used for livestock, however efficiently, it means that there will be less available to grow other food or biofuels. As a result, hungry people may be forced to farm on ever more marginal lands with – among other things – damaging consequences for carbon storage.

Bearing in mind the multiple pressures on land use, global increases in population, the importance of other non-climate related environmental issues, the ethical obligation to care well for the animals we use and the limitation of technological-managerial solutions, a key conclusion we would draw is that if we are serious about tackling food-related greenhouse gas emissions, we need to consider making significant reductions in our overall production of livestock products, while seeking to maximise the benefits that livestock can bring. An inherently linked priority is to investigate how the British public might be encouraged to reduce substantially their consumption of meat and dairy products.

At current profit levels, a decline in production and consumption could terminally damage UK farmers and so a demand reduction scenario needs to be considered very carefully. But in our view it *does* need to be considered. Serious efforts to tackle climate change mean that we may be forced to consider options that we now find unthinkable. Such options may include reassessing current economic systems and ways of doing business.

Unfortunately economics are beyond the scope of this paper, although in future work we intend to explore this very fundamental area in detail. We simply note for now that we have a situation today where meat has never been cheaper and more plentiful – and yet farmers are struggling. While limits on production within this economic framework could clearly be fatal to farmers, even current levels of production are hardly helping. We may need to explore policies that trigger actions along the whole of the supply chain – the supermarkets in particular – to ensure that the external costs of livestock products are internalised and that farmers receive a fair return for their efforts.

In short, we may need to eat fewer livestock products, and – if farming is to survive – pay more for them.

[13] Earthtrends, July 2006 Monthly Update: World Population Growth - Past, Present, and Future, World Resources Institute August 1, 2006 http://earthtrends.wri.org/updates/node/61 accessed 10 June 2007

INTRODUCTION

Purpose

Global consumption of livestock products is growing rapidly. At the same time we urgently need to curb the growth in anthropogenically generated greenhouse gas (GHG) emissions. There is a growing body of research which argues that the livestock sector – and in particular ruminants[14] – account for a significant proportion of these emissions.

This paper explores the contribution that our consumption of livestock products in the UK makes to the emission of greenhouse gases, and in particular the complexities associated with attempts at quantifying these impacts. The report is intended as a contribution to the wider issue of livestock production and its broad range of environmental impacts.

The livestock-GHG relationship is a tangled one, thanks both to the complexity and variability of what goes into the livestock system, some of which are by-products from other agricultural systems, and to the many and diverse products that result from the livestock production process. These include meat, milk and other edible products, leather, manure, and wool as well as benefits such as soil quality, species diversity and landscape aesthetics – sometimes described as 'environmental services'. This paper, drawing upon a wide range of existing studies, attempts to articulate some of these complexities, draw conclusions where possible, and point to areas where further research is needed.

Taking as its situating context the imperative to reduce greenhouse gas emissions by 60%[15] or even 90%[16] by the year 2050, we consider whether our need for a range of goods, both edible and inedible, might be met in ways that carry a lower burden of greenhouse gases. We ask how far a burden reduction might be achieved by modifying the way we farm and manage animals, and explore a range of mitigation strategies that have been put forward. We then move on to consider how far we might need to think about substituting livestock goods and services with non-animal alternatives before sketching out a series of 'scenarios,' that highlight the implications of possible different ways forward for the livestock sector in the UK.

While the main focus of the paper is on greenhouse gas emissions, other issues, such as animal welfare, the aesthetic/amenity value of the landscape and some of the international development dimensions, are partially explored in order to frame our greenhouse gas focus. In addition, while the bulk of the discussion concentrates on production within the UK, there is some exploration of the global situation and trends, since, as with other types of food, the livestock supply chain is global in its reach.

The paper has various limitations that should be borne in mind. First, our focus is on greenhouse gases only and where the term 'emissions' is used it should be taken as short hand for greenhouse gas emissions alone. Other highly polluting air- and water-borne emissions such as ammonia or nitrate water pollution are not included even though there is potential for pollution swapping – situations where action to reduce nitrous oxide for instance (a potent greenhouse gas), can lead to increases in

[14] Ruminants include cows, sheep and goats
[15] *UK Draft Climate Change Bill*, Defra, 2007
[16] *Beyond Stern: From the Climate Change Programme Review to the Draft Climate Change Bill: Seventh Report of Session 2006–07* Report, together with formal minutes, oral and written evidence, Environmental Audit Committee, House of Commons, July 2007

ammonia emissions. It is our view, however, that since the greenhouse gas issue is complex enough as it stands, introducing another dimension at this stage would simply lengthen this paper even further. In addition, work on other environmental pollutants and the pollution swapping issue is already the subject of ongoing research by others.

The second limitation is that the paper focuses very heavily on cattle farming. While the beef and dairy sectors are the most complex systems and perhaps dominate as far as greenhouse gas emissions are concerned, pigs and poultry also make very significant contributions. We simply note here that this paper represents a starting point in our research and we intend to undertake a fuller treatment of pigs and poultry in future work.

As a third limitation, we limit our analysis of greenhouse gas impacts largely to emissions generated up to the farm gate. While we do explore the leather, slaughtering and by-products sectors our discussion concerns the way they relate to and influence the upstream agricultural production stage rather than the emissions they themselves generate.

Our rationale for focusing largely on agricultural stage emissions is that it is generally agreed that post-farm gate emissions are far less significant by comparison.[17] Post farm gate emissions may be easier to tackle too since there is only one gas of any significance to address – carbon dioxide – in contrast with the agricultural stage where we need to contend with three key gases, carbon dioxide, methane and nitrous oxide. There is, moreover, an ongoing body of research already underway focusing on the latter stages of the supply chain[18] as well as policies to target emissions[19] and hence duplication was felt to be unnecessary.

Finally, a very major absence in this report is the economic dimension, particularly with respect to rural farming communities in the UK. Approaches to reducing emissions from the livestock sector should not be at the expense of farmers, especially those working on the margins of economic viability. In a future paper we intend to consider these fundamental economic aspects in some detail.

Structure

The first part of the paper examines trends in the consumption and production of meat and dairy products both in the UK and globally. It then describes the policy context within which farming is situated and how current policy developments are likely to influence the nature and geographical spread of livestock farming.

Section 2 looks at how animals are reared in the UK.

Section 3 reviews studies which quantify the contribution that the meat and dairy sector makes to greenhouse gas emissions from UK, EU and global perspectives.

Sections 4 and 5 are the heart of the paper. Here we seek to engage with the issues that confuse efforts to quantify emissions from the livestock sector, particularly beef and dairy herds since these tend not only to be the most 'difficult' animal type but also those with perhaps the greatest global warming impact.

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[17] Berlin J. (2002). Environmental life cycle assessment (LCA) of Swedish semi-hard cheese, *International Dairy Journal* 12 (2002) 939–953.
[18] For instance Defra's dairy road mapping work
[19] The Climate Change Agreements, for instance

Section 4 explores the feed *inputs* to the livestock production process: energy, feed and land. As regards feed, the main constituents – cereals, oilseeds, by-products and grass – and the greenhouse gas emissions associated with their production are explored. The discussion on land examines the concept of its opportunity cost and the greenhouse gas implications of using land for purposes other than livestock production.

Section 5 examines the *outputs* of livestock rearing – food, non-food products, manure and landscape aesthetics and biodiversity – in the context of our need for these products. In the first part we examine food – the role that meat and dairy products play in the British diet and we compare this contribution with official nutritional recommendations. The second part looks at non-food products such as leather, tallow and wool. Part three focuses on the livestock sector's contribution to soil fertility and quality and to carbon sequestration through the production of manure and through grazing. Finally we explore the contributions that livestock make to our aesthetic appreciation of the landscape and to its biological diversity.

The sixth section considers some of the strategies and approaches that have been put forward, and in some cases, implemented as a means of reducing meat and dairy related greenhouse gas emissions. It goes on to discuss what the animal welfare implications of some of these strategies might be.

Section 7 discusses the implications of the analysis presented in this paper and draws a few conclusions. Using a scenarios approach we sketch out a number of ways in which greenhouse gas emissions from the livestock sector might be tackled and what the implications might be for other social, ethical, environmental and economic concerns.

SECTION 1: THE LIVESTOCK SECTOR – AN OVERVIEW

This section briefly outlines trends in the production and consumption of meat and dairy products in the UK. It also examines the policy influences on current livestock farming practice, focusing mainly on UK/EU policy but touching too on international developments. Finally broader global trends in the production and consumption of livestock products are discussed. Note that leather and wool are not explored here as they are dealt with in Section 5.2.

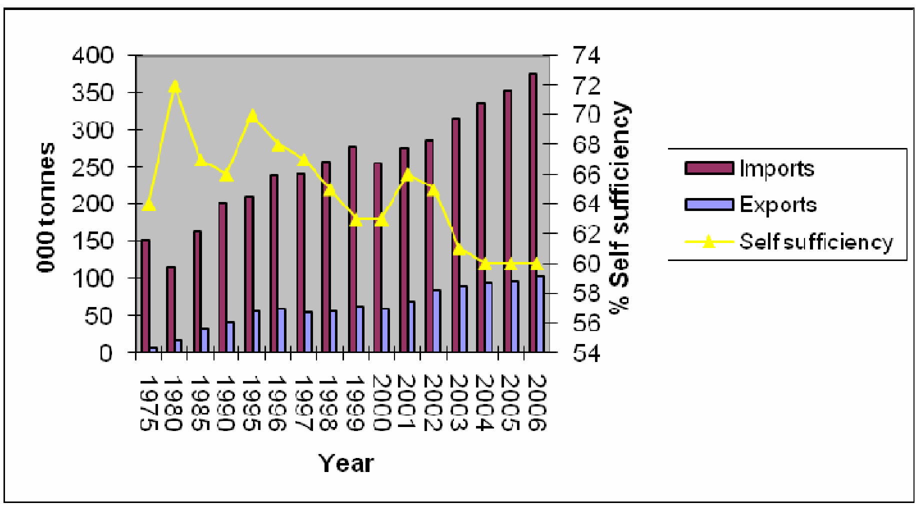
1.1 Livestock production in the UK

The UK is a major European producer of meat and dairy products. In 2005 we were Europe's fourth largest producer of beef,[20] the third largest of milk,[21] and the largest producer of sheep meat.[22] We are also Europe's second largest poultry meat producer.[23] Nevertheless our self-sufficiency in many livestock products is showing gradual signs of decline.

1.1.a Beef

Beef self-sufficiency stands at 80%. Roughly 60% of what we import is brought in from Ireland, 13% from Brazil and the remainder from the Netherlands, Germany, Uruguay and a range of other countries.[24] We also export small quantities of beef to our European neighbours – an amount equivalent to about 1.5% of total production.[25] Regarding longer-term trends in imports and exports, the BSE crisis has triggered a considerable growth in imports over the last ten years, as Figure 1 shows. Exports by contrast fell drastically and are only just starting to creep up again.

Figure 1: Trends in imports, exports and self-sufficiency of beef



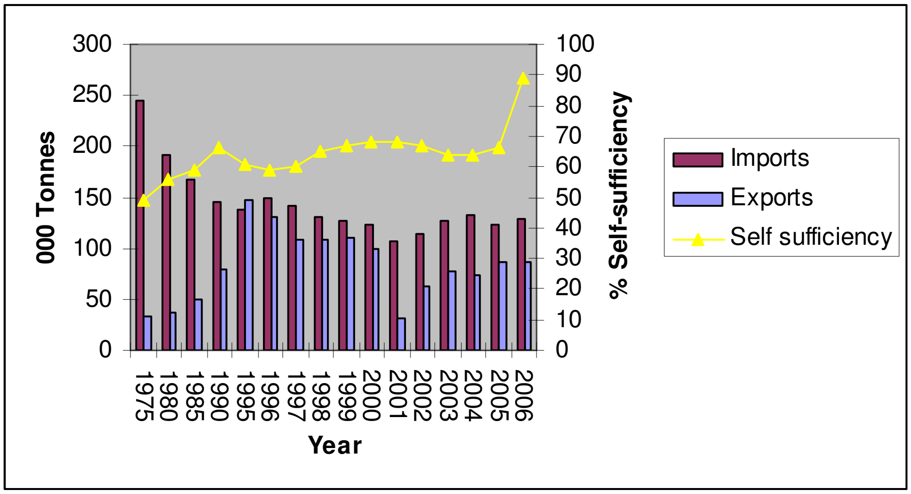
Source: Meat and Livestock Commission, 2007

[20] Eurostat 2005 data
[21] Eurostat 2005 data
[22] Eurostat 2005 data
[23] Eurostat 2005 data
[24] Meat and Livestock Commission, 2006 data http://www.mlc.org.uk/news/beefmarkets.asp
[25] 2005 figures – 2006 export volumes are higher largely because of increased production levels

1.1.b Sheep meat

Self-sufficiency in sheep meat has been hovering at around 65% for the last 7 or 8 years before increasing significantly in 2006. New Zealand is the main source of imports at 73%, followed by Australia at 11% with the remaining volumes supplied by other countries.[26] Notwithstanding our relatively low self-sufficiency we nevertheless export around a quarter of what we produce, much of it to France. While the volume of meat we import is lower than what we export, both are in decline, reflecting falling consumer demand for sheep meat.

Figure 2: UK trends in imports, exports and self-sufficiency of sheep meat



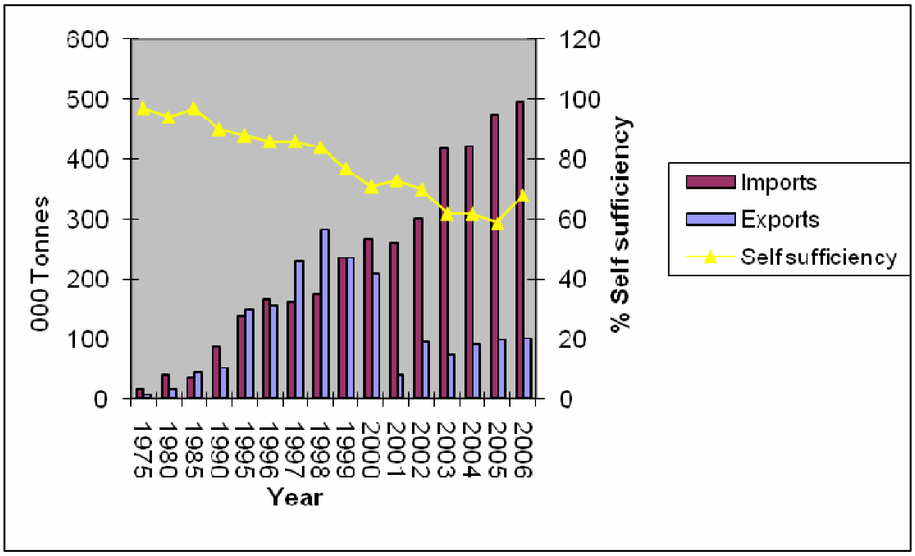
Source: Meat and Livestock Commission, 2007

1.1.c Pork

For pork, we are between 60-70% self sufficient, depending on the year. The bulk of our imports (44%) come in from Denmark, with the Netherlands, Germany, Belgium and France accounting for the bulk of the remainder.[27] We also export around 17% of our pork to Europe, and indeed to countries from which we also import. Figure 3 shows that up until the mid 1990s, imports and exports were fairly evenly balanced. Beyond that point, exports fell dramatically while imports continued to grow steadily. This decline in exports was due to several reasons.[28] The first was the introduction of new welfare legislation (the stall and tether ban) which caused a mass exodus from the industry by indoor farmers who were unable, or unwilling, to change their sow housing in time for its introduction in 1999. While the legislation was EU wide, the UK was one of the first countries to implement it and so costs for UK producers rose relative to those of other countries. UK consumers unfortunately showed themselves unwilling to pay for more expensive meat and bought the cheaper imports instead. The situation was exacerbated by the ban on the use of meat and bonemeal (post-BSE) as a feed source, the result being that farmers had to buy in more expensive protein sources. All these factors, combined with a series of diseases affecting the pig sector led to a major decline in the breeding herd and to subsequent pig meat production.

[26] Meat and Livestock Commission, 2006 data http://www.mlc.org.uk/news/sheepmarkets.asp
[27] Meat and Livestock Commission, 2006 data http://www.mlc.org.uk/news/porkmarkets.asp
[28] Zoe Davies, Defra, pers. comm. August 2007

Figure 3: UK trends in imports, exports and self-sufficiency of pork

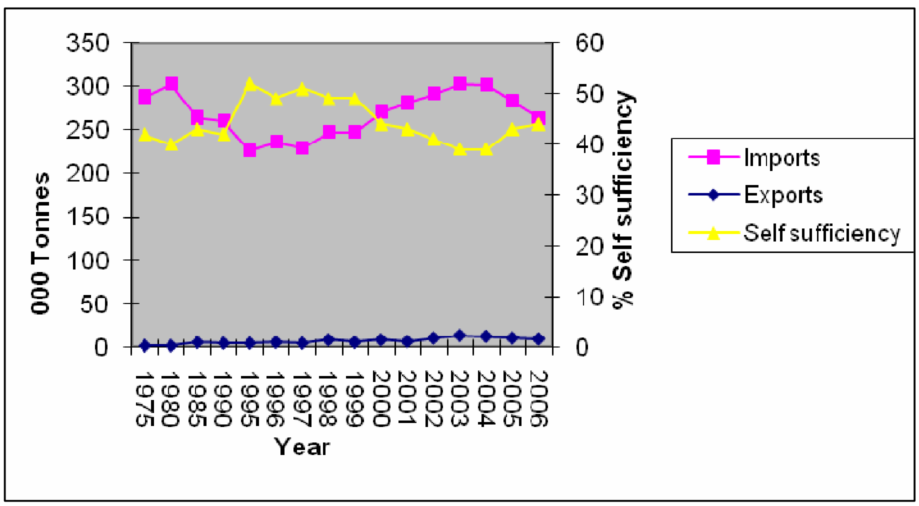


Source: Meat and Livestock Commission, 2007

1.1.d Bacon

Bacon self-sufficiency is lower still, at 44%, although once again, we export small volumes (5% of production) in addition to importing (mainly from the Netherlands and Denmark and, to a lesser extent, Germany). Our level of imports is vastly greater than our exports.

Figure 4: UK trends in imports, exports and self-sufficiency of bacon



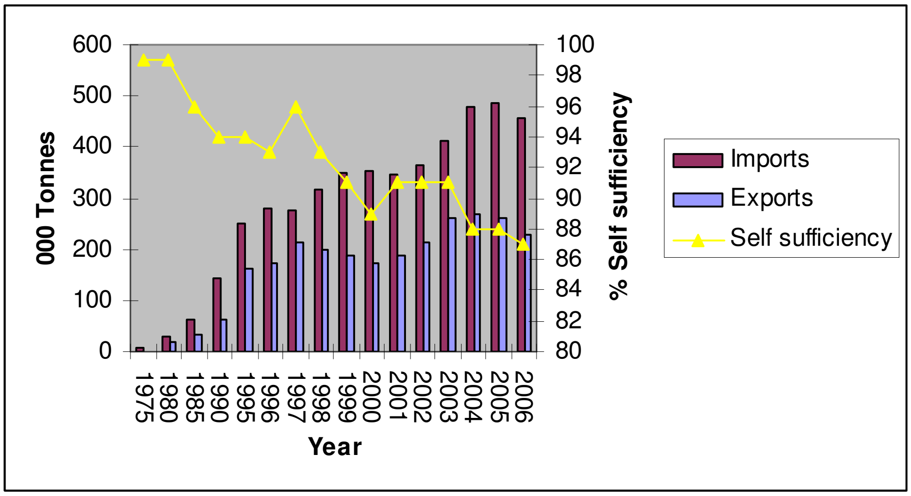
Source: Meat and Livestock Commission, 2007

1.1.e Poultry

Poultry self-sufficiency is, relatively speaking, high (88%), although it is showing a steady decline. Most of our chicken imports (72%) come from Europe, but 18% are from Asia and 10% from South America. Interestingly, although we import 466,975 tonnes of chicken, we also export around half that quantity. From the figures available it appears that we import higher value cuts and export the lower value ones;

the value of imports works out at around £1.89 per kg whereas for exports it is half this at £0.92 per kg. Since all the trends suggest that our preference for chicken portions (such as breast or thigh) rather than whole birds is likely to grow, we are likely to see an increase in international trade, selling the bits of the carcass that we don't want (feet or wings, for example) and buying those that we do.[29]

Figure 5: UK trends in imports, exports and self-sufficiency of poultry



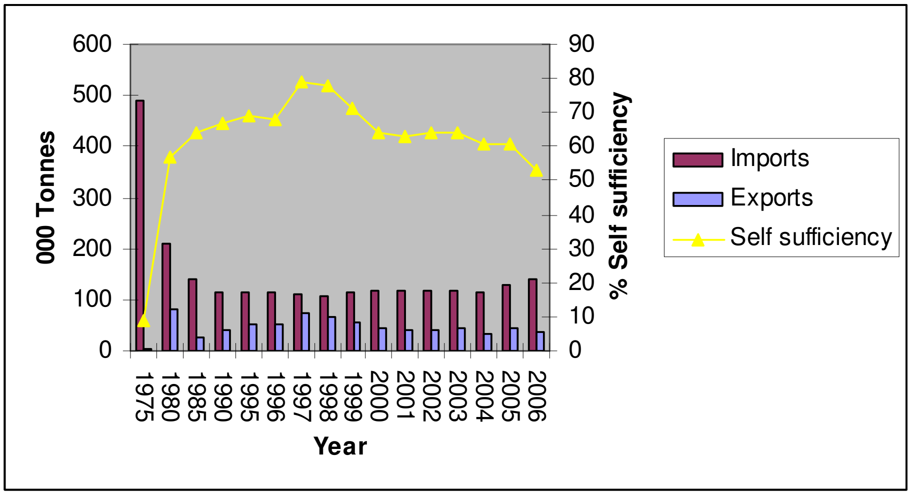
Source: *Agriculture in the United Kingdom*, Defra, 2007

1.1.f Dairy products

The UK continues to be more or less self sufficient in milk although small quantities are imported and, to a greater extent, exported. Data for yoghurt are harder to come by: Using information provided by the Milk Development Council[30], Mintel[31] and the Family Food Survey[32] we estimate that imported yoghurt accounts for 30-42% of all yoghurt on the UK market. Self-sufficiency in butter and cheese are both low at 53% and 60% respectively, as Figures 6 and 7 show. We also trade in other milk products such as dried skimmed milk powder, cream and condensed milk.

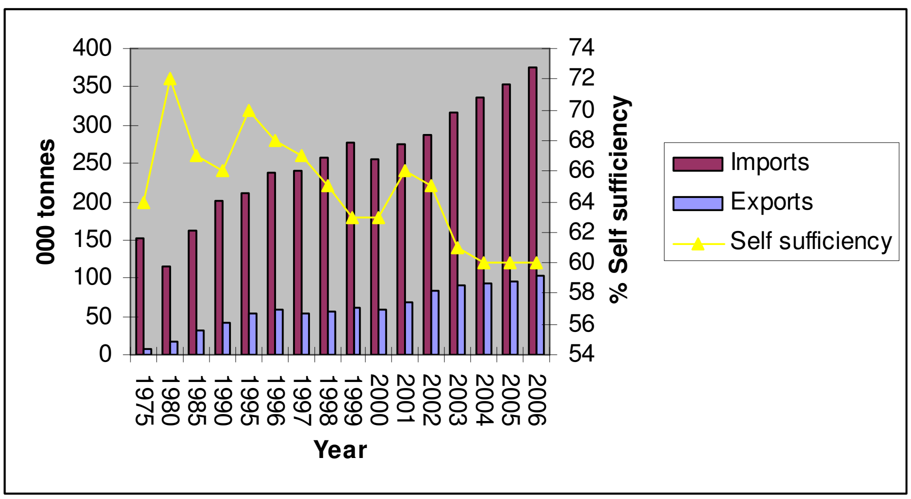
[29] British Poultry Council, 12 month period to October 2006
[30] *Dairy Facts and Figures 2003*, Milk Development Council, 2003
[31] *Yogurts - UK - July 2006*, Mintel 2006
[32] *Family Food*, Defra, 2002/3

Figure 6: UK trends in imports, exports and self-sufficiency of butter



Source: *Agriculture in the United Kingdom*, Defra, 2007

Figure 7: UK trends in imports, exports and self-sufficiency of cheese



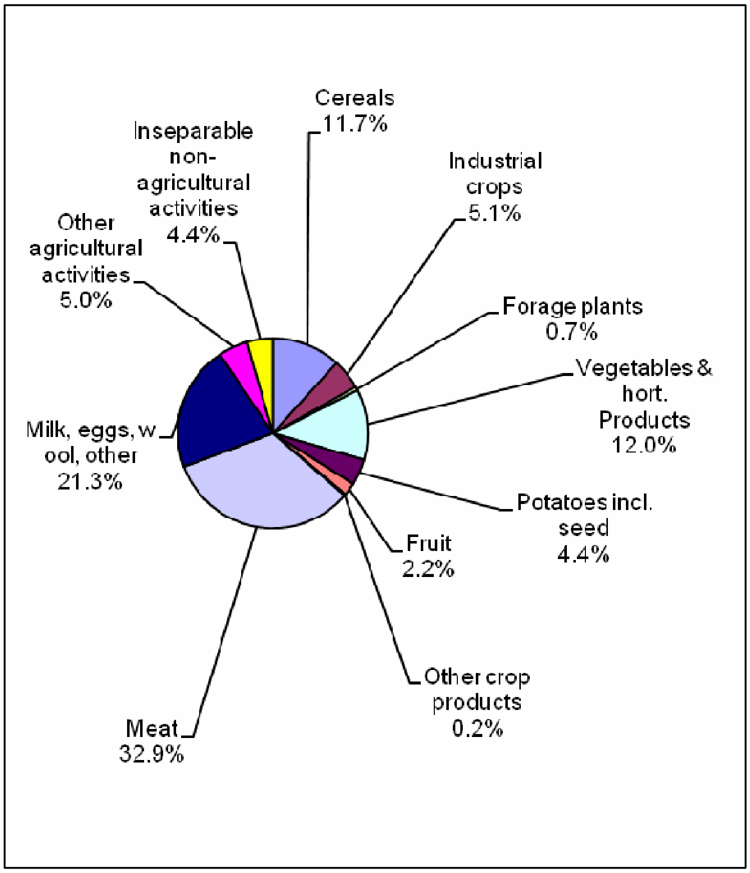
Source: *Agriculture in the United Kingdom*, Defra, 2007

1.2 Contribution to the UK economy

The agricultural sector as a whole contributes about 1% to the UK economy[33] and of this, livestock production account for about 55%, as Figure 8 shows.

[33] *The Blue Book, 2006 Edition*, Office for National Statistics, Table 2.1 http://www.statistics.gov.uk/downloads/theme_economy/BlueBook2006.pdf

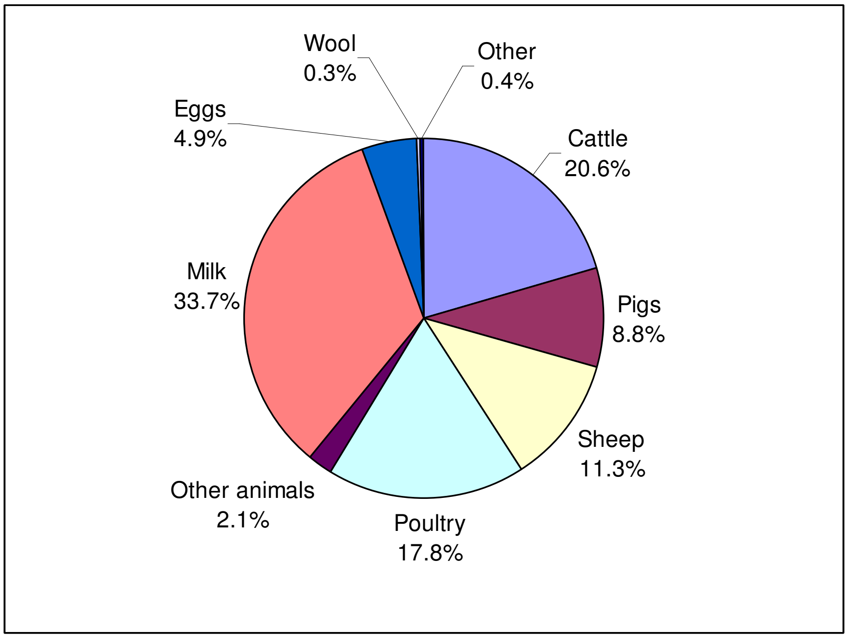
Figure 8: Contribution of different commodities to total agricultural production value



Source: *Agriculture in the United Kingdom,* 2005 (2004 values), Table 8.1
http://statistics.defra.gov.uk/esg/publications/auk/2005/8-1.xls
Note: Livestock data include the value of gross fixed capital formation

Within the livestock sector itself, dairying contributes the greatest proportion to overall livestock value.

Figure 9: Contribution of different livestock products to livestock-related production value



Source: *Agriculture in the United Kingdom,* 2005 (2004 values), Table 8.1
http://statistics.defra.gov.uk/esg/publications/auk/2005/8-1.xls
Note: Livestock data include the value of gross fixed capital formation

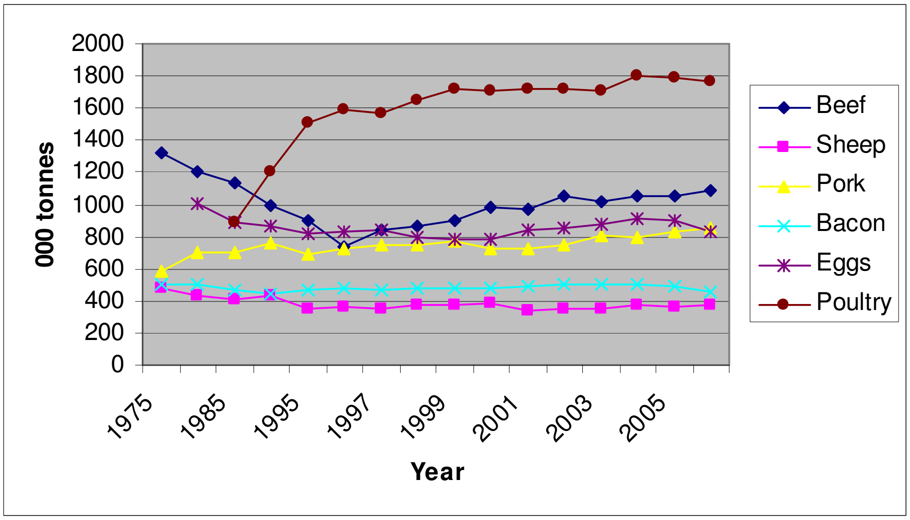
1.3 Meat and dairy consumption in the UK

As Figure 10 shows, UK consumption of meat and eggs, measured in overall tonnes, has remained more or less level over time, with the exception of poultry meat, where consumption has doubled in the last twenty years. During this time too, the UK population has grown by 7%,[34] and so consumption in per capita terms may have fallen very slightly in all areas except for poultry.

As regards milk, about half of all milk produced in the UK is consumed directly in liquid form. The remaining half is processed into yoghurt, cheese, butter and so forth. Despite a slight rise between 2002-3 and 2003-4, we are seeing a general downward trend in the consumption of milk, butter and dairy products,[35] [36] a trend that is only partly compensated by the growth in yoghurt, fromage frais, dairy deserts and cheese.

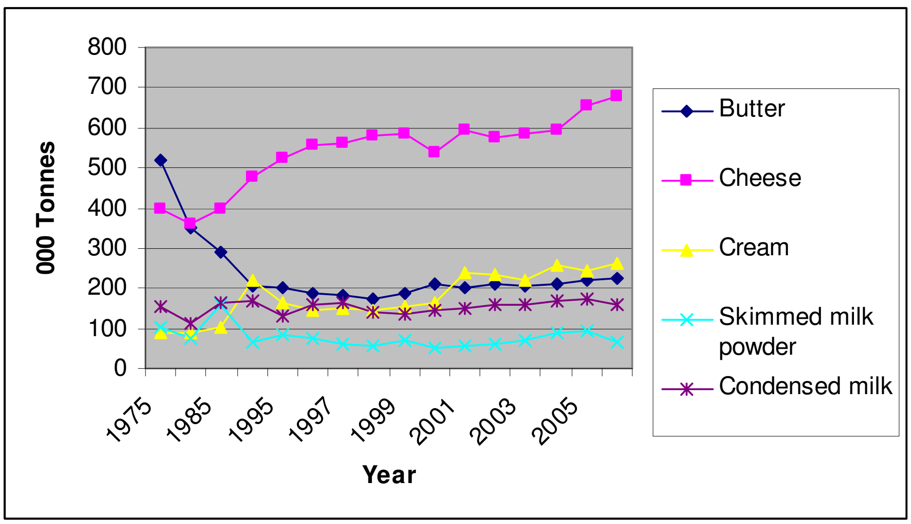
[34] Office for National Statistics, years 1976 and 2005 compared
[35] *Dairy statistics: an insider's guide*, Milk Development Council, 2006, http://www.mdcdatum.org.uk/PDF/Pocketbook.pdf
[36] *Family Food*, 2003: dataset UK consumption of food and drink, 1974-2003/4 http://statistics.defra.gov.uk/esg/publications/efs/datasets/efscons.xls

Figure 10: Trends in UK consumption of meat and eggs 1975-2006



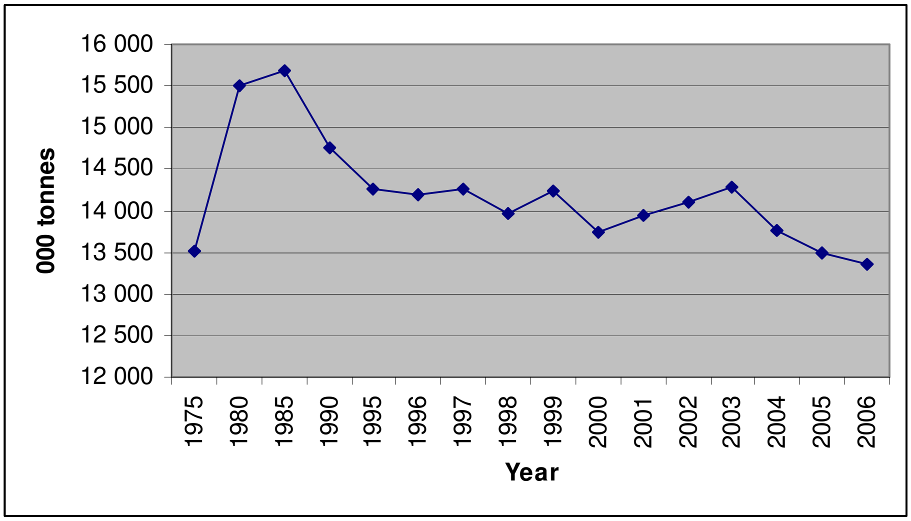
Sources: Data for beef, sheep, pork and bacon are from the Meat and Livestock Commission website. Data for eggs and poultry are from *Agriculture in the UK*, Defra 2006. Note: These figures are for supplies available on the market for consumption and include imports minus exports.

Figure 11: Trends in UK consumption of dairy products 1975-2006



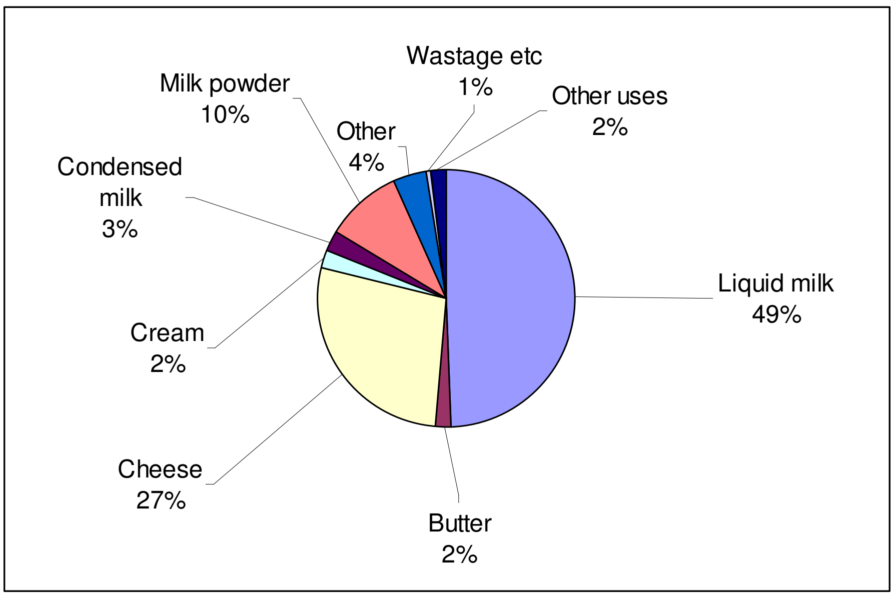
Source: *Agriculture in the UK*, Defra, 2006. Note: These figures are for supplies available on the market for consumption and include imports minus exports.

Figure 12: Trends in UK consumption of liquid milk 1975 – 2006



Source: *Agriculture in the UK*, Defra 2006. Note: These figures are for supplies available on the market for consumption and include imports minus exports.

Figure 13: Milk uses by food type



Source: *Agriculture in the United Kingdom*, 2005, Table 5.17
http://statistics.defra.gov.uk/esg/publications/auk/2005/5-17.xls
Note: 'Other uses' includes farmhouse consumption, milk fed to stock and on farm waste. Excludes suckled milk.

1.4 Production and consumption: International trends

At a global level, livestock production currently accounts for some 40% of the gross value of world agriculture, and its share is rising.[37] Over the next few decades we are likely to see rapid increases both in livestock production and in consumption,

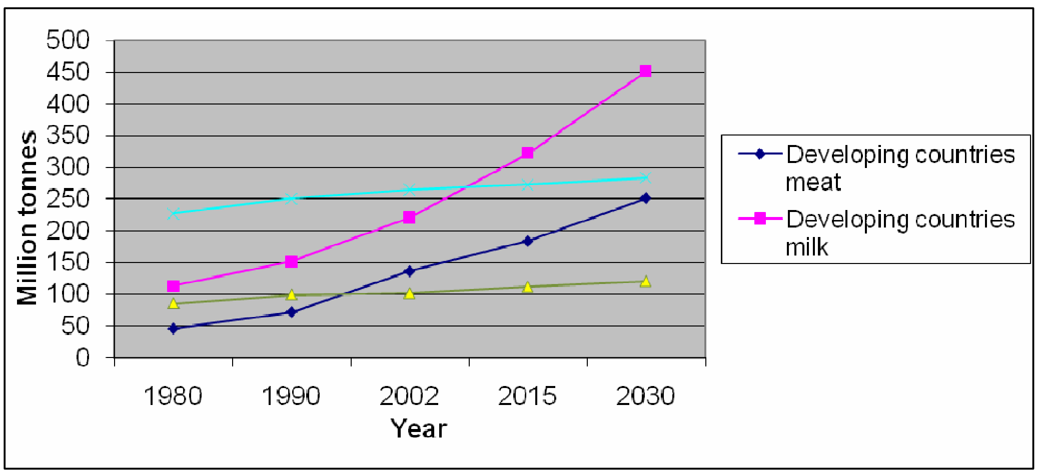
[37] *World agriculture: towards 2015/2*030, Summary report, FAO, Rome August 2002
http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/004/y3557e/y3557e00.HTM

before growth starts to slow. While the Food and Agriculture Organisation (FAO) observes that the bulk of global growth in livestock production may in fact have now peaked, and that future growth will occur at diminishing rates, this view is disputed elsewhere, as we discuss in Section 4.[38] Either way, there will still be significant growth in demand. Figure 14, using FAO data shows that in the developing world, demand for meat and milk consumption, is set to double between 2002 and 2030.

Some of this increase reflects the growth in world population: The world population is expected to grow to around 9 million by 2050,[39] as compared with 6.6 million today.[40] However it also reflects a growth in *per capita* demand for meat and dairy products, itself a result of economic development.

In developed countries, growth will be more moderate – meat consumption is set to grow by around 50% and the increase in milk consumption will be slight. It is important to note, however, that these countries are already starting from a high per-capita level of meat and dairy consumption.

Figure 14: Past and projected trends in milk and meat consumption (total consumption)



Source: *Livestock's Long Shadow – Environmental Issues and Options*, FAO, December 2006

The growth in livestock production will not be even across all livestock types. Generally speaking, poultry and pork products are expected to account for most of the increase, while ruminants will take a far smaller share.[41] [42] This is indicative of changing tastes, but it also reflects the growth in more intensive farming practices on smaller land areas. These practices tend to be adopted for the rearing of monogastrics[43] more than for ruminants, particularly in the developing world.[44]

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[38] Keyzer M.A, Merbis M.D, Pavel I.F.P.W., van Wesenbeeck C.F.A. (2005). Diet shifts towards meat and the effects on cereal use: can we feed the animals in 2030? *Ecological Economics* Volume 55, Issue 2, pp 187-202
[39] *Livestock's Long Shadow – Environmental Issues and Options*, FAO, December 2006
[40] US Census Bureau, http://www.census.gov/main/www/popclock.html accessed 13 August 2007
[41] *Livestock's Long Shadow – Environmental Issues and Options*, FAO, December 2006
[42] IFPRI (2001). *2020 Global Food Outlook: Trends, Alternatives, and Choices.* Edited by Mark W. Rosegrant; Michael S. Paisner, Siet Meijer, and Julie Witcover. International Food Policy Research Institute, Washington D.C
[43] Such as pigs and poultry

Figures 15 and 16, using data from the International Food Policy Research Institute[45], illustrate this trend, showing the breakdown of demand by meat type in 1997, and the projected breakdown in 2020.

Figure 15: Global meat demand by animal type 1997

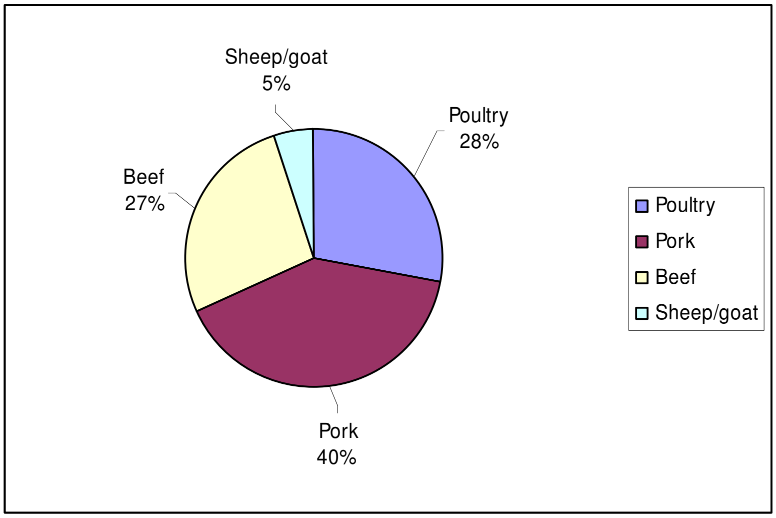
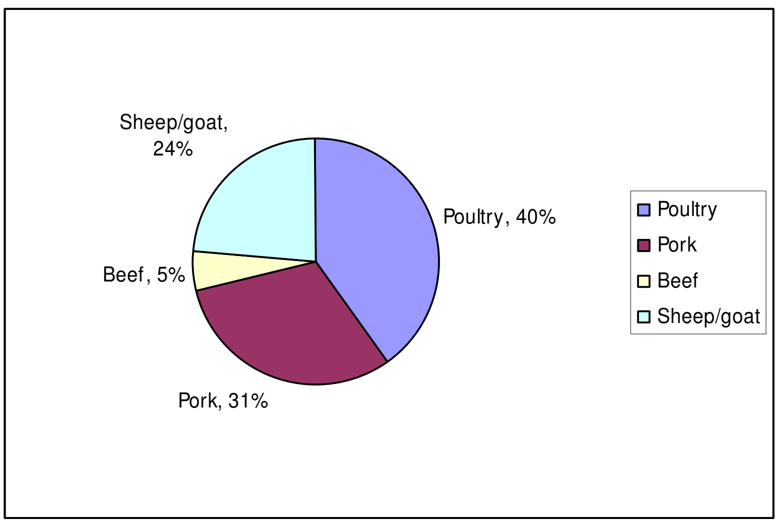


Figure 16: Projected global meat demand by animal type 2020



Source: IFPRI (2001). *2020 Global Food Outlook: Trends, Alternatives, and Choices*. Edited by Mark W. Rosegrant; Michael S. Paisner, Siet Meijer, and Julie Witcover. International Food Policy Research Institute, Washington D.C

The FAO also anticipates that livestock production is likely to be more clustered spatially for a variety of geographical and economic reasons, and the trend towards larger, often vertically integrated agro-food enterprises is likely to continue, alongside the marginalisation of smaller farmers.[46]

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[44] *Livestock's Long Shadow – Environmental Issues and Options*, FAO, December 2006
[45] For consistency FAO data should be used, but these were not available
[46] *Livestock's Long Shadow – Environmental Issues and Options*, FAO, December 2006

1.5 The policy context

1.5.a Common Agricultural Policy

Following major reform of the Common Agricultural Policy (CAP) in 2003, the years 2005-2012 are seeing a progressive shift within Europe away from agricultural subsidies based on production, to area-based payments. Such payments are conditional on 'cross compliance' with minimum environmental and other standards. The intended outcome is that there will be less of an incentive to produce agricultural outputs and more focus on fostering 'environmental goods.'

Detailed implementation of the scheme varies in different EU member countries. In the UK, under the Single Payment Scheme, farmers receive a single flat area-based payment. The new scheme currently runs in parallel with the various older schemes it replaces but over the period up until 2012, payments under the old schemes are being progressively reduced each year as payments under the new scheme increase.[47] Additional funds are available to farmers who meet higher environmental standards under the voluntary 'Environmental Stewardship' scheme. In England, farmers' uptake of Environmental Stewardship Schemes since 2005 means the area covered by agri-environment schemes is just over four million hectares, about 45 per cent of available farmland.[48]

Since the Single Payments Scheme was only introduced in 2005 it is still too early to know what long-term effects it is likely to have on the livestock sector. However, preliminary observations[49] suggest that there may well be significant structural changes. Sheep are expected to become more common on lowland areas and less so on the uplands. Beef cattle numbers will decline overall, with marked decreases on the uplands. A dual system of production may emerge; one characterised by more intensive, commercial, mainstream beef, using feed cereals and arable by-products; and the other by less intensive production to meet consumer demand for slow reared, quality meat. The possible implications of these changes are evaluated further through use of scenarios in Section 7.

For dairy farms, the picture will be mixed, with increases in some traditional dairy areas and reductions in the existing and least productive semi-natural grazed lowland areas. The trend towards fewer but larger farms concentrated in lowland areas is also likely to continue.

Pig and poultry farmers have historically never received CAP support and as such they will be less affected by the CAP changes. However, now that payments are made on an area basis, outdoor pig producers will be eligible for payments on their land.

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[47] In the dairy sector in particular, there is still a significant guaranteed price element in support alongside the SPS. The dairy sector is also unusual in that its output is limited by production quotas

[48] *Good Farming, Better Environment: State of the farmed environment in England and Wales,* Environment Agency / National Farmers Union, December 2006 http://publications.environment-agency.gov.uk/pdf/GEHO0406BKEP-e-e.pdf

[49] *Agricultural Change and Environment Observatory Programme*, Annual Review 2006, Defra, 2007

1.5.b Other legislation and initiatives

Of course the CAP reforms are not the only influence on change – other policies will have a strong input too.[50]

As regards environmental regulations, of key importance is the EU Nitrates Directive (91/676/EC),which seeks to reduce the impacts of nitrates escaping into water and air. In 2002, 55% of England was designated as a Nitrate Vulnerable Zone (NVZ). Farmers within NVZs are required to implement various measures as regards the use of fertilisers (including manure) and the storage of manure, slurry and silage.[51] [52]

The Water Framework Directive (WFD) 2000/16/EC is another important piece of legislation. The WFD came into force in December 2000 and requires all inland and coastal waters to reach "good ecological" status by 2015 through the delivery of a series of environmental objectives for river basin areas. A plan for each river basin must be in place by December 2009.

To aid the achievement of this goal, in 2006 Defra rolled out its England Catchment Sensitive Farming Delivery Initiative. Forty catchments across England have been identified as priority areas for action and farmers will be assisted in ways of improving farm practices so as to reduce water pollution from agriculture.

The EU's Integrated Pollution Prevention and Control Directive (IPPC)[53] (enacted in the UK as the UK Pollution Prevention and Control (PPC) Act 1999) regulates and is intended to reduce emissions from polluting activities. These include intensive pig and poultry farms – the regulations affect aspects of a variety of farm activities including raw materials use, waste, slurry and manure management, livestock housing, energy and accident management.[54]

In 2006 EU published proposals for establishing a Soil Framework Directive.[55] This would require Member States to take measures to protect and improve their soil. These include assessing the impact of policies on soil quality and degradation, taking precautionary measures to protect soil functions, to limit soil sealing and to prevent soil contamination, and developing strategies to identify and manage soil erosion, compaction and the loss of organic matter.

As regards waste, the UK's Waste Management Regulations (2006), also known as the Agricultural Waste Regulations, provide farmers with a range of options for dealing with their farm waste. Linked to this are the Animal By-products regulations which lay down specific requirements for the treatment of those livestock products that do not enter the human food chain (see Section 5.3).

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[50] Clothier L (2006). *Analysis of recent data on dairy cows in England and implications for the environment,* Defra Agricultural Change and Environment Observatory Research Report No. 03 http://www.defra.gov.uk/farm/policy/observatory/research/pdf/observatory03.pdf

[51] http://www.defra.gov.uk/farm/policy/observatory/research/pdf/observatory03.pdf

[52] *Guidelines for Farmers In NVZs* - England, Defra, 2002

[53] Integrated Pollution Prevention and Control Directive (Council Directive 96/61/EC)

[54] *IPPC Technical Guidance Note Integrated Pollution Prevention and Control (IPPC): Intensive Farming. How to comply. Guidance for intensive pig and poultry farmers* Environment Agency, April 2006

[55] Proposal for a Directive of the European Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC, European Commission, Brussels, 22.9.2006 COM(2006) 232 final http://ec.europa.eu/environment/soil/pdf/com_2006_0232_en.pdf

Concerning animal health and welfare, in 2006, Government passed the Animal Welfare Act. This places a duty of care on those dealing with animals actively to look after an animal's welfare in addition to ensuring that it does not suffer.

Other legislation affecting farmers to a greater or lesser degree includes the Bathing Water Directive (enacted in UK law in 2003), the 1979 Shell Fisheries Directive and various agreements on air quality including the UNECE Convention on Long-range Transboundary Air Pollution and – of course – the Kyoto Protocol, binding the UK to achieving a 12.5% reduction on 1990 emissions by 2012.

At a more specific level are Defra proposals for cost sharing animal disease with industry,[56] and the end (for cattle) of the Over Thirty Month Scheme[57] and its replacement with the Older Cattle Disposal Scheme (OCDS)[58]

It is important to note, however, that environmentally relevant trends in agriculture are driven at least as much by market, socio-economic and technological factors as by the policy framework.[59] The growing consumer preference for production methods that are organic, or that meet higher animal welfare standards, or that produce meat meeting particular quality standards, will also have an effect on future production.

Crucially, so will economics. Dairy farmers in particular tend to receive very low returns for their efforts. According to a 2007 survey undertaken by the Milk Development Council, 16% of dairy farmers are planning to leave the sector during the next two years; a move which could cause a 7% drop in milk production.[60] In April 2007, Tesco announced that it would be offering direct contracts to 850 dairy farmers, paying them nearly 40% above the average market price (22 pence/litre instead of 16 pence/litre). Since Tesco takes about 27% of the total UK liquid milk market,[61] this action is likely to have a considerable, and beneficial impact, particularly if other retailers decide to adopt similar plans themselves. However the situation is currently very fragile indeed and what happens over the next few years is critical. Outbreaks of disease such as Bovine Tuberculosis, Foot and Mouth and Bluetongue have also had a major impact on the economic viability, and morale, of the sector.

Finally, one emerging development that could affect the livestock sector very considerably is the global rush to grow biofuels, aided in part by measures such as the EU biofuels Directive[62] and a range of subsidies.[63] Increasing biofuels production

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[56] The *Responsibility and cost sharing for animal health and welfare proposal* would aim to place responsibilities both on government and industry to share the cost of managing animal disease, the intention being that the overall risks and costs are reduced. http://www.defra.gov.uk/animalh/ahws/sharing/index.htm

[57] This rule was put in place to prevent meat from cattle aged over thirty months from entering the food supply. BSE was mostly found in cattle over thirty months old.

[58] an exceptional market support measure providing for disposal of and compensation for cattle born before 1 August 1996.

[59] International Institute for Environmental Policy (2002). *Environmental integration and the CAP. A report to the European Commission*, DG. Agriculture; Brussels

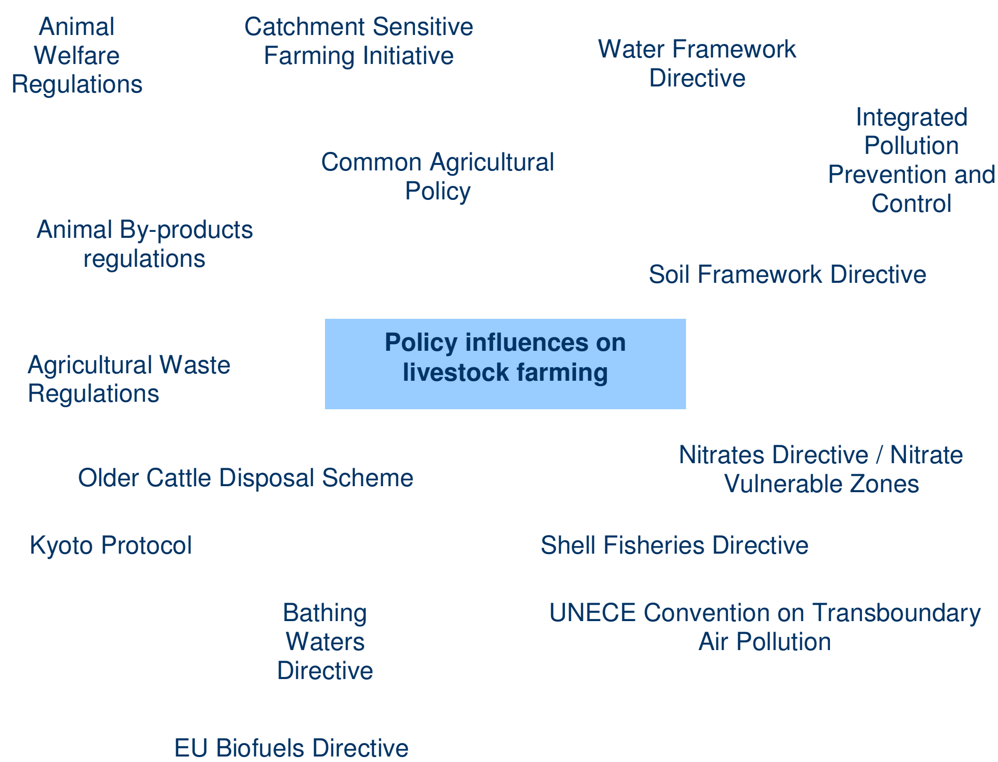
[60] Farmers Intentions Survey, Milk Development Council, April 2007

[61] *Tesco announcement in line with innovation, relationships and efficiency focus*, says MDC, Milk Development Council News release, 4 April 2007

[62] Directive 2003/30/EC of the European Parliament and of the Council
Of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport, Official Journal of the European Union, http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_123/l_12320030517en00420046.pdf

may push up the cost of agricultural inputs and affect livestock production negatively in other ways too, although some synergies may emerge too.[64] [65]

Figure 17: Policy influences on livestock farming



1.6 The future impact of climate change

Climate change may also affect the relative profitability and suitability of farm systems, both livestock and arable, and as such this is an area which is receiving increasing attention. [66] [67] [68] [69] [70]

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[63] Doornbosch R and Steeblik R (2007). *Biofuels: Is the cure worse than the disease? Paper prepared by the Roundtable on Sustainable Development for the OECD*, September 2007, Paris

[64] Doornbosch R and Steeblik R (2007). *Biofuels: Is the cure worse than the disease? Paper prepared by the Roundtable on Sustainable Development for the OECD*, September 2007, Paris

[65] OECD-FAO *Agricultural Outlook 2007-2016*, OECD/FAO, 2007

[66] *Agriculture and Climate Change*, National Farmers Union, November 2005

[67] *Impacts, Adaptation and Vulnerability*, Fourth Assessment Report, Intergovernmental Panel on Climate Change, 2007 *Impacts, Adaptation and Vulnerability*, Fourth Assessment Report, Intergovernmental Panel on Climate Change, 2007

[68] Warren R, Arnell N, Nicholls R, Levy P and Price J (2006). *Understanding the regional impacts of climate change: Tyndall Centre for Climate Change* Research Report Prepared for the Stern Review on the Economics of Climate Change

In 2006 Defra awarded funding to the Farming Futures project. This is a collaboration between the National Farmers Union, the Country Land and Business Association, the Applied Research Forum (representing all the agricultural levy boards) and the NGO Forum for the Future, the aim being to raise farmers' awareness of the impacts of climate change on their businesses and to provide them with practical advice (through fact sheets, case studies and so forth) on how they can prepare for and manage these impacts as well as reduce their own contribution to climate changing emissions. At present it is still too early to know what, if any, the impacts of the project have been. However, according to a survey commissioned by Farming Futures, more than half of all 385 farmers surveyed believe they have already been affected by climate change, 70% believe that climate change will be beneficial to their business, and around half feel that they can have an effect on limiting climate change.[71]

As regards the likely impacts on agriculture, estimates suggest that on current trends, temperatures in the UK may increase by between 1ºC and 5ºC,[72] depending on the region and the scenario used.[73] Summer warming will be greater in the South East than the North West. Under a high emissions scenario, summer rainfall may decrease by 50% in the 2080s while precipitation could increase by 30% in the winter. Demand for irrigation in the UK is projected to grow by around 20% by the 2020s and around 30% by the 2050s.[74]

Up until 2050, the impact of climate change on UK agriculture as a whole may be favourable. At temperature increases of up to 1-3°C (depending on the crop), productivity is likely to increase,[75] beyond that point it falls. The growing season will lengthen and there will be a decline in the number of frosty days. While this will reduce the incidence of frost damage it might also help spread the incidence and prevalence of certain pest and disease outbreaks since they will no longer be killed off by frosty spells. More frequent flooding and heavier rainfall in the winter is likely

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69 See presentations given at climate change and irrigation conference *Climate Changing UK Irrigation in a Global Market* Seminar, UK Irrigation Association, 01 March 2007

70 See also presentations given at *The UK Agricultural and Rural Economy: Impacts of Climate Change,* conference jointly organised by the UK Climate Impacts Programme (UKCIP), the National Farmers' Union (NFU), and the Country Land and Business Association (CLA), Ashdown House, London, 28 September 2006 http://www.ukcip.org.uk/resources/presentations/downloads.asp?ID=51

71 *Project AE134: Communicating climate change to farmers: Detailed survey findings – December 2006, and June 2007*, Research commissioned by Farming Futures and undertaken by Associa

72 Hulme M., Jenkins, G.J., Lu X., Turnpenny J.R., Mitchell T.D., Jones R.G., Lowe J., Murphy J.M., Hassell D., Boorman P., McDonald R. and Hill S. (2002) *Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report*, Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK. 120pp

73 The UKCIP emissions scenarios closely follow those adopted by the IPPC – see Nakicenovic N and Swart R (Eds). *Emissions Scenarios: Special Report of the Intergovernmental Panel on Climate Change*, IPCC, 2000

74 *Climate Change and its Potential Impacts*, presentation given by Roger Street, UK Climate Impacts Programme, at *Climate Changing UK Irrigation in a Global Market* Seminar, UK Irrigation Association, 01 March 2007

75 *Impacts, Adaptation and Vulnerability*, Fourth Assessment Report, Intergovernmental Panel on Climate Change, 2007

to exacerbate current problems of soil leaching and chemical contamination of waterways.[76]

Clearly climate induced changes on arable farming will in turn affect livestock because much of their feed is arable dependent. Over time, moreover, areas currently unsuitable for cereal production may become suitable and may be used for food, for animal feed or for biofuels; this, we speculate, could in turn affect the spread of livestock production and even incentivise a shift away from livestock farming in favour of arable production. As regards livestock health, increases in summer temperature may, for example, increase the incidence of heat stress and might also change current patterns and types of livestock diseases.

[76] *Impacts, Adaptation and Vulnerability*, Fourth Assessment Report, Intergovernmental Panel on Climate Change, 2007

SECTION 2: WHAT ANIMALS EAT AND HOW THEY ARE REARED

This section looks at how animals are fed and raised in the UK. It begins by looking at the various types of feed given to livestock and the differences between livestock types. It then takes a look at cattle feeding and rearing systems, distinguishing between beef and dairy herds. Pig and poultry systems are then described in somewhat less detail, largely because they tend to be more simple. Sheep rearing is not discussed, largely because they are fed very little by way of supplements (except around lambing time) and simply graze on pasture.

2.1 Feed inputs: All livestock

The ruminant diet consists consist of fresh grass and silage together with prepared animal feed, although some indoor beef rearing systems are almost entirely cereal and maize silage based. Pigs and poultry on the whole consume prepared feed containing a high proportion of cereals.

Over 20 million tonnes of prepared feed is purchased annually in the UK.[77] This feed tends to be classified by Defra into three categories. The first type, known as compounds or blends, comprises a mixture of cereals (mainly barley and wheat), proteins (including soy, maize or rape oilseed cake) and 'miscellaneous' feedstuffs such as molasses cake and citrus pulp. Cereal by-products including wheat gluten, rice husks and so forth are also added to the mix. Compound feed accounts for around half of all animal feed consumed and it usually takes a pelletised or (in the case of some pigs) a liquid form.

Falling into the second category are the individual or 'straight' raw materials themselves. These can either be concentrates of high energy value (cereals, cereal offals, proteins and other high energy feeds) or else non-concentrates of low energy value, such as hay.

Finally, the third category covers on-farm production of supplementary fodder crops such as peas or beans; these are either consumed directly by the animals on-farm or sold to neighbouring farms. This last is termed 'inter/intra farm transfer'.

Table 1 gives a breakdown of the main ingredients in compound feed. As an average, wheat and barley together make up about 37% of the total by weight, while oilseed cake accounts for a further 24.5%. However this general picture does not accurately capture the huge variability of different compound formulations, which will, vary widely by manufacturer and by time of year. Such compounds tend to be produced to a 'least cost formulation,' meaning that manufacturers make use of the cheapest inputs at the time to produce a feed that meets certain defined nutritional criteria.

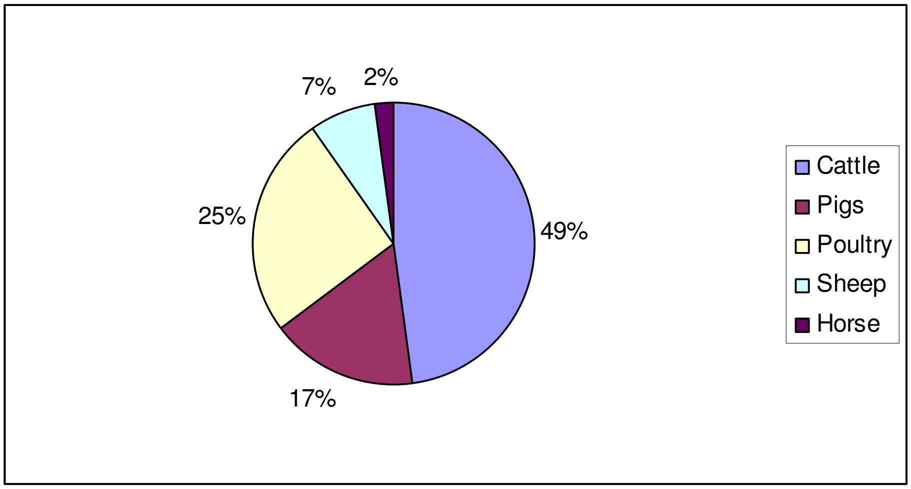
[77] *Agriculture in the United Kingdom*, Table 5.2 – 2004 figures used http://statistics.defra.gov.uk/esg/publications/auk/2005/Chapter5.pdf

Table 1: Raw materials usage of compounded animal feed, 2005

Raw material	000 Tonnes	% contribution
Wheat	2844.20	31.45
Barley	521.39	5.77
Oats	32.05	0.35
Whole and flaked maize	83.33	0.92
Rice bran extractions	26.69	0.30
Maize gluten feed	304.40	3.37
Wheat feed	823.81	9.11
Other cereals by-products	173.78	1.92
Distillery by-products	243.31	2.69
Whole oilseeds	48.95	0.54
Oilseed rape cake and meal	615.57	6.81
Soya cake and meal	887.67	9.82
Sunflower cake and meal	265.56	2.94
Other oilseed cake and meal (2)	399.36	4.42
Field Beans	83.10	0.92
Field Peas	35.45	0.39
Dried Sugar Beet Pulp	209.02	2.31
Molasses	275.90	3.05
Citrus and other fruit pulp	79.66	0.88
Poultry meal and Other meal (3)	7.41	0.08
Fish meal	122.08	1.35
Minerals	401.03	4.43
Oil and fat	183.01	2.02
Protein concentrates (5)	21.39	0.24
Other materials (6)	223.78	2.47
Confectionery by-products	131.88	1.46

Source: Raw *materials usage in production of animal feeding stuffs in Great Britain*, Defra 2005 http://statistics.defra.gov.uk/esg/datasets/hstcomps.xls

Figure 18: Share of total compound feed produced, by livestock type



Source: *Production of compounds, blends and other processed feeding stuffs in Great Britain*, Feb 2007 (note that these are figures for GB and not UK so Northern Ireland is excluded)

The make up of compound feed will also vary according to the animal. It has unfortunately proved impossible to find a breakdown of different feed ingredients by animal type as this tends to be commercially sensitive information. Indeed many authors have highlighted the problems of securing accurate data or of publishing information on feed formulation.[78] [79]

According to Defra[80] and other sources[81] [82], however, the cereal incorporation rate for pig and poultry feed is around 60%. For cattle we calculate that cereals constitute a much lower 22% of compound feed.[83]

In addition to compound feed, the remaining 10 million tonnes of feed given to animals is made up of straight concentrates (cereals or proteins), non-concentrates and on-farm forage crops. Cattle consume by far the largest share of non-compounded cereals. Of the 3 million tonnes of wheat and barley fed as 'straights' to livestock, 2 million went to cattle.[84] They also consume by far the largest share of straight protein concentrates.[85]

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[78] Casey J W, Holden N M (2006). Quantification of GHG emissions from suckler-beef production in Ireland, *Agricultural Systems* 90 79–98

[79] Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on www.silsoe.cranfield.ac.uk, and www.defra.gov.uk

[80] GB Animal Feed Statistical Notice, Defra April 2007 http://statistics.defra.gov.uk/esg/statnot/mcompspn.pdf accessed 9 June 2007

[81] *Pigs UK*, Biffaward, 2006

[82] *Poultry UK*, Biffaward 2006

[83] The average cereal incorporation rate for feed as a whole is 37%. For pigs and poultry it is 60% so the figure was calculated on the basis of the grain available for the cattle's overall compound feed intake after pig and poultry feed in total and pig and poultry cereals were deducted.

[84] *Grain fed to livestock 2002/2003 England and Wales*, Defra, Table 2 http://statistics.defra.gov.uk/esg/statnot/gflsur.pdf

[85] *GB Animal Feed Statistical Not*ice, Defra April 2007 http://statistics.defra.gov.uk/esg/statnot/mcompspn.pdf accessed 9 June 2007

2.2 Beef and dairy systems

The beef and dairy industries are highly specialised. Different business enterprises specialise in different elements of the rearing cycle, from breeding, to weaning to finishing.

In very basic terms, cattle are kept in the UK for two purposes – for milk and for meat.[86] Over the years animal breeding has led to the development of cattle which are better for one or the other purpose. So, breeds suitable for eating tend to have good muscle quality while those for milk tend naturally to yield either high quantities or a high quality of milk, over a long and consistent lactation.

The most common dairy breed is the familiar black and white Holstein-Friesian which can yield between 5,000 and 10,000 litres of milk a year depending on the feed and management she receives. On average, dairy cows calve once every 385 days,[87] and give birth to either a pure dairy or a 'beef cross'[88] calf. In the latter case the father will be chosen from a beef breed.

Dairy herds need to be restocked at the rate of roughly 20% a year to replace cows that no longer produce milk (as a result of old age, ill health, or poor yield).[89] In order to achieve this 20% replacement rate, roughly half the best yielding dairy cows are impregnated with the semen from a dairy bull, although the proportion varies by system and year. Dairy cows that have reached the end of their productive lives are slaughtered and enter the meat chain. However their bodies yield very little meat as they have been bred in such a way that all their energy is directed into milk production.

The remaining milk cows are crossed with beef bulls, such as Charolais, Hereford and Aberdeen Angus breeds and their offspring reared for human consumption. In addition to these cross-breeds the pure dairy bred bull calves, born as a by-product of dairy heifer breeding, are also generally fattened as beef bulls or steers (neutered males).

Suckler beef on the other hand is obtained from cattle bred specifically for their meat-yielding properties. These properties include the quality and quantity of muscle they put on (conformation) and the efficiency and rapidity with which they grow. A suckler calf is the offspring of a pure bred male (sire) and either a pure bred beef female (dam) or a beef-dairy cross. In other words they are of between 75-100% pure beef pedigree. The calf is fed on mother's milk until it is weaned at about 6 months. It can grow rapidly (up to 1.5 kg/day), and produces a high quality carcass. The weaned

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[86] The following paragraphs are based on information provided by Robert Newbery, NFU, pers. comm., July 2005

[87] Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on www.silsoe.cranfield.ac.uk, and www.defra.gov.uk

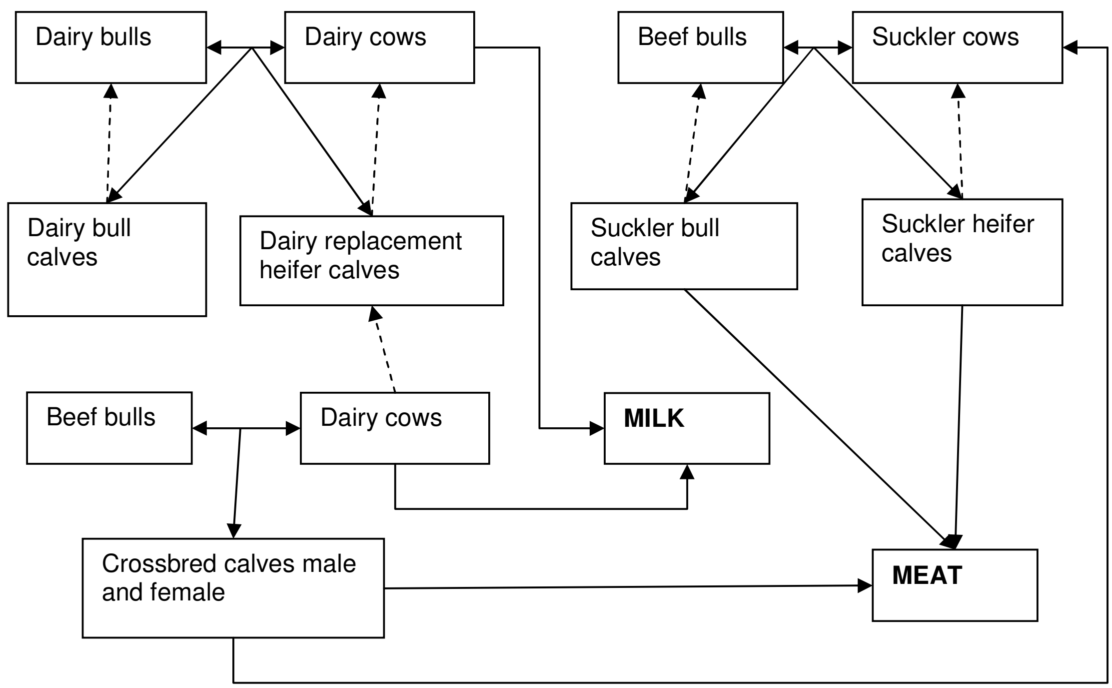
[88] Beef cross – in this instance a beef breed crossed with a dairy breed cow, i.e. Holstein Friesian X Hereford

[89] In Casey JW and Holden NM (2005). The Relationship between Greenhouse Gas Emissions and the Intensity of Milk Production in Ireland, *Journal of Environmental Quality*, 34:429–436 the replacement rate is taken to be 16%. In Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on www.silsoe.cranfield.ac.uk, and www.defra.gov.uk a range between 16% and 30% is given.

calf is referred to as a store animal[90] and is either finished by the breeder or is sold on to another farm

Some of the male beef cattle are castrated, partly to avoid unwanted breeding where cattle are raised in mixed sex groups and partly because steers are less aggressive, easier to manage and can be reared outside with less difficulty – bulls charging around the countryside tend to be fairly unwelcome. On the downside steers have a slower growth rate than their uncastrated counterparts. Bulls are generally kept inside and slaughtered by the age of 12-15 months whereas steers and heifers take around 18-24 months to reach slaughter weight. Figure 19 gives a schematic and highly simplified illustration of how the beef and dairy systems interact.

Figure 19: Interactions among the beef and dairy herds



Note that very few males are kept for breeding purposes; only those with the most suitable genetic qualities are reared and as such the gene pool of the UK herd is fairly small. The remainder are slaughtered, sometimes at birth.

Cows are usually inseminated artificially, and 'embryo transfer' – when an embryo from one cow is transferred into the uterus of another – is also practiced. One technological development is the ability to sex semen. While still at the early stages, in theory a dairy producer could impregnate the requisite number of cows with female sperm as milk replacers. The rest would be impregnated with male sperm and the resulting calves would be sold on to the beef sector. This would deal with the problem of unwanted male calves.

[90] This refers to its readiness to start its phase of rapid growth post-puberty

The type of diet fed to ruminants in the UK varies widely depending, among other things, on the type of system (intensive versus extensive, organic versus conventional) the farmer adopts. What they eat will also vary according to the time of year (including the time of calving) and the life stage of the animal. The diet of dairy cattle will be different from that of premium beef cattle whose diets will in turn differ from beef cattle reared for the non-premium market. Individual farmers will also have different preferences and practices. In short, there are many possible variants.

Notwithstanding this diversity, cattle in all systems will consume, to a lesser or greater extent, and in varying proportions, some or all of the following food types:

a. fresh forage/grass;
b. conserved forage, and
c. prepared feeds (compounds and concentrates as described above).

Animal feed is usually discussed in terms of its dry matter content – in other words its substance once the water content is discounted. Grass, for example, will have a lower dry matter content per kg than oilseed cake.

2.2.a Feeding the dairy herd[91]

Approximately 20-30% of a dairy cow's energy and protein requirements are for basic maintenance, with the remainder used to fuel milk production.[92]

A dairy cow will consume an average of about 20-22 kg dry matter a day, although in some high-yielding systems she can eat up to 28 kg. While grass is the best way, economically speaking, of feeding an animal it cannot provide the most concentrated nutrition, hence the use of other bought-in feed. In particular, a high yielding dairy cow cannot satisfy her metabolic requirements from a forage-based diet alone and as the proportion of high-genetic merit cows (cows with high milk yield potential) has increased (as cow numbers have fallen) so has the reliance on dietary supplementation. The farmer will strike a balance between economic efficiency and milk output; decisions have to be made based on the price of different feedstuffs relative to one another and to the income gained from the milk output.

One estimate suggests[93] that one slightly above-average yielding cow, producing around 7,500 litres of milk a year and consuming around 20 kg dry matter a day will consume around 7.3 tonnes dry matter a year. Of this, about a sixth will come from concentrates and compound feed, as discussed above. The remaining 6 tonnes will consist of silage (from maize or grass) and fresh forage. A third or so will be in fresh form and the remainder will be preserved as silage. Nix (2005)[94] gives higher figures at around 0.25-0.35 kg of concentrates per litre of milk per day.

Other sources estimate that,[95] for dairy cows, between March and September about 50% of their diets (dry weight matter) consists of fresh forage and the remainder of prepared feeds. In the winter, 50% of their feed is silage and 50% concentrates.

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[91] Much of this information was supplied by Bruce Woodacre, international dairy consultant, pers. comm. June 2005
[92] Defra, *pers. comm.* August 2007
[93] Bruce Woodacre, international dairy consultant, pers. comm. June 2005
[94] Nix J (2005). *Farm Management Pocketbook*, Imperial College London, 35th Edition
[95] Les Crompton and Jonathan Mills, Animal Science Research Group, Department of Agriculture, University of Reading, pers. comm., May 2005

Expressed in terms of energy, the grass/silage element makes up roughly 40-45% of the diet; in terms of energy protein the grass: concentrates ratio would be 30:70.

A 1994 paper by Hopkins[96] estimated that, averaged over all the feeding systems, around 75% of the diet of ruminants is supplied by forage (including silage). A later paper by the same author, however, (2003)[97] gives a lower figure of 60%. The reason for this discrepancy[98] is that the use of compound feed for ruminants increased over this time, and continues to increase.
Clearly the variation in estimates reflects the range of different systems and different farmer preferences.

Variations in the UK's weather will also, clearly, affect what is fed.[99] Grass grows rapidly in the spring, and the productivity slows in the summer months. Productivity increases once again in the autumn before slowing down very considerably in the winter. To ensure year round supplies of forage, grass or maize is conserved in the late spring (at the peak time of productivity). Hay is made in the drier early summer months, and some silage making may also follow in mid or late summer. Hence the choice of feeding grass, silage or concentrates is very much influenced by the time of year.

Williams notes[100] that before forage conservation was made more reliable (by ensiling, rather than hay making), most milk was based on spring calving and summer grass, with relatively small amounts of concentrates in winter. Spare milk produced over the summer was used to make butter, cheese, milk powder and so forth. However today, since summer production is dependent on the vagaries of the weather, autumn calving has grown in popularity. The feeding regime is more predictable with measurable and monitorable quantities of silage and concentrates given.

Calves born from dairy cows will be fed on formula milk and concentrates from birth. The type of diet they consume after the weaning/rearing phase will depend upon whether they being raised as milkers or for meat (see Figure 19 above).

2.2.b Feeding the beef herd [101]

As described above, a beef animal may be either the offspring of dairy cows or of a dedicated beef sire and possibly a beef dam. One study[102] estimates that 35% of beef calves originate from beef suckler herds. Most of these (over 60%) will be reared in the uplands on grass. Of the 40% of suckler beef reared in the lowlands, 40% are finished intensively on cereals and silage.

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[96] Hopkins A. & Hopkins J.J. (1994) UK grasslands now: agricultural production and nature conservation. In: Haggar R.J. & Peel S. (eds) *Grassland Management and Nature Conservation. British Grassland Society Occasional Symposium No. 28, pp 10-19*

[97] Wilkins R.J., Hopkins A. and Hatch D.J. (2003) Grassland in Europe. *Journal of Grassland Science* (Japan) 49, 258-266

[98] Alan Hopkins IGER, pers. comm., 27th May 2005

[99] Adrian Williams, Cranfield University, pers. comm., July 2007

[100] Adrian Williams, Cranfield University, pers. comm., July 2007

[101] Much of this information was supplied by Bruce Woodacre, international dairy consultant, pers. comm. June 2005

[102] Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on www.silsoe.cranfield.ac.uk, and www.defra.gov.uk

In these suckler herds, the spring dams (females calving in the spring) eat grass silage in the winter and grass in the summer. Little by way of concentrates is given. However in suckler winter calving herds, the dams will consume around 10% of their ration (in terms of dry matter) as concentrates, either in straight or compounded form.

The calves produced from either herd eat grass or silage as well as their mother's milk for the first six months of their life, although a proportion may also be fed concentrates in the fifth and sixth months.

The calves will then be sold. Some will go to 'store' producers where they will be kept on silage and grass for 3-9 months before being sold on to finishers. Others will be sold directly to finishers who prepare the animals for slaughter. Some of these finishers will be intensive and the animals will be fed for 4-8 months on compounds and/or mixtures of straights, plus a little straw. Other finishers will be semi-intensive; a larger proportion of their diet will be silage, although compounds will still be fed.

As noted, pure dairy-bred calves also enter the meat chain; indeed, these calves account for 65% of all meat output. They will be reared for the first 12 weeks of their life on formula milk and concentrates. Some will then go onto store producers, as above. Others will go directly to semi-intensive finishers and will be fed grass during the summer, and silage and concentrates during the winter.[103] Others will go to intensive finishers where they will consume a mixture of oilseed cake, straights and straw. 45% of dairy calves are ready for slaughter by 20 months, 25% within 2 years and only 15% will be reared for a longer period than this.[104]

2.2.c How ruminants digest food

The beauty of ruminants (as it were) is that they can utilise what other, monogastric animals cannot: fibrous foods with low energy value.

The stomachs of ruminants contain four divisions, the rumen, reticulum, omasum and the abomasum. When food is swallowed it first enters the rumen. Here it is retained while it is anaerobically fermented by the rumen's large and diverse microbial population. These microbial organisms break down the compounds in food to produce volatile fatty acids, carbon dioxide, methane, cell material, heat and ammonia. Volatile fatty acids and various other substances are absorbed through the rumen wall into the blood stream and transported to body tissues, including the udder, where they are used as sources of energy for maintenance, growth, reproduction, and milk production. The cow derives 60 to 70 % of its energy from the volatile fatty acids produced in the rumen.[105]

The ammonia (NH_3) which these microbial organisms produce from the breakdown of protein is used for their growth; rumen microbes convert the ammonia and organic acids into amino acids that are used to aid their growth. In other words, plant nitrogen is converted into microbial protein and consumed in this form by the cow. Non-protein nitrogen sources such as urea, ammonium salts, nitrates, and other

[103] Bruce Woodacre, international dairy consultant, pers. comm. June 2005
[104] Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on www.silsoe.cranfield.ac.uk, and www.defra.gov.uk
[105] Seymour WM, Campbell DR and Johnson ZB. (2005). Relationships between rumen volatile fatty acid concentrations and milk production in dairy cows: a literature study, *Animal Feed Science and Technology*, Volume 119, Issues 1-2, Pages 155-169

compounds added to the diet may also input ammonia in the diet. Excess ammonia is mostly absorbed from the rumen into the blood stream, but small amounts may pass into the lower digestive tract and be excreted in urine as urea.

For microbial organisms to utilise the ammonia they also, like us, need carbohydrate as a fuel source. Hence achieving the right balance of nitrogen-containing and starch-containing food in the ruminant diet is very important.

The digesting food, together with dead microbial organisms, then moves from the rumen into the second stomach, the reticulum. Here it is broken down into lumps, or cuds before moving into the omasum, the third stomach, where the food is broken down even more. Some of the nutrients are absorbed into the blood stream. Finally the food passes into the fourth stomach, the abomasum, where the food is broken down by digestive fluids and from where it finally enters the intestine. The abomasum performs similar functions to the stomach found in pigs and humans and is sometimes called the ‘true stomach’.

As regards feed, for ruminants the balance between starch- and protein- containing foods determines both the animal’s growth and the emissions it produces.

Nitrogen is the basic building block of DNA and proteins. It is essential to life. Thanks to their unique digestive system and the microbial organisms living in the rumen, cattle (and other ruminants) are able to capture and use nitrogen-containing protein in two ways.

Protein is available to cattle both as rumen degradable protein (RDP) and as rumen undegradeable protein (RUP). Degradable protein is the kind that can be broken down by the microbial organisms in the rumen. The more the protein is broken down and used (in combination with starch) in the microbial metabolic process, the more microbial organisms are produced. These organisms represent a high quality source of protein and when they die they are digested. In this way, microbial organisms are important both as a means by which ruminants can digest protein sources that would not otherwise be available and also as a protein source in their own right.

Rumen undegradeable protein (RUP), also known as bypass protein, is the other form of protein consumed by cattle. This form of protein cannot be broken down by the microbial organisms and as such does not aid microbial growth. Instead the RUP passes straight through the rumen into the abomasum where it is absorbed by the body much as our human bodies absorb protein. For dairy cows and calves in very intensive systems where high milk yields are of paramount importance, rumen undegradeable protein is particularly important since it provides an essential supplement to microbial protein. A dairy cow’s protein requirements are about 18% of total energy needs although beef cattle will need less and lactating cows will need more, particularly at some points in the lactation.

Since microbial organisms provide such an important source of protein, the aim of most industrialised feeding systems is to maximise microbial growth within the rumen while also providing good sources of rumen undegradeable protein.[106] In order to do so it is important that the ruminant diet contains good sources of starches and sugars so that the microbial organisms can metabolise.

[106] Before the BSE outbreak a major source of RUP was of animal origin – meat and bone meal. With this option no longer available soy is more widely used.

This has a bearing on the emission of gases. If there is not enough fermentable carbohydrate available in the rumen to balance the free ammonia generated by the degradation of protein, then rumen ammonia levels increase. This is because these carbohydrates are necessary for the microbial organisms' growth and reproduction; where carbohydrates are lacking then microbial growth is impeded and there will not enough microbial organisms to 'breathe in' the ammonia. The excess ammonia is instead absorbed through the wall of the rumen and travels to the liver, where it is metabolized to urea. This nitrogen containing urea, on leaving the animals, may in time form ammonia and nitrous oxide.

On the other hand, too much fermentable carbohydrate in the presence of too much protein can also lead to unwanted emissions. The more the microbial organisms grow, the more dead microbial organisms are produced. If too much (relative to the animal's requirements) is produced, the microbial organisms pass out of the body in the form of urea. The right balance is therefore required.

Methane is another major product of the digestive process. It is mainly emitted by eructation (burps) or as part of the respiration process. Enteric fermentation accounts for about 80% of methane emissions from ruminant livestock, with the remainder attributable to manure.[107]

Ultimately the cow, digestively speaking, is a very inefficient animal. Around 70-80% – often more – of the nitrogen entering the ruminant system is lost as waste.[108] Any excess feeding of proteins will lead to waste over and above this figure. There will, therefore, always be waste but the amount of nitrogen wasted will increase in proportion with the excess of nitrogen ingested and not required. On the other hand the more concentrate that is fed to the animal the greater the milk yield – up to a point. The challenge lies in feeding sufficient protein to achieve higher yields without on the other hand leading to greater nitrogen losses.

2.3 Poultry and egg systems

2.3.a Broilers

Compared with cattle, poultry systems are rather more straightforward. Most of the chickens we eat in the UK are raised in intensive systems in large purpose-built houses, on deep litter of chopped straw or wood shavings. Chickens are kept for about 40 days, until they reach a weight of around 2.2 kg. Turkeys are slaughtered at around 20 weeks when they weigh 13 kg.[109]

The mainstream broiler industry is highly integrated and concentrated. The processor companies often own or control all stages of production, from the supply of day-old chicks (they also usually own at least some of the breeder capacity and hatchery facilities) through feedstuff manufacture and supply to delivery of the poultry meat to the retailer. 60% of broiler chickens today are grown on farms owned directly by processors; the rest are grown by independent farmers, almost all of whom are contracted to a processor.

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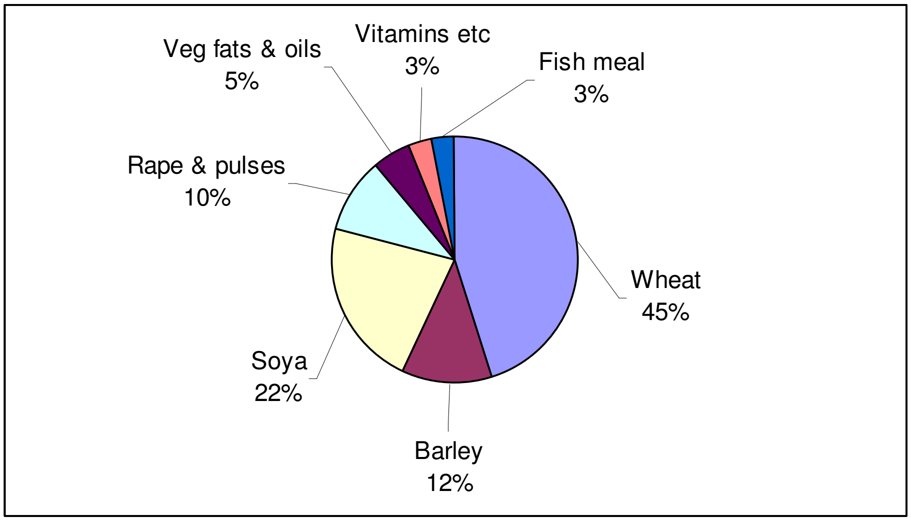
[107] Monteney G-J, Bannink A and Chadwick D. (2006) Greenhouse gas abatement strategies for animal husbandry, *Agriculture, Ecosystems and Environment* 112 163–170
[108] Rotz C A. (2004). Management to reduce nitrogen losses in animal production *Journal of Animal Science*. 2004. 82:E119-E137, American Society of Animal Science
[109] *Poultry UK*, Biffaward, 2006

In addition, feed is normally supplied from the processor's own mill. While independent poultry rearers contracted to processors may have some freedom in choosing their supplier, this freedom is limited by the fact that, apart from wholly owned mills belonging to processors, there are only two major companies left manufacturing poultry rations in the UK. There are also a number of smaller local mills also manufacture small volumes of feed for independent and niche market growers. Other than size, the major difference between the largest businesses in the sector and all of the others is the integrated nature of the operations.[110]

Of the raw material input to the chicken feed milling sector, about 89% consists of cereals, soy, oilseeds and pulses as Figure 20 shows.

Figure 20: Ingredients in poultry feed



Source: *Poultry UK*, Biffaward, 2006

2.3.b Egg layers

As with broiler systems, egg production is a highly concentrated industry. 90% of eggs produced in the UK come from 28 companies.[111]

Two thirds of the eggs produced in the UK come from caged systems. In already standing conventional caged systems, a minimum of 550 cm² per bird is required. However systems built since 2003 must allow 750 cm² per bird and the cages be 'enriched,' as it is called, with a nest, perching space and a scratching area. Food is supplied in troughs fitted to the cage fronts and an automatic water supply is provided. The units are kept at an even temperature and are well ventilated. Electric lighting provides an optimum day length throughout the year.

Barn systems produce around 7% of eggs sold in the UK. Here the hen house has a series of perches and feeders at different levels and the stocking density must be no greater than 9 hens per square metre of useable floor space. Perches for the birds must be installed to allow 15 centimetres of perch per hen. Similar to the barn system is deep litter production where the entire floor area should be solid with a litter of straw, wood shavings, sand or turf. The existing maximum permissible stocking

[110] *Poultry UK*, Biffaward, 2006
[111] *FAWC Report on Stockmanship and Farm Animal Welfare*, Farm Animal Welfare Council, London, June 2007 http://www.fawc.org.uk/pdf/stockmanship-report0607.pdf

density for the deep litter system is lower, at 7 birds per m^2 although no perches need be provided.

The free range system is the third alternative; this produces around 27% of eggs produced in the UK. Under the Welfare of Laying Hens Directive, free range hens must have continuous daytime access to runs which are mainly covered with vegetation and with a maximum stocking density of 2,500 birds per hectare. The hen house conditions for free range hens must comply with the regulations for birds kept in barn systems, or deep litter stocked at 7 birds per square metre when no perches are provided.

Hens producing organic eggs are always free range. In addition, hens must be fed an organically produced diet and ranged on organic land.

2.4 Pig systems

In contrast with poultry production, pig farming is a far less integrated industry. Only about 5% of breeding pigs and 28% of rearing and finishing pigs are grown on farms under the direct control of processors; the majority are reared on independent farms. Many of these are, however, contracted to a processor, some directly but the majority through producer groups.

2.4.a What pigs eat

Pigs consume both prepared compound feed and by-products from other parts of the agricultural and food industries. It is actually not possible to give a figure for the total amount of feed nor of by-products used in the pig industry since the data are not available.

Pig compound feed is largely made up of cereals (60%) and oilseeds and pulses (29%). The remaining 11% is comprised of oils, vitamins, minerals and amino acids. Co and by-products will vary according to availability and include biscuit fragments, whey, yoghurt tank washings and brewing by-products.

Approximately 30% of pig producers currently use liquid feeds as opposed to dry compound feed or home-mixed rations. Liquid feeding is not new to the industry, but UK producers have been slow to take advantage of it, mainly because of the high capital cost of conversion. Liquid feed is made of whey or potato starch with cereals, oilmeals and various vitamins added.

2.4.b Rearing pigs

There are three main stages in pig rearing. The first encompasses activities to do with breeding, gestation and farrowing. After the piglets are born they are kept with their mothers until they are 4 weeks old and weigh about 7 kg. The pigs are then weaned, at which point they move onto the second or nursery stage.

The second focuses on fattening the pigs up until they reach around 35 kg. After this they enter the final or 'finishing stage' where they continue to be reared until they are about 18-22 weeks old and weigh 80-110 kg. They are then slaughtered. Each stage in a pig's life requires a different diet. While some farms will undertake all stages in the pig rearing process, others may focus on just one or two of the stages.

2.4.c Housing systems

Pigs can be reared either in indoor or in outdoor systems. To complicate the matter, in some farms the two systems are combined. Outdoor production is growing in popularity, partly because outdoor systems are not regulated under IPPC (see Section 1) and it is estimated that up to 30% of the breeding herd is reared outdoors.[112]

Indoor pigs, still the majority of the British herd, are kept in one of three different types of housing.

Deep litter systems use absorbent bedding material (most commonly straw) to keep the stocked area clean and dry. It is common for two areas to be provided, a warm and comfortable lying area and a cold dunging area.

Scraped systems have discrete areas for lying and dunging, and a tractor-mounted or automatic scraper removes manure. A limited amount of bedding such as sand, shredded paper or wood shavings is used.

Slatted systems use no bedding. The floor is slatted so that dung and urine can fall through either into a slurry channel. Slats may cover either the whole area, or a part of it. Under the 2001 EU directive 2001/93/EC, '*pigs must have permanent access to a sufficient quantity of material to enable proper investigation and manipulation activities, such as straw, hay, wood, sawdust, mushroom compost, peat or a mixture of such*'. However, the UK Code of Practice effectively allows the use of other objects, such as footballs and chains, even though it says '*that long-term use of such items is not, therefore, recommended unless they are used in conjunction with materials such as those listed above, or are changed on a weekly basis'*.[113]

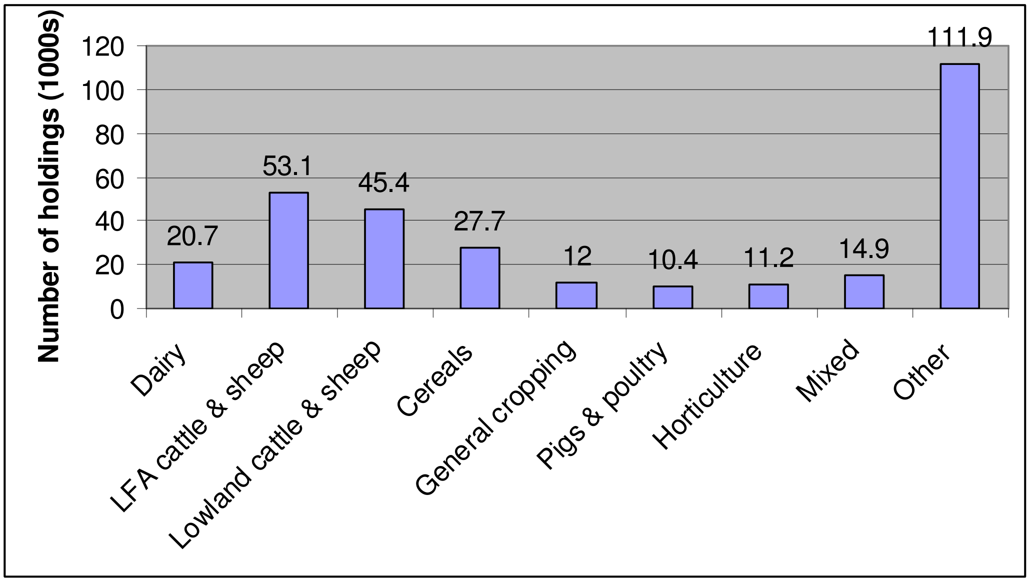
In addition, there are special housing arrangements for farrowing and lactating sows.

2.5 Farms and specialisation

Most farms in the UK specialise either in livestock or in arable production, as Figure 21 shows.

[112] *Pigs UK*, Biffaward 2006
[113] *Code of Recommendations for the Welfare of Livestock: Pigs*, Defra, 2003

Figure 21: Number of agricultural holdings in the UK 2004 by farm type



Source: *Agriculture in the UK*, Defra 2004 data
Note: the category 'other' includes a range of enterprises including specialist mushroom growers, horse breeders and hobby farmers.

There are only a few mixed farms in the UK – 14,900 in 2004 as compared with 108,900 livestock-only farms – nearly an order of magnitude less.[114] However, the picture is a little less clear-cut than these figures would suggest. According to the Defra classification system a 'mixed' farm is where more than a third but not more than two thirds of the economic value of the farm comes from cropping, and the same from livestock production. There will be many arable farms which keep a small herd of dairy cows or vice versa, but which are not classified as 'mixed' because the economic value of the minority farming type is less than a third of the total farm value.[115]

It would be interesting to see how far the make up of organic farms reflects the national situation. Are there a greater proportion of mixed farms or do farms also tend to be highly specialised? Unfortunately data for organic farms are not available.[116] The question is relevant to the discussion in Section 6.4 which explores the relative merits of organic versus conventional farming in terms of its greenhouse gas reduction potential.

[114] *Agriculture in the UK*, Defra 2004 data
[115] Defra statistics division, pers. comm., July 2007
[116] Defra statistics division, pers. comm., July 2007

SECTION 3: QUANTIFYING LIVESTOCK SECTOR GREENHOUSE GAS EMISSIONS – A LITERATURE REVIEW

This section reviews attempts that have been made to quantify greenhouse gas emissions from the livestock sector. We begin by looking at global estimates before examining studies focusing on the EU, UK and other country-level scales. We then look at the range of figures that have been calculated for animal-specific greenhouse gas impacts.

The gases we focus on are carbon dioxide, methane and nitrous oxide. Refrigerant gases, although used in the meat supply chain from the point of slaughter (or milking) onwards, are not discussed here since the impacts are less significant than the other greenhouse gases for the livestock chain. Refrigeration and its contribution to greenhouse gas emissions has, moreover, been examined in a separate FCRN working paper.[117]

As Table 2 shows, the livestock sector generates greenhouse gas emissions at every stage in its life cycle.

Table 2: Livestock life cycle stage and associated emissions

	Life cycle stage	Process creating emission	Type of emission
1	Production of animal feed; silage production; grassland maintenance	Production of nitrogenous and other fertilisers, agricultural machinery, pesticides and other inputs	N_2O emissions from grazing land, fodder crops and fertiliser production; CO_2 from fertiliser production;
2	Animal housing and maintenance, associated machinery	Heating, lighting, milking etc.	CO_2
3	Digestion (ruminants)	Enteric fermentation	CH_4,
4	Waste products	Manure and urine	CH_4 and N_2O
5	Slaughtering, processing, waste treatment	Machinery, cooking, cooling, chilling, lighting, leather and wool production, rendering and incineration	CO_2 and refrigerant emissions
6	Transport, storage, packaging	Transport, chilling, lighting, and MAP[118] gas production	CO_2 and refrigerant emissions
7	Domestic consumption	Refrigeration and cooking	CO_2 and refrigerant emissions
8	Waste disposal	Transport, composting, anaerobic digestion and incineration	CO_2, CH_4 and N_2O

These are the direct, or first order impacts and numerous studies have sought to quantify them, particularly up to the farm gate (stages 1-4 in the table above).

[117] Garnett T. *Food refrigeration: what is the contribution to greenhouse gas emissions and how might emissions be reduced?* A working paper produced as part of the Food Climate Research Network, Centre for Environmental Strategy, University of Surrey, April 2007
[118] Modified Atmosphere Packaging

There are also the very important second order effects to take into account. One of these might be called the opportunity cost of land take:[119] The possibility that existing land, historically allocated to livestock production (either pasture or arable land used for feed cropping), could be used for another purpose, one that might actually lead to lower greenhouse gas emissions or even help sequester carbon. The use of land for biofuel[120] or food production, or for forestry are two such examples of alternative uses.

An additional consequence of livestock farming is lost carbon sequestration: The conversion of hitherto non-agricultural land such as forest or savannah land to livestock rearing and associated feed production. This has serious consequences for the planet's natural capacity to store carbon; indeed the FAO estimates that globally, livestock related land use change leads to the release of 2.4 billion tonnes of carbon dioxide a year, equivalent to approximately 7% of global greenhouse gas emissions.

On the other hand, pastures for animal grazing are typically not ploughed and as such provide a sink for carbon emissions. A change of land use to arable, where land *is* ploughed, would lead to the release of carbon dioxide. While as it stands, land used for pasture tends in any case to be unsuitable for arable production, the situation might change either because rising global temperatures make such cultivation possible or as a consequence of changing economic conditions.

These second order impacts and what if? scenarios tend not to be discussed in the life cycle studies we review in this section. They are, however, explored in some detail in Sections 4 and 5 below.

3.1 Global level estimates

The FAO is increasingly turning its attention to the negative environmental impact of livestock production. It estimates that once all factors are taken into account, livestock account for about 18% of total anthropogenic greenhouse gas emissions. This figure, unusually, takes into account the lost carbon sequestration potential of land cleared for the production of feed or for grazing livestock. This last issue is specifically applicable to the UK in so far as feed (and to a lesser extent beef) is imported from deforested regions.

The FAO figure is a global one. Its magnitude reflects the fact that in less developed countries, agricultural impacts will be relatively more important than those from other industry sectors. In the developed, world where there are other competing emission sources such as transport, manufacturing and domestic energy use, the contribution livestock make to greenhouse gas emissions will be relatively lower, although in absolute terms (owing to greater animal numbers) the opposite may be true.

[119] Berlin D, Uhlin H-E. (2004). Opportunity cost principles for life cycle assessment: toward strategic decision making in agriculture, *Progress in Industrial Ecology*, Vol. 1, Nos. 1/2/3, 187

[120] the merits of biofuel production, some kinds in particular, are highly questionable, but are considered here as alternative possibilities to using land for livestock rearing.

3.2 EU level estimates

One EU report[121] draws upon both top-down and bottom up studies of the environmental impacts of products consumed in the EU, including food. On the basis of environmental input-output calculations it concludes that the food sector in its entirety accounts for up to 31% of the EU-25's greenhouse gas emissions. Meat and dairy products account for about half of all food related emissions. The report also reviews life cycle studies showing a range of estimates from 4% to 22%, depending on the products included or excluded, the methods used and the delimiting boundaries.[122]

As regards agriculture specifically, the contribution it makes to overall EU greenhouse gas emission appears to be declining. This in part is due to a reduction in beef and dairy cattle numbers,[123] in turn a response to changes in CAP. Note, however, that feed and other imports are not included in this figure, nor are the second order impacts highlighted above. These will be discussed further in Sections 3 and 4.

3.3 Country level estimates

3.3.a United Kingdom

The UK's total greenhouse gas emissions stand at around 179 million tonnes of carbon equivalent (2005 figures).[124] These are the emissions that result from activities associated with UK *production*, but they do not include emissions associated with our *consumption* of imported goods and services, nor do they exclude those resulting from goods and services that are exported.

According to the UK's greenhouse gas inventory, agricultural activities as a whole contribute 7% to the UK's greenhouse gas emissions.[125] Note that this figure does not include fertiliser production, any transport associated with agricultural production nor agricultural production overseas associated with UK consumption. Agriculture is of course also responsible for a range of other very important pollutants: It accounts for 90% of all UK ammonia emissions[126] and is the single largest source of diffuse water pollution;[127] the key pollutants being nitrogen, phosphorous and sediment. These environmental concerns are not addressed in this report, since the primary focus is greenhouse gas emissions (although the potential for pollution swapping is touched upon in Section 6).

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[121] *Environmental impact of products (EIPRO): Analysis of the life cycle environmental impacts related to the total final consumption of the EU25*, European Commission Technical Report EUR 22284 EN, May 2006

[122] Includes a small share for narcotics

[123] *Annual European Community greenhouse gas inventory 1990–2005 and inventory report 2007*. Submission to the UNFCCC Secretariat. Version 27 May 2007, Technical report No 7/2007, European Environment Agency, Brussels, 2007

[124] *UK Greenhouse Gas Inventory 1990 to 2005: Annual Report for submission under the Framework Convention on Climate Change*, Defra, UK, 2007

[125] *Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland: 1990 – 2005*, Report to Department for Environment, Food and Rural Affairs, The Scottish Executive, The Welsh, Assembly Government and The Northern Ireland Department of Environment, AEA Technology, 2007

[126] *Agriculture in the United Kingdom*, Defra 2006

[127] http://www.defra.gov.uk/farm/environment/water/csf/index.htm

A few studies have sought to quantify UK *consumption-related* rather than simply *production*-related greenhouse gases. One recent study was commissioned by the Carbon Trust and undertaken by the University of Surrey.[128] Another was undertaken by the Stockholm Environment Institute for the World Wide Fund for Nature.[129] However these studies consider only carbon dioxide emissions and not the full basket of greenhouse gases. In the UK, carbon dioxide accounts for 85% of total greenhouse gas, with the remaining 15% made up of nitrous oxide, methane and other gases. It would be reasonable (although open to challenge) to assume that imported goods contain the same embedded make-up, making the total consumption related figure 15% greater than the carbon dioxide alone.

Using the Carbon Trust report as a baseline for carbon dioxide emissions, and adding this 15% onto the carbon dioxide total, we estimate that total consumption-related greenhouse gas emissions in the UK amount to around 204 million tonnes of carbon equivalent.

As regards food's contribution to this total, there have been several informal attempts to quantify food related emissions in the UK. One study estimates total emissions associated with the *production* of food in the UK to account for 22% of the UK greenhouse gas production total.[130] According to our calculations, the impacts associated with our *consumption* of food in the UK contribute around 19% of total consumption related emissions (that is, all the greenhouse gases embedded in our consumption of goods and services)[131] although owing to incomplete data this is likely to be an underestimate. Preliminary analysis by Defra yields a very similar figure.[132]

The Carbon Trust study puts carbon emissions from food consumption at 13% of the UK total.[133] Note again that this study is a carbon dioxide only analysis; nitrous oxide and methane, both of which are very important contributors to total food chain emissions, are not considered.

As regards meat-[134] and dairy-related greenhouse gas emissions, we provide two estimates here based on two methods of calculation. Both figures are partial, and likely to be underestimates since data are lacking in some areas.

The first table gives emissions arising from the UK's *production* of livestock products, while the second takes a consumption oriented approach, thereby including imports and excluding exports. Note that since the *consumption* related impacts of meat and dairy products are being calculated here, their contribution to greenhouse gas emissions is given in terms of their contribution to total UK *consumption*-oriented greenhouse gas emissions.

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[128] *The carbon emissions generated in all that we consume*, The Carbon Trust, London, January 2006

[129] *Counting consumption: CO_2 emissions, material flows and Ecological Footprint of the* UK by region and devolved country, WWF-UK, 2006

[130] *Achieving the UK's Climate Change Commitments: the efficiency of the food cycle*, e3 Consulting, 2002.

[131] Garnett T (2007). *UK food consumption related greenhouse gas emissions,* working draft, FCRN, http://www.fcrn.org.uk/frcnresearch/publications/Overall%20food%20GHGs.doc

[132] Preliminary analysis by Defra (2007), pers. comm. August 2007

[133] *The carbon emissions generated in all that we consume*, The Carbon Trust, January 2006

[134] From all sources as well as eggs

Table 3: Greenhouse gas emissions from UK production of livestock products

Total from livestock 2005	**Tonnes CO_2e**	**%**	**Source**
Methane	18,443,000	2.81	NETCEN 2007 submission[135]
Nitrous oxide soil emissions*	17,484,000	2.67	* includes nitrous oxide from excreta, grazing land and 50% from cereals – Source: http://www.apis.ac.uk/overview/pollutants/overview_N2O.htm
Fertiliser production	4,651,620	0.71	T. Garnett based on data provided by AIC and British Survey of Fertiliser Practice: data shows livestock related fertiliser use accounts for approx 64% total fertiliser use
Total	**40,468,620**	**6.19**	
Post farm gate stages	**Tonnes CO_2e**	**%**	**Source**
Milk processing	884,455	0.13	Milk Development Council
British Meat Processors Association Climate Change Agreement (CCA) – doesn't include all processors	350,000	0.05	Ray Gluckman, Enviros[136]
British Poultry Council CCA	300,000	0.05	Ray Gluckman, Enviros
Agricultural Industries Confederation CCA – Feed production	600,000	0.09	Ray Gluckman, Enviros
UK Renderers' Association CCA	400,000	0.06	Ray Gluckman, Enviros
Food and Drink Federation members – meat (est. 3/4 of meat and fish)	52,500	0.01	Ray Gluckman, Enviros
Total for post farm gate	**2,586,955**	**0.40**	
Total for pre and post farm gate stages	**43,055,575**	**6.59**	

Note: CO_2e or carbon dioxide equivalent is the universal unit of measurement to indicate the global warming potential of greenhouse gases, expressed in terms of the global warming potential of one unit of carbon dioxide.

[135] *UK Greenhouse Gas Inventory 1990 to 2005: Annual Report for submission under the Framework Convention on Climate Change*, Defra, UK, 2007
[136] Enviros Consultants are responsible for managing the Climate Change Agreements for most of the eligible food sectors

Table 4: Greenhouse gas emissions from UK consumption of livestock products (including imports minus exports)

Total from livestock	CO_2e/tonne	Total consumption (tonnes) 2006	Total tonnes CO_2e	Contribution to UK CO_2e emissions %
beef	16	1,086,000	17,376,000	2.32
pig (pork & bacon)	6.4	1,310,000	8,384,000	1.12
poultry	4.6	1,795,000	8,257,000	1.10
sheep	17	372,000	6,324,000	0.85
eggs*	5.5	537,000	2,953,500	0.40
Milk and products	1.06	13,361,000	14,162,660	1.89
Total up to farm gate			**57,457,160**	**7.69**
Total for post farm gate			**2,586,955**	**0.35**
Totals for pre and post farm gate			**60,044,115**	**8.03**

Sources: for CO_2e per tonne of product: Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University & Defra. For total volumes consumed, data sources are the same as for Figures 10 and 11 For total UK consumption related greenhouse gases see Garnett T (2007). *UK food consumption related greenhouse gas emissions*, working draft, FCRN http://www.fcrn.org.uk/frcnresearch/publications/Overall%20food%20GHGs.doc
* 20,000 eggs weigh approximately one tonne.
Note: emissions generated during the manufacture and import of processed livestock products are not included, nor are emissions generated during the course of transporting, retailing, and home storage/cooking of livestock products.

As this table shows, our *production* of livestock products in the UK contributes over 6% to the UK's greenhouse gas emissions (or 6.6% if post farm gate impacts are included). This is interesting in the light of the greenhouse gas inventory cited above, which puts agricultural activities in total at 7% of all UK greenhouse gas emission (note again, that this figure does not include fertiliser production). There will of course be some differences in the calculations and variabilities in the data used. Nevertheless, it is clear that livestock production is by far the major contributor to UK agricultural greenhouse gas emissions.

If we consider impacts arising from the consumption of livestock products, the figure, as a proportion of total consumption related greenhouse gases, rises to 8%.

3.3.b Belgium

A Belgian study[137] quantifies greenhouse gas emissions resulting from the national consumption of pork, beef and poultry. The calculations cover carbon dioxide, methane and nitrous oxide generated during the production of fertilisers and feed, animal production, slaughtering, processing, packaging, distribution and waste treatment. The study concludes that meat consumption accounts for around 4% of Belgium's total greenhouse gas emissions. Beef accounts for more than half of

[137] See *Greenhouse gas emissions reduction and material flows* Final report, IDD - Institut Wallon - VITO, Federal Office for Scientific, Technical and Cultural Affairs, Belgium, 2001.

these and poultry only 8%. The Belgian study is interesting, but the findings do not automatically apply to the UK situation because there will be national variations in overall consumption of meat and of the relative make up of different kinds of meat in the diet.

For example, the Belgians tend to eat more beef and pork than we do in the UK, but less sheep meat and poultry. Table 5 below gives 2002 FAO statistics for per capita annual supply of the four main meat types for the UK and Belgium. Supply is not the same as consumption, but the figures below give an indication of the level of total consumption and the balance between different meat products.

Table 5: Per capita a supply of meat products (kg) in 2002:

	UK	**Belgium**
Beef	19.2	19.7
Pork	25.7	35.4
Poultry	28.9	19.6
Mutton	5.9	1.5
Total	**79.7**	**76.2**

Source: FAO stat 2002

There will also be differences in farming practices – Belgian farming tends to be more intensive with higher stocking densities.[138] Of course, the relative contribution made by other industrial and domestic sectors to national emissions also needs to be factored in. Clearly the study is very partial, since it leaves out sheep meat, eggs and dairy products. If these foods are included, then the figures are likely to be significantly higher.

3.3.c The Netherlands

There have also been Dutch studies that provide useful points of comparison. Kramer et al.[139] calculate that meat, meat products and fish account for 28% of total food consumption related greenhouse gas emissions, while dairy products contribute a further 23%, making the two sectors together amount to half of all food related impacts.

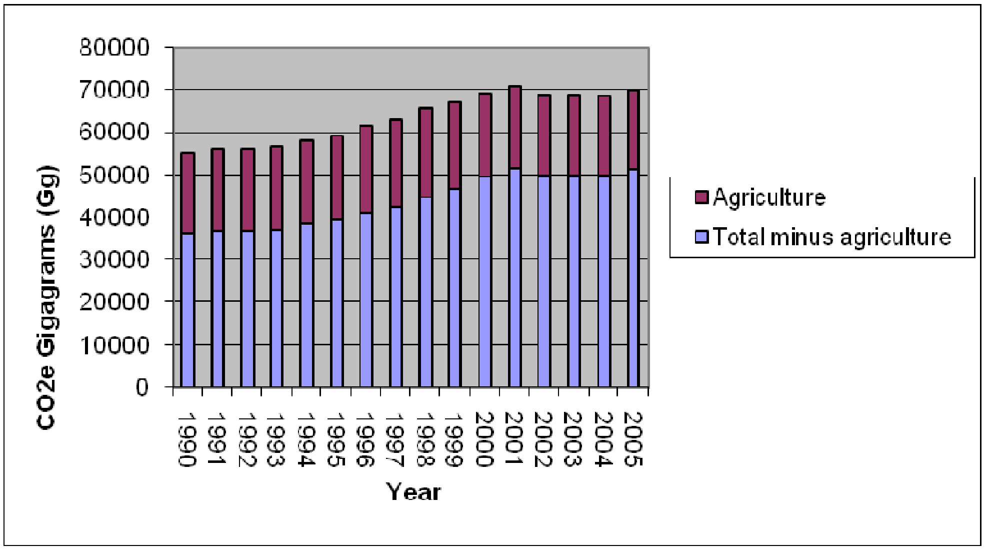
3.3.d Ireland

Ireland is unusual in that it is densely populated with livestock but sparsely populated with people. Hence, in 2005 agriculture accounted for 26% of Ireland's total greenhouse gas emissions, and much of this is attributable to cattle farming.[140] While agriculture's share of total greenhouse gas emissions has fallen since 1990 (when it stood at over 34%) this largely reflects the significant overall growth in greenhouse gas emissions from other sectors of Ireland's economy. In fact

[138] F. Colson, V. Chatellier and K. Daniel, *Using the Farm Accounts Data Network (FADN) to identify the structural characteristics and economic performance of EU cattle systems*, Institut National de la Recherche Agronomique, undated
http://www.macaulay.ac.uk/elpen/work1/translation.html
[139] Kramer K J, Moll H C, Nonhebel S, Wilting H C (1999). Greenhouse gas emissions related to Dutch food consumption, *Energy Policy* 27 203-216
[140] Environmental Protection Agency, Ireland, Emissions Data Time Series for 1990 – 2005
http://coe.epa.ie/ghg/emissions.jsp accessed 19 August 2007, Dublin, Ireland, 2007

emissions from agriculture today are only 3% lower than they were in 1990, albeit 12% lower than the period of peak agricultural emissions in 1997-1998.

Figure 22: Trends in overall and agricultural greenhouse gas emissions in Ireland



Such decline in emissions as there has been largely reflects the reduction in livestock numbers.[141] Taking milk as an example, while dairy cattle numbers fell by 17% between 1990 and 2005,[142] milk output has remained the same[143] due to changes in breeding and feeding regimes. This said, while milk yields per cow have increased, these have been at the expense of reproductive ability and survival rates.[144]

3.4 Greenhouse gas emissions by animal type

The greenhouse gas intensity of different livestock products varies widely. Table 6 summarises the range of different values given for emissions per kilogram of livestock product. Most of the studies we consider quantify emissions from particular farms or compare emissions from two or three different farming systems, taking individual farms as representative of the group.[145] While these studies are illuminating in that they identify environmental hotspots, highlight the environmental implications of certain farming practices, and show the differences between livestock types, the figures they give for on-farm emissions cannot simply be scaled up. 'Site

[141] Environmental Accounts for Ireland 1997-2005, Central Statistics Office

[142] Dairy Cow Numbers and Milk Yields 1975-2005, Central Statistics Office, http://www.agriculture.gov.ie/index.jsp?file=publicat/compendium2006/listoftabs.xml accessed 19 August 2007

[143] Milk Output and Disposal (Whole Milk Only), 1990- 2004, Central Statistics Office, http://www.agriculture.gov.ie/index.jsp?file=publicat/compendium2006/listoftabs.xml accessed 19 August 2007

[144] Dillon P, Berry DP, Evans RD, Buckley F, Horan B. Consequences of genetic selection for increased milk production in European seasonal pasture-based systems of milk production, *Livestock Science* 99 (2006) 141– 158

[145] Haas, G. Wetterich, F. Köpke, U. (2001). Comparing intensive, extensified and organic grassland farming in Southern Germany by process life cycle assessment, *Agriculture, Ecosystems and Environment* 83 43–53

dependency'[146] – the specifics of a particular farm, its soil, climate and its management practices – make it very difficult to extrapolate from the individual to the system level. In addition the scope and boundaries chosen will differ among individual studies can the functional unit (some, for instance, use the carcass weight and others the live weight). Hence for assessing national level emissions from a particular sector, livestock in this case, top-down calculations may be preferable.

Where a specific comparison has been made between different farming systems (such as conventional versus organic), the *notes* column provides further details. The issue of conventional versus organic production is discussed in detail in Section 6.4.

As this table shows, ruminant livestock products appear to be considerably more greenhouse gas intensive than the outputs of pig and poultry systems. However, as we discuss later, a straight 'on the face of it' comparison does not take into account other important qualifying factors – the second order impacts already touched upon and discussed further below.

Table 6: Range of values for greenhouse gas emissions by livestock type

Product type	Unit	Quantity	Source	Notes
Beef	**kg/lw/yr**	11.1 - 13	Casey J W, Holden N M, Quantification of greenhouse gas emissions from suckler-beef production in Ireland, Agricultural Systems 90 (2006) 79–98	Organic emissions lower
Beef	**kg/carcass**	15.8 - 16.2 - 25.8	Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.	Conventional lowest, organic medium, 100% suckler (nothing from dairy chain) highest
Dairy	**kg/ECM**	0.92 - 1.51	Casey JW and Holden NM. The Relationship between Greenhouse Gas Emissions and the Intensity of Milk Production in Ireland, *Journal of Environmental Quality*, 34:429–436 (2005)	Range depends on variables but no significant difference between organic and conventional
Dairy	**kg/ECM**	0.95 - 1.07	Cederberg C and Mattson B. (2000) *Life cycle assessment of milk production — a comparison of conventional and organic farming*, Journal of Cleaner Production 8 (2000) 49–60	Organic have higher emissions due to higher methane output
Dairy	**kg/ECM**	0.64 - 1.07	Cederberg C and Stadig M. |(2003) System Expansion and Allocation in Life Cycle Assessment of Milk and Beef Production *Int J LCA 8* (6) 350 – 356	Range depends on whether some emissions are allocated to beef production or not

[146] Milà i Canals L (2003): *Contributions to LCA Methodology for Agricultural Systems. Site-dependency and soil degradation impact assessment*. PhD thesis. Available from http://www.tdx.cesca.es/TDX-1222103-154811/ (ISBN: 84-688-3285-5)

Product type	Unit	Quantity	Source	Notes
Dairy	**l/FCM**	1.06 - 1.23	Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.	Organic higher
Dairy	**kg milk**	1.03 - 1.2	Lovett D.K., Shalloo L., Dillon P., O'Mara F.P. (2006) A systems approach to quantify greenhouse gas fluxes from pastoral dairy production as affected by management regime, *Agricultural Systems 88*	Range depends on genetic merit and level of concentrates fed
Pig	**kg/lw**	2.3 - 3.97	Basset-Mens C and van der Werf H M G. (2005) Scenario-based environmental assessment of farming systems: the case of pig production in France, *Agriculture, Ecosystems and Environment 105* 127–144	Organic higher
Pig	**kg/carcass**	5.64 - 6.36	Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.	Organic lower emissions
Poultry	**kg/carcass**	4.5 - 5.48 - 6.68	Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.	Caged least emissions, free-range medium, organic most
Eggs	**kg (approx 20)**	5.25 - 6.18 - 7	Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.	caged conventional least, then free-range, organic most
Sheep	**kg**	10.1 - 17.5	Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.	conventional highest, organic lowest

Note: ECM stands for Energy Corrected Milk (milk blended to achieve a uniform calorific value per given quantity), while FCM stands for Fat corrected Milk (milk blended to achieve a uniform fat content – in the UK for whole milk this is 3.5%. As functional units they are very similar).

3.5 Review summary

The studies reviewed here indicate that livestock make a very considerable contribution to greenhouse gas emissions at whatever scale one chooses to examine.

However, it is important to emphasise that the studies do not necessarily take into account the emissions that livestock (and ruminant livestock in particular) help save.

If we did not eat meat or drink milk we would have to expend energy, and emit greenhouse gases to produce substitute foods. If we did not have leather, wool, manure or any of the animal-derived substances that are used by the oleochemicals industry, we would have to grow or manufacture substitutes. These studies also overlook the fact that livestock make use of waste food and by-products that may be going spare, and graze on land that cannot be used productively for any other form of agriculture. In other words while considerable quantities of greenhouse gases are generated it is undoubtedly the case that were livestock *not* being reared, certain levels of emissions would still be emitted in order to produce substitutes for the goods that livestock currently provide, such as food, leather, wool, fertiliser and (by consuming food waste and by-products) waste-disposal services. This *what if?* aspect to quantifying emissions is receiving increasing attention in life cycle analysis, and is usually termed 'prospective consequential' analysis to distinguish between 'retrospective attributional' studies that simply seek to account for existing impacts.[147]

The balancing and counterbalancing issues to consider when quantifying livestock greenhouse gases are discussed in Sections 4 and 5 that follow. Section 4 looks at what goes *in* to the livestock system and the various factors to consider when quantifying emissions arising from those inputs. Section 5 looks at how what comes *out* of the system – the outputs – affects the accuracy of attempts to quantify ruminant sector emissions. In both sections, the discussion is confined largely to the agricultural stage although we also look at some post-slaughter activities (leather and wool manufacture, rendering and pet food manufacture) to see to what extent these downstream activities actually affect the upstream production of livestock themselves.

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[147] Weidema B. (2003) *Market information in life cycle assessment*, Environmental Project No. 863 2003 Miljøprojekt, Danish Environmental Protection Agency

SECTION 4: INPUTS TO THE LIVESTOCK SYSTEM – EXAMINING THE COMPLEXITIES

Livestock production requires many inputs, all of which lead to the generation of greenhouse gas emissions.

These inputs can roughly be divided into three categories. First, there are the direct energy inputs that are needed for lighting, heating, farm machinery, the maintenance of buildings and so forth.

A second major input is animal feed. Feed – both bought-in feedstuffs such as concentrates, and pasture – will have required energy both for their cultivation and manufacture and for the production and transport of nitrogenous fertilisers. All this will have generated emissions of carbon dioxide and nitrous oxide. Some feedstuffs, such as feed cereals and fertilised grass land, will be grown specifically for livestock. Other feeds will be by- or co-products from other agricultural systems or from other areas of the food chain.

A third input is land; land both for the direct grazing of ruminant livestock and, less directly, for the cultivation of feed inputs for all livestock types. Land use has a bearing on greenhouse gas emissions in a number of ways: In particular it raises the question of its opportunity cost – that is, whether the land dedicated to livestock rearing could be put to an alternative use that might be more productive and less greenhouse gas intensive.

This section explores the intricate trade-offs that need to be considered in any attempts to quantify the greenhouse gas impacts of these inputs. The main questions addressed are as follows:

1. To what extent do livestock make use of the by-products of other processes? Can these by-products be classed as valuable co-products in their own right? To what extent does the need for by- or co-products for animal feed drive production of these crops in the first place?
2. If these by- or co-products were not used for animal feed what might they be used for instead? Could, for instance, they be used as feedstocks for biofuels production?
3. To what extent do livestock graze upon land that could not be productively used for any other purpose? Or do they take land away from other potential agricultural activities?
4. What is the opportunity cost of using land either directly or indirectly for animal feed? Might the land be used in ways which actually help reduce greenhouse gas emissions, examples being for the production of biofuels or for forestry?
5. How does the quality of the feed relate to the quantity of methane emissions resulting from the digestion process and might there be a conflict between the goals of reducing the energy intensity of the feed inputs on the one hand and the quantity of methane outputs on the other?

4.1 Energy inputs

Farm energy inputs for fuelling machinery, heat, light and so forth will generate carbon dioxide emissions. However, their total contribution to the system's

greenhouse gas emissions is small. Casey and Holden[148] estimate on-farm diesel and electricity use to account for 5% of the total CO_2e generated by an average Irish dairy farm. Schil et al. give a very similar 4-5% for a Dutch dairy farm.[149] For pig and poultry systems the relative importance of on farm fuel use will be higher (since methane emissions are lower) although overall fossil fuel use per kg of product is still lower than it is for cattle systems.[150] Farm energy use is not explored any further in this paper since the contribution is so low.

4.2 Feed inputs

Section 2 has already looked at what livestock eat. The paragraphs that follow take each of the main feed constituents in turn and explore their implications for greenhouse gas emissions.

4.2.a Cereals fed to livestock: Exploring the arguments

In the UK, as mentioned above, livestock in the UK consume more than half[151] [152] of the more than 20 million tonnes of cereals produced and consumed in the UK. For wheat alone the proportion is over 50%[153] and for barley over 62%.[154] At a global level, the FAO calculates that a third of world cereal production is used to feed livestock.[155] The World Resources Institute puts the figure higher at 37%.[156]

This discussion examines the position that since animals are not especially efficient converters of plant food to animal food, cereals now fed to livestock might more efficiently be fed directly to humans or used for another purpose. Specifically, it considers three questions. The first is whether the cereals currently being grown to feed animals could be used to feed humans instead. This is the argument advanced by various academics and pressure groups.[157] [158] [159] [160] Second, could the cereals be used as a feedstock for biofuel production?

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[148] Casey J W and Holden N M (2005). Analysis of greenhouse gas emissions from the average Irish milk production system, *Agricultural Systems 86* 97–114

[149] Schils R L M, Verhagen A Aarts H F M and Šebek L B J (2005). A farm level approach to define successful mitigation strategies for GHG emissions from ruminant livestock systems, *Nutrient Cycling in Agroecosystems* 71. 163-175

[150] Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on www.silsoe.cranfield.ac.uk, and www.defra.gov.uk

[151] *Agriculture in the UK 2006* - 2005 figures: figures derived from tables 5.1, 5.2, 5.3, 5.4

[152] Home Grown Cereals Authority, Market Information Supply and Demand, average for years 2001-2004/5 http://www.hgca.com/document.aspx?fn=load&media_id=2806&publicationId=99

[153] *Agriculture in the United Kingdom 2006,* Defra Table 5.2

[154] *Agriculture in the United Kingdom 2006,* Defra Table 5.3

[155] *World Agriculture: towards 2015/2030. Summary report*, FAO, 2002 http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/004/y3557e/y3557e00.htm

[156] World Resources Institute: *Food Security: Grain fed to livestock as a percent of total grain consumed* 2003/4 data http://earthtrends.wri.org/

[157] Gold M (2004). *The Global Benefits of Eating Less Meat*, Compassion in World Farming Trust

[158] Vegan Society http://www.vegansociety.com/html/environment/land/ accessed 19 August 2007

[159] Goodland R. (1997) Environmental sustainability in agriculture: diet matters *Ecological Economics*, *Volume 23, Issue 3*, *5*, *Pages 189-200*

The third question is this: Could we use the land currently devoted to growing feed cereals either to produce *other* forms of food for human consumption (such as vegetables or legumes) or for the production of non-cereal forms of biomass?

Before doing so, it may be useful to consider how cereal consumption differs among livestock types. Table 7 shows both the absolute quantity of cereals each type of livestock consumes, and the ratio of cereal consumption to livestock product output – how much cereal we need to feed them to gain a tonne of milk or meat. Note that in addition to cereals, other feeds will be given including oilseeds, peas and beans, various by-products and (for ruminants) silage, and as discussed in Section 2, data for these inputs are hard to come by. As such the data shown below only give a partial representation of feed inputs and do *not* show the feed conversion efficiency of different livestock types (the ratio of feed energy consumed to carcass energy produced).

Table 7: Cereal consumption by livestock type and in relation to total livestock products produced

	Total cereal consumption	**Cereal consumption as % UK total cereal production**	**Livestock products – dressed carcass weight – (tonnes)**	**Tonnes cereal consumed per tonne meat**	**Notes**
Poultry meat	2,184,950	10.60	5,972,000	**0.37**	
Pig meat	994241	4.82	785,000	**1.27**	
Beef & dairy	3,054,680	14.82	4,332,250	**0.71**	Volume of milk divided by four to give it very approximate calorific value to beef[161]
Total	**6,233,871**	**30.24**			

Notes**:** *Poultry*: Assumes 60% cereal incorporation rate. Feed data and carcass weights from weights from *Agriculture in the United Kingdom*, Defra 2006
Pigs: Assumes 60% cereal incorporation rate. Feed data from Pigs UK, Biffaward, 2006 Carcass weights from *Agriculture in the United Kingdom*, Defra 2006
Beef and dairy: Figure includes consumption of cereals in straight form. A 22% cereal incorporation rate is assumed for compounds based calculations made from data available in *Grain fed to livestock* 2002/2003 England and Wales, Defra. http://statistics.defra.gov.uk/esg/statnot/gflsur.pdf Carcass weights and milk volumes from Agriculture in the United Kingdom, Defra 2006
Note: This table shows cereal consumption by the livestock sector to amount to 30% of total cereal production when the Defra figure highlighted above gives a higher figure. This may be partly explained by the exclusion of egg layers from the calculations. They will also consume feed. Very small quantities are also consumed by sheep although they will not make much difference to the figures.

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[160] De Boer J, Helms M, Aiking H. (2006). Protein consumption and sustainability: Diet diversity in EU-15, *Ecological Economics* 59 pp. 267-274
[161] Beef contains 200-300 calories/100g (depending on fattiness) whereas milk contains 30-60 calories per 100g. Data obtained from USDA Food and Nutrient Database, accessed 1/08/07 http://www.ars.usda.gov/Services/docs.htm?docid=7783

This table is very approximate. As we say, this is not an exercise in calculating feed conversion efficiency and it should be noted that the feed conversion efficiency of poultry and pigs are estimated elsewhere to be far more efficient than the figure given here, poultry more so than pigs.[162] [163] To our knowledge there are no studies that specifically look at cereal rather than overall feed intakes. The aim here is simply to highlight the different ways in which cereal utilisation can be viewed. This overview can help inform the discussion as to the relative greenhouse gas efficiency among livestock types bearing in mind competition for cereals from other sources.

The differences between livestock types are interesting. The total volume of cereals consumed by cattle is larger than any other livestock type simply because they are bigger animals and there are many of them. However, relative to the amount of meat (or dairy products) they produce, their consumption is midway between pigs and poultry. In addition, they can also utilise, albeit inefficiently, a wider range of foods, many of which are inedible to other livestock.

Note that while pigs appear the most efficient, despite the fact that cereals feature prominently in their diets, they also consume large quantities of oilseeds, particularly soy[164] and their feed conversion efficiency is not as great as that of poultry. Poultry rank as the most cereal intensive livestock. Egg layers are excluded from the table because the data are not available. Sheep are also excluded since they consume very little compound feed.

Box 1: The global picture

Globally in 2002 some 670 million tonnes of cereals were fed to livestock, representing just over a third of total world cereal use.[165] Most of this, at two thirds, was consumed by livestock in the developed world.

It should be noted that the proportion of grain fed to livestock has fallen slightly since the 39% of the 1970s.[166] There are various reasons for this. They include changes in genetics (the breeding of more efficient animals), changes in livestock management, the use of hormones such as BST in some countries to increase productivity, and a shift in favour of poultry products, which have a greater feed conversion efficiency.[167] There are suggestions, however, that all the wins here have been won and the trends are unlikely to continue.

In addition, meat production in some developing countries is shifting rapidly toward more commercial intensive production systems, that rely more heavily on cereal feed than do backyard or small-scale producers. Baseline projections for the future, therefore, assume that demand for feed will match meat production more closely than it has in recent years.[168]

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162 *Poultry UK*, Biffaward, 2006
163 *Pigs UK*, Biffaward 2006
164 Soffe, R.J. (eds) (1995) *Primrose McConnell's The Agricultural Notebook* (19th Edition), Blackwell Science, Oxford
165 *Livestock's Long Shadow – Environmental Issues and Options*, FAO, December 2006
166 World Resources Institute: *Food Security: Grain fed to livestock as a percent of total grain consumed* 2003/4 data http://earthtrends.wri.org/
167 *Global Food Projections to 2020: Emerging Trends and Alternative Futures*, Rosegrant M. W., M. S. Paisner, S. Meijer, and J. Witcover. 2001. Washington D.C.: International Food Policy Research Institute. http://www.ifpri.org/pubs/fpr/fpr30.pdf
168 Rosegrant M. W., M. S. Paisner, S. Meijer, and J. Witcover. 2001. *Global Food Projections to 2020: Emerging Trends and Alternative Futures*, International Food Policy Research Institute, Washington D.C. http://www.ifpri.org/pubs/fpr/fpr30.pdf

Could cereals be fed more directly to humans?

The discussion here focuses largely on wheat since in the UK barley tends not to feature much in the human diet (except when brewed to make beer). In the past, however, barley was a staple for poorer people and the meal was often used to make bread or barley cakes.

As regards wheat, of the nearly 14 million tonnes we use each year, the greatest share, (52% in 2005),[169] is used to feed livestock. A smaller proportion – 41% in 2005 – is milled for flour. Note that this 14 million tonnes is net of imports and exports. We actually produce nearly 15 million tonnes of wheat each year, of which around two and half million tonnes are exported. A small quantity of wheat is also imported, largely for breadmaking.

All wheat is not 'equal'. Its suitability for various uses depends heavily on its protein content as well as on other factors such as endosperm colour, water absorption potential and flavour. The protein content is, however, critically important to the formation of gluten; it is this that gives bread its elastic texture and ability to form the light airiness that characterises today's industrially produced bread.

Box 2: Wheat classification

There are four classifications for wheat bought for milling: Groups 1, 2, 3 and 4. Group 1 and 2 varieties are preferred for breadmaking. Group 3 varieties can be used for biscuit and cake making and may also be used for bioethanol production if the market and technology develops. Group 4 varieties tend only to be used only for animal feed although these too could be suitable for biofuel.

Wheat quality is measured in a number of ways. These include its protein content (for breadmaking, this needs to be high at around 13% on a dry matter basis), the endosperm texture (hard or soft), its specific weight and its Hagberg falling time. The latter is a measure of the viscosity of a suspension of flour. A low Hagberg falling number (often due to weather) is undesirable for commercial breadmaking and its main cause is the presence of the enzyme α-amylase in flour, resulting in the degradation of starch to simple sugars. These in turn cause a 'sticky crumb' structure, and a caramelised crust during the baking process. Breadmaking varieties need to have a Hagberg falling time of at least 250.

On the whole, the higher the yield, the lower the protein content will be since the protein content tends to be diluted with high yielders. Feed wheat varieties tend to give higher yields.[170] Arid conditions, which lead to lower yields, also produce wheat with a higher protein content. UK farms yield around 8 tonnes/wheat/hectare whereas in the US, where protein contents tend to be very high indeed, productivity hovers at a mere 2.7 tonnes/ha.[171]

The gluten content of the wheat is determined not just by its variety, but by other factors such as the availability of nitrogen in the soil during ear formation and grain

[169] *Agriculture in the United Kingdom*, Defra 2005, Table 5.2 http://statistics.defra.gov.uk/esg/publications/auk/2005/5-2.xls

[170] Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on www.silsoe.cranfield.ac.uk, and www.defra.gov.uk

[171] US Department of Agriculture, Wheat data: yearbook tables

filling, the weather (particularly rainfall levels) and the timing of harvest.[172] Hence breadmaking wheat cannot be grown in all areas of the UK. Box 2 summarises the main types of wheat in the UK by end purpose.

Most in demand in the UK is wheat with a high gluten content, since 60% of the flour we use is for breadmaking,[173] and wheat of this kind fetches the highest prices.

Today, around 70% of the bread flour we use is of UK origin,[174] and of all flour 80% is UK grown.[175] This was not always the case. In the nineteenth century, most of the wheat we used for breadmaking was imported from North America since the wheat produced there met the specific characteristics needed for the production of a high rising loaf.[176] However the 1960s saw a concerted shift in the UK away from imports and towards increased used of domestically produced wheat. Several factors contributed to this. For a start, the newly established European Economic Community (EEC) placed heavy import tariffs upon imported wheat. Wheat breeders in turn responded to the price rise by developing new higher protein wheat varieties that thrived in the British climate. In addition, the Chorleywood breadmaking process (CBP), invented in 1961, had, by the mid 1960s become widespread. The CBP bypasses the traditional long fermentation period through the use of chemical improvers and a very intense mechanical mixing, which rapidly develops the gluten structure and beats air into the dough. This not only dramatically reduces the time taken to produce a loaf but, conveniently, can achieve results using wheat with a lower protein content.

High rising bread has therefore been taken for granted for at least a couple of hundred years. Before the nineteenth century, however, we did not import bread--making wheat, nor did we have access to high gluten wheat varieties. As such, the bread eaten then tended to be denser than is produced today. Older cookery books will yield dozens of recipes for bread using both softer indigenous British wheat and various other grains such as barley and oats.[177] According to some commentators, traditionally grown wheat might produce heavy bread, but its flavour is preferable to North American imports and to the modern high gluten varieties.[178] Moreover, many European countries whose land yields fairly low protein wheat varieties have adapted their bread making accordingly. French bread for instance uses fairly low gluten flour; the light airy texture is achieved by injecting steam into the bread ovens, which allows the dough to expand to its maximum capacity before a hard crust begins to form.[179] [180] German and Scandinavian bread on the other hand, is just heavy, and this is the way people like it.

Returning to the UK, it is clear that bread made from feed grade wheat would be very different from the soft, airy bread we know today, bread with a high moisture content

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172 Home Grown Cereals Authority, http://www.hgca.com/WMG/quality.html accessed 24 May 2005

173 Flour Advisory Bureau http://www.fabflour.co.uk/Freestyle.asp?PageID=235 accessed 31 May 2005

174 Julian Bell, Home Grown Cereals Authority, pers. comm. June 2005

175 Flour Advisory Bureau http://www.fabflour.co.uk/Freestyle.asp?PageID=235 accessed 31 May 2005

176 The product of a drier climate and lower yields

177 See for example the recipes collected in: David E, *English Bread and Yeast Cookery*, Penguin, New ed. 2001

178 David E, *English Bread and Yeast Cookery*, Penguin, New ed. 2001

179 David E, *English Bread and Yeast Cookery*, Penguin, New ed. 2001

180 It would be interesting to compare energy use in French bakeries and commercial British bakeries

and with keeping qualities of several days or more. By no means, however, does this mean that good bread cannot be made with the softer wheat currently used to feed animals.

Not all wheat consumed by livestock is of a feed grade variety. Some is actually of a food grade variety, which for one reason or another is used for feed. This may be because the crop fails to make the breadmaking standard (due to weather conditions); or there are may be economic or logistical issues at play. High quality wheat needs to be stored separately from other forms and this can be difficult in situations when different kinds of wheat are grown, but where storage space is limited. Sometimes the premiums available for high quality wheat are not worth the additional costs associated with storage or transport to a buyer who specialises in that quality of wheat.[181]

In short then, much of the wheat grown to feed animals could be used to feed humans, although it would not necessarily be suitable for making the kind of bread to which we have become accustomed. At present, with sales of bread continuing to decline,[182] there is little evidence of demand for more wheat for breadmaking in the UK, partly because livestock products substitute as food source – put simply, meat is eaten instead of wheat. This is very different from the situation in many developed world countries where cereals account for the bulk of people's calorie and protein intake.[183] Were meat and dairy consumption to decline, the calorie deficit would have to be met by cereal and other plant-based foods and land allocated (here or overseas) for that purpose. The land could also be used to grow cereals for export (which might actually end up being used as animal feed).

Another possibility is to grow cereals for biofuels production.

Could feed cereals be used for biofuels?

At the outset it is important to distinguish between biomass in the generality and biofuels more particularly. All biomass is essentially living matter (plant or animal) and contains carbon and hydrogen. Biomass can simply be dried and burned to produce heat and power. It can also be processed and converted into liquid biofuels. Oil rich crops, such as rapeseed, are turned into biodiesel through an esterification process while bioethanol is manufactured from sugary crops such as wheat, or sugar beet and involves distillation. Biomass can also be fermented to produce biogas (methane).

The EU has recently set new targets for biofuel production. At an EU level, biofuels should constitute 5.75% of the overall supply of petrol and diesel-type fuels by 2010,[184] although member states can set their own individual targets. The UK target is 5% by volume or 3.5% in energy terms.[185]

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[181] Renwick A and Coombe S (2003). *The UK Cereals and Oilseeds Subsectors*, Rural Business Unit, University of Cambridge, document prepared for the Home Grown Cereals Authority, London; and Julian Bell, Home Grown Cereals Authority, pers. comm., June 2005

[182] UK household purchased quantities of food and drink, *Family Food*, Defra 2007

[183] Summary of Food and Agricultural Statistics 2003, FAO, Rome, 2003

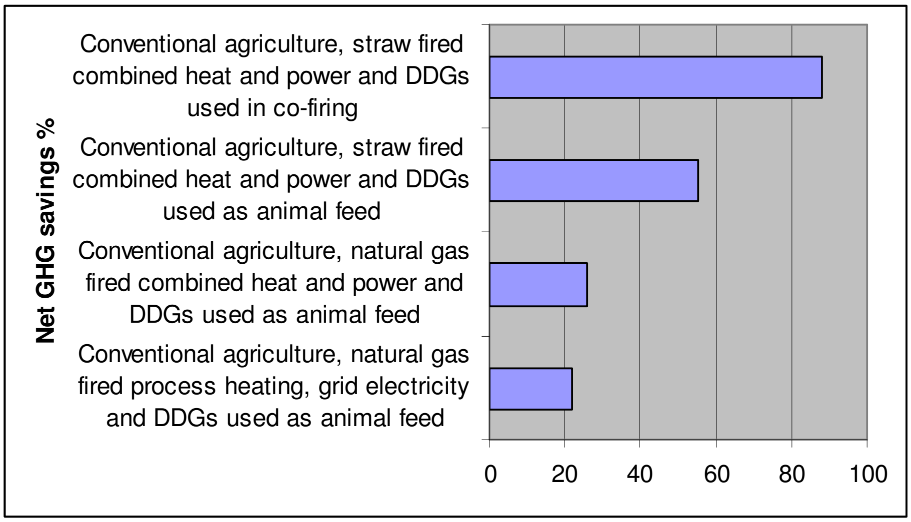
[184] *Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport*, Official Journal of the European Union, http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_123/l_12320030517en00420046.pdf

[185] Communication from the Commission to the Council and the European Parliament: *Biofuels Progress Report: Report on the progress made in the use of biofuels and other renewable fuels in the Member States of the European Union*, Brussels, 10.1.2007

There have been a large number of studies examining the scope for using biomass, including wheat and cereal-derived products for biofuels.[186] [187] [188] One report for the Home Grown Cereals Authority (HGCA) [189] examines the potential for diverting the 3 million tonnes of cereals currently exported to biofuel production instead. Taking into account the fertiliser inputs to the cultivation process this particular report concludes that the greenhouse gas intensity of bioethanol from wheat is only 36% of the equivalent calorific value of petrol. Rape-derived biodiesel is 47% of the greenhouse gas intensity of diesel.

A subsequent report for the HGCA concludes that 2-3 million tonnes of biofuels (biodiesel and bioethanol) could be produced in the UK '*without disruption of land use or existing habitats*'.[190]

Figure 23: Net greenhouse gas savings from wheat bioethanol compared with petrol/diesel



Source: *Carbon life cycle analysis: What is the net contribution of bioenergy to CO_2 abatement?*, Presentation given by Nigel Mortimer, Northern Energy at "Bioenergy – Green Gold?" a Conference held by Defra and the Agricultural Economics Society, London, 31 January 2007

To this might be added all the agricultural residues such as straw and spent brewers grains which are currently fed to animals. Using these residues to co-fire the combustion process significantly improves the greenhouse gas efficiency of biofuels

[186] Elsayed M A, Matthews R and Mortimer N.D (2003). *Carbon and energy balances for a range of biofuels options*, Project number B/B6/00784/REP URN/03/836, Resources Research Unit, Sheffield Hallam University, report commissioned by the Department for Trade and Industry

[187] *Well-to-Wheel Evaluation for Production of Ethanol from Wheat: A Report by the Low CVP Fuels Working Group*, WTW Sub-Group, FWG-P-04-024, October 2004

[188] Woods, J and Bauen A. (2003). *Technology Status Review and Carbon Abatement Potential of Renewable Transport Fuels in the UK*, DTI New and Renewable Energy Programme, Department for Trade and Industry

[189] Turley D, McKay H and Boatman, N (2005). *Environmental impacts of cereal and oilseed rape cropping in the UK and assessment of the potential impacts arising from cultivation for liquid biofuel production*, Research Review No. 54, Home Grown Cereals Authority

[190] Billins, P, Woods J and Tipper R. (2005). *Developing Carbon and Greenhouse Gas Assurance for Bioethanol Production in the UK*, NF1105, Home Grown Cereals Authority, November

production. Such a move would mean that either the production of dedicated cereal crops for livestock feed would need to increase, or the number of livestock our agricultural system could support would fall.

More radically still, it would be technically possible to use the cereals currently grown for animal feed as a biofuels feedstock. Indeed, the lower protein content of animal feed (and high carbohydrate content) lends itself well to this purpose.

There many ways in which biofuels and livestock production complement each other. During bioethanol production, alcohol is produced, leaving a residual product rich in protein, fibre, various micronutrients and yeast. This then could lead to an increased supply of domestically produced high protein feeds, which in turn could partly offset imports of soy or home production of protein crops such as field peas and beans. On the other hand there could be a reduction in the availability of carbohydrate rich feedstuff (e.g. cereals) that, as highlighted in Section 2 is also essential to the diet of farmed animals.[191]

In short, feeding crops to livestock is not necessarily the only use for the cereals (and oilseeds – discussed later in this section) that we grow. The physical potential for using feed cereals for other purposes certainly exists and as the price of petroleum oil increases so the economics may well swing more in the direction of biofuel production.

This is by no means a good thing, environmentally speaking. There are very considerable environmental concerns associated with the use of crops for biofuel.[192] It seems very likely that ever more vulnerable and biodiverse habitats will be destroyed, particularly in the developing world, as more and more land is taken over for monocultural production of biofuels.[193] [194]

One approach to this concern might be to argue strongly the case for the UK investing considerably in domestic biofuels production to avoid the need to buy in palm and soy-based biofuels from Asia and South America. Given the size of the UK and the land available, however, domestic biofuels production is never going to make much of a dent on our demand for fuel.

In addition to the devastating impact on fragile habitats, considerable energy is required both to produce the nitrogen fertilisers needed, and for the subsequent conversion of the grains into biofuel. One study finds that when the extra nitrous oxide emissions from biofuel production are calculated in CO_2-equivalent global warming terms, and compared with the quasi-cooling effect of “saving” emissions of fossil fuel-derived carbon dioxide, the outcome is that the production of commonly used biofuels, such as biodiesel from rapeseed and bioethanol from corn (maize), can contribute as much or more to global warming by nitrous oxide emissions than to cooling by fossil fuel savings.[195]

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[191] Adrian Williams, Cranfield University, pers. comm., July 2007

[192] Doornbosch R and Steeblik R (2007). *Biofuels: Is the cure worse than the disease? Paper prepared by the Roundtable on Sustainable Development for the OECD*, September 2007, Paris

[193] Scott Wilson, IISD and John Clement (2007). *Sustainable Commodities: A report to the Department for Environment*, Food and Rural Affairs. Contractor name. Defra, London.

[194] *The use of palm oil for biofuel and as biomass for energy: Friends of the Earth's position Briefing*, Friends of the Earth, August 2006

[195] Crutzen PJ, Mosier AR, Smith KA, Winiwarter W. (2007). N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels *Atmospheric Chemistry*

4.2.b Oilseeds

Oilseeds are both protein and energy dense and as such they play a very important role in the diets of all livestock. Note that although there is a slight difference between the terms cake or meal, for the purposes of simplicity, they are used here interchangeably. Oilseeds are rarely consumed whole; instead livestock eat the cake or meal which is the residue of the oil extraction process.

In the EU-25 as a whole, oilseed cake or meal made up 27% of compound animal feed.[196] Defra figures for the UK put the share at approximately 26%.[197] Oilseeds will also be consumed in 'straight,' uncompounded form.

Soy, rapeseed, cottonseed and sunflower seeds are the most important oilseeds used in animal feed as Table 8 shows.[198]

Table 8: World oilmeal/cake production (1991-2001)

	Million tonnes	% of total
Total meals	174.2	100
Soybean cake	106.3	61
Rape and mustard cake	20.4	11.7
Cottonseed cake	12.6	7.1
Sunflowerseed cake	10.7	6.1
Groundnut cake	6.8	3.9
Palmkernel cake	3.3	1.9
Copra cake	1.8	1
Sesameseed cake	0.8	0.4
Fish meal	0.7	0.4
Meat meal	0.7	0.4
Oilseed cakes, other	10.0	5.7

Source: FAO stat cited in *The role of soybean in fighting world hunger*, FAO Commodities and Trade Division, Basic Foodstuffs Service, study based on a paper presented at the VIIth World Soybean Research Conference held in Foz do Iguassu, Brazil, 1-5 March 2004. The paper was prepared by P. Thoenes, et al., of the FAO

Soy is clearly the most significant of these, accounting for over 60% by weight of total oilseed cake produced globally. The United States Department for Agriculture estimates for 2002 put the figure higher still at 69%.[199] In the EU feed sector, soy

and Physics Discussions 7, 11191–11205, 2007 www.atmos-chem-phys-discuss.net/7/11191/2007/

[196] European Feed Manufacturers' Association (FEFAC) http://www.fefac.org/doc/FEFAC%20newsletter1_march05.pdf accessed 11 May 2005

[197] *Raw materials usage in retail production of animal feedingstuffs in Great Britain*, Defra, 2006/7 Figures

[198] It has not proved possible to find more recent figures

[199] Cited in *Proteins From Oilseeds* Nick Bajjalieh, paper presented at FAO workshop *Protein Sources for the Animal Feed Industry*: Expert Consultation and Workshop Bangkok, 29 April - 3 May 2002, FAO 2002

accounts for 65 % of all proteins used, although only 2% of soy used is EU-grown.[200] Europe is in fact the world's single largest importer of soybean meal and second-largest importer of soybeans.[201]

At the UK level, Defra figures put soy's share of total oilseeds in compound feed at a slightly lower 40%, but evidently soy still dominates over other oilseeds.[202] Non-EU soy imports (mainly from South America) account for 75% of the UK's oilcake imports and 24% of total feed imports.[203]

A full discussion of oilseeds consumed by livestock would need to cover all the oilseeds produced. However, owing to time and resource limitations we focus here specifically on soy. Soy merits particular attention because it is associated with certain second order environmental impacts which are not always accounted for in traditional life cycle analysis.[204]

Specifically this section seeks to address three questions:

- How important is soy in the diet of livestock, and in the human diet, and why?
- What is the relationship between demand for soy oil, for soymeal and for meat?
- What are the broader issues as regards soy production and the emission of greenhouse gases?

It should be noted at the outset that there will be no discussion of the GM debate, important though this issue may be. What is of concern here is the relationship between soy oil and soymeal/cake production and the implications for quantifying emissions from the ruminant livestock sector.

The importance of soy in the diet of livestock and humans.

Ultimately, decisions as to the precise protein make up of animal feed are based on a compromise between the price of the protein commodities, and the nutritional requirement: this last can vary not only between species but also within species – say between a high and a low yielding dairy cow.

This said, and as the figures above show, soy is a very important element in the diet of livestock since soybeans have several practical and nutritional advantages over other oilseeds. Compared with rape seed (which can be and is grown in the UK) soy has a higher protein and lower fibre content. Soy is also less oily and more protein-rich than other seeds and so the extraction process produces a relatively greater proportion of cake to oil.

In particular, soy is the preferred ingredient for pig and poultry diets as it contains a better mix of the essential amino acids needed by animals (mainly higher lysine) which makes it more digestible – an important consideration for monogastrics. In ruminant diets, rapeseed is more commonly substituted because it is cheaper and

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[200] *Feed and Food Statistical Yearbook*, 2005, FEFAC (European Feed Manufacturers' Federation).

[201] Economic Research Service USDA, April 2005 http://www.ers.usda.gov/Briefing/SoybeansOilCrops/trade.htm

[202] Source: Raw materials usage in production of animal feedingstuffs in Great Britain, Defra 2006/7

[203] H M Revenue and Customs Data prepared by Trade statistics, Agricultural Statistics and Analysis Division, DEFRA

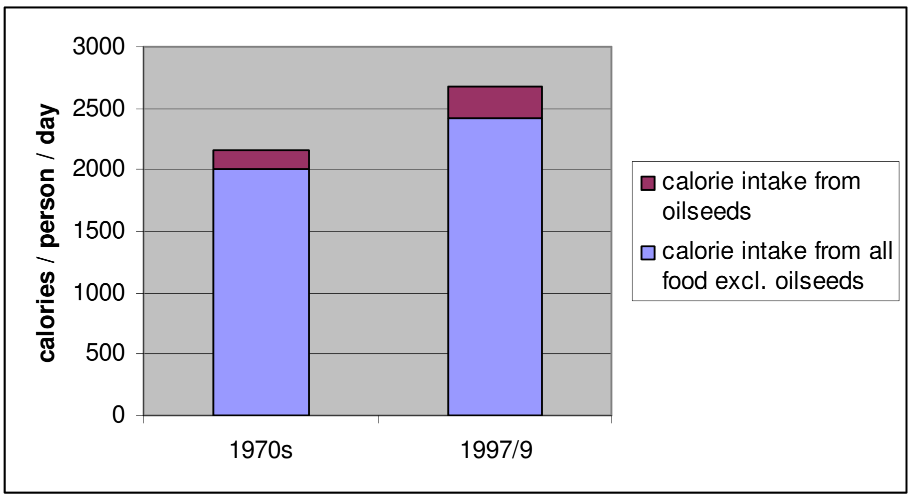
[204] Palmoil production has similar second order impacts, but is not discussed here as it is a far smaller player than soy on the animal feed market

achieving a specific amino acid mix is less of an issue. Ruminants can also cope with certain anti-nutritional properties in rapeseed (these are also being bred out of the crop).[205]

Soy also has great importance in the human diet. It is the single most widely consumed vegetable oil worldwide, accounting for 20% of global vegetable oil production.[206] Some soy products such as tofu, tempeh, meat substitutes, soy milk (including infant formula) soy flour and so forth are also consumed and soy protein is also included in a range of household foods such as bread and ready meals.

Soy products have a very high protein content and many studies suggest that they confer a range of other benefits. There are, however, also some studies suggesting that soy consumption, particularly by infants, may have effects that are poorly understood and which may be negative.[207 208] Whatever the merits or otherwise of soybean products, however, the vast majority of soy is consumed in the form of oil and here, as with other vegetable oils, its contribution is largely one of calories and fat. Some of this oil is used for cooking in private homes. Its main use though is as a key fat ingredient in industrial food manufacturing, where, closely followed by palm oil, it is the most commonly used fat.

Figure 24: Changes in relative contribution of oilseeds to per capita calorie intake in the developing world



Source: *World agriculture: towards 2015/2030, An FAO perspective*. FAO, Earthscan, UK 2003

Soy oil and oilseeds in general have made a major contribution to increasing food consumption in the developing world. In the mid-1970s, for instance, oilcrop

[205] Zoe Davies, Defra, pers. comm., April 2007
[206] *The role of soybean in fighting world hunger*, FAO Commodities and Trade Division, Basic Foodstuffs Service, study based on a paper presented at the VIIth World Soybean Research Conference held in Foz do Iguassu, Brazil, 1-5 March 2004. The paper was prepared by P. Thoenes, et alia, of the FAO
[207] Sharpe R M, Martin M, Morris K, Greig I, McKinnell C, McNeilly and Walker M. (2002). Infant feeding with soy formula milk: effects on the testis and on blood testosterone levels in marmoset monkeys during the period of neonatal testicular activity, *Human Reproduction*, Volume 17, Number 7, pp. 1692-1703(12)
[208] *Phytoestrogens and Health*, Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment, Food Standards Agency, 2003

products supplied only 144 kcal/person/day, or 6.7% of the total availability of 2,152 calories of the developing countries. By 1997/99 oilseeds contributed 262 kcal to total food supplies, or 9.8% of a total which itself had risen to 2,680 kcal. In practice, just over 1 out of every 5 calories added to the consumption levels of people in developing countries comes from oilseeds.[209]

In the future, the calorific contribution of vegetable oils to the developing world diet is likely to be maintained and indeed to grow. The FAO[210] estimates that 44 out of every 100 additional calories in the period to 2030 may come from these products, and soy will account for a large proportion of this increase.

Notwithstanding its growing importance in the developing world, at the moment the vast majority of soy oil is consumed in the *developed* world. Average per capita availability of soymeal in developed countries is in fact over four times greater than in the developing world. And for those developing countries whose populations are officially classed as undernourished, soy consumption is very low indeed – less than half of that calculated for developing countries as a whole'[211] and roughly 8-10 times less than consumption in the developed world.

How much do we need soy? In the developed world there is no shortage of food and we are certainly not short of oils and fats in our diet. We already consume more oils and fats than recommended by the World Health Organisation/Food and Agriculture Organisation (WHO/FAO) guidelines,[212] a subject explored more fully in Section 5 below. Given the growth in the number of those classed as obese, there is a plausible argument to be made for actually reducing our consumption of soy oil, and of vegetable oils in general. This has relevance for the discussion that follows regarding the relationship between soil oil, soymeal and livestock production.

Soy oil, soymeal and livestock production: exploring the relationship

The starting point here is the following question: Should soymeal be classed as a by-product of soy oil or a co-product; or indeed should it rightly be defined as the main output of soy production? If a co- or main product then this would suggest that demand for meat is actually driving growth in soybean cultivation. There is also the complicating factor of biodiesel to consider; soy and other oilseeds are increasingly being grown so that the oil can be converted into biodiesel.[213]

Measured by weight, every 100 kg of soybean yields 20 kg of oil and 80 kg of cake or meal.[214] We have already observed that soy produces a lower yield of oil but a relatively higher quantity of high quality protein than other oilseeds. While on a weight basis the oil is more valuable than the cake, in absolute terms the reverse is true, since the absolute amount of cake produced is so much greater than the oil.

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[209] *World agriculture: towards 2015/2030, An FAO perspective*. FAO, Earthscan, UK 2003
[210] *World agriculture: towards 2015/2030, An FAO perspective*. FAO, Earthscan, UK 2003
[211] *The role of soybean in fighting world hunger*, FAO Commodities and Trade Division, Basic Foodstuffs Service, study based on a paper presented at the VIIth World Soybean Research Conference held in Foz do Iguassu, Brazil, 1-5 March 2004. The paper was prepared by P. Thoenes, et alia, of the FAO
[212] *The role of soybean in fighting world hunger*, FAO Commodities and Trade Division, Basic Foodstuffs Service, study based on a paper presented at the VIIth World Soybean Research Conference held in Foz do Iguassu, Brazil, 1-5 March 2004. The paper was prepared by P. Thoenes, et al, of the FAO
[213] *Food Outlook No.4*, FAO, December 2004
[214] Nonhebel S (2004). On resource use in food production systems: the value of livestock as 'rest-stream upgrading system', *Ecological Economics* 48 221-230

The relative economic balance between soymeal and soy oil fluctuates, but as a general rule the cake and oil account for two thirds and one third of the crop's economic value respectively.[215] And while soy oil ranks in value as one of the less valuable vegetable oils (peanut, cottonseed, corn and rapeseed oils attract higher market prices), soymeal cake carries the highest value of the oilseed cakes.[216] Economically, therefore, soycake should by no means be classed as a by-product since it has very considerable economic value in its own right.

So does demand for the soycake as a feedstuff actually drive growth in soybean production? In short – yes. The FAO notes that the rapid rise in the demand for compound feed has contributed considerably, if indirectly to the rise in soybean and soy oil production.[217] The International Food Policy Research Institute states that '*Feed demand has been the most dynamic source of growth [in soy production*]',[218] and this view is shared by the WWF[219] and other observers.[220]

This said, there are other drivers behind the growth in soybean production too. As we note, the recent surge in petrol prices is spurring growth in oilseed production for biofuels. According to private sector estimates, globally, some 10% of vegetable oil production (mainly soy and rape) could be used for biofuel during 2006/7.[221] Rapeseed oil, the second most important oilseed as regards animal feed is particularly important as a biofuel. Hence while growth in demand for meat has historically driven growth in soybean cultivation, it is possible that the situation will change in future years. On the other hand, since the oil yield for soy is lower than for other oilcrops, livestock may continue to provide the major impetus for cultivation of this particular oilcrop.

Interestingly the growth in biofuels production could have both positive and negative consequences for livestock farmers. Higher crude oil prices will increase the cost of farming in general, including livestock farming. On the other hand, the growth in biofuels may increase the availability of animal feed, as and when the by-products of the biofuels production process achieve a consistent and desirable quality.[222] At present, however, growing demand for cereals and oilseeds for biofuels production is driving up prices and as such is a major concern for livestock farmers.[223]

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[215] December 2004 Oilcrops market assessment, http://www.fao.org/ES/ESC/en/20953/21017/index.html FAO, site accessed 27 April 2005
[216] Oil World Statistics www.oilworld.biz
[217] *The role of soybean in fighting world hunger*, FAO Commodities and Trade Division, Basic Foodstuffs Service, study based on a paper presented at the VIIth World Soybean Research Conference held in Foz do Iguassu, Brazil, 1-5 March 2004. The paper was prepared by P. Thoenes, et alia, of the FAO
[218] *Global Food Projections to 2020: Emerging Trends and Alternative Futures*, Rosegrant M. W., M. S. Paisner, S. Meijer, and J. Witcover. 2001. Washington D.C.: International Food Policy Research Institute. http://www.ifpri.org/pubs/fpr/fpr30.pdf
[219] Bickel U and Dros J M (2003).*The Impacts of Soybean Cultivation on Brazilian Ecosystems*, Ulrike Bickel and Jan Maarten Dros, WWF, October 2003 http://www.panda.org/downloads/forests/impactsofsoybean.pdf
[220] Shwedel K, Reca A and Scaff R. (2005) *The Oilseed Industry: Surviving in a Changing Competitive Environment*, Kenneth, Alejandro Reca, Ricardo Scaff, Rabobank, http://www.rabobank.com/Images/Rabobank_The_Oliseed_Industry_2005_Shwedel_January 2005_tcm25-12245.pdf
[221] *Food Outlook No.4*, FAO, December 2006
[222] Opportunities and Implications of Using the Co-Products from Biofuel Production as Feeds for Livestock, Home-Grown Cereals Authority English Beef and Lamb Executive & British Pig Executive, April 2007
[223] OECD-FAO *Agricultural Outlook 2007-2016*, OECD/FAO, 2007

Soy and greenhouse gas emissions

Emissions from soy arise both from the agricultural process itself and from its contribution to (among other things) deforestation and the ensuing emissions. We do not attempt to quantify these emissions; instead the following paragraphs discuss what issues might need to be considered when making such a calculation.

In the right context, soy cultivation serves a valuable environmental function. For small holder farming, soy is important in crop rotations since as a legume, it has nitrogen fixing properties.[224] Soy cultivation therefore improves soil fertility, increases the yield of other crops and reduces the need for other fertiliser inputs.

However, the amount of soy produced by smallholders is negligible when compared to the output of highly intensive and industrialised soy farmers. Four countries – USA, Brazil, Argentina and China – account for almost 90% of world output.[225] Asia (excluding China) and Africa, the two regions where most of the food insecure countries are located (and where small-scale soy production is most likely to be found), together account for only 5% of production.

Growth in US soy production is now slowing due to limits on the amount of land available. The major areas of soy expansion, therefore, are in South America, China and India. Of these, South America is by far the most significant and it is here that soy production's environmental – and more specifically greenhouse gas – impacts loom largest.

Brazil is the world's second largest producer of soybeans. It produces 24% of the world's soy output[226] (63% of EU imports of soy come from Brazil,[227] largely because of its GM-free credentials) and much of the environmental controversy surrounding this soy production relates to the 5.1 million square kilometre region called the Legal Amazonia.[228] This vast tract of land is of global environmental importance, with diverse and invaluable natural ecosystems, including one of the world's largest tropical rainforests, as well as an extensive area of savannah land – the 'Cerrado'. Legal Amazonia is also home to a significant and growing portion of Brazil's agricultural economy, including 31% of the nation's pasture, 30% of its beef cattle herd, 21% of its total agricultural land, and 27% of its cultivated soybean acreage.

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[224] *The role of soybean in fighting world hunger*, FAO Commodities and Trade Division, Basic Foodstuffs Service, study based on a paper presented at the VIIth World Soybean Research Conference held in Foz do Iguassu, Brazil, 1-5 March 2004. The paper was prepared by P. Thoenes, et alia, of the FAO

[225] USDA, Oilseeds – soybean 2006 http://www.pecad.fas.usda.gov/cropexplorer/cropview/CommodityView.cfm?startrow=1&cropid=2222000&selected_year=2006 accessed June 2007

[226] *The role of soybean in fighting world hunger*, FAO Commodities and Trade Division, Basic Foodstuffs Service, study based on a paper presented at the VIIth World Soybean Research Conference held in Foz do Iguassu, Brazil, 1-5 March 2004. The paper was prepared by P. Thoenes, et alia, of the FAO

[227] ISTA Mielke, Oil World Annual 2004, Hamburg, May 2004 cited in Jan Maarten Dros, *Managing the Soy Boom: Two scenarios of soy production expansion in South America*, WWF, June 2004 http://www.panda.org/downloads/forests/managingthesoyboomenglish_nbvt.pdf

[228] *An outlook on growth in Brazilian soy industry*, Brazilian Vegetable Oil Industries Association, (Abiove) presentation made at First Roundtable on Sustainable Soy Conference, 17-18 March 2005 http://www.responsiblesoy.org/downloads/7-Fabio Trigueirinho.pps accessed 26 May 2005

The Brazilian government has estimated that, since 1978, roughly 60 million hectares of forest land have been cleared from the Legal Amazonia region, the result of logging, mining, human settlement, construction of transport infrastructure, and the establishment of both subsistence and large-scale commercial agricultural enterprises.[229] This level of deforestation represents a loss of over 13% of the original ecosystem, as well as the fragmentation of a much larger portion of the rainforest.[230] In Brazil as a whole the land area under soybean cultivation nearly doubled in the last decade, rising from 11.7 million hectares in 1994 to 21.0 million hectares in 2003. Some of the highest growth rates were, and continue to be, in the frontier states encompassing Legal Amazonia.[231]

The Brazilian Vegetable Oils Industry Association (ABIOVE) points out that, at present, soybean production occupies only 1.2% of the total land area in Legal Amazonia and dismisses this as 'not significant.'[232] The USDA gives a higher figure – 4%.[233] However ABIOVE's conclusion can be challenged on two counts. The first is that soybean cultivation is forecast to grow rapidly over the coming decades. It is conservatively estimated that area used for cultivating soybean in the region could increase by more than 40 million hectares.[234] The WWF and others note that following its accession to the World Trade Organisation (WTO) China is poised to become a major importer of Brazilian soy,[235] [236] which could put further pressure on the sector and encourage unsustainable production practices, including in the Legal Amazonia region.

In 2004 the Brazilian government did in fact put in a range of measures to protect the rainforest and curb illegal deforestation and these have been effective so far in slowing down the rate of loss. It remains to be seen, however, how effectively these

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[229] Production Estimates and Crop Assessment Division Foreign Agricultural Service, USDA, January 2004 http://www.fas.usda.gov/pecad2/highlights/2004/01/Amazon/Amazon_soybeans.htm accessed 26 May 2005

[230] *Production Estimates and Crop Assessment Division Foreign Agricultural Service*, USDA, January 2004 http://www.fas.usda.gov/pecad2/highlights/2004/01/Amazon/Amazon_soybeans.htm accessed 26 May 2005

[231] *Production Estimates and Crop Assessment Division Foreign Agricultural Service*, USDA, January 2004

[232] *An outlook on growth in Brazilian soy industry*, Brazilian Vegetable Oil Industries Association, (Abiove) presentation made at First Roundtable on Sustainable Soy Conference, 17-18 March 2005 http://www.responsiblesoy.org/downloads/7-Fabio Trigueirinho.pps accessed 26 May 2005

[233] Production Estimates and Crop Assessment Division Foreign Agricultural Service, USDA, January 2004 http://www.fas.usda.gov/pecad2/highlights/2004/01/Amazon/Amazon_soybeans.htm accessed 26 May 2005

[234] *Production Estimates and Crop Assessment Division Foreign Agricultural Service*, USDA, January 2004 http://www.fas.usda.gov/pecad2/highlights/2004/01/Amazon/Amazon_soybeans.htm accessed 26 May 2005

[235] Rosegrant M. W., M. S. Paisner, S. Meijer, and J. Witcover (2001). *Global Food Projections to 2020: Emerging Trends and Alternative Futures*, International Food Policy Research Institute, Washington D.C http://www.ifpri.org/pubs/fpr/fpr30.pdf

[236] *Sustainability assessment of export-led growth in soy production in Brazil*, World Wide Fund for Nature, November http://www.panda.org/downloads/policy/soylongeng.pdf

measures will be enforced in coming years and how far they will be able to counter very strong forces for deforestation.[237]

The second point to mention is that soybean cultivation not only makes use of land in its own right, but is also an important 'push' factor for deforestation by other industries. In other words, although the area under soy production may not be enormous (at present) and may not take place directly on virgin rainforest, it takes land away from other uses, such as smallholder cultivation and cattle rearing, pushing these enterprises into the rainforest. As a highly profitable industry, it also provides income to purchase land for other purposes, including logging.[238] In other words, by acting as an important driver of deforestation in the region, soybean cultivation represents a serious threat to the Amazon environment.[239] [240] With public attention now focusing very heavily on soy and its environmental impacts, various industry players and non-governmental organisations have come together to form the Roundtable on Sustainable Soy. This body has been developing a set of criteria that can be applied to the responsible production, processing and trading of soy on a global basis.

How does all this relate to greenhouse gas emissions?

As with all major industrial crops, soy production and processing requires energy both directly for its cultivation (farm machinery, oil extraction and so forth) and for the production of fertilisers. Although soy is a legume and as such capable of fixing nitrogen directly from the atmosphere, other fertilisers are still applied to soybean crops, and nitrous oxide emissions via the processes of nitrification and denitrification will still occur. Hence some of the carbon dioxide emissions resulting from energy inputs as well as any nitrous oxide emitted should be attributed to soycake, and thus to the livestock who are its end consumers. This allocation process is normally undertaken in life cycle analysis.[241] [242]

However to these direct impacts should be added the indirect ones; the emissions of carbon dioxide that result from the land clearance required for soybean cultivation. Forests store carbon; deforestation releases it. As argued above, soy cultivation (with meat consumption as significant driver here) has been responsible both directly and indirectly for the destruction of tracts of carbon-storing rainforest and savannah land.

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[237] Nepstad D C, Stickler C M, Almeida O T (2006). Globalization of the Amazon Soy and Beef Industries: Opportunities for Conservation, *Conservation Biology* Volume 20, No. 6, 1595–1603

[238] ISTA Mielke, Oil World Annual 2004, Hamburg, May 2004 cited in Jan Maarten Dros, *Managing the Soy Boom: Two scenarios of soy production expansion in South America*, WWF, June 2004
http://www.panda.org/downloads/forests/managingthesoyboomenglish_nbvt.pdf

[239] Woods Hole Research Centre http://www.whrc.org/southamerica/agric_expans.htm

[240] ISTA Mielke, Oil World Annual 2004, Hamburg, May 2004 cited in Jan Maarten Dros, *Managing the Soy Boom: Two scenarios of soy production expansion in South America*, WWF, June 2004
http://www.panda.org/downloads/forests/managingthesoyboomenglish_nbvt.pdf

[241] Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on www.silsoe.cranfield.ac.uk, and www.defra.gov.uk

[242] Nonhebel S (2004). On resource use in food production systems: the value of livestock as 'rest-stream upgrading system', *Ecological Economics* 48 (2004) 221-230

The carbon dioxide losses that result could be very considerable. Evidence suggests that changes in tropical land use (*not* total global land use) since the 1980s may account for a quarter of all anthropogenic carbon emissions, with the other three quarters resulting from fossil fuel use.[243] Soy as a driver of land use change in the tropics should therefore take responsibility for a share of the resulting carbon dioxide emissions. And a proportion of this should be allocated to the livestock sector since, as argued earlier, soybean production is heavily driven by demand for meat.

Quantifying the carbon emissions resulting from rainforest destruction as a result of the UK (or EU or global, depending on the scale chosen) livestock sector is not easy and is well beyond the scope of this paper. However any attempts to do so may need to consider the following questions:

- What share of rainforest loss should be assigned to soybean cultivation, based not only on its physical land take but also on its impact on other forms of land use?
- How should carbon dioxide impacts be calculated and to what extent should a historical approach be adopted (in other words taking into account rainforest destruction since the 1980s)?
- How should carbon dioxide emissions be allocated between soy oil and soybeans?
- What percentage overall do Brazilian soybeans make up of UK (or EU, or global) animal feed (perhaps broken down by livestock type) and how does this affect quantification of UK emissions from the livestock sector?

It should be noted that, with the exception of the FAO (2006) report, none of the life cycle analyses or other studies we have highlighted take the deforestation issue into account when quantifying livestock related greenhouse gas emissions.

The discussion here has focused solely upon soy as a major input to the UK animal feed sector. It is, however, also very important to note, as many commentators do, that cattle ranching is by far the most significant use of agricultural land in the Amazon. 86% of the agricultural land area is used for grazing livestock, and the USDA notes that this is likely to be an underestimate as known deforestation exceeds official government estimates.[244] Brazil is the world's largest beef exporter[245] and accounts for 13% of the UK's imports (Ireland being our main supplier).[246] Since a nearly a third of the beef we consume is imported, this means that Brazilian beef accounts for about 4% of the beef we consume.

Finally, it is interesting to note that there is another twist to the relationship between soy and meat consumption. The WWF notes[247] that European demand for soy has grown since the EU banned the use of meat and bone meal in animal feed.

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243 Houghton, R.A. **(**1999). The annual net flux of carbon to the atmosphere from changes in land use, 1850-1990. *Tellues Series B – Chemical and physical meteorology*, 51(2): 298-313

244 *Production Estimates and Crop Assessment Division Foreign Agricultural Service*, USDA, January 2004 http://www.fas.usda.gov/pecad2/highlights/2004/01/Amazon/Amazon_soybeans.htm accessed 26 May 2005

245 Food Outlook: Global Market Analysis, Food and Agriculture Organisation December 2006 http://www.fao.org/docrep/009/j8126e/j8126e10.htm

246 Meat and Livestock Commission UK Beef Market Trends, 2006 figures http://www.mlc.org.uk/news/beefmarkets.asp

247 *Sustainability assessment of export-led growth in soy production in Brazil*, World Wide Fund for Nature, November http://www.panda.org/downloads/policy/soylongeng.pdf

Alternative proteins needed to be found and soy has proven to be a highly suitable substitute. The issue is discussed further in the section on rendering, below.

4.2.c By-products

A wide range of by-products from other agricultural sectors are also used as animal feed. These include molasses cake (from cane or beet sugar production) spent hops and brewers grains, vegetable residues, citrus pulp, straw, rice husks, bagasse (spent sugar canes) and so forth. Until recently catering waste from schools, restaurants and so forth was fed as swill to pigs. However a national ban was introduced in 2001 following the Foot and Mouth Outbreak as part of a tightening of biosecurity measures since 2003 an EU ban was introduced under the Animal By-products Regulation (EC) No. 1774/2002.

Some by-products are rich in sugar or protein, but many are very fibrous and simply bulk out the diet. In total, by-products constitute about a third of all compound animal feed,[248] but the proportion will vary by animal type and according to the feed formulation. Pigs for example will not be able to digest the more fibrous by-products and so these tend to be given to cattle. There is very little by-product content in chicken feed.

There can at times be a conflict between the goals of improving feed efficiency and those of making use of available by-products. Where livestock are fed on dedicated feedstuffs, energy will be used and both carbon dioxide and nitrous oxide will be emitted during the course of its cultivation. By-products on the other hand, are less emission intensive since the bulk of impacts can be allocated to the main product. On the other hand, some by-products will be fibrous and hence induce higher enteric methane emissions in the ruminant livestock that consume them.

We consider here two questions with respect to by-products. The first is: how much livestock production do such by-products actually support? And second, are there, or could there be alternative uses for these by-products which might have merit in terms of greenhouse gas emission reductions?

It has already been noted that by-products constitute about a third of compound feed in the UK. Since 'straights' fed to livestock tend not to be by-products (we do not classify oilcakes as a by-product) the overall proportion of by-products in the diet is actually fairly low.

At a global level, Fadel[249] attempts to quantify how much of a contribution by-products could theoretically make to dairy farming and milk production. Using FAO 1993 data, he quantifies the global production of 24 selected by-products which he divides into three groups:

1. Crop residues: Straw and husks from wheat, maize, rice and barley
2. Oilseed residues: Soy, cottonseed, rape, palm kernel, sunflower and sesame
3. Miscellaneous: Almond hulls, bagasse, citrus pulp, molasses and so forth

Note that we have already suggested above that oilseeds cannot justifiably be called by-products.

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[248] Source: Raw *materials usage in production of animal feedingstuffs in Great Britain*, Defra 2005 http://statistics.defra.gov.uk/esg/datasets/hstcomps.xls

[249] Fadel, J. (1999) Quantitative analyses of selected plant by-product feedstuffs, a global perspective. *Animal Feed Science and Technology* 79, 255–268

For each of these 24 crops, Fadel specifies their various nutritional characteristics such as dry matter, metabolisable energy (based on ruminant metabolic systems) and their crude protein content, doing so both on a country and on a global basis.

He then goes onto calculate the amount of milk that could be produced from the use of by-products alone as animal feed. It is important to note that for this calculation he excludes the category 'crop residues' as well as bagasse and soapstock oil; all other by-products are included. His rationale for making these exclusions is that crop residues and bagasse have very low nutritive value. Straws tend to be used as bedding and will only be used as ruminant feed if other feeds are not available. Bagasse is also used as a feedstock to fuel the sugar refining process. Soapstock oils are used to make soap.

Using these data, and bearing in mind these exclusions, Fadel calculates that the energy from world-wide plant by-product feedstuffs is sufficient to support the production of 435 million metric tonnes of milk. By including bagasse the volume could top 500 million tonnes. Presumably – although the study does not mention this – the dairy cows could also be eaten once their milk supply stops although the meat would be of poor quality and in many parts of the world there would also be religious and cultural prohibitions in place.

In 1993 global cow milk production was 460 million tonnes (compared with 523 million tonnes in 2004).[250] [251] Thus the nutritional content of by-products could in theory cover the production of 80% of that year's total milk output. On the other hand, if soy and other oilseed cakes are excluded, the volume of available by-products drops by about 25%.[252] Defined in terms of nutritional value, availability is lower still.

Importantly, the study does not model the impacts that different types of by-product feed would have on methane emissions from enteric fermentation. The impact will of course very much depend on the type of by-product being fed. Very bulky fibrous by-products will be methanogenic. On the other hand, where a certain by-product actually replaces a fibrous feedstuff such as hay, its use may in fact lead to a reduction in methane emissions.[253]

What is more, the by-products may be produced at some distance from the stomachs they are intended to fill. Fadel did not consider the environmental impacts of transporting by-products[254] and whether these would outweigh the benefits of by-product utilisation. This clearly would need to form part of full analysis.

Finally, the paper does not consider the opportunity cost of using by-products for feed; that is, the possibility that they could be used a feedstock for biofuels production instead. Options include burning the waste for heat or anaerobically digesting them to produce methane. Some crop residues are in fact already being used as biofuels in the developing world and research is ongoing to develop ways of extend their use. As highlighted, bagasse often provides a fuel source for the sugar refining process and there is often spare left over for fuelling other activities. Rice husks and cassava straw can also be used. Biofuel generation from waste fruit and vegetable manufacturing is also possible, but at the present their use is limited due to

[250] http://faostat.fao.org/site/410/DesktopDefault.aspx?PageID=410 accessed 1/08/07
[251] Note that 2004 is the most recent year for which FAO provides aggregated global data.
[252] Fadel J, pers. comm., 2006
[253] Fadel J, pers. comm., 2006
[254] Fadel J, pers. comm., 2006

the high cost of material collection and transport.[255] In the UK considerable policy attention is now being placed on the scope for on-farm and other forms of anaerobic digestion for agricultural and food waste.[256]

As with the by-products for feed question, we need to know how much energy these crops could actually generate. We are not aware of any studies that look specifically at this. However, one Defra-commissioned UK study calculates that if agricultural crop waste, food waste, manures and green waste were treated through thermal processing technologies and/or anaerobic digestion, they could generate between 349 and 3,236 MJ-eq per tonne.[257] Once again transport considerations come into play; any treatment system would need to be fairly localised or the transport costs, both environmental and economic, would probably outweigh any savings.

A particular consideration for the developing world is whether the local population would benefit more from livestock rearing or from energy generation. Unfortunately a full consideration of this question is beyond the scope of this study but it is likely that the answer will be highly context specific.

In short then, ruminants do indeed make use of crop residues and other agricultural by-products. However current levels of livestock production can not be sustained on by-products alone and there may at times be trade offs between the goals of utilising by-products and of reducing methane emissions (discussed in more detail below). In addition, the potential for using by-products as a feedstock for biofuels, instead of for animal feed, needs also to be considered.

4.2.d Grass and pasture

Ruminants have a major advantage over other farmed animals: They can utilise grass whereas other animals cannot.

However, grass is not a 'free' resource. It, like all other kinds of managed land, receives inputs, such as fertiliser, both from organic and inorganic sources. There are also, as we discuss, other environmental impacts associated with pasture land that have a bearing on greenhouse gas emissions. In the winter months, cows and beef cattle also eat grass in its fermented form as silage, a process which requires additional energy to produce.

As regards inputs, most grassland (excluding rough grazing land) receives mineral and/or organic nitrogen and other fertilisers, with the amount applied varying by site, by type of livestock being grazed and by the age of the grass. Generally speaking, grass under five years old receives higher applications than more established grass. Application rates are very slightly lower than those applied to wheat.[258] Of the total 18.4 million hectares of agricultural land in the UK, around 6.9 million hectares, or 37%, is classed as grassland for grazing, herbage or silage production. This figure

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[255] Sriroth, K. *Outlook of biomass utilization as biofuel in Thailand*, Cassava and Starch Technology Research Unit, Kasetsart University, Bangkok, Paper presented in Biomass-Asia Workshop 2005. January 19-21, 2005. Tsukuba City, Japan.
[256] *UK Biomass Strategy*, Defra, Department for Trade and Industry and Department for Transport, 2007
[257] *Carbon Balances and Energy Impacts of the Management of UK Wastes* Defra R&D Project WRT 237, Final Report, ERM December 2006

[258] *The British Survey of Fertiliser Practice: fertiliser use on farm crops for crop year 2002*, Defra / Scottish Executive 2003

excludes land given over to rough grazing. As such, through its dependence on fertilisers, grazing land makes a contribution to greenhouse gas emissions additional to those generated by the livestock themselves.

Where land is overgrazed, there are additional problems since overgrazing is responsible for lost carbon sequestration and hence greenhouse gas emissions. While overgrazing is certainly a problem in some parts of the UK, the problem is particularly acute in many areas of the developing world. The demand for grazing land and for the cultivation of animal feed have been major drivers for deforestation and land clearance[259] and this clearly has implications for the emission of greenhouse gases, as discussed above. Indeed the FAO estimates that livestock-related land use change leads to the release of 2.4 billion tonnes of carbon dioxide a year, equivalent to approximately 7% of global greenhouse gas emissions.

On the other hand, in the UK at least, many observers note that the rearing of ruminants on grassland makes use of land that is not suitable for other purposes.[260] Certainly cereals could not be grown in many areas currently put to grass, at least not to any commercially viable extent, since soils tend to be shallow to cultivate or the gradient too steep for tractors. But could such land instead be used to grow biomass for fuel?

This is an area that has not been studied in any great depth. Initial comments by Rothamsted Research indicate that some upland could indeed be used for biomass production; either the naturally occurring biomass could be harvested, or dedicated biomass crops such as short rotation coppice willow could possibly be grown.[261] Yields, and hence income, are likely to be low; however, if increasing demand for non-fossil fuel alternatives pushes up the price of biomass, so the minimum yield needed to make the crops profitable will fall. On the other hand, with low yields, the quantity of greenhouse gases emitted during the course of harvesting and transporting the biomass might be such that it is not worth it, environmentally speaking.

A major unknown, however, is the extent to which cultivating these upland areas could lead to significant carbon dioxide emissions from the soil. Grasslands sequester large quantities of carbon. If livestock were simply removed from grasslands and the land left to revert to wilderness, the carbon would continue to be accumulated in the soil. But any change of activity that disrupted the soil surface would result in carbon losses. One might argue, then, that by keeping pasture land in economic use, livestock help sequester carbon. Were the livestock to be removed from this land, and the land put to alternative uses, there is a risk that carbon will be taken out of the soil and returned to the atmosphere.

The issue is, however, primarily one of economics. At present, livestock grazing on grassland makes carbon sequestration 'pay'. No other use will, at present. The

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[259] de Haan C, Steinfeld H and Blackburn H (1997). *Livestock grazing systems & the environment: Finding a balance*. Paper presented at the *Livestock Systems and the Environment* conference, organised by the Commission of the European Communities, Food and Agriculture Organization of the United Nations, World Bank, 1997

[260] Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on www.silsoe.cranfield.ac.uk, and www.defra.gov.uk

[261] Andrew Riche, Rothamsted Research, pers. comm., May 2007

question that may need asking is whether it is possible to put this grassland to any other use that is both viable and carbon sequestering.

As it stands, there may well be a useful area of 'lower-upland' that could be exploited for bioenergy, but there will still be large areas where biomass production is not viable, both from an economic and greenhouse gas/energy cycling perspective.[262] This would suggest that – short of abandonment – continued grazing is for now the only realistic option. Ironically, observers suggest that that next few years are likely to see hill sheep, beef and dairy production moving out of the uplands and into the lowlands, where farming is more profitable.[263]

4.3 Land

This discussion about pasture land and alternative land uses opens up a much wider debate about all land – both pasture and arable – that is currently used for feeding animals. Could land that is presently used for one purpose be better used for another? By better we mean in a way that helps reduce carbon dioxide emissions while providing us with some of the goods we need.

To some extent we have already considered this question in relation to cereals and grassland. However the issue does merit further and more general consideration. The combined effects of a changing climate and increased population pressure mean we need to reassess very strategically the uses to which land is put, taking into account not just economic trends but what is environmentally optimal.

The possibility of using the land differently is defined by Berlin and Uhlin as the opportunity cost, a concept which is, the authors argue, currently lacking in classical life cycle analyses.[264]

The authors go on to say that *'Different use of land is associated with different benefits but also with costs. In a decision-making situation the cost of employing a given asset can, according to the opportunity cost principles, be established by estimating the highest-valued opportunity that must be foregone or lost. The most appropriate measure when calculating the opportunity cost of different land use is accordingly the utility that could be derived from an alternative use. This is often expressed in monetary terms but … can also be expressed in, for example, reduced amount of greenhouse gases released'*.[265]

Bearing in mind this opportunity cost principle, the following paragraphs explore two questions:

[262] Andrew Riche, Rothamsted Research, pers. comm., May 2007
[263] Agricultural Change & Environment Observatory Programme OBS 04: *The environmental implications of the 2003 CAP reforms in England : Synthesis report from external observatory projects OBS 01,02,03*, report prepared for Defra by the Central Science Laboratory, York and the Countryside and Community Research Unit, University of Gloucestershire
[264] Berlin D, Uhlin H-E. (2004). Opportunity cost principles for life cycle assessment: toward strategic decision making in agriculture, *Progress in Industrial Ecology*, Vol. 1, Nos. 1/2/3, 187
[265] Berlin D, Uhlin H-E. (2004). Opportunity cost principles for life cycle assessment: toward strategic decision making in agriculture, *Progress in Industrial Ecology*, Vol. 1, Nos. 1/2/3, 187

4.3.a Could the land currently use for livestock be cultivated or managed in ways which helps reduce the emission of greenhouse gases?

It has already been suggested above that land currently devoted, either directly or indirectly, to livestock production could in fact be used for other purposes. These include biofuels or biomass production on areas currently devoted to cereals and (to a lesser extent) on grazing land.

A relevant study by Nonhebel[266] examines three hypothetical systems for producing both protein for human consumption and biofuels for energy and assesses which of the systems requires least use of land. She looks at land take rather than energy use or greenhouse gas emissions but her approach is useful because it takes on board the opportunity cost principle and her method could readily be applied to greenhouse gas emissions.

In the first livestock-based system she examines the waste streams – which the paper terms 'rest-streams' – from other agricultural processes that are used to feed pigs. A certain amount of additional land is also allocated to energy crop production.

The second system is livestock free. The rest-streams from other agricultural processes are used to generate biofuel rather than for feed. To meet human protein requirements an additional portion of land is used to grow protein crops.

In the third system, dedicated feed crops such as cereals are grown to feed the pigs. The rest streams from other agricultural processes are then used as biofuels.

As a basis for calculating protein consumption levels Nonhebel uses current Dutch recommended levels for meat consumption (100 g/day).[267] She also assumes current average Dutch oil and sugar consumption patterns; she allocates their waste streams to animal feed in system one (note that we have already questioned the assumption that oilseed cake is a genuine by-product) and to biofuel production in systems two and three.

Note that this is clearly a simplistic model. Plant- and meat-based proteins are not automatically substitutable (as we discuss in Section 5 below) and for livestock, there will be nutritional differences between a diet based on by-products and one based on dedicated feedcrops.

Given these parameters Nonhebel calculates that the rest streams associated with sugar beet and vegetable oil consumption are capable of providing 90 g out of the 100 g of recommended daily meat consumption (actual Dutch meat consumption levels are slightly higher at 120 g). It is important to note that the WHO recommends lower sugar and fat intakes than those actually consumed in the Netherlands,[268 269] which stand at 40 kg of sugar per person and 30 kg of vegetable oil (50 kg fats in total) a year.[270]

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266 Nonhebel S (2004). On resource use in food production systems: the value of livestock as 'rest-stream upgrading system', *Ecological Economics* 48, 221-230
267 She does not give a source for this recommendation
268 Srinivasan C.S, Irz X, Shankar B (2006). An assessment of the potential consumption impacts of WHO dietary norms in OECD countries, *Food Policy 31*, 53–77
269 Mazzocchi M & Bruce Traill W B. (2005). Nutrition, health and economic policies in Europe. *Acta Agriculturae Scand Section C*2: 138-149
270 Nonhebel S (2004). On resource use in food production systems: the value of livestock as 'rest-stream upgrading system', *Ecological Economics* 48 221-230

The study concludes that the land area requirements for the first two systems (using by-products for animal feed and livestock-free systems) are similar but that the system where crops are grown directly for feed require nearly 25% more land.

Importantly, Nonhebel emphasises several points in her discussion. First, she states that '*the production of vegetable oil is strongly intertwined with the production of feed. This implies that a part of the acreage attributed to oil production should be attributed to meat*' – something her study does not do but which would make a useful subject for further work. From a greenhouse gas perspective the corollary would be that a proportion of oilcrop production related emissions should be allocated to the animal feed.

Second, Nonhebel stresses that her conclusions are '*based on the assumption that oil consumption is not a subject for debate. When major changes in the oil or sugar consumption takes place, the whole system changes, and the function of meat as an upgrading system also changes'.* As noted before, she assumes for her calculations existing levels of oil and sugar consumption rather than recommended nutritional levels even though fat and oil consumption patterns in the Netherlands are higher than those recommended.

Hence, if lower levels of oils and sugars were consumed, the meat that could be produced from these by-products might also decline. Increased production of dedicated cereal feed inputs would then need to increase to supply the recommended meat consumption levels, which would in turn increase both the land needed for livestock production and greenhouse gas emissions resulting from inputs to the cereal production process. How the recommended meat consumption levels relate to broader protein and iron nutritional requirements is uncertain; the WHO does not make recommendations as to the quantity of meat consumed but rather the quantity of protein needed.

Finally, the Nonhebel paper also points to the critical importance of market prices in shifting the balance in favour of one system or another. It notes '*the price of energy is much lower than that of meat. When rest-streams of the oil [seed] industry are sold as an energy source, a far lower price will be gained….The vegetable oils prices [would] have to double to maintain the same financial returns within this branch of industry'*.

4.3.b Might the land be put to better use feeding people directly or for the production of other forms of livestock?

This second question is made up of several sub questions. How efficient is it to feed grain to animals and then animals to humans? What are the greenhouse gas implications of devoting land to livestock and its associated feed production compared with using it directly to grow plant crops for food? Do we have enough land to feed everyone and, more particularly, can we feed everyone on a meat-based diet? What, from a greenhouse gas point of view is the best way of meeting people's nutritional needs? Might it be more effective to feed cereals directly to hungry people? An attempt is made here to explore some of these questions.

It has been often argued that the cereals used to feed animals would be more efficiently and sustainably used to feed people directly.[271 272 273] Such arguments

[271] Goodland, R. (1997) Environmental sustainability in agriculture: diet matters, *Ecological Economics*, 23 189-200

often focus on more than just the energy aspect of the feed issue process; they also highlight our growing world population and the limits to the amount of land available for production. Since this paper is concerned primarily with greenhouse gas emissions, this discussion will focus only on the feed conversion efficiency issue.

Various authors have calculated the feed energy required to produce a calorie of animal protein. The feed conversion efficiency argument has a major bearing on the emission of greenhouse gases since losses of energy through the production chain – from fossil fuel inputs to plant nutrients to animal nutrients – represents a 'waste' of energy and hence 'unnecessary' emissions of carbon dioxide.

Cohen, for instance[274] assumes that 10 kcal of plant feed are required to produce 1 kcal of animal. Brown and Kane[275] calculate that feedlot cattle consume 7 kg grain, for every 1 kg of live weight they yield. Their figures for pork, poultry and fish are 4 kg, 2 kg and 2 kg respectively. Cheese and eggs require 3 kg and 2.6 kg of grain per kg of product. Goodland uses Brown and Kane's data to make similar points but notes where animals '*are restricted to recycling products (household scraps, peelings, agricultural residues) that would otherwise be wasted or would pollute, they must be ranked as efficient converters'*.[276]

However the feed conversion ratio has improved significantly over time. For broiler chickens reared in conventional farm systems it stands at 1.8 (at the finishing stage),[277] for eggs the conversion ratio is around 2[278] for while for finishing pigs (it is now 2.75.[279] The efficiency of beef cattle is much more difficult to estimate since much will depend upon the breed and the feeding regime. The feed conversion ratio can vary between 5 and 10.[280]

On the face of it, and looking just at livestock products, it appears that poultry and pigs are much more efficient converters of plant energy into animal energy, and, moreover, as monogastrics, produce far less by way of methane emissions. From a greenhouse gas perspective then, policies to encourage a switch to consumption of these products would appear to make sense and indeed, as Section 1 has shown, this is in any case the way trends are heading. But when trying to compare the greenhouse gas emissions of different animals it is important also to examine the second order impacts and lost opportunities resulting from the *type* of feed the animals consume.

Thus, while studies do indeed show poultry and pigs to be more efficient converters of energy into protein and to generate fewer greenhouse gas emissions than ruminants, it is also the case that their diet is cereal dependent to a far greater extent

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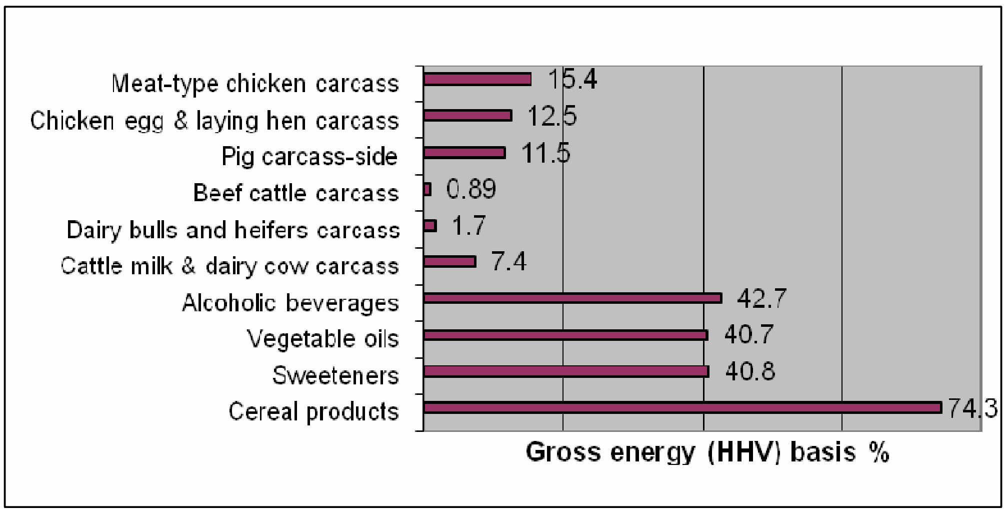
[272] Gold, M. (2004) *The global benefits of eating less meat*, Compassion in World Farming Trust, Petersfield, Hampshire.
[273] Gerbens-Leenes, P.W.; Nonhebel, S (2002). Consumption Patterns and Their Effects on Land Required for Food *Ecological Economics* 42 S. 185-199.
[274] Cohen J. 1995. *How many people can the earth support?* Norton, New York, p532.
[275] Brown L.R., Kane, H. 1994. *Full House: Reassessing the Earth's Population Carrying Capacity*. Norton, New York, p261.
[276] Goodland, R. (1997) Environmental sustainability in agriculture: diet matters, *Ecological Economics*, 23 189-200
[277] *Poultry UK*, Biffaward, 2006
[278] Chen Y.C. Nakthong Cand Chen T.C. (2005). Improvement of Laying Hen Performance by Dietary Prebiotic Chicory Oligofructose and Inulin *International Journal of Poultry Science* 4 (2): 103-108,
[279] *Pig Year Book 2007*, British Pig Executive, 2007
[280] Meat and Livestock Commission, pers. comm., September 2007

than that of ruminants. More so than ruminants then, pigs and poultry consume grains that could arguably be consumed by humans. This said, at current levels of production and yield, cereal feeding is essential to the diets of both monogastrics and ruminants and indeed as Table 7 has shown, ruminants in fact consume large volumes of cereals. A diet of grass and by-products alone would support a considerably smaller number of cattle.

Note that feed conversion efficiency is relevant only to the edible outputs of the livestock sector – meat, eggs and dairy products. It does not take into account the non-edible outputs of livestock production such as manure, leather, wool and so forth. If these are taken into account, the relative efficiencies might look quite different.

How do the conversion efficiencies of animal compare with plant products? Wirsenius[281] compares the conversion efficiency of a range of animal and plant foods and these are shown in Figure 25. The efficiency of plant-based foods is significantly higher than livestock products. Note that these are world averages – efficiencies in the UK will be greater for all these foods.

Figure 25: Average conversion efficiency of principle food sub-systems



Source: Wirsenius S (2003). *Efficiencies and biomass appropriation of food commodities on global and regional levels*, Agricultural Systems 77 219–255
Note: HHV: higher heating value. Conversion efficiency' is defined as product generated in a sub-system divided by the feed intake (animal commodities) or feedstock use (processed vegetable commodities) of the sub-system. Thus, it reflects the efficiency of the processes of converting phytomass into animal and processed vegetable food

The figures look striking. It is, however, important to note (as above) that they mask the fact that not all land is equally suited to all types of production. It may also be over-simplistic to argue that if we reared fewer animals we could grow more grain to feed people directly. The report *World agriculture: towards 2015/2030*,[282] observes that the '*use of cereals is often perceived as a threat to food security, since it appears to remove from the market supplies of essential foods that would otherwise be available to poor countries and families, thereby raising food prices. However, it*

[281] Wirsenius S. (2003). Efficiencies and biomass appropriation of food commodities on global and regional levels, *Agricultural Systems* 77 219–255
[282] *World agriculture: towards 2015/2030*, Summary report FAO, Rome, August 2002

is important to realize that if these cereals were not used as feed, they would probably not be produced at all, so would not be available as food in any case'.

The report goes on to argue that the use of cereals as feed may actually help food security. The commercial livestock sector is responsive to the price of cereals: Whenever shortages raise prices, livestock producers tend to switch to other feeds, releasing more cereals for food use – although note that this does not happen in the highly cereals dependent commercial pig and poultry sectors.[283] As a result, the report concludes, the availability of cereals for food may contract less than it would have done otherwise. In short, the use of cereals as feed serves as a buffer, protecting food intakes from supply variations. The FAO also predicts that demand for cereal feed for livestock will be slower than it has been, partly because the growth in demand for livestock products will not be as rapid and partly because most of the growth in demand for meat will be for pork and poultry products, which are more efficient converters of feed to protein, as highlighted above.

Keyzer at al.[284] take issue with the sort of conclusions expressed by the FAO's predictions. They argue that notwithstanding pricing structures, in future years it may well not be physically possible to feed enough livestock to meet demand. Per capita demand for meat is likely to rise faster than often suggested on the basis of fixed income elasticities[285] because in most developing countries a significant part of the population has just entered, or is on the verge of entering, the income bracket where a proportionately more significant fraction of income is spent on meat. The authors also argue that on the producer side, feed/meat ratios in developing countries will increase in the next decades, rather than fall as is commonly assumed in most projection models, notwithstanding predicted technological progress in feeding and crop yield increases. This, they argue is because the by-products and crop residuals that are traditionally used for animal feeds are becoming increasingly scarce and can no longer be regarded as a free input. As a result, more dedicated feed crops will be grown.

In conclusion the authors somewhat starkly state that compared with other factors that are generally expected to affect the future world food situation, such as the GM issue and the impact of climate change on agriculture, the significance of rising demand for meat will be greater still. They cite a study[286] which estimates the potential losses of cereal production as a result of climate change in 2080 of 105 million tons (sic). They then conclude that even if these losses came about earlier than expected (by 2030) the impacts would be minor compared with the projected livestock-driven 1900 million ton (sic) increase in demand for feed cereal.

Biofuels pose another serious source of competition. As the price of oil continues to rise, growing crops for fuel presents itself as an attractive alternative to growing crops for food – and for feed. There will, as discussed earlier, be both conflicts and synergies with the livestock sector, but future years are certainly likely to see conflicts

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[283] Zoe Davies, Defra, pers. comm. July 2007

[284] Keyzer M A, Merbis M D, Pavel I F P W, van Wesenbeeck C F A. (2005). Diet shifts towards meat and the effects on cereal use: can we feed the animals in 2030? *Ecological Economics* Volume 55*,* Issue 2, Pp 187-202

[285] The assumption that a rise in demand for meat will rise uniformly with income rises

[286] Fischer, G, Shah, M, van Velthuizen, H, andNachtergaele, FO, (2001). *Global agro-ecological assessment for agriculture in the 21st century*. International Institute of Applied System Analysis, Laxebburg.

between the use of land for food, for feed and for fuel, and different strategies will be adopted in different parts of the world.

SECTION 5: OUTPUTS FROM THE LIVESTOCK SYSTEM

The previous section looked at what goes into the livestock system and the complexities associated with attributing greenhouse gas emissions to these inputs.

This section looks at the outputs – at the edible and non edible, tangible and non tangible goods resulting from the ruminant livestock production. These include meat and dairy products, leather, wool, rendered products, manure and, less quantifiably (and for want of a better phrase) 'environmental services'. Each of these outputs is taken in turn, with the following questions running through as a common thread:

- What benefits do we gain from the livestock sector?
- Are all these benefits accurately accounted for in standard life cycle analysis?
- Do we need all these benefits and if so how much of them do we need?
- Might there be alternative ways of meeting our needs for these sorts of products and would greater or fewer emissions of greenhouse gas emissions result from such substitution?

We begin with looking at food.

5.1 Food – meat and dairy products

This section looks at the role of meat and dairy products in our diet. It begins by considering key WHO and national level nutritional guidelines with respect to protein, fat, iron, calcium and vitamin B12, and compares these recommendations with what we actually eat. It then examines the role that meat and dairy products might play in moving us closer to or further away from these nutritional ideals and the implications for agricultural production. Finally, we explore whether there are ways of achieving our nutritional goals at less greenhouse gas 'cost'.

5.1.a How should we be eating and how do we actually eat?

International nutritional advice is very consistent. The World Health Organisation (WHO), the UK's Department of Health (DH), as well as government health departments overseas[287] all emphasise that we should be eating more fruit and vegetables, and less fat (particularly saturated), sugar and salt. Fruit and vegetables can play an important role in the prevention of chronic diseases such as heart disease, cancer, diabetes and obesity, and in the prevention and alleviation of several micronutrient deficiencies, especially in less developed countries.[288]

The WHO[289] would have us eat at least 400 g of fruit and vegetables per day (excluding potatoes and other starchy tubers). The UK DH translates this

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[287] See *Preparation and use of food-based dietary guidelines*, Report of a joint FAO/WHO consultation Nicosia, Cyprus, 1996 http://www.fao.org/documents/show_cdr.asp?url_file=/DOCREP/x0243e/x0243e10.htm for a comparison of different country recommendations

[288] *Diet, nutrition and the prevention of chronic diseases*. Report of a Joint FAO/WHO Expert Consultation. Geneva, World Health Organization, 2003

[289] *Diet, nutrition and the prevention of chronic diseases*. Report of a Joint FAO/WHO Expert Consultation. Geneva, World Health Organization, 2003
(WHO Technical Report Series, No. 916).

recommendation into at least five (80 g) portions of fruit and vegetables a day.[290] The US recommendations have recently increased, and now between five and nine portions of fruit and vegetables a day are considered optimum although it is unclear how this directly relates to the five a day guidelines as some portion sizes (9 grapes!) seem rather small.[291]

As for fat, the Department of Health recommends this should constitute no more than 35% of calorie intake, with saturated fat at 11% or below. The joint FAO WHO Expert Group on nutrition recommends lower levels still, at between 15-30% of energy intake, with saturated fat at less than 10%.[292] Other expert research teams also prefer these lower levels.[293]

Protein intake recommendations feature less prominently in national level recommendations. The DH makes no specific recommendations since the average British diet (see below) is not protein-limited. Protein can be scarce in other parts of the world, however, and the WHO recommends that adults should consume on average 0.6 g of protein per kg of body weight a day. [294] Its recommended 'safe allowance' (a higher safer quantity translating into less than 2.5% risk of deficiency for an individual) is 0.75g, a figure which is now in the process of being revised up to 0.83 g/kg/day.[295] [296] Consumption at these levels translates very roughly into 10-15% of total daily energy intake.

Recommended iron intake levels stand at 8.7 mg for men and 14.8 mg for women. [297] For calcium the figures are 700 mg, with more for adolescents and pregnant women.

Table 9 shows how the average UK diet compares with nutritional recommendations.

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290 Food Standards Agency 2007 http://www.eatwell.gov.uk/healthydiet/eighttipssection/8tips/#cat294228

291 *Eat 5 to 9 a day for better health* http://www.5aday.gov/9aday/index.html accessed 10 May 2005

292 *Diet, Nutrition and the Prevention of Chronic Diseases*, Report of a Joint FAO/WHO Expert Consultation, WHO Technical Report Series 916, WHO, Geneva, 2003 (table 6)

293 EURODIET: Nutrition and lifestyles for healthy diets in Europe, Science and Policy Implications, Crete, June 2000. http://eurodiet.med.uoc.gr/ or http://europa.eu.int/comm/health/ph/programmes/health/reports/report01_en.pdf site accessed 3 May 2005

294 FAO/WHO UNU 1985.

295 Dr Joe Millward, University of Surrey, pers. comm., May 2005

296 Institute of Medicine. Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients). Washington, DC: National Academy Press, 2002.

297 Webb, G P, *Nutrition: a health promotion approach*, second edition, Arnold, London, 2002 ISBN 0 340 76069 9

Table 9: UK average nutritional intakes as compared with recommended intakes

Food category	Daily nutritional recommendations	Actual UK consumption
Fruit and vegetables	Five (UK) or more (US) portions (1 portion is @90 g) >400 g a day (WHO)	3.4 portions[298] – lower for children
Overall fat	15-30% (WHO) 35% (UK)	37.6% (2003-4)[299]
Saturated fat	11% (UK) < 10% (WHO)	14.7% (2003-4)[300]
Protein	0.6-0.75-0.83 g/kg/day. For an average 65 kg British woman this is 39-53.95 g. For an average 80 kg man this is 48-66.4g.[301]	72 g plus 10 g from food eaten out = 77.5 g (2003-4)[302]
Iron	The Referent Nutrient Intake is 8.7 mg (men) and 14.8 mg (women)[303]	Average 12.7 mg[304]
Calcium	700 mg – more for some population groups	1,002 mg[305]
Vitamin B12	1.5 μg[306]	6.6 μg[307]

The following paragraphs look in a little more detail at these individual nutrients. Fruit and vegetable consumption is not considered since it has little bearing on meat consumption except in so far as vegetarians tend to eat more of them than omnivores.[308] [309]

[298] *Family Food*, 2002-3, Defra
[299] Quantities of Purchases of Food and Drink and Derived Energy and Nutrient Intakes in the UK, 2003-4, DEFRA, April 2005 http://statistics.defra.gov.uk/esg/statnot/efsuk.pdf
[300] Quantities of Purchases of Food and Drink and Derived Energy and Nutrient Intakes in the UK, 2003-4, DEFRA, April 2005 http://statistics.defra.gov.uk/esg/statnot/efsuk.pdf
[301] based on average UK male and female weights : see *The Scotsman*, 2 September 2004, Hourglass figure fills out as women upsize http://thescotsman.scotsman.com/uk.cfm?id=1027942004
[302] UK household and eating out energy and nutrient intakes derived from food and drink, *Family Food*, Defra 2005/6
[303] Webb, G P (2002). *Nutrition: a health promotion approach*. Second edition, Arnold, London, ISBN 0 340 76069 9
[304] UK household energy and nutrient intakes derived from food and drink, *Family Food*, Defra 2005/6
[305] UK household energy and nutrient intakes derived from food and drink, *Family Food*, Defra 2005/6
[306] *Risk Assessment: Vitamin B12, Expert Group on Vitamins and Minerals*, Food Standards Agency, 2003
[307] UK household energy and nutrient intakes derived from food and drink, *Family Food*, Defra 2005/6
[308] Davey G K, Spencer E A, Appleby P N, Allen N E, Knox K H and Key T J. (2003). EPIC–Oxford: lifestyle characteristics and nutrient intakes in a cohort of 33 883 meat-eaters and 31 546 non meat-eaters in the UK, *Public Health Nutrition* 6(3), 259–268

Protein

On average each of us in the UK derives 72 g of protein a day from foods we eat at home.[310] To this should be added a daily extra 10 g from food eaten out,[311] meaning that our total protein consumption amounts to about 82 g/person/day. On average then, we consume between 25 and 50% more protein than our bodies actually require based on the protein-for-weight requirement ranges given in Table 9 above. Excessive protein intake at these levels poses absolutely no health risks. The question rather, is whether by consuming less protein – by consuming fewer animal products, by consuming less protein overall, or by substituting other food groups such as fruit and vegetables or carbohydrates – we might help increase or decrease food related emissions of greenhouse gas emissions.

Most of our protein comes from animal sources. Of the 72 g consumed at home, 43.7 g of protein is of animal origin, or around 61% of our daily protein intake. The animal-derived proportion for foods eaten out is not available.

By contrast the global average figure for animal protein intake is currently 28.7 g per person a day.[312] The developing world average is lower still at a daily 21 g.[313] Globally meat and dairy products contribute an average 10% to daily calorie intake. In the developed world the figure is twice this, at 20%. In developing countries only 6% of daily calories come from meat and dairy products,[314] and it should be remembered that daily calorie intake will also be lower, so in absolute terms, the amount will be very little indeed.

Back in the UK, the 43.7 g of animal protein alone that we consume is sufficient to fulfil the average protein recommendations of an *average* weight British woman and most of the requirements of an *average* weight man.[315] However the term 'average' for men and women does not necessarily mean ideal; only 50% of men and women fall within the BMI[316] normal weight range and 38% women and 44% men are classed as obese or overweight.[317] If the average weight were to fall (as is desirable, for various health reasons), this will translate into lower needs for protein, as well as for other nutrients, such as fat.

The total quantity of protein, and the total quantity of animal protein in our diets, has declined very slightly since 1975. This said, so too has our reported calorie intake (although it has increased relative to our energy needs, hence the rise in obesity.

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309 Key T J, Appleby P N and Rosell M S. (2006). Health effects of vegetarian and vegan diets, *Proceedings of the Nutrition Society*, 65: 35-41

310 UK household energy and nutrient intakes derived from food and drink, *Family Food*, Defra 2005/6

311 UK eating out energy and nutrient intakes derived from food and drink, *Family Food*, Defra 2005/6

312 FAOstat 2002 data. Note that this figure is for food availability; the UK figures are for reported food consumption. Real food consumption is likely to be less than food availability since some of that 'available' food will be spoilt or wasted. In effect the global average consumption of animal protein will be less than that 28.7g.

313 FAO stat 2002 data. Note as above.

314 Summary of Food and Agricultural Statistics 2003, FAO, Rome, 2003

315 Based on average UK male and female weights: see *The Scotsman*, 2 September 2004, Hourglass figure fills out as women upsize.
http://thescotsman.scotsman.com/uk.cfm?id=1027942004

316 Body Mass Index

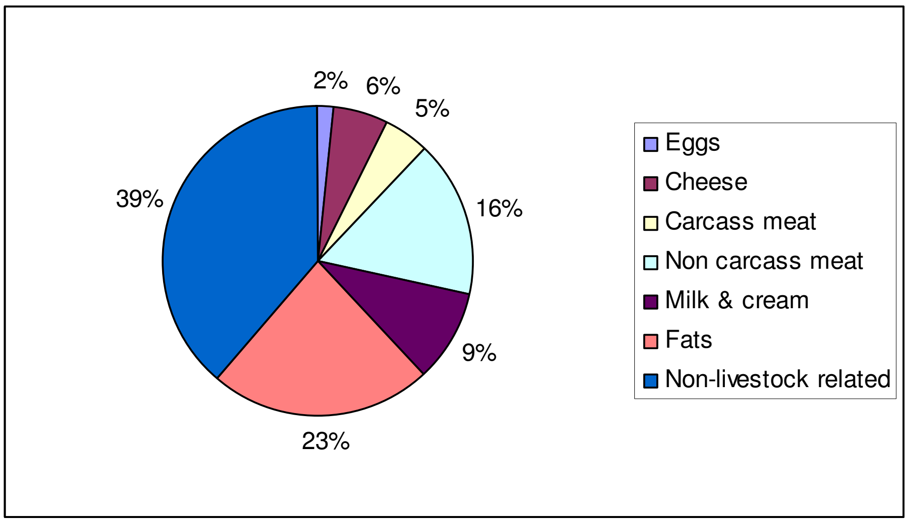
317 *UK National Sizing Survey: SizeUK. Size UK average measurements for men and women*, http://www.fashion.arts.ac.uk/docs/sizeuk_analysis.pdf

Reported intakes also tend to be lower than actual intakes).[318] As such, the relative importance of animal protein (excluding fat), in terms of its contribution to total calorie intake, has actually slightly increased – from 7.46% of total calorie intake to 8.6%.[319]

Fat

In the UK both overall and saturated fat intakes are higher than DH and WHO recommendations. Meat, eggs and dairy products collectively account for 38% of our total fat intakes. Oils and fats, both of animal and vegetable origin, contribute a further 23%. Foods classed as 'non-livestock related' account for 39% of our fat consumption but many, such as bakery products, will contain eggs, dairy products or animal fats. In all then, livestock products account for a sizeable percentage of our total fat intakes.

Figure 26: Contribution of livestock products to average UK fat intakes



Source*: UK Purchases and Expenditure on Food and Drink and Derived Energy and Nutrient Intakes 2005-06*

Lean meat is relatively low in fat[320] and is in fact rich in the polyunsaturated fatty acids that confer positive health benefits. Processed meat on the other hand, such as sausages, burgers and corned beef can be very high not only in fat, but in saturated fat (although lower fat versions are becoming available). Processed meats happen to be more popular than lean meats, with price and convenience presumably factors here. On an average day we consume nearly four times more processed meat than we do lean.[321] The relationship between vegetable oil and meat consumption has already been discussed in Section 4 but this relationship might also be worth considering from a nutritional perspective. Might the demand for meat, by increasing availability of vegetable oils, actually contribute to our higher than recommended levels of fat intake? It has also been noted above that most soy oil is used not for domestic cooking but for industrial production of processed foods. It is therefore probable that many processed meat products will contain soy oil and possibly other soy products such as soy protein as well.

Iron

[318] *Family Food*, 2002-3, Defra. Chapter 2, Table 2.3.
[319] Calculations based on 1g protein = 4kcal
[320] http://www.eatwell.gov.uk/healthydiet/foodmyths/
[321] UK household purchased quantities of food and drink, *Family Food*, Defra 2005/6

The average British citizen takes in about 12.7 mg of iron a day from all sources.[322] The referent nutrient intake level for men is 8.7 mg and for women 14.8 mg[323] However, the population average disguises the fact that many subsections of the population are anaemic, particularly pregnant and menstruating women and adolescents.[324] Indeed, around 25% of women in the UK have iron intakes below the Lower Reference Nutrient Intake[325] and this rises to more than 40% of women aged 19-34. By contrast for men (who have lower iron requirements) the figure is just 1%.[326]

As regards the actual incidence of anaemia, the problem is clearly one of global proportions. As Table 10 shows, the problem is most acute in the world's poorest countries but it still affects a great many people even in Europe.

Table 10: Incidence of anaemia – world wide and in selected regions

	Children up to 5 years	**Pregnant women**	**Non-pregnant women**
	% affected	% affected	% affected
World	47.4	41.8	30.2
Africa	64.6	55.8	44.4
Europe	16.7	18.7	15.2

Source*: Nutritional Anemia*, Sight and Life Press, Basel, Switzerland, 2007 available at http://www.who.int/nutrition/publications/anaemia_iron_pub/en/index.html

The main dietary function of iron is to form part of the haemoglobin complex that carries the oxygen in red blood cells. Animal-based iron sources constitute only 20% of total iron intake.[327] However their importance in the diet is much greater than the figure would suggest, since they assist in the absorption of non-meat (or non-haem) iron from sources such as green vegetables, fortified breakfast cereals, bread, pulses, dried fruits and nuts. Vitamin C from fruit and vegetables and alcohol also increases the absorption of non-haem iron. Coffee, tea, cocoa and dairy products, on the other hand, reduce iron absorption.[328]

Red meat is an excellent source of haem iron. However, most of our meat-origin iron actually comes from processed meat products (which also tend to be high in fat) – compare 0.4 mg iron person/day from carcass meat with 1.2 from non carcass meat.[329] [330] Since processed meats tend to be mixed with other ingredients, some of

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[322] UK household energy and nutrient intakes derived from food and drink, *Family Food*, Defra 2005/6

[323] Webb, G P (2002). *Nutrition: a health promotion approach*, Second edition, Arnold, London, 2002 ISBN 0 340 76069 9

[324] *Iron deficiency in Europe*, Serge Hercberg, Paul Preziosi and Pilar Galan Public Health Nutrition: 4(2B), 537-545

[325] The amount of a nutrient that is enough for only the small number of people who have low requirements (2.5%).

[326] National Diet & Nutrition Survey: Adults aged 19 to 64, Volume 5, Food Standards Agency, 2004

[327] *Family Food* 2004/5, Defra, Chapter 5 (data for later years not available)

[328] Webb, G P, *Nutrition: a health promotion approach* (2002). Second edition, Arnold, London, ISBN 0 340 76069 9

[329] Table 5.2 Estimated intakes from different types of household food in 2005-06 in *Family Food 2005/06*, Defra, 2007

the iron from processed foods will come from non-haem sources and so its value as a source of iron will be lower than the value of carcass meat. Nevertheless the difference in the figures is striking and suggests that in meeting our iron needs we are exceeding recommended fat and saturated fat levels.

A paper published in the American Journal of Clinical Nutrition[331] concludes that the while '*iron and zinc from vegetarian diets are generally less bioavailable than from non-vegetarian diets because of reduced meat intake as well as the tendency to consume more phytic acid and other plant-based inhibitors of iron and zinc absorption… in Western countries with varied and abundant food supplies, it is not clear that this reduced bioavailability has any functional consequences. Although vegetarians tend to have lower iron stores than omnivores, they appear to have no greater incidence of iron deficiency anaemia*'.

Calcium

Calcium is needed for bone health and in particular to prevent osteoporosis, a condition that increase vulnerability to bone fractures. As with iron, while at the population level we are meeting our calcium requirements, there are deficiencies among certain groups such as adolescent girls and pregnant women.

In the UK, milk and dairy products provide most of our calcium and these animal products contain much more calcium, weight for weight than most vegetable-based foods (although soy products can be rich sources).

However, there appears to be a complex relationship between body's ability to absorb the mineral from calcium rich foods (such as milk), the consumption of animal protein (which is also present in these dairy foods) and the consumption of other foods such as fruit and vegetables and fibrous cereals and pulses.

Some research concludes that a diet rich in animal products actually hinders the body's ability to absorb calcium[332] [333] There is also increasing research to suggest that high levels of fruit and vegetable consumption can be beneficial for bone health [334] [335] [336] [337] Both these factors have fuelled the arguments of, for instance, vegan groups.[338] [339]

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[330] Note that additional livestock derived iron will also be obtained from dairy products and eggs

[331] Hunt, J.R. (2003). Bioavailability of iron, zinc, and other trace minerals from vegetarian diets, *American Journal of Clinical Nutrition*, Vol. 78, No. 3, 633S-639S

[332] Kerstetter JE, O'Brien KO, Insogna KL (2003). Low protein intake: the impact on calcium and bone homeostasis in humans. *Journal of Nutrition* 133:855S-61S.

[333] Sellmeyer D E, Stone K L, Sebastian A, Cummings SR. (2001). A high ratio of dietary animal to vegetable protein increases the rate of bone loss and the risk of fracture in postmenopausal women *American Journal of Clinical Nutrition* 73:118–22

[334] Prynne C J, Mishra G D, O'Connell M A, Muniz G, Laskey M A, Yan L, Prentice A and Ginty F. (2006). Fruit and vegetable intakes and bone mineral status: a cross-sectional study in 5 age and sex cohorts1–3 *American Journal of Clinical Nutrition* 83:1420–8.

[335] Macdonald H M, New S A, Golden M N H, Campbell M K, Reid D M. (2004). Nutritional associations with bone loss during the menopausal transition: evidence of a beneficial effect of calcium, alcohol, and fruit and vegetable nutrients and of a detrimental effect of fatty Acids 1–4 *American Journal of Clinical Nutrition* 79:155– 65.

[336] Vatanparast H, Baxter-Jones A, Faulkner R A, Bailey D A, Whiting S J. (2005). Positive effects of vegetable and fruit consumption and calcium intake on bone mineral accrual in boys during growth from childhood to adolescence: the University of Saskatchewan Pediatric Bone Mineral Accrual Study1–3 *American Journal of Clinical Nutrition* 82:700–6.

The most recent view, however, is that protein has both a positive and negative effect on the body's ability to absorb calcium. The optimum situation is one where there is an adequate supply of calcium-containing foods combined with adequate dietary protein and high fruit and vegetable intakes (which aid absorption, provided they are not too fibrous).[340] In other words, a diet rich in dairy products in combination with high intakes of fruit and vegetables would fit the bill here, although it is also perfectly possible to obtain adequate calcium from non-animal sources.

It is important to note that diet is not the only factor affecting calcium deposition in the bones. Weight bearing exercise also has a vital part to play in developing and maintaining strong bones, and the growing incidence of osteoporosis worldwide is likely to be linked to declining levels of physical activity. Genetics will also play a part although the interactions between genetics and lifestyle are complex.[341]

Vitamin B12

This vitamin plays an essential part in the production of red blood cells, in the functioning of the nervous system, and in the manufacture of folic acid. B12 also helps release energy from the food we eat. Low levels of vitamin B12 can lead to a form of anaemia leading to fatigue, tingling and numbness of the limbs. More severe deficiencies cause damage to the nerve cells, the spinal cord and the brain and in extreme cases paralysis or death may result. The daily requirement for Vitamin B12 is 1.5µg a day and at national level the average diet amply supplies us with this vitamin.[342]

However, vitamin B12 is found only in animal products and in microorganisms including yeast and as a result vegans or those consuming very low quantities of animal products may be at risk of deficiency.[343] Traditionally plant-based diets will have contained Vitamin B12 since foods will have come into contact with animal matter through faecal contamination, insects eaten inadvertently along with the food and so forth. With improved standards of hygiene these sources are no longer available to people existing solely on plant-based diets (not on balance a bad thing...). Since, however, many breakfast cereals and soy products are now fortified with Vitamin B12 (and yeast extract is also a rich source), vegans consuming these products can in fact manage an adequate intake. This said, survey findings from the Oxford EPIC study show that vegans had intakes well below the recommended level – 0.41 µg/day for men and 0.49µg/day for women compared with the recommended 1.5 µg/day,[344] although the study also suggests that true intakes may well be higher

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[337] New SA, Robins SP, Campbell MK, Martin JC, Garton MJ, Bolton-Smith C. (2001). Dietary influences on bone mass and bone metabolism: further evidence of a positive link between fruit and vegetable consumption and bone health? *American Journal of Clinical Nutrition* 73:118–22.

[338] http://www.vegansociety.com/html/food/nutrition/calcium.php

[339] http://www.vegsource.com/articles/calcium_update.htm

[340] Am J Clin Nutr 2003;77:1337–41 – see letters to the editor by Susan A New and D Joe Millward and by Bess Dawson-Hughes

[341] *Human Vitamin and Mineral Requirements:, Report of a joint FAO/WHO* expert consultation, Bangkok, Thailand, FAO/WHO, Rome, 2001

[342] *The National Diet & Nutrition Survey: adults aged 19 to 64 years: Vitamin and mineral intake and urinary analytes*, Food Standards Agency, 2003

[343] *Risk Assessment: Vitamin B12, Expert Group on Vitamins and Minerals*, Food Standards Agency, 2003

[344] Davey G K, Spencer E A, Appleby P N, Allen N E, Knox K H and Key T J. (2003). EPIC–Oxford: lifestyle characteristics and nutrient intakes in a cohort of 33 883 meat-eaters and 31 546 non meat-eaters in the UK, *Public Health Nutrition* 6(3), 259–268

than the reported findings due to an increase in vitamin B12 fortification since the survey was carried out.

Other nutrients

It is worth noting here that there is currently increasing interest in the potential contribution of certain types of meat to Omega-3 fatty acids. Research suggests that grass fed ruminant livestock often have higher ratios of Omega-3:6 fatty acids[345] [346] albeit still at levels that are only a fraction of that obtainable from oily fish. Incidentally grass fed animals[347] are also generally considered to have a better flavour,[348] [349] although perceptions regarding the latter will very much reflect cultural norms.[350]

In theory, meat with a higher nutritional value can be eaten in smaller quantities, since more nutrients are available per quantity consumed. Put simplistically, this means that fewer greenhouse gases will be emitted per given quantity of nutritional value. In practice of course, this argument does not have any bearing on how and how much people choose to eat in real life; what people consider to be a portion reflects habit and cultural norms rather than any detailed assessment of nutritional potential. This said, higher prices for products with better nutritional properties may to some extent influence portion size as might other public awareness and consumer behaviour campaigns around food and lifestyle. This important area is beyond the scope of this paper, but we intend to explore it further in future work.

5.1.b Do we need meat and dairy products?

From the discussion above it would appear that meat and dairy products are, nutritionally speaking, a bit of a curate's egg. Although a valuable source of essential nutrients (iron, calcium, Vitamin B12 and protein), in many cases these foods oversupply them (protein, fat).

Neither the UK government's Department of Health or the Food Standards Agency specifies how much by way of livestock foods it is nutritionally optimal to consume. Nor does the nutritional advice specifically endorse a meat-based diet although it

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345 Aurousseau B, Bauchart D, Calichon E, Micol D and Priolo A. (2004). Effect of grass or concentrate feeding systems and rate of growth on triglyceride and phospholipid and their fatty acids in the M. longissimus thoracis of lambs, *Meat Science* Volume 66, Issue 3, March, Pages 531-541

346 Demirel G, Ozpinar H, Nazli B and Keser O. (2006). Fatty acids of lamb meat from two breeds fed different forage: concentrate ratio, *Meat Science* Volume 72, Issue 2, Pages 229-235

347 Wood J.D., Richardson R. I., Scollan N. D., Hopkins A., Dunn R., Buller H. and Whittington F. M. (2007) Quality of meat from biodiverse grassland. In: Hopkins J.J. (Ed) *High Value Grasslands: providing biodiversity a clean environment and premium products. British Grassland Society Occasional Symposium No 38.* Cirencester: British Grassland Society

348 Ventanas S, Ruiz J, García C and Ventanas J. (2007). Preference and juiciness of Iberian dry-cured loin as affected by intramuscular fat content, crossbreeding and rearing system *Meat Science* Volume 77, Issue 3, Pages 324-330

349 Fisher, A.V., Enser, M., Richardson, R.I., Wood, J.D., Nute, G.R., Kurt, E., Sinclair, L.A. and Wilkinson, R.G. 2000. Fatty acid composition and eating quality of lamb types derived from four diverse breed times production systems. *Meat Science*, 55: 141-147

350 Sañudo C, Alfonso M, San Julián R., Thorkelsson G., Valdimarsdottir T., Zygoyiannis D., Stamataris C., Piasentier E., Mills C., , Berge P., Dransfield E., Nute G.R., Enser M. and Fisher A.V. Meat Science (2007). Regional variation in the hedonic evaluation of lamb meat from diverse production systems by consumers in six European countries, *Meat Science*, Vol 74 Issue 4, pp 610-621

does veer in its favour.[351] The Government's Eatwell plate[352] recommends that about a fifth of our diet should consist of 'meat fish or alternatives'. A further fifth is to be given over to dairy products. An alternative vegetarian healthy eating plate is not available although there are suggestions for eating healthily as a vegetarian on the Food Standards Agency website.[353]

The nutritional emphasis of government advice is less on individual foods but on their quality. So for example recommendations for improving the nutritional value of meat-based diets are to consume 'lean' meat. For vegetarians the advice is to ensure that adequate quantities of foods rich in protein, iron and calcium are included. Vegans are simply cautioned about vitamin B12 intakes and referred to the Vegan Society's website.

In the US, however, the sufficiency of non-meat (or dairy) diets is more specifically addressed. A position paper by the American Dietetic Association states that well-planned vegan, lacto-vegetarian, and lacto-ovo-vegetarian diets are appropriate for all stages of the life cycle, including infancy, childhood, adolescence, pregnancy and lactation.[354]

In summary, it would appear that a vegetarian diet is fully capable of meeting our needs for a full range of amino acids and of supplying a nutritionally balanced diet, and can indeed compare favourably with the diet of meat eaters depending on the nature both of the vegetarian, and the meat-based diet.[355] [356] [357] [358] A balanced vegan diet is also possible, although much harder to achieve.

While individual preferences will vary, as a general rule, eating small (and considerably less than currently consumed) quantities of good quality meat and dairy products may be the easiest route to achieving a good, nutritionally balanced diet. While meat and dairy products need not be essential in our diets, their presence in small quantities, can make healthy eating much easier.

That said, livestock do not produce only lean meat. They also produce fat and various other body parts that at present find their way into less healthy foods, such as fatty mince, burgers, sausages and so forth.

There may be a health/environment conflict here. Many of these less healthy foods, are, arguably, resource efficient. If we didn't eat them we would either have to export our problem (to countries which like the bits we do not) or dispose of it in other ways.

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[351] See, for example, the healthy eating recommendations on the Food Standards Agency website at http://www.eatwell.gov.uk/healthydiet/

[352] The eatwell plate is an updated version of 'The Balance of Good Health' plate, a pictorial representation developed by the Department of Health of the basic constituents of a nutritionally balanced diet. See http://www.food.gov.uk/healthiereating/eatwellplate/

[353] http://www.eatwell.gov.uk/healthydiet/vegaveg/

[354] *Position of the American Dietetic Association and Dieticians of Canada: Vegetarian diets*, Journal of the American Dietetic Association, ADA, 2003

[355] Appleby PN, Thorogood M, Mann JI, Key TJ. (1999). The Oxford Vegetarian Study: an overview. *American Journal of Clinical Nutrition*; **70** (3 Suppl): 525S-531S

[356] Key, T J. et al. (1999) Health Benefits of a vegetarian diet. *Proceedings of the Nutrition Society* v.58 p.271-5

[357] Sanders, T.A. (1999) The nutritional adequacy of plant-based diets, *Proceedings of the Nutrition Society*, 58,265-269

[358] Millward, D.J. (1999) The nutritional value of plant-based diets in relation to human amino acid and protein requirements. *Proceedings of the Nutrition Society*, (1999) 58, 249-260

The one entails additional transport and transport-refrigeration related energy[359] while the other represents a waste of embodied greenhouse gas emissions, a concern we explore further in the section on rendering, below (Section 3.3.a). In other words, there can at times be a trade off between nutritional goals (eat lean meat) and environmental ones (be resource efficient).

Offal is an interesting exception. Some offal (such as liver or kidney) is very nutritious and increased consumption (over and above what finds its way into processed foods) would improve the resource efficiency of livestock production. However our enthusiasm for it appears to be small and rapidly diminishing. Total offal consumption in 2005 was around 100,000 tonnes – this includes both offal directly bought and consumed and offal in processed foods such as steak and kidney pie.[360] By contrast, the amount available for human consumption was more than seven times that figure at 725,435 tonnes, and this does not include the large amounts that are also imported.

This means that in theory, the meat sector is more wasteful than it needs to be, nutritionally speaking. One could very simplistically argue that a more 'nose to tail' approach to meat consumption might actually reduce the number of livestock that need to be reared. Some offal can be (and is) exported, but UK meat still suffers from a BSE-induced image problem in potential importing countries. Of course there is also legislation that prevents certain types of material entering the market for human consumption. As with the situation domestically, market opportunities come and go in a very short period of time. This generally results in an erratic international trade market with relatively short-term opportunities.[361] As such, a great deal of edible meat is either turned into pet food, or rendered and then landfilled.

5.1.c Diet and agricultural production: are we producing the right kind of food?

One study[362] investigates the potential impact of WHO/FAO nutritional recommendations for fat, protein and sugar intake on the consumption, production and trade of a selection of food products for a defined number of countries. The products examined were meats, dairy products and eggs, vegetable oils, animal fats and cereals, and in essence the study considers what would happen to the production and trade of these goods were the countries in question to consume at levels that accorded with WHO/FAO nutritional guidelines. These recommendations are as follows: the level of fat in the diet should not exceed 30% of total energy; protein should not exceed 15% of total energy;[363] sugar no more than 10%; alcoholic beverage intakes should not increase and the total energy in the diet should not decline relative to the baseline.

The study looks at 35 countries (mostly Western Europe and North America, as well as a few Middle Eastern and Eastern European countries) whose average per capita intakes of fat contribute more than 30% to daily calorie intake. This is of course not a

[359] Note that we also import as well as export offal according to season
[360] *A Review Of The Red Meat Offal & By-Products Industry*, English Beef and Lamb Executive, June 2006
[361] *A Review Of The Red Meat Offal & By-Products Industry*, English Beef and Lamb Executive, June 2006 (Appendix 2)
[362] Srinivasan CS, Irz X, Shankar B. (2006). An assessment of the potential consumption impacts of WHO dietary norms in OECD countries *Food Policy* 31 (2006) 53–77
[363] The authors do not explain where this recommendation comes from although it commonly used and very roughly accords with the more specific body-weight based protein recommendations set out above.

global perspective. Importantly the study does not look at what overall food production levels might look like were the twenty countries whose fat intakes fall *below* the minimum recommended fat intake threshold to increase their consumption. It also excludes the majority of developing world countries whose fat intakes falls within the 15-30% acceptable intake range. Moreover, the report does not take into account future population growth – it is simply a snapshot of the situation today.

The authors nevertheless conclude that meeting these nutritional objectives would require substantial changes in production and consumption. We would need to reduce consumption of meat, vegetable oils, eggs and dairy products and eat more cereal-based products, pulses, fruits and vegetables.

More specifically, consumption of vegetable oils would drop by 30%, dairy products by 28%, sugar by 24% and animal fats by 30%. Pig meat would fall by 13.5%, and mutton and goat by 14.5%. On the other hand, cereal consumption would rise by 31% and fruits and vegetables by 25% and 21% respectively. For oils, consumption of the most dominant, soy, would need to decline by 28%.

Beef and poultry are interesting exceptions. Beef consumption could in fact rise while poultry consumption would drop by only 1.7%. This is because the authors class these meats as low in fat (although pork from pigs reared in the UK is in fact now leaner than beef).

Notwithstanding the rise in cereal consumption the paper calculates a very small increase in overall production requirements since its greater use as a human food is almost entirely offset by the reduction in demand for feed-cereals.

This study has relevance to the discussion here because it suggests that in order to improve our diets, we should indeed be eating fewer meat and dairy products, and shifting away from growing cereals for animal feed to their production for direct human consumption. The paper also indicates a significant reduction in oil, particularly soy oil consumption, which has a bearing on the soy issues explored in Section 4 above.

What is more, the paper is interesting because it looks at *needs* rather than *demand*. Most FAO and other food projects look at current and future levels of demand.[364] [365] Approaches that seek to define what it is we need and then explore possible strategies that might help us meet those needs (both as regards supplying the necessary foods and in shaping consumer expectations and behaviour) would clearly have benefits for sustainability.

As a start, it might be helpful to develop the work of this study further, this time taking a global perspective, one that considers not only nutritional global needs today, but also future needs in the context of the projected global increase in population over coming years.

5.1.d Meat and dairy foods: Some conclusions

This section has looked at how we eat in the UK and how this compares with nutritional recommendations. Focusing on a range of nutrients we find that, for

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[364] *OECD-FAO Agricultural Outlook 2006-2015*, OECD/FAO 2006
[365] Rosegrant M W, Paisner M S, Meijer S and Witcover J (eds). (2001) *2020 Global Food Outlook: Trends, Alternatives, and Choices.* International Food Policy Research Institute, Washington D.C

protein, current consumption levels are more than required and that all, or almost all our daily protein needs are being met by animal products, a situation very different from populations in the developing world. While animal products provide very useful and readily bio-available sources of iron and calcium, they are not essential. It is also the case that animal products, in the largely processed form we consume them today, over-supply us with fat, both directly and indirectly owing to the link between meat and vegetable oil production and consumption.

With the growing problems posed by an increasingly overweight population, Government is making great efforts to encourage us to achieve and maintain healthy weights; in practice this means that for many people weight loss is desirable. A reduction in weight will, on average, also reduce our protein requirements from all sources, since they are calculated on the basis of body mass. If we were to eat along the lines recommended by the WHO/FAO there would be a reduced need both for meat and for vegetable oil production.

Often the meat debate has, from a nutritional point of view, been polarised between those promoting vegetarian/vegan diets[366] and those advocating the merits of meat consumption.[367] The reality may be much more nuanced; significant reductions in meat and dairy products (particularly of certain types) may be advisable from a health point of view, but that is not the same as eliminating them from the diet altogether. Indeed, while not essential, small quantities of meat and dairy products can make the achievement of a healthy diet easier and more palatable. Within this 'eat less meat context' and providing the rest of the diet is healthy, the consumption of all parts of the animal, rather than just lean muscle, is preferable from a resource and greenhouse gas perspective. We would also note that a lacto-vegetarian diet is not necessarily preferable to a meat-based one,[368] environmentally speaking, since dairy products are highly greenhouse gas intensive. In addition, the meat and dairy chains are highly interconnected as Section 2 showed.

Finally for this section, it is worth framing the meat and nutrition debate in the context of the larger ongoing debate as to the direction public nutrition policy should follow, a debate that has been followed closely by Lang and Heasman.[369] Growing research effort in the developed world is focusing upon the development of nutritionally enhanced foods.[370] The approach is a highly individualised one, the goal being to optimise individual nutritional wellbeing. Genetics plays a large part here – nutritional diets should take into account an individual's personal genetic makeup. Lang and Heasman call this 'optimised' approach the 'Life Sciences' paradigm. Its opposing paradigm, the 'Ecologically Integrated' approach takes a more publicly, whole-population oriented approach, seeking to integrate public and environmental health concerns. Its stance is utilitarian, focusing on what is best for most, within the context of our relationship with the environment. We would argue that this approach may be useful in helping to guide health policy as regards meat consumption as well as other foods, such as fish, in the context of collapsing fish stocks.

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[366] http://www.vegansociety.com/html/food/nutrition/iron.php
[367] http://www.meatmatters.com/sections/health/index.php
[368] Collins, A and Fairchild, R (2007). Sustainable Food Consumption at a Sub-national Level: An Ecological Footprint, Nutritional and Economic Analysis, *Journal of Environmental Policy & Planning*, 9:1, 5 - 30
[369] Lang T., Heasman M. (2004). *Food Wars: the global battle for mouths, minds and markets*, Earthscan, London
[370] See for example some of the research projects undertaken by Campden and Chorleywood Food Research Association, Leatherhead Food International and the Institute of Food Research

5.2 Non food – Materials

In addition to meat and milk, livestock yield a range of other products. Once these are taken into consideration, the greenhouse gas impacts of eating meat and dairy products may be much lower (on a per/kg basis), since some emissions resulting from livestock production should rightfully be allocated to these different products. Once again the opportunity cost issue arises, but from a different angle: If we did not have recourse to the leather, wool and other products that the meat and livestock sector generates, we would have to produce or manufacture these goods by other means, which would themselves require inputs of energy and generate greenhouse gas emissions.

This section explores two main questions. The first considers the extent to which the non-food outputs of the meat sector are essential. Of the total output of leather, wool and so forth, how much do we actually *need* in order to meet our basic needs and how much do we simply use because it is there and has a market value? If meat production were to decline, would we actually face shortage of these basic goods?

The second focuses on the opportunity cost of producing wool, leather and other substitutes. If we had to produce these from other materials, what would be the implications for greenhouse gas emissions?

Clearly both questions do not take account of the basic market principles of supply and demand. In the real world we do not stop buying things just because we don't need them, however 'need' is defined. As demand for leather grows, output increases and prices fall. As output increases, prices fall further and demand increases further. People buy more shoes and manufacturers use leather to produce items that, were the price of leather higher, would otherwise have been made using some other material, or indeed not made at all. As such there is no such thing, economically speaking, as a minimum requirement for leather. However a focus on needs, (as with the nutrition paper discussed above) is intrinsic to any attempt at understanding what 'one planet living' might look like[371] – a concept that World-Wide Fund for Nature has defined and Defra and other agencies are currently developing. As such this section explores the extent to which we 'need' the non-food outputs of the livestock sector and how much of them, from a greenhouse gas perspective, we can 'afford'.

5.2.a Leather

This section examines trends in the production of hides, skins, finished leather and manufactured leather goods, both from a UK and a global perspective.

It is important to clarify at the outset the distinct differences between the following stages in leather production and their associated terminology: Raw hides and skins; leather; and manufactured leather goods. Raw hides and skins are what are obtained after flaying an animal. These undergo a temporary preservation process which allows them to be stored and transported.

To turn these hides and skins into leather they need to be tanned; this produces a chemically and biologically stable material. There are many different qualities of

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[371] This is a concept that the World Wide Fund for Nature has defined and Defra has implicitly endorsed – see http://www.sustainable-development.gov.uk/what/priority/consumption-production/index.htm#Problem

leather (compare leather soles with kid gloves), and these different qualities will entail different processes.

The third stage of the process is the manufacture of finished goods, such as footwear or upholstery. For brevity, the acronym is HSFLLG is used to refer collectively to hides and skins, finished leather and leather goods.

The global production chain

Significant international trade takes place at all three stages in the process. The developed world produces most of the world's raw hides and skins. Indeed, some 80% of the value of international export trade originates from North America, Europe and Oceania.[372]

It is in the developing world, however, where leather *production* – that is the tanning of leather – mostly takes place. Once the leather has been tanned, over half (54%) of this finished leather is reimported back to the developed world, mainly Europe, where it is turned into shoes. Italy is Europe's leading leather goods manufacturer.

However 46% remains in the developing world where it is manufactured into finished leather goods, with China by far the largest producer.[373] The developing world's share of exports in tanned leather and finished leather goods has increased very markedly. So too has its share of HSFLLG's total value, which has grown from 26-44% in the last twenty years.[374]

The last twenty years have in fact seen rapid growth in leather production. Global production of raw cattle hides grew 24% between 1984-2004 – a faster growth than the production of cattle meat, at 19% over the same period.[375] This – on the face of it – improbable statistic most likely reflects better utilisation (rather than dumping) of cattle hides and better techniques for preservation.

As regards the UK, we produce very little by way of leather or leather products. Because of labour and other costs, most shoe and leather goods manufacture takes place overseas. There are around 25-30 tanneries in the UK, most of which focus on the initial treating and exporting of raw hides.

Economic value of hides and skins, finished leather and leather goods

On average, the hide or skin accounts for about 10-12% of dead carcass weight[376] and about 7-8% of the carcass value (although sheepskins in particular are quite volatile in price and can vary in price from 5-25% of the total value).[377]

The average 1999-2002 value of exported raw hides and skins, leather and leather shoes amounted to almost US $44,000 million, placing hides and skins among the

[372] *World statistical compendium for raw hides and skins, leather and leather footwear 1984-2002*, FAO 2003
[373] *World statistical compendium for raw hides and skins, leather and leather footwear 1984-2002*, FAO 2003
[374] *World statistical compendium for raw hides and skins, leather and leather footwear 1984-2002*, FAO 2003
[375] FAO stat
[376] FAOstat 2004 http://faostat.fao.org/faostat/servlet/XteServlet3?Areas=862&Items=%3E1806&Items=867&Items=957&Items=919&Elements=41&Years=2004&Format=Table&Xaxis=Years&Yaxis=Countries&Aggregate=&Calculate=&Domain=SUA&ItemTypes=Production.Livestock.Primary&language=EN accessed13/5/05
[377] Paul Pearson, British Leather Confederation, pers. comm., May 2005

most important traded commodities – more so, by a very significant degree, than trade in meat, rubber, cotton, coffee, tea, rice or sugar. The value of traded raw hides and skins alone (which amount to just 10% of the total value of HSFLLG and are exported mainly by developed countries) is comparable, at US $4,417 million, to cotton at $6,363 million, tea $2,825 million, rice $5,642 million or rubber $3,085 million.[378]

In addition to its absolute value as a globally traded commodity, the rate of growth in HSFLLG has also been significant. Between 1984-1986 and 1999-2001, the annual average growth in export value was 1.4% for hides and skins, 8.8% for leather and 6.1% for footwear.[379] Interestingly, the average annual rate of growth in the value of bovine meat was lower than all of these, at 1.04%.[380]

What is more, the HSFLLG average rate of growth in value has been higher than the growth in output. In other words, the leather trade is becoming relatively more valuable as time passes.

From a developmental perspective, it is arguable that the leather industry contributes to economic development in low income countries, although there will clearly be many associated concerns as regards working conditions, pay and so forth.

Of course the value of trade in a good is not the same as its total production value and most meat tends to be consumed in its country of origin, while leather is heavily traded. Hence it is not possible to compare the economic value of meat products and of HSFLLG.

Leather and direct greenhouse gas emissions

The discussion here focuses first on the 'simple' direct greenhouse gas impacts of leather production, before going on to examine the complexities of the relationship between leather production, meat production and the allocation of greenhouse gas emissions.

As regards direct impacts, we know of no studies that estimate the total *global* energy requirements of the HSFLLG sector and its ensuing greenhouse gas emissions.

One LCA of leather produced by Catalan industries[381] puts greenhouse gas emissions per tonne of salted hide at around 5.4 tonnes carbon equivalent. The study takes into account emissions generated by livestock at the rearing stage and allocates 7.7% of all agricultural impacts generated during the course of rearing the livestock to the leather itself (based on an economic allocation of the hide's value).

[378] *World statistical compendium for raw hides and skins, leather and leather footwear 1984-2002*, FAO 2003
[379] *World statistical compendium for raw hides and skins, leather and leather footwear 1984-2002*, FAO 2003
[380] FAOstat http://faostat.fao.org/faostat/servlet/XteServlet3?Areas=801&Items=2071&Elements=92&Years=2001&Years=2000&Years=1999&Years=1998&Years=1997&Years=1996&Years=1995&Years=1994&Years=1993&Years=1992&Years=1991&Years=1990&Years=1989&Years=1988&Years=1987&Years=1986&Years=1985&Years=1984&Format=Table&Xaxis=Years&Yaxis=Countries&Aggregate=&Calculate=&Domain=SUA&ItemTypes=Trade.CropsLivestockProducts&language=EN site accessed 29 May 2005
[381] Milà i Canals L, Domènech X, Rieradevall J, Puig R and Fullana P. (2002). Use of Life Cycle Assessment in the Procedure for the Establishment of Environmental Criteria in the Catalan Eco-label of Leather *Int J LCA 7* (1) 39 – 46

Interestingly, even with this small percentage allocation the study finds that slightly under two thirds of all leather's impacts (two thirds of that 7.7%) are still attributable to farm stages. The actual tanning process accounts for only a third of greenhouse gas emissions. Given that the tanning process is acknowledged to be energy intensive (it qualifies for a Climate Change Agreement in the UK), this finding once again throws into relief the greenhouse gas intensity of the actual rearing process itself.

As regards UK tanning emissions, data from the sector's CCA show that carbon dioxide (the only greenhouse gas that is produced in any significant quantity) amounts to around 9,777 tonnes carbon equivalent (equivalent to 0.005% of the UK's production of greenhouse gas emissions). Note that the figure is for the actual tanning stage alone.

The apparently small figure masks the true level of emissions associated with leather produced for UK consumption. A third of hides are exported and most leather goods are manufactured overseas and imported into the UK. As far as we are aware, no consumption related estimates have been undertaken, and it would be very difficult to quantify emissions based simply on import figures since there is wide variation among countries in the efficiency and emissions resulting from their leather industries. Generally speaking, leather production in the developing world (where most leather and manufactured goods production is located) will operate to lower standards than in developed countries.[382]

It should also be noted that every 100 kg of raw hide yields only 20 kg of leather; the rest is either solid waste or effluent.[383] Solid waste consists mainly of fat and protein. There are a number of plants that currently recover fat and render it although none uses the resultant tallow as a fuel source.

The fat and protein can also be fermented and work is underway to develop bioethanol from these tannery wastes. This is, however, still at the experimental stage. One plant is piloting the gasification of solid tannery wastes, and it appears that the process is now ready for commercial development.[384] A question, however, still exists as to whether the fuel fully qualifies as renewable, and this uncertainty could delay commercialisation. In addition, the industry as it stands would have difficulty in meeting the emission limits imposed by the EU Waste Incineration Directive[385] without significant additional expenditure on abatement; and this in turn affects the economic viability of the processes.

Waste is also produced at the finished leather making stage, usually from inadequately tanned (and hence putrefied) hides and defective hides. In some developing world countries, skins and hides are thrown away simply because their commercial value goes unrecognised.[386] As with all products, resource waste also represents wasted greenhouse gas emissions and often means that energy will need

[382] *Trade, sanitary and environmental policy linkages in the hides, skins and leather processing sector*. Committee on Commodity Problems, Intergovernmental Group on Meat: Sub-group on Hides and Skins: Seventh session, Food and Agriculture Organisation, Rome, 4 - 6 June 2001
[383] Paul Pearson, British Leather Confederation, pers. comm., May 2005
[384] Paul Pearson, British Leather Confederation, pers. comm., August 2007
[385] Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the Incineration of Waste
http://www.cen.eu/cenorm/businessdomains/businessdomains/chemistry/200076ec.pdf
[386] *World statistical compendium for raw hides and skins, leather and leather footwear 1984-2002*, FAO 2003

to be consumed during the course of dealing with the waste. This is particularly true with waste at the leather production stage.

It is important to emphasise that leather production give rise to a number of other major environmental impacts. These include emissions of leather dust, hydrogen sulphide, chromium compounds and water suspended solids, sulphates, chromium and ammonia.[387] [388] These environmental impacts may be one reason (in addition to cheap labour costs) why the tanning industry has located to developing world countries where environmental legislation is far more lax.

Leather, meat and indirect greenhouse gas emissions: exploring the relationship

What bearing does leather production have on the meat-greenhouse gas issue apart from the obvious emissions generated during the tanning and trading processes? As highlighted, there may be a case for allocating emissions from the livestock rearing process to all the output products (meat, milk, leather and so forth), in which case the individual emissions from each of these goods would be less than if they were all allocated to, say, meat. As already seen, the Catalan study allocates 7.7% of all farm stage emissions to leather, meaning that meat related emissions will be only 92% of what they are generally calculated to be, as usually a full allocation is made to the edible output. Table 6 in Section 3 above provides examples. Economic or any other sort of allocation does not, however, address some of the more fundamental questions about leather and its impacts. When allocating emissions from livestock production to leather we might usefully ask whether leather production simply makes use of part of an animal that would otherwise have gone to waste or whether the relationship is more complex. Is leather just a by-product or is its status more that of a co-product? If the latter, might growing global demand for leather in any way influence the growth in livestock production?

Of course, in a very fundamental sense we only have leather because we consume meat; animals are not killed just for their skins, in contrast, say, with the fur trade. As such, it is very much a by-product.

Perhaps the co- versus by-product question is in fact a red herring since whatever the classification, livestock related emissions as a whole (as opposed to meat, or milk) remain the same. Perhaps it is more helpful instead to ask how much leather is required for us meet basic needs and how many livestock would be needed to ensure this sufficient supply. Put from the other side, if meat production were to decline, would we run short of leather and other livestock derived goods?

This question of course depends upon the extent to which leather can be termed 'essential'. And if the term does have meaning for leather then do all leather products qualify?

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[387] Integrated Pollution Prevention and Control, *Reference document on Best Available Techniques for the Tanning of Hides and Skins*, European Commission 2003 http://eippcb.jrc.es/pages/FActivities.htm

[388] *Environmental Impacts and Mitigation Costs Associated with Cloth and Leather Exports from Pakistan*: A Report on Trade and Sustainable Development submitted by Sustainable Development Policy Institute and IUCN-P to IISD Canada for the ISD/IUCN/IDRC Project on *Building Capacity for Trade and Sustainable Development in Developing Countries*, Shahrukh Rafi Khan, Mahmood A. Khwaja, Abdul Matin Khan, Haider Ghani and Sajid Kazmi, Islamabad, 1999

As with all discussions about 'needs' the answers will be subjective.[389] [390] One might reasonably argue that a resilient, breathable material of some sort is required for many uses and that leather fits this definition well. As to which leather products are more essential than others, judgements here will always be arbitrary. Traditionally footwear has been the main output of leather production. For instance the FAO in its leather compendium gives footwear and nothing else as an indicator of trends in the production and trade of manufactured leather goods.[391] One might suppose than shoes are rather more necessary than luxury car upholstery although judgements such as these can always be questioned, and of course when it comes to shoes, there will always be people who own dozens of rather less than practical pairs.

Taking footwear – provisos attached – as a marker for 'essential leather,' the figures show that the proportion of light bovine leather going into shoe uppers, still the chief end use, has levelled off at around 56 %.[392] While the proportion of bovine leather utilised for footwear in developing countries rose as their industries expanded, in the developed countries, the share of light bovine leather going into leather shoes fell, reflecting the growth in other uses for leather, mainly clothing and upholstery. If sheep and goat leathers are also taken into account, less than half the world's total leather production is utilised in footwear (note that Table 11 does not include these).

Table 11: Leather use by end product

Leather use by end product 2003	**Million square feet**	**% of total**
Footwear	10835	56
Garments	2205	11.4
Automotive	1220	6.3
Furniture	2420	12.5
Gloves	850	4.4
Other leather products	1820	9.4
Total	**19350**	**100**

Source: International Council of Tanners, http://www.tannerscouncilict.org/statistics.htm (industry estimates)

This is a somewhat speculative argument, but it serves to indicate that the 'need' for leather is almost certainly less than the actual supply, although by exactly how much is not known. In short, if livestock production were to fall, we would not go barefoot.

Of course we still need clothing, furniture upholstery and so forth and some of these are made of leather. Substituting cotton, rubber, plastic, linen and other materials, will still have an environmental impact and will still produce greenhouse gas emissions (especially if livestock production does not fall and the animal skins,

389 Jackson, T., Jager, W., Stagl, S. (2004) 'Beyond Insatiability – needs theory, consumption and sustainability', in Reisch, L and I Røpke (eds), *Consumption – perspectives from Ecological Economics*, Edward Elgar, Cheltenham 2004

390 Jackson, T and N Marks (1999). Consumption, Sustainable Welfare and Human Needs - with reference to UK expenditure patterns 1954 - 1994, *Ecological Economics* 28(3), 421-442.

391 *World statistical compendium for raw hides and skins, leather and leather footwear 1984-2002*, FAO 2003

392 *World statistical compendium for raw hides and skins, leather and leather footwear 1984-2002*, FAO 2003

instead of being used for leather are disposed of in another way). The durability of alternative fabrics, relative to that of leather, will also need to be taken into account. However, while there are a few (although only a few) life cycle analyses of these products[393] [394] it is beyond the scope of this paper to undertake a detailed consideration. This would be a complex undertaking and many judgements would need to be made as to what extent substitutes are indeed substitutable. It may of course not be necessary to find a comparative match for every leather product we now manufacture. Were, say, leather jackets to become prohibitively expensive, we would not necessarily turn to buying PVC or linen jackets instead. Many such goods tend to be classed as luxuries and, therefore, as the price increases, demand can fall in absolute terms with no substitution effects occurring

Ultimately, questions as to how much of any of these goods we ultimately 'need' will remain. These questions are relevant not just to leather or to livestock products in general, but to the full and multiplying range of consumer goods and services that populate our lifestyles, and that contribute so greatly to greenhouse gas emissions in the developed world.[395] [396]

As far as the environmental impacts of dedicated synthetic leather-substitutes are concerned, no comparative research here appears to have been undertaken. The only statements on this issue are from vegetarian websites[397] which criticise the environmental impacts of leather production, or from representatives of the leather industry, who argue that leather is a natural by-product and that oil-based substitute materials carry with them their own environmental burden.[398]

To conclude this section, it appears that while leather cannot be said to drive demand for livestock production – and in this sense it is very much a by-product – it certainly improves its economic viability and has spawned a major and thriving global industry in its own right. As a by-product, the utilisation of hides to manufacture leather goods certainly yields genuine environmental benefits. By meeting our needs for shoes, clothing and other goods, leather avoids the generation of emissions that would ensue from the production of substitute fabrics. These should be taken account when considering emissions from the livestock sector.

Nevertheless we almost certainly produce more leather than we 'need' (bearing the above discussion in mind), and as such, measures to reduce livestock numbers in order to reduce greenhouse gas emissions would not necessarily lead to the increased production of leather-substitutes. Hence the argument that leather (and livestock) production helps avoid the generation of emissions resulting from the production of substitute fabrics cannot be invoked since these goods are not strictly

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[393] Kalliala E M, and Nousiainen P (1999). Life cycle assessment: environmental profile of cotton and polyester-cotton fabrics, *AUTEX Research Journal Vol 1, No.1*, http://www.autex.org/v1n1/2264_99.pdf

[394] Laursen, S.E., Hansen, J., Bagh J., Jensen, O.K. and Werther, I. (1997). *Environmental assessment of textiles. Life cycle screening of the production of textiles containing cotton, wool, viscose, polyester or acrylic fibres*. Environmental project no. 369. Ministry of the Environment and Energy. Danish Environmental Protection Agency.

[395] *Environmental impact of products (EIPRO): Analysis of the life cycle environmental impacts related to the total final consumption of the EU25*, European Commission Technical Report EUR 22284 EN , May 2006

[396] *The carbon emissions generated in all that we consume*, The Carbon Trust, London, January 2006

[397] See, for example http://veggie.org/veggie/leatheraltfaq.html, http://www.vegsoc.org/info/clothing.html,

[398] see http://www.tannerscouncilict.org/perspective.htm

needed and might not even be produced. The extra production of 'unnecessary' leather should therefore be counted as an additional burden rather than a benefit, since its production is in any case highly energy intensive.

Finally, it is important to note that much of the growth in leather and leather goods production has occurred, and continues to occur, in the developing world. Many livelihoods depend upon leather industry. While the interactions between environmental and economic objectives have not been discussed here, a fuller, more multidimensional study would need to take into account this international development perspective.

5.2.b Wool

The UK produces about 36,000 tonnes a year, which, at a global level makes it a very small player, accounting for about only 2.4% of total global wool production.[399] [400] The main world producers are Australia (27% of global output) followed by China and New Zealand.[401] Wool in total, however, accounts for only 1.9% of total world textiles (2006 data),[402] while synthetic fibres account for more than half the world's textile manufacture. While cotton, wool and silk make up about 45% of the natural fibres total, the vast majority of this will be cotton.[403] According to Australia's Department of Agriculture, Fisheries and Forestry, the coming years are likely to see increasing competition from synthetic fibres and a declining in demand for wool.[404]

The quality of wool varies considerably by sheep breed, and the choice of breed to farm is in turn dictated by climatic conditions. British sheep are hardy animals and tend to produce a coarser type of wool,[405] around 70% of which goes to make carpets, with the remaining 30% used to produce suits, jumpers and as a stuffing for mattresses and futons.

Roughly 70-80% of British wool is actually exported, in its raw 'greasy' state (as it is called), as semi-processed wool or in finished goods. Wool produced overseas is imported into the UK to be blended and we also import finished wool garments. Wools from warmer climates such as Australia tend to be softer and hence more suitable for clothing.

The price of wool is very low indeed, averaging at auction about 68 p/kg or roughly £1.50 for the average fleece.[406] These low prices reflect competition from cheap imported wool and the strength of sterling against the US dollar (the latter is used by many emerging economies including China and India). Given its low value, wool can be seen as very much a by-product of the sheep farming industry. Farmers primarily rear and breed sheep for the value of the meat – the wool contributes very little

[399] Wool Statistics, British Wool, http://www.britishwool.org.uk/pdf/Factsheet4.pdf
[400] *Australia's Wool Industry*, Wool facts, Australian Wool Innovation Ltd 2007 http://www.wool.com.au/mediaLibrary/attachments/Education/24528_AWI_WoolFactsv3.pdf
[401] *Australia's Wool Industry*, Wool facts, Australian Wool Innovation Ltd 2007 http://www.wool.com.au/mediaLibrary/attachments/Education/24528_AWI_WoolFactsv3.pdf
[402] Wool Statistics, British Wool, http://www.britishwool.org.uk/pdf/Factsheet4.pdf
[403] Allwood JA, Laursen SE, de Rodriguez CM, Bocken NMP. (2006). *Well Dressed? The present and future sustainability of clothing and textiles in the UK*, University of Cambridge
[404] *Australian Agriculture and Food Sector Stocktake*, Government of Australia, Department of Agriculture, Fisheries and Forestry, 2005
[405] British Wool Marketing Board, pers. comm., April 2007
[406] Price quoted as at April 2007

indeed to overall farm income. Indeed it has often been observed[407] [408] [409] that the cost of paying shearers can be greater than the value of the wool itself.[410]

To improve its economic position, the wool industry is seeking new markets to exploit, one of these being as an insulating fibre for buildings. This is a very small sector at the moment and the price of wool insulation currently compares unfavourably with fibreglass and other mainstream alternatives. It is possible, however, that as environmental concerns move up the agenda, the value of wool as an effective insulating fibre may grow.

As it stands we probably produce more wool than is 'needed' given the current economic situation and the growing demand for synthetic fibres. Note that the questions we raised about our 'need' for leather apply equally to other textiles.

If on the other hand the use of wool were to increase, and actually substitute for synthetics, there could conceivably be an environmental gain, although there appears to be very little research on this issue. Table 12 provides calculations based on data provided in a report published by the Danish Environment Protection Agency.[411]

Table 12: Energy use in manufacture of selected textile fibres

Textile	MJ/kg textile
Cotton	48.65
Wool	8
Viscose	70
Polyester	109.41
Acrylic	157

Source*: Environmental Assessment of Textiles*, Environmental Project 369 Danish Environment Protection Agency, 1997
Note: Energy use covers agricultural stages through to the production of finished fibre, but does not include spinning, weaving etc. Energy use only is considered and not the full range of greenhouse gases.

The figure for wool is the lowest of them all. Note, however, that the comparison is based on energy use and not greenhouse gas emissions. According to Williams et al., carbon dioxide emissions account for only 19% of the total greenhouse gas burden of sheep production. In addition, the 8 MJ figure represents only the farming stage and no other subsequent processes, which will include various cleaning and scouring techniques, while the figures for the other textiles take into account all stages in the fibre production.

However, while these emissions would suggest that the figure for wool is a serious underestimate, there could also be grounds for seeing it as an overestimate. The

[407] UK Agriculture http://www.ukagriculture.com/livestock/sheep_wool_production.cfm accessed 21 August 2007
[408] Dismal trend continues for price of lamb - and wool, *The Scotsman*, 26 July 2007
[409] *Using the wool no-one wants* 5 October 2006, BBC News http://news.bbc.co.uk/1/hi/business/5317358.stm
[410] it nevertheless needs to be done for welfare reasons
[411] *Environmental Assessment of Textiles*, Environmental Project 369 Danish Environment Protection Agency, 1997

study makes its calculations the basis of a 60:40 allocation between meat and wool. This seems rather extraordinary (in the light of the figures given above) and perhaps reflects the fact that as an extensive system, energy inputs for sheep farming are so low that shearing accounts for a relatively large share. On the other hand, sheep need to be sheared for welfare reasons whether or not the wool is being put to use. We suggest that the allocation is very much up for challenge. In which case the percentage of production-stage emissions to be allocated to wool fall, and once again it appears that wool compares very favourably with the other textiles.

Whatever the benefits or otherwise, policies to reduce sheep livestock rearing are unlikely to affect the world textiles market very much either way.

5.3 Other animal products

Once the animal is slaughtered, the hide is removed and the animal is cut up, deboned and eviscerated.

While carcass meat is the most significant product from the abattoir, by-products such as hides, blood, fat, bone and offal are also produced. Indeed the profitability of an abattoir will often depend on the extent to which these materials are utilised.[412]

From the abattoir, carcasses, boned meat and edible by-products intended for human consumption (such as certain forms of offal) are distributed on a wholesale basis to meat processing plants or butchers where they are further processed into various cuts or processed meats. Retail cuts are packaged and then further distributed to retail outlets. The remainder is categorised as a Category 1, 2 or 3 by-product (the distinctions are important – see Box 3) and then sent through other channels – either pet food manufacturer or rendering.

Box 3: Waste categories

Category 1 material includes Transmissible Spongiform Encephalopathy (TSE) suspects, specified risk material (SRM) and condemned whole animals.
Category 2 material includes animals that die (other than cattle and sheep containing SRM), animals killed to eradicate an epizootic disease, and manure and digestive tract content.
Category 3 material includes parts of slaughtered animal *that are fit for human consumption, but are not intended for human consumption* either for commercial reasons or because of consumer choice. Other Category 3 materials include feathers, blood and animal parts *that are deemed unfit for human consumption, but derive from carcasses that are approved as fit for human consumption*.

Typically, around 27-40% of an animal's carcass is lean carcass meat (depending on the type of animal). A further 30% or so is also edible and includes offal. Some of this edible meat is sold as it is, some finds its way into processed foods and some is used for pet feed. Note that petfood often uses the lower value cuts of perfectly edible carcass meat too[413] an issue we discuss below. The remainder (excluding the

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[412] *Cleaner Production Assessment in Meat Processing*. Prepared by COWI Consulting Engineers and Planners AS, Denmark for United Nations Environment Programme Division of Technology, Industry and Economics and Danish Environmental Protection Agency 2000
[413] *A Review Of The Red Meat Offal & By-Products Industry*, English Beef and Lamb Executive, June 2006

hide which goes for leather) goes for rendering. Table 13 gives a break down of the main carcass categories by animal type.

Table 13: Main parts of a carcass by animal type

	Cattle kg/head (carcass weight 318kg)	% live weight	Sheep kg/head (carcass weight 20kg)	% live weight	Pigs kg/head (carcass weight 76kg)	% live weight
Carcass lean	192.54	***32.09***	11.70	***27.76***	41.08	***40.53***
Edible human*	122.61	***20.44***	9.11	***21.62***	33.86	***33.41***
Petfood	4.91	***0.82***	1.30	***3.08***	1.37	***1.35***
Rendering	64.46	***10.74***	8.50	***20.17***	14.89	***14.69***
Specified risk materials	98.52	***16.42***	1.76	***4.18***	0.00	***0.00***
Hide and skin	42.49	***7.08***	4.66	***11.06***	0.00	***0.00***
Gut content	74.45	***12.41***	5.11	***12.13***	10.15	***10.01***
Total live weight	599.98	***100.00***	42.14	***100.00***	101.35	***100.00***

Source: *A Review Of The Red Meat Offal & By-products Industry*, English Beef and Lamb Executive, June 2006
*Although this category is technically fit for human consumption in theory much of it goes to pet food

5.3.a Rendered products

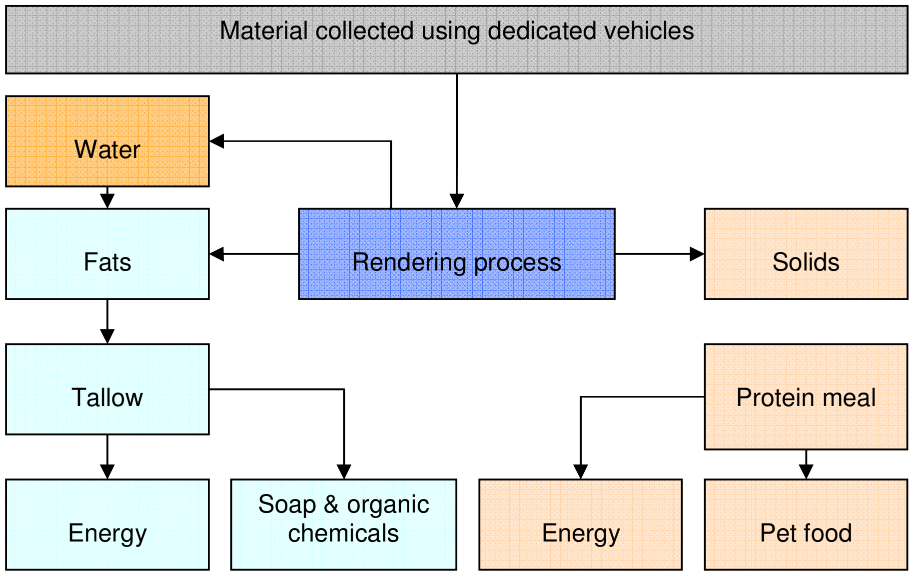
Over 2 million tonnes of by-products a year go for rendering in the UK.[414] Animal by-products are separated at the slaughterhouse into the different risk categories detailed above, stored in dedicated containers and then collected by the rendering firm.[415]

There are 26 rendering plants in the UK.[416] Some of these plants may specialise in dealing with different categories – plants dealing with Category 3 (low risk) by-products for example may or may not deal with Categories 1 and 2 (high risk). Equally, some rendering plants specialise in rendering a particular animal type (animals have different rendering requirements owing to their different body compositions), while others will take all kinds.

Figure 27 illustrates in simplified form the various stages in the rendering process.

[414] David Green, UK Renderers' Association, pers. comm., October 2007
[415] *Pigs UK*, Biffa, 2006
[416] David Green, UK Renderers' Association, pers. comm. October 2007

Figure 27: The Rendering process



Source: Prosper de Mulder, http://www.pdm-group.co.uk/by-product_processing/background.html

At the rendering plant, the matter is crushed, ground and then heated to reduce the moisture content and kill pathogens. Since matter for rendering has a high water content and low calorific value, fuel needs to be added, although this can be supplied by the tallow produced from previous batches as we discuss below.

The melted fat is then separated from the solids (protein) by centrifugion and the solids are ground into powder.[417] A large volume of water effluent is also produced.

The tallow that is produced from the fat has various uses depending on its category status. Category 3 tallow is used in pet foods and Category 2 tallow for oleochemical production (nothing above Category 3 can be used for pet food). Note that lard (which is also a form of tallow) cannot be produced from Category 3 material, but is instead produced from materials entering the human food chain – in other words, once a product goes for rendering, it must not re-enter the human food chain.

The only use for Category 1 tallow is as a fuel. Around 140,000 tonnes of tallow are combusted at rendering plants a year, all of which is a direct replacement for fossil fuels.[418] The tallow generates an estimated 5.6 PJ of heating value.[419] Indeed, of the boilers and thermal oxidisers currently installed at UK rendering plants some 80% use tallow as the fuel input to the rendering process. On a Category 1 or Category 2 rendering plant (where higher risk materials are processed) the tallow produced is usually more than enough to provide the whole heating requirement of the plant. The excess is usually sold to Category 3 plants where the tallow produced has a higher economic value as a pet food ingredient and so is not combusted, or occasionally it is used in other facilities such as abattoirs.

[417] UK Renderers' Association http://www.ukra.co.uk/Factsheet_frame.htm
[418] UK Renderers Association, pers. comm., June 2007
[419] Assuming that the calorific value of tallow is around 40GJ per tonne (see http://vegburner.co.uk/oils.htm)

In one sense this fuel source is renewable in so far as we are likely to go on farming animals. But the term is also misleading as it would not need to be used as a fuel source if there was no waste stream – from which it itself originates – in the first place. And of course the energy recovery, and hence carbon dioxide saving gained from such an approach will never be sufficient to balance the total emissions generated during the course of rearing the livestock, and no one would suggest as much.

As regards protein solids, Category 3 material finds its way into pet food. Chicken feathers are rendered and then used as compost.[420] However neither of these are allowable routes for Category 1 and 2 protein solids – indeed for these categories there are serious disposal problems. In the past, the bone meal had a steady market value as an animal feed. However, following the BSE crisis and the ban in 1996 on the use of any meat and bone meal in feed given to farmed animals, alternative uses for the meal have had to be found. One route has been to use the MBM as a fuel in combined heat and power plants. Some MBM is also mixed with other materials and used as an ancillary fuel for cement production. Since it has a high calcium salt content the MBM is also used as a raw material in the cement.[421] [422]

In addition to thermal processing (to produce heat and power), anaerobic digestion is an area which is receiving close attention among renderers. Its use for products going for rendering is growing in Germany. Somewhat ironically, however, farmers are beginning to find that instead of feeding and rearing animals, and then digesting the waste parts of the carcass, a more direct, economic and environmentally effective route is to bypass the animals themselves entirely and switch instead to feed crops directly as an input to the anaerobic digestion process.[423]

The BSE crisis is in fact an interesting example of how the goal of efficiency (using by-products as inputs into another process) can clash with other priorities, in this case human and animal health and wellbeing. Once a model example of closed loop recycling, animal protein meal has been demoted to a very unwanted by-product.[424] It is worth bearing in mind that future regulations may swing the environmental balance in other areas too, either in a positive or negative direction.

However, one approach to mitigating the environmental impacts of the livestock rearing process for the time being is for the rendering (and waste services industry in general) to develop its potential as an energy provider.

Another is to ensure that all parts of the animal that can be eaten, *are* eaten. Since wasted resources represent a waste of embodied greenhouse gas emissions, it is arguable (although somewhat simplistic) that if more value is gained from an animal's carcass, and if some of that value is reflected in higher farm incomes, then there will be less need to rear as many animals in the first place.

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[420] David Green, UK Renderers Association, pers. comm., June 2007
[421] http://www.pdm-group.co.uk
[422] David Green, UK Renderers Association, pers. comm., June 2007
[423] *Methane gas: Threats and opportunities*, Owen Yeatman, Biogas Nord Ltd. Presentation given at Dairy UK conference, *Dairy farming and the environment: What lies ahead*? Dairy UK, Stoneleigh Park, 5 June 2007
[424] Nonhebel, S., Elferink, E.V, *The use of by-products from food industry as basis for livestock feed and the consequences for the analysis of the environmental impacts of meat consumption* in Niels Halberg (ed.) *Life Cycle Assessment in the Agri-food sector: Proceedings from the 4th International Conference*, October 6-8, 2003, Bygholm, Denmark, Danish Institute of Agricultural Sciences Department of Agroecology

At present, the animal carcass is not utilised to its best potential. Many Category 3 by-products are in fact rendered alongside Category 1 and 2 products, since many abattoirs have insufficient resources to separate Category 3 material from other types.[425] One source estimates that over a quarter of a million tonnes of edible Category 3 by-products are downgraded to Categories 2 or 1.[426] There are also situations when edible whole chickens – spent egg layers – are simply sent for rendering because there is no demand either for whole birds (we just want the breast), or for meat that might not be optimally tender and quick to cook.[427]

And it is also the case that large volumes of meat products, suitable for human consumption, go to feed domestic pets instead.

5.3.b Pet food

Animal parts (or fish) used by the pet food industry must, by law, be fit for human consumption – that is, it must be meet the highest tier of Category 3 specifications. Most of the animal products used by the pet food industry consist of offals and other body parts which have no market value as regards human consumption, but which may in other parts of the world be commonly consumed.

The raw ingredients may obtained directly from the slaughterhouse; alternatively (or additionally), they may come from the renderer after the raw ingredients have been processed. Rendered material for pet food is usually referred to as PAP (Processed Animal Protein) to highlight that it is from Category 3 animals. Both meat (offals, head meat and so forth) and a certain proportion of bone (the 'ash' content in the ingredients list) will be used. The Pet Food Manufacturers' Association estimates that it utilises around 630,000 tonnes of animal by-products a year.[428]

The use of parts that are actually edible to humans to feed domestic animals raises some interesting questions in relation to the avoidance of wasted greenhouse gas emissions through better resource utilisation. If people in the UK started to eat more of the body parts (tripe, tongue, sweetbreads, chicken feet, pigs trotters) that are eaten – often with relish – by people in other countries, not to mention old boiling fowls and the lower value cuts of meat, what would be the impact be both on the pet food manufacturing industry and on the waistlines of our domestic pets? Pets must of course eat and one might then say that feeding these body parts to cats and dogs is represents good resource utilisation.

This 'what if' question invites several answers, all of which are speculative. Manufacturers may of course simply source more animal products from abroad, an option which once again highlights the need to adopt an international perspective on livestock production and consumption. On the other hand, they may also reformulate their feeds to some extent and incorporate a higher proportion of non-animal ingredients. Alternatively, as more animal products go for human food consumption, the volume of Category 3 products available will decline, their value will go up, and there will be incentives for better carcass utilisation – for instance by more rigorous separation of animal by-products into their appropriate risk categories. Either way, it

[425]: *The Gut Room Fact Sheet*, Red Meat Industry Forum, 2007 http://www.redmeatindustryforum.org.uk/images/upload/documents/Gutroom(v10).pdf accessed August 2007
[426] David Green, UK Renderers Association, pers. comm. October 2007
[427] David Green, UK Renderers Association, pers. comm. October 2007
[428] Pet Food Manufacturers Association/Ipsos Mori, 2006 data

is unlikely that our cats and dogs will starve and it may mean that fewer farm animals need to be reared in the first place.

5.3.c Other food by-products

Note that in addition to products that go from the slaughterhouse to the renderer's, waste meat from (say) retailers, food manufacturers and food service outlets also needs to be disposed of. Since the introduction of the 2003 Animal By-products Regulations,[429] these foods cannot be landfilled any more and so some companies such as Prosper de Mulder are using this waste as a renewable energy source.[430] Anaerobic digestion of waste food is also being developed further. Some companies, such as Energy Power Resources (EPR)[431] burn chicken litter to produce energy. Indeed EPR combusts approximately 700,000 tonnes of litter each year and says that this generates around 60 MW of electricity.[432] Assuming, for simplicity, that the litter is replacing the use of gas in a combined cycle plant with an efficiency close to 50% and operating with a capacity factor of about 70%, the chicken litter therefore helps avoid the emission of approximately 40,470 tonnes of carbon (equivalent to 0.025% of the UK's greenhouse gas emissions). EPR also burns Category 3 meat and bone meal, and the ash from the combustion process is then used as a fertiliser.

5.4 Manure, soil management and quality

Manure has an important role to play in improving the quality and fertility of soil. It returns to the soil a range of nutrients, including nitrogen, phosphorous and potassium. In addition to nutrients, manure improves the soil's structure and its ability to retain water, and helps create and maintain a better climate for soil micro-flora and fauna. It has been shown that soil fertilised with manure is more biologically active and fertile than soil fertilised by mineral fertilisers alone.[433] Manure also has a role in building up the carbon storage potential of the soil. In many farming systems, particularly in the developing world, manure is the only fertiliser input the farmers have at their disposal.

It also has substantial economic value. It has been estimated that globally, around 22% of total nitrogen and 38% of phosphate applied to the soil is of animal origin. Most (55% or 3.1 billion tonnes of dry matter) of this manure comes from beef cattle.[434]

Manure also has a role in greenhouse gas avoidance. By substituting for energy-intensive nitrogenous fertilisers, manure helps avoid emissions of greenhouse gases that might otherwise have been emitted. This said, manure represents a fraction of the feeds the animals have consumed, and these in turn will usually have been fertilised with synthetic fertilisers,[435] so the relationship is curiously circular.

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[429] Statutory Instrument 2003 No. 1482: *The Animal By-Products Regulations 2003*, http://www.opsi.gov.uk/SI/si2003/20031482.htm

[430] http://www.pdm-group.co.uk

[431] Energy Power Resources www.eprl.co.uk

[432] Teresa Watcher, Energy Power Resources, pers. comm. August 2007

[433] Fließbach A, Oberholzer H-R, Gunst L and Mäder P. (2007). Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming, *Agriculture, Ecosystems & Environment Volume* 118, Issues 1-4

[434] Cited in *Animal waste management in livestock farms: practical environmental policies and reviews*, UNEP, undated http://www.agrifood-forum.net/home.asp accessed 3 May 2005

[435] Daniel Kindred, ADAS, pers. comm. June 2007

Livestock – or rather the manure they produce – can also play an important part in crop rotations. The Defra-funded MANNER program[436] shows that the amount available to plants for uptake following application will vary according to the manure type (cattle or pigs, manure or slurry), and the time of application – less is available during autumn and winter applications than during spring and summer time.

While the vast majority of manures produced are applied back to the land (possibly following a period of storage) often they are not applied optimally and so nutrients can be over or under-supplied to the soil and subsequent crop. The quality of manure can also be inconsistent and variable. As a result, the true value of nutrients in the manure may not be fully quantifiable or exploited. Perhaps as a result of this uncertainty, farmers may not reduce their inorganic fertiliser applications to take into account the nutrients supplied by the manure.

However, with legislation affecting Nitrate Vulnerable Zones (NVZ) farmers now have to take note of the nutrient nitrogen value of manures, and not exceed a maximum limit of nitrogen application per hectare. Various initiatives and tools help with this, such as ADAS's computerised PLANET[437] and MANNER[438] tools, and future years may see more considered approaches to manure-fertiliser combinations becoming more widespread together with more accurate diagnoses of manure's nutrient content.

There are, however, very few mixed farms in the UK and so for specialist arable farms, manure can play little or no part in the crop rotation. The geographical specialisation of farming in the UK, with dairy herds mainly in the West and arable in the East means that the manure is not necessarily near to where it is needed. Many pig and poultry units without enough land export manure to neighbouring arable farms, but there will still be localised surpluses and shortages.

Manure has its downsides too. As it breaks down in the soil it emits nitrous oxide and methane. According to one estimate, the nitrous oxide and methane emissions from animal manure alone contribute to more than 5% of total anthropogenic greenhouse gas emissions.[439] The main contributor here is nitrous oxide – compare 1,092 million tonnes CO_2e/year for nitrous oxide with 368 million tonnes CO_2e/year for methane.[440]

In addition to greenhouse gases, manure can also generate ammonia emissions and pollute groundwater creating additional environmental problems. Emissions can be reduced through good timing of application, but this may not always be possible. Lack of on-farm storage capacity means that farmers apply the manure when it is available rather than when its application is optimal. Sometimes access to the land for spreading can be limited due to water-logging or frozen soil.

Notwithstanding the pros and cons of manure, around a third of all cereals grown worldwide are, as we have already observed, used to feed animals. With fewer livestock, the need for nitrogenous and other fertilisers might actually fall since we

[436] *Managing Livestock Manures: Making better use of livestock manures on arable land*, IGER, ADAS and Silsoe Research Institute, 2nd Edition, 2001
[437] www.planet4farmers.co.uk
[438] http://www.adas.co.uk/manner/frameset.html
[439] *Livestock's Long Shadow – Environmental Issues and Options*, FAO, December 2006 – See Table 3.12
[440] *Livestock's Long Shadow – Environmental Issues and Options*, FAO, December 2006 – See Tables 3.8 and 3.11

would not need to grow so many feed crops. On the other hand, in a context of lower livestock production we would need to grow substitute foods and their cultivation would require fertiliser inputs, either of synthetic or natural origin (such as legumes). Once these two are balanced out it may be (as the study discussed in 5.1 suggests[441]) that the total quantity of cereals grown would stay more or less the same. There would, however, be less need to fertilise grazing land. This said, within a context of a growing global population the need for food will grow, as will the need for soil inputs from whatever source.

Finally, as highlighted, manure provides more than nutrients; it also has a role in improving the soil texture and structure. One might need to consider the extent to which substitute materials (such as compost or anaerobic digestion digestate[442] from non-animal sources) also have these properties and what the environmental impacts of any such substitution might be.

In short, manure is valuable – but it is also a problem. Some of the options for reducing the negative impacts of manure are discussed in Section 6 below. One question to consider is whether a shift to lower levels of livestock production reared in mixed (livestock-arable) farms might be one way to optimise the benefits of manure while minimising the disbenefits. There is also a need for further research to establish whether in mixed farming systems, the nutrient flows that result from crop-animal rotations produce greenhouse gas emission levels that are different from the sum of the disaggregated parts.[443] Clearly the gains would need to be balanced against any disbenefits – one study finds in fact that soils fertilised with manure produce more nitrous oxide over longer periods than those fertilised with mineral inputs.[444] Arable production moreover does not always thrive in the wetter parts of Britain where livestock dominate.

5.4.a Soil carbon sequestration

Grasslands act as sinks for carbon. While established grasslands (as with forests) do not continue to take carbon out of the atmosphere to any particularly significant degree the point here is that any *changes* in land use that that disrupt the soil (ploughing, say, or construction activities) will cause releases of stored carbon into the atmosphere. Hence, one might argue that livestock, by giving grasslands an economic function, has an important role to play in maintaining pasture land and, as such, to prevent it from being used for another purpose. This said, if we decided to assign environmental value to the land, maintain it undisrupted as a public good and pay farmers for doing so, then, whether or not the livestock were there, the same effect would be achieved.

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441 Srinivasan CS, Irz X, Shankar B. (2006). An assessment of the potential consumption impacts of WHO dietary norms in OECD countries *Food Policy* 31 53–77

442 digestate is the solid material remaining after the anaerobic digestion of a biodegradable feedstock

443 The work of Williams et al. referred to already in this report (Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra) takes this disaggregated approach, but future work by the authors will be considering how to incorporate the more 'holistic' approach (for want of a better phrase) into the model.'

444 Jones SK, Rees RM, Skiba UM, Ball BC (2007). Influence of organic and mineral N fertiliser on N_2O fluxes from a temperate grassland, *Agriculture, Ecosystems and Environment* 121 74–83

One study finds, however, that the carbon sequestering consequences of grazing animals is undermined by their role in increasing nitrous oxide fluxes from grasslands over and above fluxes that would have occurred on ungrazed pasture.[445] This 'grazing effect' as the authors call it is likely to reflect the deposition of urine and dung, which create nitrous oxide hotspots together with the trampling action of their hooves, which compacts the soil.

5.5 Biological diversity and landscape aesthetics

Grazing sheep and cattle have shaped the countryside we know today. Their presence on the land and their grazing activities have helped foster a rich diversity of plant and other species as well as the 'look' of the countryside, with its hedgerows and stone walls. To remove livestock from traditionally grazed areas would change what is traditionally thought to be the 'traditional' or 'quintessential' British countryside.

This section considers the following questions: How do livestock help maintain the landscape we know and value? How and to what extent might they also *damage* the landscape? How fixed are our notions of what constitutes a traditional or aesthetically valued landscape? Is there an optimum level of livestock grazing such that this value is preserved while livestock related greenhouse gases are reduced?

At the right stocking density, grazing livestock can enhance grassland species diversity. Their constant nibbling, chomping and stamping controls the vigour of dominant or invasive species, allowing other less robust plants to thrive. Different livestock species will also graze in different ways and at different levels and this variety too is beneficial to species diversity. Hence land that is grazed by different kinds of livestock, providing it is not over-grazed, will lead to a varied and diverse biological landscape. On the other hand a monopoly by one grazing species on a particular area can lead to a landscape with somewhat limited biodiversity.

Nonetheless, livestock grazing can not only enhance the landscape, but also harm it. In developing countries particularly, overgrazing is a serious problem. Around 20% of the world's pastures and rangelands, with 73% of rangelands in dry areas have been degraded to some extent, mainly as a result of livestock action.[446]

In the UK too overgrazing has been one of the main contributors to organic soil degradation,[447] accounting for 36% of all reductions in soil quality. While sheep are the main cause, cattle also contribute to, and exacerbate the problem.[448] The area of eroded land in the uplands (not just organic soils) is reported to be increasing at a

[445] Flechard C.R, Ambus P., Skiba U., Rees R.M., Hensen A., van Amstel A., van den Pol-van Dasselaar A., Soussana J. F., Jones M., Clifton-Brown J., Raschi A., Horvath L., Neftel A., Jocher M., Ammann C., Leifeld J., Fuhrer J., Calanca P., Thalman E., Pilegaard K., Di Marco C., Campbell C., Nemitz E., Hargreaves K.J., Levy P.E., Ball B.C., Jones S.K., van de Bulk W.C.M., Groot T., Blom M., Domingues R., Kasper G., Allard V., Ceschia E., Cellier P., Laville P., Henault C., Bizouard F., Abdalla M., Williams M., Baronti S., Berretti F., Grosz B. (2007). Effects of climate and management intensity on nitrous oxide emissions in grassland systems across Europe *Agriculture, Ecosystems and Environment* 121 135–152

[446] *Livestock's Long Shadow – Environmental Issues and Options*, FAO, December 2006

[447] Organic soils include peat, stagnopodzols, stagnohumic gleys, humic-alluvial gleys, humic sandy gley and humic gleys

[448] *Vulnerability of organic soils in England and Wales*, Defra project SP0532 undertaken by the Universities of Leeds, Manchester and Durham

rate of 500 hectares per annum, and it has been estimated that 2.5 % of the total upland area is now eroding.[449]

Overgrazing is listed as the major agricultural reason for 'unfavourable conditions' on Sites of Scientific Interest. 36.16% of the area not meeting the PSA (Public Service Agreement) target has been classified as such because of overgrazing.[450] With the wetter winters that are expected as our climate changes, excessive grazing could lead to a vicious cycle of environmental degradation

By contrast, undergrazing accounts for only 5.94% of areas whose conditions are deemed 'unfavourable'. This said, while at present this is less of a problem than overgrazing, one might speculate that were livestock numbers to be reduced, the problem of undergrazing would increase. English Nature notes that, following the introduction of the Single Payment Scheme, farming in many hill areas is no longer commercially viable, meaning that livestock numbers may decline. Hence the problem of undergrazing could well grow.[451]

It is also worth pointing out that much of our grazing land is not biodiverse at all, the result of high fertiliser application levels and the sowing of very simple grass-clover mixes. According to one 2002 report over 95% of semi-natural grasslands no longer have any significant wildlife conservation interest.[452]

The type of farming practiced plays an influential role in determining the biodiversity of grazing land. One study points out that while grass monocultures grown to feed intensively reared cattle are of limited botanical and biodiversity value, extensive dairying plays an important role in the preserving landscapes and biodiversity in marginal areas.[453] Another study, however, finds that biodiversity status is poor both for intensively and extensively grazed grasslands.[454]

5.5.a Our notions of 'tradition'

Our view of what 'traditional' means very much mirrors what we know and are used to. The managed forests of medieval Britain were doubtless also considered to be 'traditional' at the time.

The notion that we should let moorlands and grazed lowland return ungrazed to their 'natural' state (whatever that means) would undoubtedly be met with public outrage. People do not like change. This said, it is interesting to note that while the process of change may be painful, once a new status quo has been achieved, people are able to adjust to, and even be happy with, their new circumstances. Surveys examining

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[449] *Vulnerability of organic soils in England and Wales*, Defra project SP0532 undertaken by the Universities of Leeds, Manchester and Durham
[450] The Government's Public Service Agreement (PSA) target is to have 95% of the SSSI area in favourable or recovering condition by 2010.
[451] *The importance of livestock grazing for wildlife conservation*, English Nature, 2005 http://www.english-nature.org.uk/pubs/publication/PDF/LivestockGrazing.pdf
[452] Hopkins A and Tallowin J. (2002). *Enhancing the biodiversity and landscape value of grasslands*, IGER Innovations, Institute of Grassland and Environmental Research, 2002
[453] The implications of the CAP reform agreement for the dairy sector: An environmental perspective, Institute for European Environmental Policy, London, March 2004
[454] Tallowin J.R.B, Smith R E N, Goodyear J and Vickery J A (2005). Spatial and structural uniformity of lowland agricultural grassland in England: a context for low biodiversity, *Grass and Forage Science*, 60, 225–236

peoples attitudes to windfarms provide an interesting illustration. One DTI survey[455] found that while most people in principle support renewable energy, only a third of respondents would be happy to live within 5 km of a windfarm. However, the survey also found that the people who actually do live near to a renewable energy installation are those most in favour of renewables. The conclusion one might draw is that that exposure actually increases approval. Thus, while the prospect of change may be unappealing to most, once the change has taken place people tend to adjust.

5.5.b Towards an optimum level?

It will always be necessary to manage our landscape if want to maintain and foster biologically diverse ecosystems. One way of maintaining landscape value while reducing livestock greenhouse gases is to keep the upland extensive grazing systems and substantially reduce the lowland and intensive ones. For lowland areas there may be scope, as discussed as above, to convert them to managed biomass production, which in turn could be used as a biofuel source. While the meat produced from upland livestock may be more greenhouse gas intensive than intensively reared lowland stock owing to higher methane outputs (see Section 6), this additional burden will be more than compensated for by an overall decline in numbers. Some of the impacts that are less fully captured by life cycle analysis (such as the second order impacts from soy cultivation) will also be avoided. However a shift towards more extensive livestock grazing in upland areas, and less in the lowlands, goes contrary to some of the trends that are beginning to emerge, as discussed in Section 2, above.

5.6 Livestock outputs – some conclusions

This section has looked at some of the outputs arising from the livestock production chain. It has explored some of the benefits and costs that ensue, framing the discussion in the context of 'needs' rather than just demand. Table 14 provides a brief summary.

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[455] *Renewable Energy Awareness and Attitudes Research: Management Summary*, Department for Trade and Industry, May 2006

Table 14: Benefits and greenhouse gas costs of livestock production and consumption

Issue	Benefits	Costs (greenhouse gas emission)
Human nutrition	Meat and dairy products are an excellent source of protein, iron, calcium, vitamin B12 and other nutrients. Individual plant foods do not provide the full range of amino acids and would themselves require land for production and consume energy inputs leading to greenhouse gas outputs.	Meat and dairy products are also energy dense and high in fat and hence may be implicated in the growing problem of obesity. Since livestock and oilcrop production are linked, the added fats and calories that vegetable oils provide are associated with the meat and dairy chains. Feeding edible crops to animals represents an inefficient use of energy. The nutrients that livestock products provide can be met fully and more efficiently by consuming plants.
Animal feed issue: Cereals	Livestock consume cereals of a quality not suitable for human consumption	Feed-grade cereals are perfectly edible by humans, but would require a shift in our expectations of what (for instance) a standard bread loaf should look and taste like. Alternatively these cereals could be used as a biofuel although the benefits here in terms of greenhouse gas avoidance are very debatable.
Animal feed issue: Oilseeds	Makes use of waste by-products from vegetable oil production	Oilseed cake – soy in particular – is in fact a co-product of oil production. Growth in soy production is largely driven by growth in demand for meat. Soya production is associated with emissions of greenhouse gases not just through the manufacture of fertilisers and nitrogen emissions to soil, but also because of the deforestation that results directly and indirectly from soy production. .
Animal feed issue: Other by-products such as vegetable residues and so forth	These could not be used in any other way	These residues constitute a dwindling element in the livestock diet. Some by-products could be used as a biofuel (e.g. through anaerobic digestion) instead of going to animal feed.

Issue	Benefits	Costs (greenhouse gas emission)
Animal feed issue: Grassland	Ruminants graze on grass that could not be used for any other form of agriculture.	Lowland pasture land is often heavily fertilised and as such is not an input-free form of land. Some of this land could be in fact be used for biomass production. In upland (unfertilised) areas there are few alternative uses to grazing, other than woodland planting, but overgrazing can nevertheless be a significant problem.
Non food products: Materials	Livestock provide us with more than just food. We also gain leather, wool, and inputs to various industrial processes (e.g. glue manufacture). These would have to be manufactured in another way, and energy would inevitably be used in the process. The production of synthetic materials could in fact be more energy intensive than the livestock products for which they substitute.	Leather production is associated with significant environmental impacts. It may be that we do not need as much leather as we actually produce. While most wool is currently utilised one way or another it accounts for a very small proportion of total textile manufacture. A very significant increase in livestock numbers would be needed to make a significant contribution to total textile production (even if this was viable). The animal contribution to oleochemical production faces competition from plant-based products; in other words there is no shortage of suitable materials.
Non food products: Manure	Manure contributes to soil fertility and without it we would be more reliant on energy intensive fertilisers. It also has an important role to play in improving soil quality and structure and in increasing the carbon sequestration potential of the soil	Manure comes with its own significant downsides including nitrous oxide and methane emissions as well as other non-GHG related environmental impacts, although these impacts can be reduced through proper management. In addition a good part of our fertiliser needs are for the production of feeds that in turn go to feed livestock (In the UK 50% of our wheat crop is used for livestock feed).
Non food products: Landscape value	Livestock have shaped our landscape and we know and love it as it is. Grazing animals help nurture and maintain particular balances of flora and fauna; undergrazing will upset this balance.	We like the landscape we know; other historical periods have had (and presumably valued) other 'traditional landscapes'. Overgrazing is a problem in some parts of the UK and a major problem globally. Most of our grazing land is in fact not species diverse at all.

We do not draw any firm conclusions. However as a very provisional observation we suggest that at a certain level of production, livestock farming yields real and

important benefits. For human nutrition, the inclusion of small quantities of meat, eggs and dairy produce in our diet can, while not essential, be very helpful, although too much can contribute to problems of obesity and associated concerns. For the many nutritionally vulnerable people in the developing world, however, livestock foods can greatly enhance the quality of their diet.

Livestock farming also yields a number of valuable non-food goods such as leather and industrial by-products. However these are very probably being produced surplus to requirements given the availability of adequate competing materials.

Perhaps most significantly, livestock play a vital part in fertilising our soil, helping create and maintain biologically and aesthetically diverse landscapes, and, by putting otherwise low-value landscape to economic use, helping preserve its soil sequestering properties. Unfortunately, excessive livestock production has also helped destroy these benefits and actively created problems of soil degradation, biological impoverishment and, through overgrazing and intensive feed production, a loss in the soil's ability to sequester carbon.

We would suggest that at low levels of production, livestock farming yields positive societal and environmental gains. At present levels, however, the disbenefits outweigh the benefits.

But is it not too simplistic and indeed unrealistic to assume that a substantial reduction the number of animals we farm is the only way forward? What if we were able to reduce livestock related greenhouse gas emissions without substantially reducing livestock numbers? Are there managerial and technological ways of reducing livestock related greenhouse gas emissions? If so, what might the implications be for other ethical and environmental areas of concern?

These are the questions we consider in the section that follows.

SECTION 6: GREENHOUSE GAS MITIGATION OPTIONS

This section reviews some of the options available for reducing livestock greenhouse gas emissions and touches upon the social, economic and ethical implications of the various strategies on offer.

Countries with large ruminant populations are increasingly focusing research efforts on livestock greenhouse gas mitigation options. In the UK, Defra has published an overview of all its commissioned research on agriculture and environmental protection, including greenhouse gas mitigation between 1995-2005,[456] and is currently funding a tranche of further research.[457] [458] [459] In New Zealand, where livestock farming accounts for half the country's greenhouse gas emissions,[460] the Ministry of Agriculture and Forestry (MAF) has undertaken a detailed review[461] of mitigation options and research priorities.

The EU has also undertaken work in this area, including a system analysis of greenhouse gas emissions from European dairy production, together with an examination of possible mitigation strategies – the MIDAIR project.[462] A major study commissioned by the Institute for European Environmental Policy[463] looks at hundreds of different options for reducing emissions from dairy cattle, ranging from modifications in housing arrangements, to the use of vaccination, to larger scale changes in management and farming approach.

Most of the discussion focuses on ruminants – and indeed mainly on cattle – since, as our literature review in Section 3 has shown, this is where the bulk of research attention has focused. This focus is a measure of their importance to the UK farming economy and culture. It also reflects the fact that most life cycle analyses have found ruminants to be more greenhouse gas intensive than monogastrics, although we have argued that this is an overly simplistic conclusion.

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[456] Defra research in agriculture and environmental protection 1990-2005; summary and analysis – Defra, ES0127 http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&ProjectID=12885&FromSearch=Y&Publisher=1&SearchText=es0127&SortString=ProjectCode&SortOrder=Asc&Paging=10#Description accessed 22 August 2007

[457] *Optimising nutrition to increase carbon and nitrogen capture in ruminant products*, Defra project (LS3656)

[458] *Ruminant nutrition regimes to reduce methane and nitrogen emissions*, Defra project AC0209

[459] *A study of the scope for the application of research in animal genomics and breeding to reduce nitrogen and methane emissions from livestock-based food chains*, Defra project AC0204

[460] *New Zealand's greenhouse gas inventory 1990-2004*, Chapter 6, Ministry for the Environment, New Zealand http://www.mfe.govt.nz/publications/climate/nir-apr06/html/index.html accessed 9 June 2007

[461] O'Hara P, Freney J and Ulyatt M. (2003). *Abatement of Agricultural Non-Carbon Dioxide Greenhouse Gas Emissions: A Study of Research Requirements*. Report prepared for the Ministry of Agriculture and Forestry on behalf of the Convenor, Ministerial Group on Climate Change, the Minister of Agriculture and the Primary Industries Council

[462] *MIDAIR - Greenhouse Gas Mitigation for Organic and Conventional Dairy Production* EC, 2004, Contract No: EVK2-CT-2000-00096 http://www.ie-leipzig.de/MIDAIR.htm

[463] Weiske A. (2005). *Survey of technical and management-based mitigation measures in agriculture* Document number: MEACAP WP3 D7a, Institute for European Environmental Policy

Before discussing some of the options available we briefly describe each of the individual contributory greenhouse gases in turn, the means by which they are generated, and their relative importance to ruminant greenhouse gas emissions.

6.1 The relevant greenhouse gases

6.1.a Carbon dioxide

Livestock related carbon dioxide originates from two main sources. The first derives from the use of fossil fuels. These are used to produce fertiliser, to power farm machinery and activities related both to feed production and livestock rearing, and for all post farm gate stages all the way through to consumption and waste disposal. Up to the farmgate, livestock related fossil fuel use is low relative to other UK economic activities. This said, pig and poultry production are judged to be 'energy intensive' industries and as such qualify for Climate Change Agreements.

From the farm gate onwards, carbon dioxide is overwhelmingly more dominant than any of the other greenhouse gases, although we have already shown (see Table 3 above) that post farm gate overall emissions are minor in comparison with rearing-stage emissions.

The second, and more significant source of carbon emissions, results from land use change and degradation. At a global level, it has been estimated that livestock related land use change leads to the release of 2.4 billion tonnes of carbon dioxide a year, equivalent to approximately 7% of global greenhouse gas emissions.[464]

Unfortunately, figures for the UK are not available. While soil degradation (and subsequent carbon losses) do occur in the UK, the degradation problem is clearly more significant in the developing world. This said, some of the feed inputs to UK livestock production (as well as a small proportion of imports) will have originated from vulnerable developing world countries and as such some of these impacts should properly be allocated to UK livestock production and consumption.

6.1.b Methane

Agriculture's contribution to the UK's total methane emissions stands at about 37.5% and all of this is attributable to livestock.[465] Methane emissions arise largely from ruminant enteric fermentation; this accounts for 86% of all livestock related methane. Manure from both cattle and pigs together produce the remaining 14%.

How much methane is generated per given quantity of output (meat or milk) will vary according to diet – both the feedstuffs given and the digestibility of the pasture (which varies by season) – and to the way manure is managed.

[464] *Livestock's Long Shadow – Environmental Issues and Options*, FAO, December 2006
[465] *UK Greenhouse Gas Inventory 1990-2005: Annual Report for submission under the Framework Convention on Climate Change*, AEA Technology, April 2007

6.1.c Nitrous oxide

Nitrous oxide emissions result from or are associated with:

- The production of feed stuffs and pasture. The key issue here is the application of inorganic and organic nitrogen-containing fertilisers, the mineralisation of nitrogen in the soil and any subsequent nitrous oxide emissions
- The production of nitrogenous fertilisers (nitrous oxide is emitted in addition to carbon dioxide that results from the burning of fossil fuels)
- The amount of nitrogen containing food that is fed to livestock and how efficiently feed inputs are converted to edible output (meat, milk).
- The quantity of nitrogen that is surplus to requirements – this in turn is related to the overall quantity of proteins present in the diet – and the extent to which surpluses are 'mopped up' by other crops as part of a farm rotation cycle
- Emissions from urine and to a lesser extent manure
- Trampling by livestock which compacts the soil and creates an environment favourable to the formation of nitrous oxide
- Indirect emissions from nitrogen lost to the agricultural system e.g. through leaching, runoff or atmospheric deposition (these are poorly understood and not discussed here).

Nitrous oxide is produced through the nitrification and denitrification of the organic nitrogen in livestock urine and manure, as well as from the fertiliser nitrogen that is not taken up by plants. How much nitrous oxide is emitted depends on the composition of the manure and urine, of the type and quantity of fertiliser applied, the type of bacteria involved in the process, and the amount of oxygen and liquid in the manure system.

Fluxes of nitrous oxide emissions will moreover vary hugely according to climate, soil quality and other variables[466] and, hence, there are major uncertainties in quantifying nitrous oxide emissions.[467] In general, wet, waterlogged conditions are conducive to the emission of nitrous oxide. Box 4 summarises the nitrogen cycle and the ways in which nitrous oxide can be formed.

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[466] Conen, F., Dobbie, K.E. and Smith, K.A. (2000). Predicting N_2O emissions from agricultural land through related soil parameters. *Global Change Biology*, 6, 417-426.

[467] Oenema, O., Gebauer, G., Rodriguez, M., Sapek, A., Jarvis, S.C., Corré, W.J., Yamulki, S. (1998). Controlling nitrous oxide emissions from grassland livestock production systems. *Nutrient Cycling in Agroecosystems* 52, 141–149

Box 4: The Nitrogen cycle[468]

Nitrogen (N) is an essential component of DNA, RNA, and proteins. All organisms require nitrogen to live and grow.

Although the majority of the air we breathe is nitrogen (N_2), most of the nitrogen in the atmosphere is unavailable for use by organisms since the strong triple bond between the N atoms in N_2 molecules makes it relatively inert. For plants and animals to use nitrogen, N_2 gas must first be converted to a more chemically available form such as ammonium (NH_4+), nitrate (NO_3-), or organic nitrogen (e.g. urea – $(NH_3)_2CO$). The inert nature of N_2 means that biologically available nitrogen is often in short supply in natural ecosystems, limiting plant growth and biomass accumulation.

The movement of nitrogen between the atmosphere, biosphere, and geosphere undergoes five main processes: nitrogen fixation, nitrogen uptake (organismal growth), nitrogen mineralization (decay), nitrification, and denitrification. Microorganisms, particularly bacteria, play major roles in all of the principal nitrogen transformations. The speed of this process is affected by environmental factors that influence microbial activity, such as temperature, moisture, and resource availability.

Nitrogen Fixation

$N_2 \rightarrow NH_4$+

Through nitrogen fixation, N_2 is converted to ammonium; this is essential because it is the only way that organisms can attain nitrogen directly from the atmosphere. Certain bacteria, for example those among the genus Rhizobium, are the only organisms that fix nitrogen through metabolic processes and these bacteria often form symbiotic relationships with host plants, such as those in the legume family. In addition, high-energy natural events such as lightning, forest fires, and even hot lava flows can cause the fixation of smaller, but significant amounts of nitrogen. The high energy of these natural phenomena can break the triple bonds of N_2 molecules, thereby making individual N atoms available for chemical transformation. Fixation of nitrogen is also possible through the Haber-Bosch process. Here ammonia is made by placing nitrogen gas and hydrogen gas in a high-pressure chamber. With the addition of a suitable catalyst, and heat to speed things up, vast quantities of fixed plant-available nitrogen can be produced.

Nitrogen Uptake

$NH_4^+ \rightarrow$ Organic N

The ammonium produced by nitrogen fixing bacteria is usually quickly incorporated into protein and other organic nitrogen compounds, either by a host plant, the bacteria itself, or another soil organism.

Nitrogen Mineralization

Organic N $\rightarrow NH_4^+$

After nitrogen is incorporated into organic matter, it is often converted back into inorganic nitrogen by a process called nitrogen mineralization, otherwise known as decay. When organisms die, decomposers (such as bacteria and fungi) consume the organic matter. During decomposition, a significant amount of the nitrogen contained within the dead organism is converted to ammonium. In this form, the nitrogen is available for use by plants or for further transformation into nitrate (NO_3^-).

[468] Much of this has been adapted from http://www.visionlearning.com/library/module_viewer.php?mid=98&l=&c3=

Nitrification

$NH_4^+ \rightarrow NO_3^-$

Some of the ammonium produced by decomposition is converted to nitrate via a process called nitrification. The bacteria that carry out this reaction gain energy from it. Nitrification requires the presence of oxygen, so nitrification can happen only in oxygen-rich environments such as circulating or flowing waters and the surface layers of soils and sediments.

The process of nitrification has some important consequences. Ammonium ions are positively charged and therefore stick (are sorbed) to negatively charged clay particles and soil organic matter. The positive charge prevents ammonium nitrogen from being leached from the soil by rainfall. In contrast, the negatively charged nitrate ion is not held by soil particles and so can be washed down the soil profile, leading to decreased soil fertility and eutrophication of downstream surface and groundwaters. Nitrous oxide can also be emitted indirectly.

Denitrification

$NO_3^- \rightarrow N_2 + N_2O$

Through denitrification, oxidized forms of nitrogen such as nitrate and nitrite (NO_2^-) are converted to dinitrogen (N_2) and, to a lesser extent, nitrous oxide gas. Denitrification is an anaerobic process that is carried out by denitrifying bacteria, which convert nitrate to dinitrogen in the following sequence:

$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$.

Nitric oxide (NO) contributes to smog, and nitrous oxide (N_2O) is an important greenhouse gas, approximately 300 times more potent than carbon dioxide.

The nitrogen that is taken up by plants is then consumed by ruminants.

Depending on the management practice, the N excreted to the soil is made available to plants and thereby contributes to plant growth.

6.1.d The relative significance of carbon dioxide, nitrous oxide and methane

The relative significance of the gases will vary by livestock type and farming system.

Globally, for ruminant systems, methane and nitrous oxide tend to dominate. Olesen et al. find that nitrous oxide contributes on average about 49% of the total global warming potential of emissions and methane about 42%, leaving a carbon dioxide contribution of only 9%.[469]

A smaller study of two beef cattle farms (organic and indoors-conventional) puts slightly higher emphasis on nitrous oxide emissions (60% of total emissions for both farming systems), and less on methane (25%), but again finds carbon dioxide emissions to be relatively small at 15%.[470] A study by de Boer attributes 48-65% of

[469] Olesen JE, Schelde K, Weiske A, Weisbjerg MR, Asman WAH and Djurhuus J. (2006) Modelling greenhouse gas emissions from European conventional and organic dairy farms, *Agriculture, Ecosystems and Environment* 112 207–220

[470] Flessa, H. Ruser R. Dörsch P, Kamp T. Jimenez M.A. Munch, J.C. Beese F. (2002). Integrated evaluation of greenhouse gas emissions (CO_2 , CH_4,N_2O) from two farming systems in southern Germany, *Agriculture, Ecosystems and Environment* 91 175–189

the `global warming potential` of milk production to methane.[471] According to Schils et al.[472] for a dairy system, methane accounts for 49% of total emissions, nitrous oxide 27% and carbon dioxide 24%. Gibbons et al.[473] give the following breakdown for a mixed dairy and beef farm: Methane, 54.4% nitrous oxide 36.5% and carbon dioxide, 9.2%. Dairy cattle generate more methane than beef cattle because they need to consume more food to enable them to lactate.

The Cranfield study[474] gives breakdowns for all the main livestock types. Methane dominates for cattle and for sheep. For poultry products the impacts are split fairly evenly between carbon dioxide and nitrous oxide, while for pigs, carbon dioxide dominates, followed by nitrous oxide with methane accounting for the remaining 22%. In organic systems the relative importance of methane increases for ruminants, and nitrous oxide increases for monogastrics.

Table 15: Relative significance of different greenhouse gases by livestock type

Average farm mix*	**CO_2 (%)**	**CH_4 (%)**	**N_2O (%)**
Pig meat	47	22	32
Poultry	45	2	53
Beef	21	49	31
Sheep meat	19	50	31
Milk	24	49	27
Eggs	46	4	50
100% Org	**CO_2 (%)**	**CH_4 (%)**	**N_2O (%)**
Pig meat	49	5	46
Poultry	39	2	59
Beef	14	65	21
Sheep meat	12	63	26
Milk	18	61	21
Eggs	45	3	52

*99% non-organic

Source: Williams AG (2007) *per comm.* obtained from the model available at www.agrilca.org as described in: *Williams, A.G., Audsley, E. and Sandars, D.L. (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.*

[471] I.J.M de Boer (2003). Environmental impact assessment of conventional and organic milk production, *Livestock Production Science* 80 69-77
[472] Schils RLM, Verhagen A Aarts HFM and Šebek LBJ. (2005). A farm level approach to define successful mitigation strategies for GHG emissions from ruminant livestock systems, *Nutrient Cycling in Agroecosystems* 71. 163-175
[473] Gibbons JM, Ramsden SJ, Blake A. (2006). Modelling uncertainty in greenhouse gas emissions from UK agriculture at the farm level, *Agriculture, Ecosystems and Environment* 112, 347–355
[474] Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.

Since nitrous oxide and methane emissions are so dominant for livestock systems, most mitigation efforts tend to be focused on limiting emissions of these two gases. It is important to emphasise that all these are straightforward life cycle analyses. They do not take into account some of the more complex issues, such as lost carbon sequestration potential (in the case of soy) or the opportunity cost of land take. Once these second order impacts are taken into account, carbon dioxide grows in relative significance.

The problem with measures to reduce emissions from one particular greenhouse gas is that trade-offs can occur. For example, while a concentrates-rich diet will reduce enteric methane emissions, energy use and nitrous oxide emissions generated during the course of producing the feed and the feed inputs can increase. A diet rich in nitrogen (protein) can lead to high outputs of milk and meat, which in turn means relatively lower methane emission levels from enteric fermentation. However, they can also lead to high nitrogen surpluses that can result in nitrous oxide.[475] Several commentators have urged the need to develop mitigation strategies that acknowledge the interactions between the various gases, so that reductions in one gas are not achieved at the expense of others.[476] [477] [478] What is more, measures to reduce nitrous oxide emissions can lead to increases in ammonia;[479] this, while not a greenhouse gas, is nevertheless a major pollutant.

Another way of looking at emissions and their mitigation potential is to consider not so much the individual gases, but instead to consider the stage in the rearing process where greatest emissions occur. One study of Irish milk production[480] found that of total emissions,[481] 49% was accounted for by enteric fermentation, 21% by fertiliser, 13% by concentrate feed, 11% by dung management and 5% by electricity and diesel consumption.[482] These can not be divided neatly into methane, carbon dioxide and nitrous oxide emissions – for instance, dung management will create both methane and nitrous oxide emissions while fertiliser production and application will have generated both carbon dioxide and nitrous oxide.

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[475] Measures to reduce N_2O may also lead to increases in ammonia emissions. This is an important issue, but is beyond the scope of this paper.

[476] Oenema O, Velthof G and Kuikman P (2001). Technical and policy aspects of strategies to decrease greenhouse gas emissions from agriculture, *Nutrient Cycling in Agroecosystems*, 60: 301-315

[477] D.K. Lovett, L. Shalloo, P. Dillon, F.P. O'Mara (2006). A systems approach to quantify greenhouse gas fluxes from pastoral dairy production as affected by management regime, *Agricultural Systems*, vol 88 2-3

[478] Schils R L M, Verhagen A, Aarts H F M and Šebek L B J (2005) A farm level approach to define successful mitigation strategies for GHG emissions from ruminant livestock systems, *Nutrient Cycling in Agroecosystems* 71. 163-175

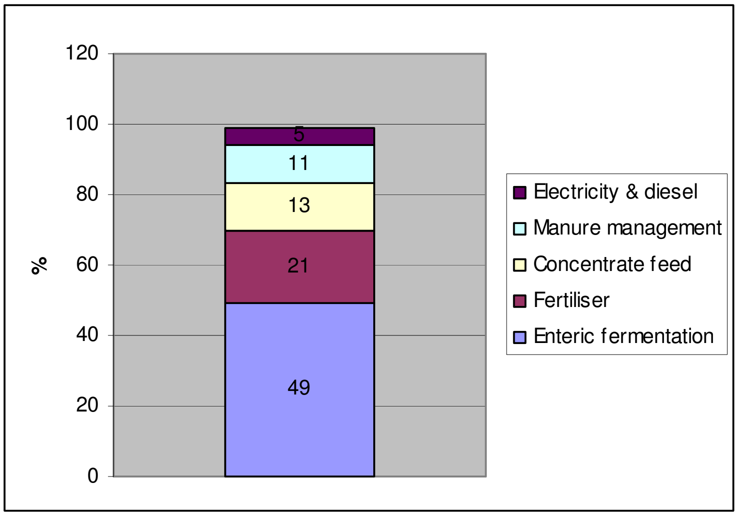
[479] Monteney G-J, Bannink A and Chadwick D. (2006) Greenhouse gas abatement strategies for animal husbandry, *Agriculture, Ecosystems and Environment* 112 163–170

[480] Casey J W and Holden N M (2005) Analysis of greenhouse gas emissions from the average Irish milk production system , *Agricultural Systems*, Agricultural Systems 86 97–114

[481] Based on economic allocation between milk and meat

[482] These figures do not add up due to rounding

Figure 28: Greenhouse gas contribution of stages up to farm gate for dairy cows



Source: Casey J W and Holden N M. Analysis of greenhouse gas emissions from the average Irish milk production system, *Agricultural Systems* 86 (2005) 97–114

6.2 The mitigation options – areas to consider

Broadly speaking, from the research we have reviewed, four main approaches to mitigating livestock greenhouse gas impacts emerge. These focus on the following areas: husbandry; the management system; the outputs and the number of livestock. These are summarised as follows:

Husbandry for productivity

- Changing the feed: Removing/reducing the causes of greenhouse gases by modifying the feed the animal consumes
- Changes to genetic make up: Increasing the quantity of meat or milk produced per animal, which, translates loosely into more milk/meat per burp, or breeding animals which emit lower levels of methane during the course of digestion
- Changes to lifespan: Increasing the fertility or longevity of livestock or shortening the fattening period

Different management systems

- Managing soil inputs
- Organic: The relative merits of conventional versus organic production
- Extensification versus intensification
- Housing: Indoor versus outdoor
- Managing energy inputs

Managing the outputs

- Manure storage and handling

Changing the numbers

- Number changes: Reducing livestock numbers over and beyond what results from increases in productivity.

The following subsections take each of these areas in turn and explore their potential in more detail, with reference to some of the wider issues they raise. The final part of this section discusses some of the implications specifically for animal welfare.

6.3 Husbandry for productivity

6.3.a Changing the feed

Section 2 briefly described the ruminant digestive process, and highlighted its complexity. An approach typical of intensive livestock rearing systems is to balance feeding in such a way as to maximise the production of useful output from the animal (meat, milk) while minimising unwanted outputs (methane and nitrous oxide).

Attempts to reduce greenhouse gas emissions by modifying feed inputs have focused on the following options:

- Adjusting diets to meet nutritional needs more closely
- Breeding new strains of grasses and cereals
- Various nutritional supplements

Each of these options, together with some of the issues they provoke, are discussed in turn. Most of the discussion here concerns cattle, since sheep consume very little by way of concentrates.

Feeding more concentrates

The type of diet fed will have a bearing on enteric and faecal methane emissions and also on nitrous oxide, initially through the application of fertilisers to grow feed or pasture and then via urine and dung. Action to reduce greenhouse gas emissions through feed adjustment tends to focus on the balance between proteins, starches and fibre in the diet. All these critically influence the levels of methane and nitrous oxide produced.

It has already been noted that ruminants are different from other farmed animals in that they are able to extract and digest protein and carbohydrates from fibrous products such as grass that other animals cannot utilise. One downside, however, is that this digestive process leads to emissions of methane.

Generally speaking, the more food an animal eats the more methane is produced. However it is also the case that the fraction of feed converted to methane decreases as feed intake,[483] and specifically feed quality,[484] increases, and so methane emissions per unit of milk or meat produced decline. This is because most emissions occur at the maintenance level of feeding; any feed given over and above this level will produce meat/milk increases at a rate greater than the rate of nitrous oxide or methane emissions. Up to a point then, a diet higher in lower-fibre concentrates including cereals and oilseeds will lead to higher outputs of milk or meat relative to methane emissions. Indeed it has been estimated that methane emissions per unit of digestible energy are generally 2-3 times higher on a low quality diet than on a

483 Mills J.A.N, Dijkstra J., Bannink A., Cammell S.B., Kebreab E., and France J. (2001). A mechanistic model of whole tract digestion and methanogenesis in the lactating dairy cow: Model development, evaluation and application, *American Society of Animal Science*, 79:1584-1597

484 'Quality' here refers to available nutrient content/unit of feed dry matter

high quality diet.[485] Put simply, it is more efficient to feed one animal well than to feed two animals the minimum amount. However there is a limit to how productive an animal can be, based on, for example, its genetic potential (see below).

It may also be that efforts to reduce methane from enteric fermentation by increasing concentrate feeds increase methane emissions from manure. One study[486] finds that increased supplements can reduce enteric fermentation, but increase methane in the manure. On balance, there was still an overall reduction in methane emissions, but the reductions were about a fifth smaller than expected.

A diet rich in concentrates will be more energy intensive to produce than diets with fewer or no concentrates, although studies show that the reductions in methane from enteric fermentation will overcompensate for the additional nitrous oxide incurred.[487] [488]

However – as we have emphasised before – including the second order impacts (lost carbon sequestration) will increase the relative importance of carbon dioxide. As such the environmental efficacy of the feed-modification approach requires further analysis that takes these second order impacts into account.

There is a risk too that concentrate-rich diets suffer from a leaky nitrogen cycle (more on this below) due to higher nitrogen fertiliser inputs and higher nitrogen surpluses in the form of urea.

Optimising the nitrogen component of feedstuffs presents a difficult challenge. Both nitrogen (the building block of protein) and carbohydrates are needed to maintain and increase microbial numbers in the rumen, which in turn aid digestion. However, their relationship is complex, and the form of nitrogen consumed (see Section 2) is as important as the presence of other nutrients. High nitrogen intakes will not necessarily increase microbial numbers.[489]

In general, protein (and hence nitrogen) requirements for ruminants are fairly low, although intensively reared dairy cattle are often fed quite high levels of protein – between about 18 to 20% of their diet measured in terms of crude protein – in order to maximise milk yields. Recently there has been a trend towards reducing this level (by about 2%) because of economic and environmental concerns, and because of research suggesting that they can manage with less.[490]

While nitrogen is vital to ruminant nutrition, excess nitrogen intake will lead to increased emissions of ammonia and nitrous oxide. This said, even when nitrogen is not given to excess, a percentage of nitrogen will still be lost. The excess nitrogen available will simply lead to nitrogen losses over and above the baseline rate of loss.

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[485] Weiske A. (2005). *Survey of technical and management-based mitigation measures in agriculture* Document number: MEACAP WP3 D7a, Institute for European Environmental Policy
[486] Hindrichsen I.K., Wettstein H.R.,. Machmüller A , Kreuzer M. (2006). Methane emission, nutrient degradation and nitrogen turnover in dairy cows and their slurry at different milk production scenarios with and without concentrate supplementation *Agriculture, Ecosystems and Environment* 113 150–161
[487] Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra.
[488] Cederberg C and Mattson B. (2000) Life cycle assessment of milk production — a comparison of conventional and organic farming, *Journal of Cleaner Production* 8 49–60
[489] Jonathan Mills, University of Reading, pers. comm. June 2005
[490] Bruce Woodacre, international dairy consultant, pers. comm. June 2005

With nitrous oxide the issue is not just about reducing the input of nitrogen through the system, but about maximising the conversion of nitrogen inputs into *useful* nitrogen outputs – milk or meat – rather than into urea, and (to a lesser extent) faeces. There are diets that, while high in nitrogen inputs (in the form of feeds and nitrogen fertiliser inputs), are nevertheless very successful at converting that feed into edible nitrogen. Alternatively, it is possible to envisage a low nitrogen input system, which nevertheless, is very *inefficient* at converting that nitrogen into edible output. An example here might be a very fibrous feed low in sugars; lack of readily fermentable carbohydrate dampens microbial activity, meaning there is less microbial protein available for digestion and conversion into edible output, and more ammonia escaping in the form of urea.

Might there be a trade off between measures to reduce nitrous oxide emissions (through optimising dietary nitrogen) and those aimed at reducing methane? The answer is that it very much depends. Changes to feed that reduce nitrous oxide emissions from cattle by increasing the starch or sugar content relative to proteins will, generally speaking, reduce methane emissions too because in both cases the cause of emissions is inadequate digestion.[491] [492] Readily fermentable starches such as sugar aid the metabolic process of the rumen microbia. This in turn enables them to use the available nitrogen and convert it into, among other things volatile fatty acids, which are absorbed through the rumen wall. Conversely, a fibrous (hence low starch) low-nitrogen diet will lead to higher emissions of methane.

For animals whose diets consists largely of forage, it can be hard to achieve the optimal protein-carbohydrate balance, and the high fibre content of the diet can reduce nitrogen use efficiency. One possibility to explore is whether increased applications of nitrogen fertiliser might increase the digestibility of the grass. Lovett[493] investigates this possibility in an in-vitro study into the effect of increased nitrogen fertiliser applications to perennial ryegrass, on the chemical composition of the pasture and the resultant characteristics of rumenal fermentation. He finds the impact on methane production per unit of organic matter digested to be limited and concludes that under grazing systems, where pasture supply does not limit animal performance, reductions in methane emissions are unlikely to be achieved through increased rates of nitrogen fertiliser applications. On this basis the reverse is also likely to be true: a reduction in nitrogen inputs into grasslands is unlikely to lead to increases in methane that outweigh the nitrous oxide savings resulting from reduced nitrogen fertiliser applications. He does, however, draw attention to studies that do find increased nitrogen fertiliser applications to reduce methane emissions.

A final option, investigated in another study,[494] is to consider whether diets based on predominantly local feedstuffs might reduce livestock related greenhouse gases. This concludes, however, that a shift to local sourcing has little effect on overall system-wide greenhouse gas emissions, since the local feedstuff chosen needed to be fed in larger quantities. Effects on emissions from enteric fermentation were not calculated.

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[491] MIDAIR - Greenhouse Gas Mitigation for Organic and Conventional Dairy Production, EC, Contract No: EVK2-CT-2000-00096
http://www.energetik-leipzig.de/Bioenergie/Midair.htm

[492] Les Crompton and Jonathan Mills, University of Reading, pers. comm.

[493] D. K. Lovett, A. Bortolozzo, P. Conaghan, P. O'Kiely and F. P. O'Mara (2004). In vitro total and methane gas production as influenced by rate of nitrogen application, season of harvest and perennial ryegrass cultivar, *Grassland and Forage Science* 59 227-232

[494] Casey JW and Holden NM (2005). Quantification of GHG emissions from suckler-beef production in Ireland *Agricultural Systems* 86 97–114

It is important to note that while changing the balance of the feed can indeed affect livestock greenhouse gas emissions, the effects are likely to be far more significant for developing world herds than those reared in countries such as the UK. Since most livestock in the developing world largely feed on rough pasture and fibrous by-products, a shift to a high concentrates diet would have a major impact. In the UK, however, efforts have already been made to improve the quality of the diet (in dairy herds especially) and so the extent to which further gains can be made will be relatively small.

Breeding new strains of grasses and cereals

On fresh forages, up to 40% of dietary nitrogen may be lost as rumen ammonia because the microbial population in the rumen is unable to incorporate much of the non-protein nitrogen released during foliar proteolysis.[495]

A study by Miller et al. (2001) shows that dairy cows fed a high-sugar strain of perennial ryegrass grass not only produced higher milk yields, but also excreted less nitrogen than cows fed ordinary ryegrass. Another study found that milk production increased by 20% and nitrogen losses to the environment were reduced by 24%. Sheep too can increase live weight by on average 12%.[496] In other words, ruminants consuming high-sugar strains can more efficiently utilise the nitrogen[497] since the rumenal microbes use the sugar as an energy source. This allows more protein to pass through to the hind gut for more efficient use. The breeding of such higher sugar strains is in fact the subject of a collaborative European research project, *Sweetgrass*.[498]

However, while these efforts may lead to reductions in nitrous oxide emissions, it may be at a cost to biodiversity.[499] Ryegrass is a very vigorous, domineering crop, and tends to push other species out of the way. The standard pasture is currently a grass-clover mix, with the grass element often being rye. More biologically diverse pastures which feature a greater mix of older plant varieties, may be fibrous and hence less digestible and more methanogenic. Hence these very honed, single-issue technological approaches to greenhouse gas reduction may give us low greenhouse gas meat and milk, but there can be a trade-off. It is worth noting that a switch to biomass production in lowland areas, as discussed in Section 4 above, is unlikely to provide a biodiverse environment either and this is an issue that needs to be considered in any discussion of biofuels.

Another way of reducing greenhouse gas emissions from animal feed is to breed cereals that are more efficient in utilising the nitrogen available in the soil. Fewer nitrogenous fertilisers will be needed, and fewer nitrates lost to the soil after the feed has passed through the animal's body. This is currently the subject of a joint Defra-

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[495] The breakdown, or degradation, of proteins in the plant leaves into their building blocks, the amino acids

[496] Lee, M.R.F., Brooks, A.E., Moorby, J.M., Humphreys, M.O., Theodorou, M.K., Macrae, J.C., Scollan, N.D. (2002): In vitro investigation into the nutritive value of Lolium perenne bred for an elevated concentration of water-soluble carbohydrate and the added effect of sample processing: freeze-dried and ground vs. frozen and thawed. *Anim. Res. 51, 269- 277* cited in Weiske A. *Survey of technical and management-based mitigation measures in agriculture* Document number: MEACAP WP3 D7a, Institute for European Environmental Policy, June 2005

[497] Miller L. A., Moorby J. M., Davies D. R., Humphreys M. O., Scollan N. D., MacRae J. C., Theodorou M. K. (2001) Increased concentration of water-soluble carbohydrate in perennial ryegrass (Lolium perenne L.): milk production from late-lactation dairy cows, *Grass and Forage Science* 56 (4), 383–394.

[498] http://www.sweetgrassineurope.org/Public_Pages/project_description.htm

[499] Mariecia Fraser, IGER, pers. comm., May 2007

industry sponsored research project[500] and of other Defra funded research.[501] It is anticipated that a 50% reduction in fertiliser nitrogen is achievable. Defra has also funded work focusing on ways of improving the nitrogen use efficiency of grasses.[502]

There is one other point to make about grassland. Emission factors for fertilised grasslands are higher than for arable crops; it has been calculated that grazed grassland accounts for about three quarters of all agricultural soil nitrous oxide emissions. On the other hand, permanent grasslands store more carbon than arable crops since root residues and other plant matter can build up in the soil if it is unploughed and undisturbed. The implications for greenhouse gas mitigation are confusing; on the one hand, grassland stores carbon; on the other nitrous oxide fluxes are greater than for cereal production. However it is also the case that background emissions from unfertilised grasslands are lower than they are for arable crops owing to the mineralisation of arable roots.[503] One conclusion to draw might be that fertiliser applications on grasslands should be reduced to a minimum although this will clearly have impacts on the number of livestock the land area can support. High sugar grass varieties have, moreover, been developed with fertiliser applications in mind. One option is to cultivate mixed grass-clover swards, meaning that no nitrogen fertiliser inputs are needed.

Feeding legumes

The nutritive value of legume forage is, in general, superior to that of grass-only pastures because of its higher protein content.[504] Confusingly, the nitrogen-use efficiency in forage legumes is lower than in grass-only forage since the higher crude protein content of the former can be higher than the cattle actually utilise.[505]

This said, forage legumes that contain condensed tannins can slow down the rate of protein degradation so that the protein is absorbed more slowly; this means that more of the nitrogen is utilised rather than being lost as urea.[506] Moreover, grass-legumes mixes that achieve a balance between the nitrogen and carbon content (for example mixtures that include the high sugar grasses discussed) would improve the

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[500] *Genetic reduction of energy use and emissions of nitrogen in cereal production (GREEN grain*) Defra project LK0959

[501] A study of the scope for the application of crop genomics and breeding to increase nitrogen economy within cereal and rapeseed-based food chains. Defra project AR0714, 2005

[502] *Identify genetic mechanisms controlling variations in nitrogen use efficiency and protein production in grass*, Defra project LS3617, 2003

[503] Dobbie K and Smith KA (2003) Nitrous oxide emission factors for agricultural soils in Great Britain: the impact of soil water-filled pore space and other controlling variables, *Global Change Biology*, Vol 9 Issue 2 Page 204 - 218

[504] Rochon J J, Doyle C J, Greef J M, Hopkins A, Molle G, Sitzia M, Scholefield D and Smith C J. (2004). Grazing legumes in Europe: a review of their status, management, benefits, research needs and future prospects. *Grass and Forage Science*, 59, 197–214

[505] Rochon J J, Doyle C J, Greef JM, Hopkins A, Molle G, Sitzia M, Scholefield D and Smith C J. (2004). Grazing legumes in Europe: a review of their status, management, benefits, research needs and future prospects. *Grass and Forage Science*, 59, 197–214 and Alan Hopkins pers. comm. September 2007

[506] Rochon J , Doyle C J, Greef J M, Hopkins A, Molle G, Sitzia M, Scholefield D and Smith C J. (2004). Grazing legumes in Europe: a review of their status, management, benefits, research needs and future prospects. *Grass and Forage Science*, 59, 197–214 and Alan Hopkins, consultant, pers. comm. October 2007

nitrogen use efficiency. Some research also shows that methane emissions are lower when leguminous forage is used instead of grass only.[507]

Nutritional and other supplements

The feeding of nutritional supplements is another approach that continues to be considered and trials have met with varying degrees of success.

One possibility is to add unsaturated fat such as coconut oil to animal rations. This keeps up the energy intensity of the diet, reduces the need for grain-based concentrates and aids the digestibility of fibre.[508] [509] On the down side, if too much of it is incorporated, the cows find it unpalatable and reject their feed.

A wide range of other feed additives have been proposed as ways of reducing methane. These include[510] [511] alternative hydrogen acceptors (that is, additives that bind hydrogen so it does not combine with carbon to form methane), halogenated compounds that act as methane analogues,[512] antibiotics, defaunating agents,[513] probiotics,[514] hexose partitioning,[515] bacteriocins, steroids and growth hormones, and naturally occurring plant compounds. Vaccination is another possibility, the purpose being to invoke an immune response to one or more of the rumen protozoa, thereby reducing methane emissions.[516] All these approaches are problematic in one way or another: Some are toxic to the microbes and the animal, some effects are short-lived since the rumenal microbes simply adapt, some are prohibitively expensive, while others still are unlikely to be accepted by the consumer due to ethical concerns.

Genetic modification has also been proposed as a way forward. The focus is either on genetically modifying the feed to improve its qualities (to produce lower methane or nitrous oxide emissions), or on altering the way feed is fermented in the rumen. While this sort of research is being pursued in other parts of the world, in the UK the ethical objections raised have so far limited further exploration.

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[507] Weiske A. (2005). *Survey of technical and management-based mitigation measures in agriculture* Document number: MEACAP WP3 D7a, Institute for European Environmental Policy

[508] Machmuller A. (2006). Medium-chain fatty acids and their potential to reduce methanogenesis in domestic ruminants, Agriculture, Ecosystems and Environment 112 107–114

[509] Jordan E, Lovett DK, Hawkins M, Callan JJ, O'Mara FP. (2006) The effect of varying levels of coconut oil on intake, digestibility and methane output from continental cross beef heifers. *Animal Science*, Volume 82, Issue 06, pp 859-865

[510] Weiske A (2005). *Survey of technical and management-based mitigation measures in agriculture* Document number: MEACAP WP3 D7a, Institute for European Environmental Policy

[511] O'Hara P, Freney J and Ulyatt M. (2003). *Abatement of Agricultural Non-Carbon Dioxide Greenhouse Gas Emissions: A Study of Research Requirements*. Report prepared for the Ministry of Agriculture and Forestry on behalf of the Convenor, Ministerial Group on Climate Change, the Minister of Agriculture and the Primary Industries Council

[512] Such as bromochloromethane, hemiacetyl of chloral and starch

[513] The removal of certain protozoa from the rumen to increase the amount of bacterial and sometimes dietary amino acids available for absorption at the small intestine.

[514] Microbial feed additives, containing live cells and a growth medium, that are developed primarily to improve animal productivity by directly influencing rumen fermentation

[515] A process of manipulating the amount of the feed carbohydrate going directly into microbial growth as opposed to fermentation, which should enhance protein utilisation.

[516] Weiske A (2005). *Survey of technical and management-based mitigation measures in agriculture* Document number: MEACAP WP3 D7a, Institute for European Environmental Policy

6.3.b Changing the genetic make-up

Breeding for higher yields

Increases in the proportion of concentrates fed to cattle have gone hand in hand with breeding programmes designed to increase potential milk yields. The focus here has been on breeding cows with 'higher genetic merit'. This rather sinister phrase refers to breeds of cows, which, when fed the right diet, produce very high milk yields. The black and white Holstein-Friesian that dominates dairy herds in the UK today is an example of a high genetic merit animal. Her make up is such that she partitions a higher proportion of nutrients into milk, relative to maintenance or growth, than other breeds.[517]

The benefits of increasing milk yields translate very simply into more milk per burp. For example, as Garnsworthy notes,[518] one million litres of milk quota can be filled by 250 cows yielding 4,000 litres or 111 cows yielding 9,000 litres. As already discussed, as milk yields increase, so methane emissions per litre decline. There are, however, associated problems with fertility, as we discuss below, and this will have a bearing on greenhouse gas emissions from the herd over time.

Breeding for multifunctionality

Efforts to increase milk yields in dairy cows have led to an increased separation between the beef and dairy herds. Dairy cows are bred to produce milk; beef herds for meat.

The overall effects on greenhouse gas emissions once both herds are considered together have been explored by a few authors. Cederberg and Stadig[519] observe that in Sweden, milk output was almost the same in the year 2000 as it was in 1990, but this was achieved with 25% fewer cows. This means that the meat which would have been produced as a by-product of the dairy system has had to be compensated for with a substantial increase (93,000) in the number of beef cattle reared. Beef imports have also shown an increase. While the overall effect of these changes is uncertain, the authors suggest that the on-going specialisation of milk production may be environmentally questionable.

Martin & Seeland[520] have calculated the effects of specialised milk production based on high milk-yielding cows for the emissions of methane, nitrogen and phosphorous. They find that per kilogram of edible protein produced (both milk and meat) overall emissions are unchanged or slightly increased when an increased number of beef cows are needed to compensate for fewer dairy cows.

In a similar vein, a study by Casey and Holden[521] examines a range of different scenarios, based on a combination of variables. They look at different combinations of feed type (ranging from standard, to largely home grown, to intensive) and

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[517] Weiske A (2005). *Survey of technical and management-based mitigation measures in agriculture* Document number: MEACAP WP3 D7a, Institute for European Environmental Policy

[518] 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 Tech*nology, 112, 211-223

[519] Cederberg C and Stadig M. (2003). System Expansion and Allocation in Life Cycle Assessment of Milk and Beef Production *Int J LCA* 8 (6) 350 – 356 (2003)

[520] Martin S and Seeland G. (1999) Effects of specialisation in cattle production on ecologically harmful emissions, *Livestock Production Science 61* 171–178

[521] Casey J W, Holden N M (2006). Quantification of GHG emissions from suckler-beef production in Ireland, Agricultural Systems 90 79–98

different breeding and maintenance regimes (beef breeds versus dairy breeds, feedlot management versus outdoor grazing). The study concludes that *'a good way to achieve a national reduction in greenhouse gas emissions from bovine production systems in Ireland would be to adopt beef production using dairy-bred animals so that the total number of bovines is reduced and the enteric fermentation emissions from the cow are allocated to both the production of milk and beef calves. This idea raises the question as to how to balance animal breeding between merit for milk production and merit for beef quality. A herd with high genetic merit for dairy production will yield calves that are relatively unsuitable for beef production.'*

The difference in the quality of meat from beef versus dairy cows is, as they note, clearly a consideration. Cederberg and Stadig do not discuss the issue of quality in their paper, but in personal communications Cederberg notes[522] that there may be ways forward. There are, for example, certain breeds such as Ayreshire and Brown Suisse which, though not as high yielding as Holsteins, do produce a reasonable balance between milk yields and eating quality. She also highlights the future potential for gender selection by sex selecting sperm for insemination. The highest yielding dairy cows could be inseminated with female sperm from good dairy bulls while the remaining dairy cows could be inseminated with a beef breed. The offspring would therefore possess good eating characteristics.

Finally, the UK Cranfield study[523] models a scenario where all beef cattle are reared in suckler herds (with no calves from the dairy herd), and finds that greenhouse gas emissions would increase by 60% compared with the current mix in the herd.

One might suggest too that from a moral perspective, breeding cattle for both milk and beef is preferable to a highly specialised situation where unwanted calves, the by-products of the dairy system, are slaughtered at birth.

6.3.c Changes to life span: Breeding for longevity and fertility

The lifetime efficiency of a cow depends on her age at first calving, the number of lactations, the calving interval, the duration of dry periods and the quantity of milk she produces when lactating. All these affect the volume of milk and greenhouse gas emissions she produces over her lifetime.

Leaving animal welfare considerations aside for a moment, a rapid turnover of milkers due to early mortality or infertility means that energy inputs and greenhouse gas outputs are 'wasted' in the process of rearing heifers before they reach their first pregnancy and lactation. Since the first two years of a cow's life are spent growing and developing, it is only after this period that she is ready for insemination. These first two years then are both economically unproductive and environmentally deleterious since the heifer is producing methane and taking in feed without actually producing milk. Once she has reached maturity, it important to keep the cow milking for as long as possible after this period so that the investment in growth and development pays off and to keep the replacement rate as low as possible. Thus an

522 Cristel Cederberg, pers. comm., 18 July 2006

523 Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on www.silsoe.cranfield.ac.uk, and www.defra.gov.uk

increase in the number of lactations per cow has the potential to reduce greenhouse gas emissions.[524]

From a this temporal perspective, improvements in dairy productivity through breeding strategies have not been an unalloyed success. These higher yielding cows are more prone to lameness, infertility and illness; they also usually have shorter life spans than lower yielding breeds. Once these factors are taken into account, the remarkable improvements in milk productivity (and concomitant decline in methane emissions per unit of output) are questionable.[525]

In recognition of this, increasing emphasis is now on achieving these goals while at the same timing optimising milk yields.[526] Garnsworthy notes that over the long term, fertility traits could be included in a genetic selection index, but in the meantime fertility can also be improved through nutritional strategies.[527] Garnsworthy calculates that efforts to restore fertility to 1995 levels could reduce methane emissions by 10-11% while further improvements still could reduce methane emissions by up to 24%. He also notes that *'nutritional strategies for improving fertility are likely to be complementary to dietary strategies already proposed for reducing emissions'* – a win-win situation.

Lovett et al.[528] make the same point. The authors developed a model to examine the relationship between, on the one hand, the relative balance of concentrates in the diet and, on the other, the genetic merit of the dairy cows. They then explored the effects on greenhouse gas emissions. The model calculates greenhouse emissions for nine farming systems over a period of three years, with each of the farms differing in the level of concentrates fed and the cows' pedigree index (genetic yield potential).

The authors examine all possible combinations of three different levels of feed supplementation and three different types of genetic make-up, and measure all sources and outputs of greenhouse gases both on farm, and indirect, such as concentrate feed production. The 'second order' impacts discussed in Section 4 are, however, not considered. Two levels of enteric fermentation emissions are used: One for concentrate feeds and a higher one for grazed pasture, with the relative emissions of each adjusted in line with their proportions in the different diets. The concentrate feed they use is a simplified soy-barley. Allocation of emissions to soymeal are made simply on an economic basis.

Crucially, since this was a three-year study, changes in fertility and herd restocking rates are also examined. The authors cap milk production at quota levels so that all systems produce the same quantity of milk. Enough heifers are retained within the system to replace dairy cows culled for voluntary and involuntary reasons, such as

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[524] Weiske A, Vabitsch A, Olesen JE, Schelde K, Michel J, Friedrich R, Kaltschmitt M. (2006). Mitigation of greenhouse gas emissions in European conventional and organic dairy farming, *Agriculture, Ecosystems and Environment* 112, 221–232

[525] 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 Tech*nology, 112, 211-223

[526] See for example a series of ongoing Defra projects: Developing technologies to improve the fertility of dairy cows (AC0205),

[527] 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 Tech*nology, 112, 211-223

[528] Lovett D.K., Shalloo L., Dillon P., O'Mara F.P. (2006) A systems approach to quantify greenhouse gas fluxes from pastoral dairy production as affected by management regime, *Agricultural Systems 88*.

sickness. In order to enable all the nine systems to be compared, annual fertiliser inputs are fixed at 330 kg N/ha/year; meaning that land areas devoted to grazing vary rather than the nitrogen application rates, to enable the complete fulfilment of the milk quota.

The study finds that as the genotype (milk yielding potential) and level of concentrate supplementation increases, the number of dairy cows required to fill the annual milk quota declines. At the same time, follower and calf numbers fall too as the concentrate supplementation increases since there are fewer cows needed to fill the annual milk quota.

However as the genotype increases, the *ratio* of the non-productive younger animals to dairy cows also increases. This is because the overall replacement rate increases.

Put simply, because fewer lactating cows are needed to fulfil the milk quota, fewer calves are needed to replace them. On the other hand, these higher yielding cows burn out more quickly and so more replacement cows are needed to take their place.

The authors came to the interesting conclusion that both on-farm and total life cycle greenhouse gas emissions increase with increasing genotype potential (i.e. yield). This is because with the reduction in herd fertility, the population of non-productive cows and the need to breed more replacement cows increases. They conclude that the greatest reductions in greenhouse gas emissions can be achieved by feeding medium-potential cows with the highest levels of concentrate feeds. This creates the optimum balance between the goals of increasing milk yield (fewer burps per litre) and minimising herd turnover (fewer 'unproductive' gas emitting cows).

As regards other animals, the faster an animal grows the fewer emissions are generated per unit of edible output. This is the main reason for the higher emissions associated with organic and free range poultry as compared with poultry in caged systems – in the latter the chickens reach slaughter weight much sooner.[529] It also provides a clear instance of the conflicts that can occur between animal welfare and greenhouse gas reduction objectives.

6.4 Different management systems

We begin here by looking at soil management; at ways of optimising nitrogen inputs while minimising nitrogen outputs, and at the implications for soil carbon storage. We then review research comparing greenhouse gas emissions from conventional and organic cattle systems before looking at intensive versus extensive systems – note that extensive systems need not be organic. Finally, we examine how limiting the time cattle spend grazing outdoors might affect greenhouse gas emissions. As with our discussion of feed inputs, our main focus is on beef and dairy cattle as this is where the main bulk of research has focused and where the greatest uncertainties lie.

[529] Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra. Available on www.silsoe.cranfield.ac.uk, and www.defra.gov.uk

6.4.a Changes to soil management

The significant contribution that arable and particularly fertilised pasture land make to agricultural nitrous oxide emissions has already been noted.

Velthof et al.[530] conclude that it is possible to reduce nitrous oxide emissions by up to 70% through better management of nitrogen flows with respect to fertiliser use, grasslands and livestock husbandry. Measures relating to soil management (that is the first two categories – the third has been discussed above) include improving soil drainage so that soils do not become waterlogged, optimising nitrogen fertiliser applications, (how much, what type and when it is applied) and substituting clover for synthetic nitrogen fertilisers.

Regarding the type of fertiliser, one study finds that switching from ammonium nitrate to urea at certain times of the year holds significant potential.[531] Spring time is considered best since silage yields following urea application in the summer months tend to be lower. However urea applications can lead to more ammonia emissions, which are not just polluting on its own, but may ultimately end up being converted to nitrous oxide.

The possibilities offered by nitrification inhibitors are also being explored. One review[532] of their potential, based on a range of national and international studies, finds that the research conclusions are in fact mixed. While most studies into their use find them to be beneficial, others report nil or negative results on nitrogen losses and plant yields, and toxic effects on some plants. Some report increasing ammonia volatilisation and it has even been suggested that inhibitors can have a priming effect on the net mineralisation of organic nitrogen in the soil. This could lead to more nitrogen losses in the long term. In short, the research as it stands indicates that while nitrification inhibitors may offer potential, they offer no magic solutions; they are instead best viewed as one useful component in a 'toolkit' of best management practices.

Reducing nitrogen fertiliser applications to grazing land is another possibility and many studies have suggested that this is a useful strategy. One three-year study sought to investigate the effects of such an approach on carbon-nitrogen flows.[533] An upland semi-natural grassland site, with high organic matter, was chosen and divided into two paddocks. One paddock received nitrogen fertiliser applications and was grazed to a target height of 6cm. The other paddock received no applications and was stocked at half the stocking density of the intensive paddock. All the main greenhouse gases – carbon dioxide, methane and nitrous oxide – were then measured over the three-year period and balanced against soil carbon storage.

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530 Velthof G L, van Beusichemb M L and Oenema O. (1998) Mitigation of nitrous oxide emission from dairy farming systems, *Environmental Pollution* 102, SI 173-178

531 *Nitrous oxide emissions from agricultural soils, and the potential for their reduction*, Defra project CC0233, 2001

532 Nitrification and Urease Inhibitors Environment Waikato Technical Report 2004/22. A review of the national and international literature on their effects on nitrate leaching, greenhouse gas emissions and ammonia volatilisation from temperate legume-based pastoral systems http://www.ew.govt.nz/publications/technicalreports/documents/TR04-22.pdf

533 Allard V, Soussana J-F, Falcimagne R, Berbigier P, Bonnefond J M, Ceschia E, D'hour P, Hénault C, Laville P, Martin C, Pinarès-Patino C. (2007) The role of grazing management for the net biome productivity and greenhouse gas budget (CO_2, N_2O and CH_4) of semi-natural grassland, *Agriculture, Ecosystems and Environment* 121 47–58

The study produced some complex results. In the first year, the intensive system was a net source of greenhouse gas emissions because the nitrous oxide and methane outweighed the effect of carbon sequestration, while the extensive one was a net sink. In year two, both paddocks became small greenhouse gas sinks. But during the final year, while both were sinks, the intensive paddock provided a greenhouse gas sink three times greater than the organic paddock.

The study finds that while reductions in fertilizer input and in stocking density strongly reduced both methane and nitrous oxide emissions per unit of land area, this has the effect of eroding the carbon storage potential of the grasslands, suggesting a trade-off between efforts to mitigate methane and nitrous oxide and those to maintain C sink activity. The authors conclude that a combination of fertiliser elimination and reduced stocking densities may not be able to increase in the short term the greenhouse gas sink per unit of land area of managed grasslands.

In other words, the soil needs some form of fertiliser in order to keep the pasture growing and to outweigh the effects of grazing, even when grazing levels are low. A couple of provisos need to be noted, however. The first is that the authors do not take into account emissions associated with fertiliser production

Second and importantly, they also note – almost as an aside – that when greenhouse gas sink activities per *unit of animal product* (measured as kg of live weight gain) are calculated over the three year average, the extensive system had a greater sink activity per unit of live weight gained. They note that this is despite the fact that, on average, the intensively reared livestock gained more weight than the extensively reared ones. Interestingly, however, they fail to point out that their data also show that the *rate* of weight gain falls in the intensive systems while it increases in the extensive ones as Table 16 shows.

Table 16: Ratio of live weight gain in kg per animal – intensive versus extensive

	Rate of live weight gain kg/animal	
Year	Intensive	Extensive
1	106	84
2	101	98
3	100	137

From this study one might observe that the preferable course of action from a greenhouse gas perspective very much depends on what one wants to achieve. If net carbon sequestration on a given area of farmland is the goal, then fertiliser applications may, as this study suggests, be the way forward. However the aim is to reduce greenhouse gas emissions per given quantity of meat, then the reverse may be true.

The observations from one interesting paper[534] suggest that, as ever, it is all a matter of achieving the right balance. They note that there is a trade off between, on the one hand, the role of nitrogen inputs in increasing land carbon sequestration inputs

[534] Scholefield D, Jarvis S C, Brown L, del Prado A, Hopkins A and Cardenas L. (2005). Feedback and feed-forward interactions between climate change and grassland-based agriculture. Source: Paper presented at *Avoiding dangerous climate change. Scientific symposium on stabilisation of greenhouse gases*, Meteorological Office, Exeter, UK,1-3 February 2005
Online at: http://www.stabilisation2005.com/posters/ Scholefield_David.pdf>

for increased carbon sequestration, and on the other, the resultant nitrous oxide emissions. They find that the best strategies for C sequestration by temperate agricultural grasslands involve intensifying from the nutrient poor state or de-intensifying from highly intensive systems. They warn, however, that the intensification of low input species rich-grassland would not be desirable in many parts of the world owing to its effects on biodiversity.

The use of artificial fertilisers is by no means the only option for improving nitrogen inputs to the soil. Legumes can provide between 100-250 kg N/ha,[535] and as much as 350 kg N/ha.[536] Such levels are below those applied to pure grass on intensive dairy farms for instance, but are comparable to amounts applied on many beef and sheep farms. In other words, many farms are spending money on mineral nitrogen that they could obtain from clover given the right management techniques and confidence.[537]

But how do legumes lead to greater or fewer soil nitrous oxide emissions than synthetic fertilisers? One paper cites a study,[538] which compared nitrous oxide fluxes from a range of fertiliser- and legume-based agricultural systems. The study found there to be little difference between the two; while peak nitrous oxide fluxes occurred in spring time in the fertilizer-based systems, fields with decomposing legume residues maintained lower peak fluxes, but sustained emissions for a longer period of time into the growing season. However once the combined greenhouse gas output (carbon dioxide, nitrous oxide and methane) associated with a range of fertilizer-based and legume-based cropping systems are all accounted for, the study finds that the global warming potential of conventionally tilled systems to be nearly three times as great as legume-based systems. This largely reflects the fossil energy required to produce fertilizers as well as the use of lime in the fertiliser-based systems. Legume-based systems may also offer possible benefits when it comes to nitrogen leaching and ammonia volatilisation.

Another study, however, points out that more research on legumes is needed – the nitrogen fixation and utilization efficiency are still insufficiently understood with regard to legumes other than white clover.[539]

Another issue to consider with respect to optimising soil nutrient management is the substitution of manure fertilisers for mineral fertiliser. As discussed above, manure has an important part to play in stimulating long-term carbon sequestration and soil fertility. However, its effects on soil nitrous oxide emissions may be less positive.

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535 Rochon J J, Doyle C J, Greef J M, Hopkins A, Molle G, Sitzia M, Scholefield D and Smith C . (2004). Grazing legumes in Europe: a review of their status, management, benefits, research needs and future prospects. *Grass and Forage Science*, 59, 197–214

536 Frame J. (2006) Forage legumes for temperate grasslands, chap 3 Nitrogen fixation. Pp 13-17. Rome : FAO

537 Rochon J J, Doyle CJ , Greef J M, Hopkins A, Molle G, Sitzia M, Scholefield D and Smith C J. (2004). Grazing legumes in Europe: a review of their status, management, benefits, research needs and future prospects. *Grass and Forage Science*, 59, 197–214

538 Robertson, G P., Paul, E A., Harwood, R R (2000). Greenhouse gases in intensive agriculture: contributions of individual gases to the radiative forcing of the atmosphere. *Science* 289, 1300– 1922. Cited in Crews T E and Peoples M B (2004). Legume versus fertilizer sources of nitrogen: ecological tradeoffs and human needs *Agriculture, Ecosystems and Environment* 102 (2004) 279–297

539 Rochon J J, Doyle C J, Greef J M, Hopkins A, Molle G, Sitzia M, Scholefield D and Smith C J. (2004). Grazing legumes in Europe: a review of their status, management, benefits, research needs and future prospects. *Grass and Forage Science*, 59, 197–214

One study[540] compared soil nitrous oxide fluxes from grassland fertilised by three different forms of organic fertiliser: Sewage sludge pellets, poultry manure and cattle slurry, and two forms of mineral fertiliser: Ammonium nitrate and urea, over a period of two years. All plots except the control received nitrogen fertilisers at a rate of 300 kg available N/ha/yr.

The study found that manure treatments can generate very much higher and longer-lived peaks of nitrous oxide emissions than the addition of mineral fertilisers. This is because the total nitrogen inputs from the manure are more readily mobilised, added to which the carbon content of the manures helps stimulate denitrification. Grass productivity was similar for all fertiliser scenarios. The authors note that their findings are similar to those shown by other studies.

They also point out that manure application led to an accumulation of nitrogen near the surface where it is vulnerable to loss and where most processes of nitrous oxide production occur. They suggest that one way of conserving this accumulated nitrogen is by deep ploughing. This of course would lead to carbon losses from the soil.

6.4.b Organic versus conventional

A great many studies have sought to compare the impacts of organic versus organic farming systems, across a range of environmental indicators, including their global warming potential. Each study has yielded different results, with some concluding in favour of organic and others of conventional systems. The discrepancies have a great deal to do with the complexities of balancing energy inputs (and hence carbon dioxide emissions), and emissions of methane and nitrous oxide. This section reviews some of these studies and seeks to draw a few conclusions with respect to greenhouse gas mitigation strategies.

One German study of two farms comparing conventional and organic cattle systems at similar stocking densities finds that while on a per-hectare basis, organic farming generates fewer emissions than conventional farming, on a per-yield basis, the two systems are similar.[541]

On the other hand, a Swedish life cycle comparison of organic and conventional dairy production by Cederberg and Mattsson[542] finds that while methane emissions are 10-15% higher from cows in organic compared with conventional production, overall emissions from organic systems per unit of milk produced are slightly lower than from conventional ones, due to lower carbon dioxide and nitrous oxide emissions. The former relate largely to concentrate feed and synthetic fertiliser production while the lower nitrous oxide emissions on organic farms result from lower nitrogen surpluses in the system. The authors also point out that there appear to be considerable variations in emission factors for methane from cattle and that this might alter the conclusions considerably.

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[540] Jones S K Rees R M. Skiba U M. and Ball B C. (2007). Influence of organic and mineral N fertiliser on N_2O fluxes from a temperate grassland, *Agriculture, Ecosystems and Environment* 121 74–83

[541] Flessa, H. Ruser R. Dörsch P, Kamp T. Jimenez M A, Munch, J.C and Beese F. (2002). Integrated evaluation of greenhouse gas emissions (CO_2, CH_4,N_2O) from two farming systems in southern Germany, *Agriculture, Ecosystems and Environment* 91, 175–189

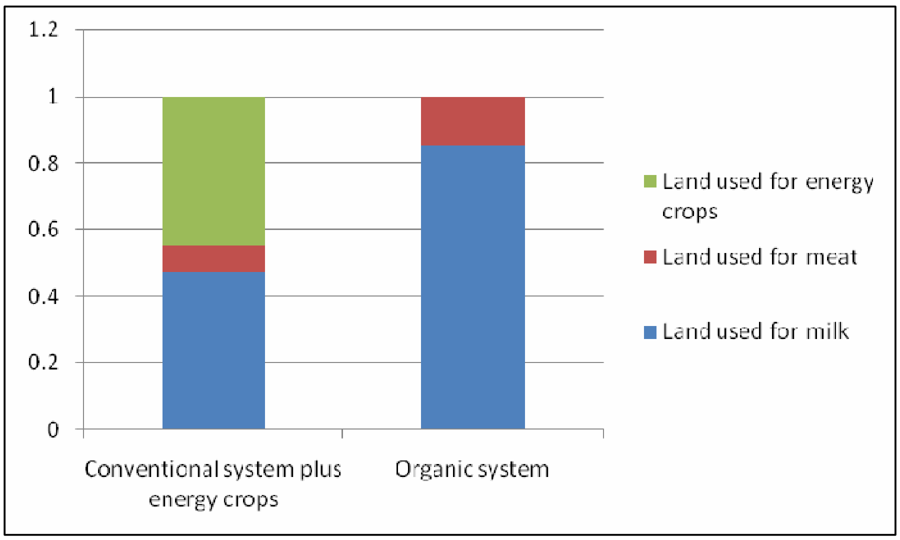
[542] Cederberg C and Mattsson B. (2002). Life cycle assessment of milk production — a comparison of conventional and organic farming, *Journal of Cleaner Production* 8 49–60

The authors suggest that for conventional systems, emissions can be reduced by, modifying the type of concentrates fed to reduce nitrogen surpluses. For organic systems they suggest that that more concentrates are fed and fewer herd replacements made.

Berlin and Uhlin, in their critique of the study,[543] challenge these conclusions. They note that organic systems use more land than conventional ones and that there is therefore an opportunity cost associated with organic production. In other words, organic systems use land that could be put to other uses, uses that might actually help reduce greenhouse gas emissions, such as energy crop cultivation.

Berlin and Uhlin therefore re-run the Cederberg and Mattsson study, but with a difference. For the same given quantity of milk, they look at what greenhouse gas emissions might be were an equivalent area to that used by organic farming to be deployed both for conventional dairy production and for energy crop cultivation. Figure 29 illustrates the principle.

Figure 29: Land allotment in the conventional-energy crop system and the organic system when 2,887 kg milk is produced



The study concludes that in fact extensive organic farming may result in higher outputs of greenhouse gases when related effects of alternative land use are considered.

The authors do not, however, take into account two important issues. First, not all land is equal. Grazing land may or may not be suitable for energy crops, as we discussed in Section 4.

Second, the authors do not take their critique to what should be its logical conclusions. If alternative land use options are to be considered, then these considerations should also apply to the land required for the production of concentrate feeds, with all its accompanying environmental costs. As discussed above, the production of soy has led to lost carbon sequestration in other parts of the world.

543 Berlin D, Uhlin H-E. Opportunity cost principles for life cycle assessment: toward strategic decision making in agriculture (2004). *Progress in Industrial Ecology*, Vol. 1, Nos. 1/2/3, 187

A comparative study by Haas et al.[544] is interesting in that it examines the trade offs between energy intensive, carbon dioxide and nitrous oxide producing inputs on the one hand (nitrogen-fertilisers, bought-in feed) and methane emissions on the other. In order to examine a range of variables it compares intensive-conventional, extensified-conventional and organic grassland farming in southern Germany. Intensive systems are characterised as those which make use of nitrogen-fertiliser inputs and imported feed and that yield relatively high milk volumes per cow. Extensive systems do not apply nitrogen-based fertilisers, but do use imported fodder. Stocking densities are lower than in the intensive system, as are milk yields. The organic system applies no nitrogen-fertilisers, buys in only limited quantities of fodder and has the same stocking density as that of the extensive system. Milk yields are lower still.

The study finds that compared with intensive systems, both extensive and organic dairy farming systems produce lower greenhouse gas emissions on a per hectare basis. When measured by milk yield, however, extensive systems have the lowest levels of greenhouse gas emissions per litre while organic and intensive systems are comparable. In other words the advantage of the extensive system is that it manages to reduce the nitrogen through-flow (by not applying nitrogen fertilisers) without reducing the digestibility of the feed (due to the import of concentrates). Again, second order greenhouse gas impacts associated with imported fodder are not explored although fertiliser and other inputs to fodder production (and associated greenhouse gas emissions are.

A paper by de Boer analysing three different comparative studies of organic and conventional farming (some of then already discussed)[545] illustrates the difficulties of forming conclusions either way. Out of the studies examined, one shows global warming potential in organic systems to be higher than conventional ones. A second finds that organic systems generate lower levels of greenhouse gases. The third study reviewed concludes that while the organic system studied produces lower emission levels than the conventional intensive one, its emissions are comparable with those from the conventional extensive farm.

Back in the UK, the Cranfield study we have already discussed several times[546] finds that for dairy and beef cattle, organic systems are more greenhouse gas intensive per unit of milk or meat, although dedicated beef suckler systems have the highest emissions of all. These findings quantify the cows' overall milk yield over a number of lactations and organic cattle are assumed, on average, to have one more lactation than conventional cows. The higher values for organic cattle reflects higher methane emissions in organic herds. While nitrous oxide emissions are lower, they do not compensate for the extra methane. This view with respect to nitrogen in organic systems is held by other studies[547] [548]

[544] Haas, G. Wetterich, F. Köpke, U. (2001). Comparing intensive, extensified and organic grassland farming in Southern Germany by process life cycle assessment, *Agriculture, Ecosystems and Environment* 83 43–53

[545] de Boer I J M. (2003). Environmental impact assessment of conventional and organic milk production, *Livestock Production Science* 80 69-77

[546] Williams AG (2007) *per comm*. obtained from the model available at www.agrilca.org as described in: *Williams, A.G., Audsley, E. and Sandars, D.L. (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report. Defra Research Project IS0205. Bedford: Cranfield University and Defra*.

[547] de Boer I J M. (2003). Environmental impact assessment of conventional and organic milk production, *Livestock Production Science* 80 69-7

Some studies do not, however, find organic systems to be more nitrogen efficient. Olesen et al.[549] find the linear increase in farm nitrogen surplus with increasing livestock density to be similar for organic and conventional dairy farms. nitrogen surplus is here defined as the difference between nitrogen inputs to the system and useful nitrogen outputs in the form of milk or meat. The authors note, however, that this assumes good farm management practices on the model farms, which for conventional farms means avoiding unnecessarily high nitrogen fertiliser inputs. Clearly not all farmers apply fertiliser at optimal levels, although undoubtedly poor management can be found whatever the system. The authors also raise the possibility their model overestimates nitrous oxide emissions derived from nitrogen leaching from the organic farms.

The authors note too that there is a tendency for nitrogen efficiencies to decline with increasing livestock density. Nitrogen efficiency is defined as the ratio of exported over imported nitrogen – hence it is a measure of how effectively nitrogen inputs are converted into useful outputs. When calculating emissions on the basis of milk production, organic farms tend to have higher emissions than conventional farms at similar farm nitrogen surplus and nitrogen efficiency – in addition to which methane emissions from organic farms will be higher. On this basis the authors conclude that organic systems may not be less greenhouse gas intensive on a yield basis than conventional farms, although note that some of the qualifications regarding nitrogen (highlighted in the paragraph above) need to be borne in mind here.

A study by IGER[550] comparing organic with conventional pasture systems also finds that although annual nitrous oxide emissions for the organic farm were lower than for the conventional farm, when nitrous oxide emissions were measured as a percentage of total nitrogen inputs to the system (nitrogen fertiliser inputs, nitrogen fixation, nitrogen deposition and nitrogen in excretal returns), emissions from the organic farm were higher. Emissions per animal were similar. The study also finds that organic farmyard manure tends to produce fewer methane and nitrous oxide emissions, owing to its higher carbon content than manure from conventional systems.

Organic-conventional comparisons for other livestock types are few and far between. The Cranfield study finds conventional chicken and egg production to be less greenhouse gas intensive than free-range and particularly organic systems. Intensive units fit more animals into a smaller space, meaning that heating and lighting requirements will be lower per animal. In addition, intensively reared chickens reach slaughter weight more quickly than their free-range or organic counterparts (in part a consequence of their inability to move around and expend energy), so heating and lighting will be need for a shorter period of time. Nitrous oxide emissions will be correspondingly lower too. With laying hens, the Cranfield study shows productivity to be higher in caged systems, presumably partly because fewer eggs are cracked or spoiled.

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[548] Dalgaard, T, Halberg, N and Kristensen, I S. (1998). Can organic farming help to reduce N-losses? *Nutrient Cycling in Agroecosystems*. 52, 277–287.

[549] Olesen JE, Schelde K, Weiske A, Weisbjerg MR, Asman WAH and Djurhuus J. (2006) Modelling greenhouse gas emissions from European conventional and organic dairy farms, *Agriculture, Ecosystems and Environment* 112 207–220

[550] Yamulki S. (2004) *Greenhouse gas emissions from organic and conventional farming systems and options for mitigation*, IGER Innovations, Institute of Grassland and Environmental Research

With pigs and sheep, the authors find organic systems to be less greenhouse gas intensive than their conventional counterparts. For sheep while both conventional and organic management systems are fairly similar in that both are extensive, organic systems have the edge here with slightly lower energy and nitrogen inputs. For pig systems, methane emissions in conventional systems tend to be higher. This is because organic pigs are generally finished outdoors with lower emissions than for housed stock, where slurry is collected under slats in anaerobic channels. However, a French study found indoor slurry-based conventional pig systems to be less greenhouse gas intensive than outdoor manure-based one.[551]

On balance then, from a review of these and other studies, conventional livestock systems appear emerge as very slightly less greenhouse gas intensive than organic systems. However a sizeable proportion of studies find the opposite to be the case so it is not really possible to come to any clear conclusion. Moreover, none of the studies we have looked at takes into account the second order impacts of the highly concentrate-intensive diets characteristic of conventional systems. It is also possible that the mixed livestock-crop rotational farming approach more characteristic of organic systems may offer some advantages with respect to nitrogen use efficiency that is not currently captured in models such as that developed by the Cranfield study authors.[552]

This said, once all the ‘on the one hands and on the other hands’ are debated and deliberated, it is quite probable that the differences in the greenhouse gas intensity of organic and conventional systems are not very significant at all, particularly since often the differences between individual farm practices (and emissions) can be greater than those between systems. In both systems there are greenhouse gas hotspots and for both systems steps will need to be taken to reduce impacts. The challenge lies in achieving reductions in ways that do not compromise other social and environmental concerns, including animal welfare, soil quality and biodiversity.

6.4.c Intensive versus extensive

The organic versus conventional debate can sometimes become polarised and emotional. An alternative approach might be to consider the relative merits of intensive versus extensive systems. Extensive systems are defined here as those that are not based on organic principles (since synthetic fertilisers may be used), but which have lower stocking densities and which may, in the case of ruminants, rely less on concentrates. The focus here is on cattle systems.

The EU Midair study[553] examining greenhouse gas emissions from European dairy production has been referred to several times. A key conclusion of this study is that farm-level greenhouse gas emissions are strongly related to the nitrogen surplus of the production, *irrespective of whether farm management is organic or conventional*. This conclusion agrees with those of other studies.[554] It also finds that nitrogen

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[551] Basset-Mens C, van der Werf H M G. (2005). Scenario-based environmental assessment of farming systems: the case of pig production in France, *Agriculture, Ecosystems and Environment* 105 127–144

[552] Point raised at meeting to investigate the Cranfield study further, held at Nobel House, Defra, 13 June 2007

[553] MIDAIR - Greenhouse Gas Mitigation for Organic and Conventional Dairy Production, EC, Contract No: EVK2-CT-2000-00096
http://www.energetik-leipzig.de/Bioenergie/Midair.htm

[554] Murphy-Bokern DPL, Roever M and Heinmeyer O. (2000). *Evaluation of conventional and organic agricultural production in relation to primary energy inputs and certain pollution gas*

surplus is correlated with livestock density and thus the intensity of the production system – in other words, the more intensive the system the less greenhouse gas efficient it is. The conclusion is that nitrogen surplus serves as an indicator of all greenhouse gas emissions, notwithstanding the fact that methane may be higher in some extensive systems. This, says the study, *'points to extensification as a possible greenhouse gas mitigation strategy to reduce emissions per area, an approach that would be in keeping with the recent CAP reforms'.* However it then goes on to dismiss its own conclusion since *'general extensification would also reduce the agricultural production with far-reaching consequences at the societal level'.*

The Casey and Holden study already discussed[555] finds that more extensive systems, using more high-yielding cows, could reduce emissions by 14-18%. While cattle are grazed at low stocking rates over a wide area, grazing is nevertheless supplemented with reasonably high levels of concentrates.[556] This means that emissions both per litre or per kg of output, and emissions per hectare are minimised. Emissions from excreta may, however, be less easy to control than in the case of housed systems.

In another paper, the authors conclude: '*A move towards fewer cows producing more milk at lower stocking rates is required. Such a move would represent extensification in terms of area, but intensification in terms of animal husbandry. The efficiency of the farm is the most important factor in terms of the balance of output per cow and feed supply. Compensating for imbalanced grass supply to feed demand by over-feeding concentrates not only erodes profit, but leads to greater carbon dioxide equivalent emissions. The quality of management per se is more important than the intensity of production….'* [557]

6.4.d Changes to housing systems

Some studies find that restricting the time cattle spend grazing could reduce nitrous oxide emissions from animal excreta. For example, one of the MIDAIR study conclusions was that the action of cattle trampling and compacting the soil and their deposition of excreta contributed significantly to nitrous oxide.[558] To complicate the picture, however, the study findings also show that nitrous oxide emissions appear to peak at intermediate levels of impact (this being the combined effect of soil compaction and the deposition of excreta), but that above a certain threshold the compaction may favour a more complete reduction of nitrate or nitrate to N_2 rather than nitrous oxide.[559] One possible option is to restrict grazing during wet periods, but the authors warn that this approach needs to be balanced against any potential nitrogen losses from indoor manure storage.

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emissions, summary of report commissioned by the Federal Ministry for Food, Agriculture and Forestry (BML), Bonn

[555] Casey JW and Holden NM (2005). Analysis of greenhouse gas emissions from the average Irish milk production system, *Agricultural Systems 86* 97–114.

[556] See previous comments about concentrates and their second order impacts

[557] Casey JW and Holden NM. (2005). The Relationship between Greenhouse Gas Emissions and the Intensity of Milk Production in Ireland, *Journal of Environmental Quality*, 34:429–436

[558] *Mitigation of N_20 emissions from grazed pastures under organic and conventional management*, MIDAIR study WP5.1 http://www.ie-leipzig.de/Bioenergie/MIDAIR_WPsummaries.pdf

[559] WP5.1: Mitigation of N_2O emissions from grazed pastures under organic and conventional management, MIDAIR, http://www.ie-leipzig.de/Bioenergie/MIDAIR_WPsummaries.pdf

Another study[560] explores this possibility further. It finds that restricting the time livestock spend grazing from 20 to 16 hours a day can markedly reduce nitrous oxide emissions from grazing land. However the stored manure from the housed livestock increases methane emissions and this, combined with the additional fuel used during the course of spreading the stored manure and producing and feeding the cattle silage means that the overall difference is virtually zero. Note that the authors do not consider a spectrum of manure management measures, such as anaerobic digestion, which could alter the conclusions.

Indeed if substantial investment were made in anaerobic digestion systems one approach might be, ironically, to maximise the methanogenic potential of manure through, for example, manipulating the diet as discussed in relation to coconut oil. The manure would then be digested and used as a fossil fuel replacement. However there will be limitations to this approach since only a small amount of coconut oil in the diet is palatable to cattle.

Finally measures that lead to livestock spending more time indoors need to be considered in terms of their impacts on animal welfare.

6.4.e Energy inputs

Taking the livestock sector as a whole, fossil energy inputs do not make a particularly significant contribution to livestock related emissions in their totality. However for poultry farming systems, energy use can be very significant indeed, accounting for around 45% of total global warming potential in intensive broiler and egg systems and 39% and 45% respectively in organic systems.[561] One option for reducing impacts here is to use renewable energy. For example, Banham Poultry in Norfolk uses dried poultry by-products to fuel a combined heat and power plant.

6.4.f An overview of management strategies

Generally speaking the conclusion that emerges again and again from the studies reviewed is that the most effective strategy for reducing greenhouse gas emissions is to optimise nitrogen use efficiency and reduce nitrogen surpluses. The efficiency of nitrogen use is taken to mean the extent to which the nitrogen input (from feed and less directly from the nitrogen fertiliser applied to the feed) is converted to useful nitrogen in the form of edible animal protein (milk, eggs, meat). In many cases optimisation will go hand in hand with a reduction in nitrogen inputs.

6.5 Managing the outputs

So far the discussion has focused on changing the productivity of the system and its overall management. Here we look at what can be done to manage the outputs, namely manure and urine, and their associated methane and nitrous oxide emissions.

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[560] Schils R L M, Verhagen A, Aarts H F M and Šebek L B J. (2005). A farm level approach to define successful mitigation strategies for GHG emissions from ruminant livestock systems, *Nutrient Cycling in Agroecosystems* 71. 163-175,

[561] Williams AG (2007) *per comm*. obtained from the model available at www.agrilca.org as described in: *Williams, A.G., Audsley, E. and Sandars, D.L. (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main Report*. Defra Research Project IS0205. Bedford: Cranfield University and Defra.

6.5.a Manure

Enteric fermentation accounts for roughly 80% of methane from dairy cattle, with manure contributing a much lower 20%.[562] For pigs the proportions are reversed, with manure contributing to 70% of methane emissions. This said, overall emissions from pigs are far lower than from cattle. While manure accounts for fewer methane emissions overall than enteric fermentation, tackling these emissions poses less of a challenge. In addition where manure is anaerobically digested, the methane can even be used as a fuel source.

The EU MIDAIR study concludes that of the manure treatment options it evaluated, both experimentally and via modelling, anaerobic digestion has the greatest potential for greenhouse gas mitigation. Not only can it substitute for fossil fuel use, but the partially composted digestate provides a readily available nitrogen fertiliser source for plants[563] and can thus substitute for mineral fertiliser use.

Anaerobic digestion is in fact attracting considerable political attention in the UK[564] and has also been the subject of Defra-commissioned research.[565] [566] In the UK there are only a few dozen anaerobic digestion plants, in contrast with Germany's 2,700.[567]

Since the publication of the May 2007 *Energy White Paper*[568] announced that energy from anaerobic digestion systems will now attract 2 Renewable Obligation Certificates (ROCs)[569] per MWh – as high a level as solar, geothermal and wave technologies.

However, in addition to financial and infrastructural barriers, anaerobic digestion also poses some environmental challenges that need to be overcome. These included the fact that the nutritional value of the digestate can be variable and inconsistent, and the impacts of spreading nitrogen rich digestate onto the land and its diffuse pollution potential are not yet clear. It is important that appropriate application methods, timing and rates are used when applying digestate, matched to the needs of the crop. Otherwise, there is a potential for ammonia and nitrous oxide emissions

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[562] Monteney G-J, Bannink A and Chadwick D. (2006) Greenhouse gas abatement strategies for animal husbandry, *Agriculture, Ecosystems and Environment* 112 163–170

[563] MIDAIR - Greenhouse Gas Mitigation for Organic and Conventional Dairy Production, EC, Contract No: EVK2-CT-2000-00096http://www.ie-leipzig.de/MIDAIR.htm

[564] *UK Biomass Strategy*, Defra, Department for Trade and Industry and Department for Transport, 2007

[565] *Optimising Inputs and Outputs from Anaerobic Digestion Processes*, Defra project WR0212 – to end 2008

[566] *Physical assessment of the environmental impacts of centralised anaerobic digestion*, Defra project CC0240, 2004

[567] *Anaerobic Digestion in Agriculture: Policies and Markets for Growth*: Report by Enviros Consulting Limited for Department for Environment, Food and Rural Affairs May 2007

[568] *Meeting the Energy Challenge: a White Paper on Energy*, Department of Trade and Industry, London, 2007

[569] The Renewables Obligation came into force in April 2002. It requires power suppliers to derive from renewables a specified proportion of the electricity they supply to their customers. A Renewables Obligation Certificates (ROCs) is issued for renewable electricity generated and is tradeable. Sewage gas attracts only 0.25 ROC/MWh generated, onshore wind 1 ROC/MWh and AD the highest level, 2 ROCs/MWh.

to increase.[570] There are also issues to be explored with respect to digestate storage and the venting of excess methane. Inefficient or poorly operated systems (leading, for instance, to uncontrolled venting of the digester or inadequate biogas storage) may in fact lead to potentially higher methane emissions than without anaerobic digestion.[571]

Anaerobic digestion systems can operate either at the farm-scale or as larger centralised installations. The advantage of the former is that the manure does not need to go anywhere and so transport-related emissions are eliminated.

However, the economy of scale offered by centralised systems has additional benefits.[572] For a start, centralised systems can take in not just manure but food waste, added to which sourcing a wider range of inputs from a wider range of suppliers guarantees more continuity of supply. Bigger systems tend to lose less heat and overheads (for gas scrubbing and electricity generation) tend to be reduced. Importantly, the quality of the digestate can be accurately analysed and a consistent output achieved – this is clearly very important for farmers wanting to apply it to their land.

One possible point to make about anaerobic digestion is that as the technical and other challenges are overcome and the potential more fully exploited, there may be pressures to keep livestock for longer periods of time in housed systems, so that more manure can be collected. This may well negatively affect animal welfare.

Where anaerobic digestion is not feasible, other measures need to be adopted. One study suggests that for slurry, a solid cover combined with a surface crust can partly eliminate methane emissions due to bacterial re-oxidation of methane at the slurry-air interface.[573] This, however, risks increasing nitrous oxide emissions.[574] [575]

With farmyard manure (FYM) heaps, it can be possible to reduce nitrous oxide emissions by maintaining anaerobic conditions in FYM heaps (by compacting them) as can the addition of high C:N ratio materials such as chopped wheat straw. However methane emissions may be greater as a result. If something is done to utilise the manure and its methane emissions (for instance through anaerobic digestion), then a win-win situation is possible.

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[570] *UK Biomass Strategy 2007*, Working paper 3: *Anaerobic Digestion*, Defra, May 2007 http://www.defra.gov.uk/ENVIRONMENT/climatechange/uk/energy/renewablefuel/pdf/ukbio0507-work3.pdf

[571] *UK Biomass Strategy 2007*, Working paper 3: *Anaerobic Digestion*, Defra, May 2007 http://www.defra.gov.uk/ENVIRONMENT/climatechange/uk/energy/renewablefuel/pdf/ukbio0507-work3.pdf

[572] Adrian Williams, Cranfield University, pers. comm., October 2007

[573] *Greenhouse Gas Mitigation for Organic and Conventional Dairy Production* (MIDAIR) - Summary http://www.energetik-leipzig.de/Bioenergie/MIDAIRsummary.pdf

[574] Hűther, L; Schuchardt, F; Wilke, T (1997) Emissions of ammonia and greenhouse gases during storage and composting of animal manures. In: *Proceedings of the international symposium "Ammonia and odour control from animal production facilities*", Vinkeloord, The Netherlands, 6-10 October 1997, edited by Voermans, J. A. M. & Monteny, G. J. Rosmalen, The Netherlands: NVTL, 421-428

[575] Berg W, Brunsch R, Pazsiczki I (2006). Greenhouse gas emissions from covered slurry compared with uncovered during storage, *Agriculture, Ecosystems and Environment* 112 129–134

Slurry systems are more greenhouse gas intensive than manure-based systems.[576] While nitrous oxide emissions from manure heaps tend to be higher, methane emissions are much lower,[577] [578] to the extent that they outweigh the higher nitrous oxide impacts.

A Defra commissioned study by the University of Nottingham[579] emphasised the importance of frequent manure spreading to reduce methane emissions. As highlighted above, this may not always be practically possible. Elmquist[580] in her study of meat and dairy systems also points out that the actual availability of land for manure spreading on farm determines how often and indeed whether the manure gets spread. She argues that when a large proportion of the feed is imported to rather than grown on the livestock farm, there is less incentive to invest in nutrient efficient techniques. She points out that in organic systems, the growing of a high proportion of feed on farm is a fundamental principle. Hence, when livestock production is more closely related to the feed production areas, *'there is probably better nutrient recycling efficiency in both systems'* although her assertion is not backed up by data.

It is also important to note that the definition of optimum fertiliser use whether from manure or other sources needs further examining. Economically optimal application levels may be different from those that are environmentally optimal. In other words under current economic conditions (the price of fertiliser versus the price of the final crop product) the optimal amount could differ from those which seek to maximise efficient nitrogen use and uptake.

6.6 Changing the numbers

Ultimately the most straightforward way to reduce greenhouse gas emissions from the livestock sector is to reduce significantly and absolutely the number of animals farmed. This is especially true from a global perspective: the many finely balanced technological and managerial approaches to mitigation identified in this paper may be simply too costly or difficult to scale up to the global level.

As for the UK, it is certainly the case that up to a point, livestock numbers can be reduced without a loss in the quantity of meat or milk produced, provided productivity increases. Indeed over the last 25 years milk output has stayed roughly the same while numbers have decreased by nearly a third. With beef too, the number of cattle reared has fallen markedly with only a slight decrease in output.[581] This has been achieved through various nutritional and breeding strategies.

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[576] *Environmental impacts of solid and liquid manure systems,* Defra project NT2010, Project undertaken by ADAS for Defra, 2002

[577] Chadwick D, Hobbs P, Laws J, Misselbrook T and Yamulki. (2005). *Manures and Farm Resources*, IGER Innovations, Institute of Grassland and Environmental Research

[578] *Nitrous oxide emissions from slurry-based and straw-based animal production systems*, Defra project CC0234, 2001

[579] *Mitigation of greenhouse gas emissions from agriculture: socio-economic costs and impacts, report commissioned by Defra*, project code CC0262, University of Nottingham, 2003

[580] Elmquist E. (2005) Environmental Systems Analysis of Arable, Meat and Milk Production, Doctoral Thesis, Faculty of Natural Resources and Agricultural Sciences, Swedish University of Agricultural Sciences, Uppsala http://diss-epsilon.slu.se/archive/00000846/01/Epsilon_Avhandling_nr_12.2005_Tryckfil.pdf

[581] *Agriculture in the United Kingdom*, Defra 2007

These trends may on the face of it somewhat contradict the point made in Section 6.3 that increasing specialisation between milk and dairy herds might have lead to overall increases in greenhouse gas emissions. We do not, however, know what the situation might have been had we combined a focus on multi-functional breeding with other measures to improve productivity – we could, conceivably have seen an even greater reduction in numbers than has been the case so far.

However, productivity can only be increased up to a point, beyond which there are damaging consequences for animal health, fertility and longevity. If really substantial emission cuts are to be achieved, the number of animals will need to be reduced over and above any efficiency gains that are possible through the approaches identified above.

This is obviously controversial. However, the UK government's consumer information website *Directgov*[582] points out that meat and dairy products have a much higher greenhouse gas and environmental burden than other foods, although it does not go so far as to advise people to eat less. However one might infer as much and a logical continuation would be that we need to produce less meat too.

Clearly production and consumption strategies would need to be integrated. If UK livestock production were to decline while our consumption levels stayed the same, we would simply import more, the effect being a possible increase in associated emissions.[583]

Problems could also arise if consumption of meat and livestock products were to fall, but production remained the same. This could lead us exporting livestock products to other countries – again, hardly a solution. Clearly production and consumption related policies would need to go hand in hand.

6.7 Mitigation options and animal welfare – what might the impacts be?

Animal welfare is critical to any discussion of livestock-related greenhouse gas emissions. Efficiency as a goal must, in a humane society, be constrained by certain ethical non-negotiables, of which animal welfare is surely one. At times, conflicts may arise between the goals of improving animal welfare and reducing greenhouse gas emissions. Since neither priority can 'give,' then some kind of third (or fourth) way needs to be found. This is what this section explores.

We begin by looking very briefly at how animal welfare has been defined in recent years. Second we consider whether conventional systems tend to be better or worse at delivering high animal welfare than their organic or more extensive counterparts. Finally we examine how it might be possible to manage such conflicts as they arise between animal welfare and greenhouse gas reduction goals.

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[582] *Greenhouse Gas Mitigation for Organic and Conventional Dairy Production* (MIDAIR) - Summary http://www.energetik-leipzig.de/Bioenergie/MIDAIRsummary.pdfhttp://www.direct.gov.uk/en/Environmentandgreenerliving/Greenerfoodanddrink/DG_064434

[583] This is not inevitably the case. One New Zealand study has sought to argue that NZ dairy products are less GHG intensive than their UK equivalents even when the transport leg between New Zealand and the UK are factored in. See: Saunders C and Barber A. (2007). *Comparative Energy and Greenhouse Gas Emissions of New Zealand's and the UK's Dairy Industry*, Research Report No. 297, Lincoln University, New Zealand The report's method and findings have however been challenged by researchers in the UK..

6.7.a Animal welfare: The whats and hows

Animal welfare is not easily defined. What it means, how one assesses it and of course what we need to do to achieve it, are all enormous and complex areas of study and practice. Numerous attempts have been made[584] – and continue to be made – at defining it and here we have neither the space nor the expertise to do the subject justice.

Put very simply, however, animal welfare researchers tend to use two ways of assessing welfare. One is to look at animals' behavioural state – their physical condition and the behaviours they display.[585] This in itself can be fraught with difficulties since the way an animal expresses pain or another emotion may easily be misjudged by humans. We may also fall into the trap of assessing an animal's response with how a human being might respond.[586]

The second way of assessing welfare is by looking at their motivations, that is, at what the animals choose to do. Chickens show a preference for dustbathing, for example, and pigs root about when given the chance.[587]

The Farm Animal Welfare Council, the independent advisory body to the Government on animal welfare, has developed five core animal welfare indicators, the 'Five Freedoms' as follows:

- Freedom from hunger and thirst – hence the need for ready access to food and water)
- Freedom from discomfort through the provision of an appropriate environment including shelter and a comfortable resting area.
- Freedom from pain, injury and disease through its prevention or by rapid diagnosis and treatment.
- Freedom to express normal behaviour through the provision of sufficient space, proper facilities and company of the animal's own kind.
- Freedom from fear and distress by ensuring that their conditions and treatment do not subject them to mental suffering.

Four of these indicators are 'freedoms *from*.'[588] They focus mainly on physical indicators of health. The fifth freedom is a 'freedom *to'* and it raises more difficult, qualitative questions as to what we mean by 'normal behaviour' particularly in the unnatural context of a farm.[589]

The concept of 'naturalness' – the notion that it is natural and hence desirable to express normal behaviour – is a very powerful one, and one which has been

[584] See Table 1 in LAYWEL: Welfare implications of changes in production systems for laying hens. Deliverable: *D 1.2 Report with consensual version of welfare definition and welfare indicators*, 2006 http://www.laywel.eu/web/pdf/deliverable%2012.pdf
[585] BBSRC Animal Welfare Initiative, accessed from website May 2007 http://www.vetschool.bris.ac.uk/bbsrc/page_01.html
[586] *Science and animal welfare: an introduction to how scientific research is helping to identify factors that influence animal welfare and to provide a basis for improving the welfare of livestock and other animals*, BBSRC, Summer 2002
[587] BBSRC Animal Welfare Initiative, accessed from website May 2007 http://www.vetschool.bris.ac.uk/bbsrc/page_01.html
[588] Špinka M (2006). How important is natural behaviour in animal farming systems? *Applied Animal Behaviour Science* 100 117–128
[589] Segerdahl P. (2007). Can natural behaviour be cultivated? The farm as local human/animal culture *Journal of Agricultural and Environmental Ethics* Volume 20, Number 2

advocated by animal welfare and environmental organisations. The more 'natural' the animal's living environment, the logic runs, the more likely it is to equate to high welfare standards. It has in fact been argued that 'naturalness' has intrinsic value itself, beyond any animal welfare benefits that it fosters.[590]

Špinka notes that naturalness is in fact a problematic concept.[591] In hens, for instance, the expression of 'normal behaviour' such as pecking may harm other members of the flock. The question thus arises as to whether 'naturalness' should be valued more than another indicator, such as mortality levels. While free range poultry tend to be able to express various forms of natural behaviour more than caged birds, mortality rates can be higher (although not inevitably so).[592] Alroe et al.[593] suggest that the value placed by the organic movement on 'naturalness' may *'call for sacrifices of individual welfare in a conventional sense in order to advance welfare from the perspective of organic farming'.* They deliberately do not judge whether this is a good or a bad thing.

Nevertheless, Špinka finds that, for three reasons, enabling animals to express natural behaviour can be a helpful general guide to improving existing husbandry systems. First, it is often more effective to allow animals to satisfy their own needs and achieve their goals than to address these needs and goals through technical means. For example, allowing piglets to suckle from their mother is not essential; they could be fed a highly-considered, highly specific diet instead. But it is simpler.

Second, he notes that many forms of natural behaviour are associated with 'positive affective experience,' examples being play exploration in pigs and dustbathing in chickens. These behaviours are not essential, but the fact that animals act this way when given the opportunity suggests that they enhance wellbeing. Similarly, Tuyttens finds[594] that the provision of natural materials such as straw for pigs and cattle enhances their welfare both because it softens hard floors and because for pigs it enables them to express natural their natural propensity to root.

Third, the performance of natural behaviour in its richness and complexity often brings long-term benefits for the animal, as it improves their ability to cope with future stresses. Špinka cites a study showing that calves who have spent several days, rather than just the first few hours with their cow mother, are more stressed in the hours immediately following the separation, but when tested 3–6 weeks later for social competence, display higher level of socially positive behaviours.

Špinka concludes that while the freedom to perform the *whole repertoire* of natural behaviour is not of itself crucial for farm animal welfare, the opportunity for animals to

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[590] Musschengeer A W (2002). Naturalness: Beyond Animal Welfare *Journal of Agricultural and Environmental Ethics*, Volume 15, Number 2

[591] Špinka M (2006). How important is natural behaviour in animal farming systems? *Applied Animal Behaviour Science* 100 117–128

[592] LayWel: Welfare implications of changes in production systems for laying hens. Deliverable 7.1: *Overall strengths and weaknesses of each defined housing system for laying hens, and detailing the overall welfare impact of each housing system*. Research project funded by the FP6 European Research Programme and national fundings from different EU countries.

[593] Alrøe HF, Vaarst M and Kristensen ES. (2001). Does Organic Farming Face Distinctive Livestock Welfare Issues? – A Conceptual Analysis, *Journal of Agricultural and Environmental Ethics*, Volume 14, Number 3

[594] Tuyttens FAM (2005). The importance of straw for pig and cattle welfare: A review *Applied Animal Behaviour Science* 92 261–282

perform at least some natural behaviours not only improves their wellbeing, but provides a promising basis for the design of husbandry systems for the future.

6.7.b Intensive versus extensive

Does all this mean that extensive systems, such as organic, generally have higher welfare standards than those that are more intensive? This is an important issue in the light of some research (highlighted but also questioned in this report) which suggests that organic production may be more greenhouse gas-intensive than intensive systems.

It is important here at the outset to make a few distinctions.

The first is that technical standards for organic production are different from practical working conditions – that is, the standards as really practiced. This will be true of organic farms as much as for conventional ones. As regards the standards themselves, Hovi et al. note[595] that while EU organic standards (see the European Commission Regulation 1804/99 (CEC, 1999)[596] do not explicitly lay down requirements for high welfare, they are strongly implicit in the regulations. The UK Soil Association sets additional specific and exacting welfare standards for farmed animals.[597] Indeed some measures that have been identified as promoting animal welfare (and that are beginning to enter EU legislation) have long been standard required practice in organic systems. One example is the 2003 EU Animal Welfare Directive[598] which requires straw or other bedding to be provided for pigs, so they can fulfil their natural rooting behaviour.

Of course while standards can provide an important and indeed essential framework for monitoring animal welfare, they can also not be followed, or followed to the letter but not the spirit. One conclusion of the LayWel report discussed further below, is that differences in terms of animal welfare *within* systems can be greater than differences *between* systems.

It is also important here to distinguish between health on the one hand and on the other, the more difficult concept of 'welfare'. The former includes a spectrum of animal complaints from mortality at one extreme to less fatal, but serious, conditions such as osteoporosis (in chickens), mastitis (in dairy cows) and general parasitic infections that particularly afflict grazing sheep and cattle. As already highlighted there may at times be a conflict between physical health and para-physical (for want of a better term) welfare objectives.

Using chickens as an example – for it is here where the differences between intensive and extensive systems are perhaps most striking – there appears to be clear evidence that more extensive systems tend to perform better across a range of *welfare* indicators. The EU LayWel programme concludes that the welfare of laying hens in conventional cages[599] is 'severely compromised'.

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[595] Hovi M, Sundrum A, Thamsborg SM (2003). Animal health and welfare in organic livestock production in Europe: current state and future challenges, *Livestock Production Science* 80 41–53
[596] Council Regulation (EC) No 1804/1999 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1999:222:0001:0028:EN:PDF
[597] See *Soil Association organic standards 2005* and *2006*
[598] These have been implemented in England through the *Welfare of Farmed Animals (England) (Amendment) Regulations* 2003
[599] LayWel: Welfare implications of changes in production systems for laying hens. *Deliverable 7.1: Overall strengths and weaknesses of each defined housing system for laying*

LayWel defines 'conventional cages' as small enclosures with welded wire mesh sloping floors. They provide equipment only for feeding, drinking, egg collection, manure removal, insertion and removal of hens, and claw shortening. These cages *'do not allow hens to fulfil behaviour priorities, preferences and needs for nesting, perching, foraging and dustbathing in particular'*. The hens also suffer from 'disuse osteoporosis' as they have no space to move around. These disadvantages are considered to outweigh the advantages of reduced parasitism, good hygiene and simpler management.

There appears therefore to be a clear conflict between the goals of animal welfare on the one hand and the Cranfield study's finding that intensive poultry systems tend to be far more greenhouse gas efficient than extensive ones.

This said, it is important to note that stocking density is by no means the be all and end all of chicken welfare. Other factors such as the proper control of temperature, humidity, and air and litter quality, is crucial to broiler chicken welfare. Jones et al. [600] note that while stocking density is certainly important, lowering stocking density *on its own*, without regard to the environment or the birds' experience, is not sufficient and indeed, in poorly managed free range systems, aggression can be a major concern.[601] The importance of considering a range of factors relevant to the animals' wellbeing may suggest that an acceptable means of achieving both welfare and greenhouse gas reduction goals is not necessarily impossible.

As regards other livestock, such as dairy herds, one health review comparing dairy organic and conventional herds found the evidence to be mixed. Taking mastitis as an example, some research finds its incidence to be higher on organic farms, some conclude the reverse, while a third body of research finds little to choose between the two. On the whole, from their review of the literature Hovi et al.[602] find that animal health does not appear to be consistently better on organic than on conventional farms. On the other hand, a Norwegian study found a comparatively better health performance in organic husbandry, particularly with respect to ketosis and mastitis, and also for milk fever.[603] For welfare, the Hovi study finds a paucity of evidence one way or another. This suggests there is a research gap to be filled.

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hens, and detailing the overall welfare impact of each housing system (2004). Research project funded by the FP6 European Research Programme and national fundings from different EU countries.

[600] Jones, T.A., Donnelly, C.A. & Dawkins, M.S. (2005). Environmental and management factors affecting the welfare of chickens on commercial farms stocked at five densities. *Poultry Science* 85: 1156-1165

[601] LayWel: Welfare implications of changes in production systems for laying hens. *Deliverable 7.1: Overall strengths and weaknesses of each defined housing system for laying hens, and detailing the overall welfare impact of each housing system* (2004). Research project funded by the FP6 European Research Programme and national fundings from different EU countries.

[602] Hovi M, Sundrum A, Thamsborg SM (2003). Animal health and welfare in organic livestock production in Europe: current state and future challenges, *Livestock Production Science* 80 41–53

[603] Hardeng F and Edge VL. (2001). Mastitis, Ketosis, and Milk Fever in 31 Organic and 93 Conventional Norwegian Dairy Herds *Journal of Dairy Science* 84:2673–2679

On average, however, it appears to be the case that organic dairy herds have more lactations[604] and live longer. Longevity, one might suggest, is a pretty fundamental indicator of wellbeing – although it is of course perfectly possible to live a happy short life or a miserable long one.

One consequence of their living longer is that organic cows give birth to more calves during their productive life-time. If the fate of approximately 25% of all male dairy-born calves is either slaughter or veal production generally abroad[605] then the overall animal welfare and ethical implications are unclear. The Soil Association is working to build up certified veal-rearing systems here in the UK and its standards actually prohibit the selling of calves for export, but they are concerned some shipments are made.[606] Again this is an area where the wellbeing of one animal (a longer life) may have downsides for the wellbeing of another, or for the herd as a whole (more male calves slaughtered or exported). It is also, one might note, an instance of single issue concerns having long-term damaging effects both for organic and non organic herds; now that the public have such a negative view of eating veal, they will not even eat the rosé kind, leading to slaughter at birth or to live exports. One might argue that more veal consumption in the UK might even lower the need for rearing beef cattle since some of the demand for beef would be taken by veal.

6.7.c Combining animal welfare with reduced greenhouse gas emissions – ways forward

The most obvious clash between the goals of greenhouse gas efficiency and of animal welfare is apparent in the case of poultry farming. With sheep, a conflict does not really arise as they all tend to be extensively reared and any welfare problems will be common to both systems. Many cattle, both dairy and beef, are also reared fairly extensively in so far as they spend time at pasture and can fulfil (some) natural behaviours. The same, incidentally, is not always the case in the US where intensive feed lots systems are common.

Where conflicts do arise, how should we respond? One approach might be to subordinate one ethical value to the other. In other words, if we consider greenhouse gas reductions to be the over-riding goal, then animal welfare may have to take second place. If we decide the opposite, then the rise in greenhouse gas emissions resulting from a shift to (well managed) extensive poultry systems may have to be countered by extra reductions from elsewhere within the food system or in society.

There are other possibilities too. One might be to decide that since conventional caged systems are optimal from a greenhouse gas perspective then the main task is to breed animals that, put simply, like living there. As the LayWel report points out, one reason why the welfare status of similar systems can vary is that different strains of bird are being reared. Some chicken breeds are more prone to feather pecking or to cannibalism than others and the report recommends that '*hens with a reduced tendency to engage in damaging pecking … will need to be selected for noncage and larger furnished cage systems, especially where beak trimming is to be phased out or*

[604] Williams, A.G., Audsley, E. and Sandars, D.L. (2006) *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* Main Report. Defra Research Project IS0205. Bedford: Cranfield University & Defra.
[605] The ban on live exports has now been lifted
[606] *How are we weighing up?* Certification News: Licence update from Soil Association Certification Ltd, Issue 58, Winter 2006/7

not permitted'.[607] Another study notes that '*Genuine improvements in bird welfare will come from setting standards that combine stocking density, safeguards on the environment, and the genetic makeup of the birds'*.[608] The same approach could, in principle, be adopted to breed animals suited to caged systems.

In other words, instead of deciding what sorts of natural environment make animals 'happy' and then trying to create an environment that mimics that naturalness, the reverse approach might be adopted: The optimum environment (from a greenhouse gas perspective) is defined and then the animals are bred specifically to thrive in it. While this may sound a little like something from an Aldous Huxley novel, humans have of course been deliberately breeding animals for domestication and hence manipulating their genetic make up for millennia.[609] As such this represents nothing new. One might nonetheless point out that just because something has been commonly practiced for ages does not of itself give it moral legitimacy, and there will certainly be moral considerations when going down this route.

More practically speaking, the breeding-for-caged-bliss approach (as it were) may also not sit well with the general public, since 'naturalness,' however ill-defined it may be, is a powerful concept. Apparent concern for high animal welfare standards is beginning to translate into growing sales of 'welfare-friendly' products such as Freedom Food Eggs[610] and conventional caged egg laying systems are likely to be outlawed in the EU-25 by 2012. This said, the UK public tends to be fairly inconsistent in its approach to animal welfare. When the higher welfare standards for pig farming became law, causing a rise in the cost of pork and bacon, consumers switched to buying imported products instead, as illustrated in Figure 3.

An alternative approach to maintaining and improving welfare standards *while also* reducing greenhouse gas emissions involves changes in our behaviour. If neither imperative can be compromised then consumers must take the slack, as it were, and eat fewer livestock products. Absolute consumption levels would need to decline such that the absolute reduction in numbers outweighs any greenhouse gas gain resulting from a shift to more extensive systems. This might be achievable if the price consumers pay for livestock products were to increase to a level that would reduce demand. Livestock related emissions would fall and the farming industry would still be viable.

The nose ringing of outdoor pigs provides an example here. The purpose of nose ringing is to prevent outdoor pigs from rooting around, excavating the soil in their paddocks and damaging cover vegetation – the rings make it too painful for the pigs to do so. On the one hand, rooting can lead to environmental pollution as it can cause soil erosion and nutrient leaching. On the other hand, nose ringing is not only a painful procedure but it also stops pigs from practising a natural behaviour that they appear very much to want to do. Defra's Animal Welfare codes very clearly classes nose ringing as a 'mutilation' that 'should be avoided wherever possible'.[611] A

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607 LayWel: Welfare implications of changes in production systems for laying hens. D*eliverable 7.2: Manual that can be used to audit the welfare of laying hens at a farm level in whatever housing system they are held*. (2004). Research project funded by the FP6 European Research Programme and national fundings from different EU countries.

608 Jones, T.A., Donnelly, C.A. & Dawkins, M.S. (2005) Environmental and management factors affecting the welfare of chickens on commercial farms stocked at five densities. *Poultry Science* 85: 1156-1165.

609 Diamond J. (1999), *Guns, Germs and Steel: The Fates of Human Societies*. W W Norton, New York.

610 *Consumer attitudes to animal welfare*. A report for Freedom Foods by IGD, March 2007

611 *Code of Recommendations for the Welfare of Livestock: Pigs*, Defra, 2003

solution is to stock pigs at lower densities than is currently the case, thereby diluting the impact of rooting. This of course is likely to increase the cost of pig production. If farmers are not to be bankrupted, the costs will need to be passed on to consumers – and we will need to accept them.

This is perhaps the crux of the issue. Many more options are open to us – both in terms of better animal welfare and in greenhouse gas emissions reduction – once we start to challenge the overwhelming assumption that cheap food is a good thing.

SECTION 7: A FEW SCENARIOS

To explore some of the mitigation options highlighted above, this section presents a few scenarios, each one sketching out a different approach to tackling greenhouse gas emissions. We use these as starting points for considering what the possible implications might be not just for greenhouse gases but for a range of other concerns, including human nutrition, animal welfare and biodiversity.

We emphasise that this exploration is very partial indeed. In future work we intend to develop these scenarios more fully, paying particular attention to the economic implications, an area that has been particularly lacking in this paper.

7.1 Letting current trends continue

This scenario sets out the situation that appears to be developing in the UK, as outlined in Section 2 above. This scenario sees intensification in some parts of the UK livestock sector; pressure to increase productivity may lead to a decline in hill farming while lowland farming is likely to intensify.

At the same time, however, there will also be a growth in organic and other more extensive production to cater for growing consumer demand for products that are perceived to be healthier, or tastier, or better for the environment or for animal welfare.

This scenario is likely to bring very minor reductions in livestock related emissions. As a result, other parts of the food industry and indeed society may have to make deeper greenhouse gas emission cuts, to ensure we meet our overall 60% emissions reduction target.[612]

Table 17: Scenario: Letting current trends continue

Area of concern	**Impact of reduction**
GHG reduction	Minor reduction
Impact on human nutrition	No change from present
Impact on non-food goods	No change from present
Rural economy	Possible benefits for farmers farming organically or in a 'value added' manner e.g. specialist breeds. Not all farmers will be able to farm in this manner since the bulk of consumer demand will continue to be for cheap food.
Soil fertility	Positive and negative impacts
Biodiversity	Possibly negative if upland farming declines in undergrazed areas but positive where overgrazing is a problem. Lowland pastures will continue to have little to offer in terms of biodiversity.

[612] Note that the adequacy of the 60% target is currently being re-examined – see *Beyond Stern: From the Climate Change Programme Review to the Draft Climate Change Bill: Seventh Report of Session 2006–07*, House of Commons Environmental Audit Committee, July 2007

Area of concern	Impact of reduction
Aesthetics	Possibly negative if upland farming declines in undergrazed areas but positive in overgrazed areas.
Land opportunity cost	Intensification may, on the face of it, improve land use efficiency but the second order impacts may counter these gains since cultivating land for feedstuffs reduces the opportunity to grow anything else. Organic systems, on the other hand, generate lower yields per area and this may mean there are fewer opportunities to use the land available for other purposes.

7.2 Maximising productivity

From a purely greenhouse gas point of view, many of the studies highlighted above conclude that intensification is the best way of achieving – to put it crudely – value for burp.

The approach in this scenario is for policy makers (or society) to set a limit on the volume of livestock-generated greenhouse gas emissions we are prepared to tolerate. A 60%+ reduction by 2050 would be in keeping with current national reduction targets. The challenge then is to work out what is the 'best' way of achieving this reduction such that the amount of meat and milk available for consumption is maximised.

This maximum productivity approach is supported by further research efforts to increase productivity (through breeding and diet) while at the same time reducing mortality levels and improving fertility. The dietary emphasis will be on improving digestibility and nutrient uptake so as to minimise methane emissions and maximise nitrogen use efficiency. Possibilities such as methane inhibitors, nutritional supplements and so forth will also be developed further. Alternatively, efforts might focus on minimising enteric methane and maximising the methanogenic potential of manure – this would then be put through anaerobic digestion systems to produce a biofuel.

As far as soil systems are concerned, the use of nitrification inhibitors, different fertiliser types and better-targeted applications will be explored. Research efforts will also focus on improving the nutritional value of milk and meat products, such as, for example, dietary manipulation to lower saturated fat and increase Omega-3 content. Legal but not enhanced animal welfare standards will be upheld and increased efforts will be made to breed animals suited to intensive production.

Table 18: Scenario: Maximising productivity

Area of concern	Impact of technological approach
GHG reduction	Reductions in the UK but probably negative impacts on other parts of the world (see land opportunity cost)
Impact on human nutrition	Nutritionally enhanced meat, eggs and dairy products on offer. On balance, however, the situation is not very different from what we have today
Impact on non-food goods	Very little impact – slight reduction in outputs since there is a slight reduction in numbers
Rural economy	Similar to situation today although there could be gains for farmers in niche areas e.g. functional meat and dairy produce

Area of concern	Impact of technological approach
Soil fertility	There is a risk of nitrogen surpluses on farm land unless nitrogen use efficiency is extremely finely balanced
Biodiversity	Most ruminant livestock rearing will be in the lowlands on pasture land that is biologically monotonous. There could be scope for fostering more species diversity in upland areas although the problem of undergrazing in some upland areas could reduce these gains
Aesthetics	Similar to situation we have today although there is likely to be a reduction in less efficient/economically viable production in upland areas; this could alter the 'look' of upland areas.
Animal welfare	Arguably negative
Land opportunity cost	Possibly increased land available for biofuels production but this could conflict with the need to grow cereals for animal feed. There would be negative second order impacts: High dependence on concentrates means lost carbon sequestration potential on land overseas.

A variation on the maximum productivity theme might be to intensify production in certain parts of the UK (freed up land could perhaps be used for biofuels production) and to promote some limited grazing in upland areas so as to maintain ecosystem diversity and preserve our traditional landscape character. This will improve the ratings for biodiversity and landscape aesthetics in some areas, but is unlikely to improve the other impact categories.

7.3 Moving to organic

Organic management is likely to lead to reductions on a per area but not necessarily on a per yield basis. The UK's overall capacity to produce milk and meat would decline. If we are able to match the amount we consume to these reduced UK production levels than overall emissions would probably decline. However this will not be the case if consumers choose to top up with imports from abroad.

Table 19: Scenario: Moving to organic

Area of concern	Impact of reduction
GHG reduction	Reduction on a per area basis but not on a per yield basis
Impact on human nutrition	If consumption were reduced, the impacts could be favourable
Impact on non-food goods	Extremely slight reduction in availability
Rural economy	This depends on CAP and other policy developments but if consumers are willing to pay more for organic / extensively produced goods, the impacts could be beneficial
Soil fertility	Mixed results; greater use of manure and legume rotations could have a positive effect
Biodiversity	Probably good
Aesthetics	Depends on the scale of livestock enterprise but probably positive
Animal welfare	Possibly beneficial

Area of concern	Impact of reduction
Land opportunity cost	Extensive production would mean less land available for other purposes. Lower reliance on concentrates means impacts on land use overseas would be lower (although note that much organic farming is still dependent on concentrates).

7.4 Intensive–extensive combinations

A further option is to combine intensive and extensive approaches. Livestock would be reared at low stocking densities but also fed fairly high levels of concentrates. The intention here is to minimise methane emissions (by feeding concentrates) and, by keeping stocking densities low, to minimise nitrogen emissions, since nitrogen containing excreta are spread over a large area. An additional approach might be to integrate the beef and dairy herds so fewer redundant (GHG emitting) animals are reared.

Table 20: Scenario: Intensive – extensive combinations

Area of concern	Impact of reduction
GHG reduction	First order reductions, although second order impacts (through concentrate supplementation and subsequent land take) are unclear and probably negative
Impact on human nutrition	Unchanged from current situation; the total output of livestock products may not change very greatly
Impact on non-food goods	Probably unchanged
Rural economy	This depends on CAP and other policy developments, but the impacts could be negative if costs increase relative to current methods.
Soil fertility	Possibly positive
Biodiversity	No change from current situation if standard grass or grass-clover mixes are sown although overgrazing problems may be reduced.
Aesthetics	No change from current situation
Animal welfare	Extensive systems may benefit animal welfare although management will be key
Land opportunity cost	High dependence on concentrates means potentially negative impacts from lost carbon sequestration overseas. Less land available in the UK for biofuels production

7.5 Livestock switching

This scenario focuses on the issue of feed conversion efficiency. The rearing and eating of beef, milk and sheep meat declines while pig and poultry farming, which are more efficient converters of feed into food, increases. The implications of these for greenhouse gas emissions are in fact very unclear since their feed is highly cereal dependent and as such they are in direct competition with cereals for human food and as a biofuel feedstock. Furthermore changes in the type of livestock farmed will need to be matched by a shift in our consumption patterns, otherwise the shortfall (in ruminant products) will be supplied by imports. There may also be problems in finding land suitable for pig and poultry farming – most are currently located in the

Eastern regions of the UK where arable production dominates. Locating pig and poultry farms in Western and Northern regions currently devoted to livestock production may be economically unviable.

Table 21: Scenario: Livestock switching

Area of concern	Impact of reduction
GHG reduction	First order reductions: there will be fewer methane emissions and renewable energy sources could reduce the carbon intensity of heating and lighting in pig and poultry units. However second order impacts will be negative. In addition there may be problems arising from pig and poultry manure surpluses
Impact on human nutrition	Mixed – chicken and (fatless) pork are lower in fat than beef and lamb. However beef and lamb are rich sources of iron and dairy products are high in calcium.
Impact on non-food goods	Possibly less available for wool and leather.
Rural economy	The impacts will be negative for cattle and sheep farmers unless they find lucrative export markets – which would defeat the whole greenhouse gas reduction purpose. The impacts on pig and poultry farmers could be mixed – more competition from more entrants to the market could simply drive prices down.
Soil fertility	Possibly negative since there will be fewer livestock to fertilise grass land
Biodiversity	Positive – grazing land can be managed to maximise biodiversity rather than grazing productivity
Aesthetics	Negative in so far as we value seeing livestock grazing on pastures
Animal welfare	This depends on the rearing system adopted
Land opportunity cost	Growth in pig and poultry production will mean more arable land is used for feed production and there is less available for food other purposes, with negative greenhouse gas implications

7.6 Marginal livestock rearing

This is the most radical of the scenarios and can be viewed as a way of using up ecological 'leftovers'. It entails grazing livestock at sustainable levels on land unsuited to other purposes, without the use of supplementary fertilisers (other than legumes and the livestocks' own manure) and supplementing feeds only with genuine by-products.

Under this scenario the task would be to quantify:

- How much land in the UK is truly unusable for other purposes such as arable farming or biomass production?
- How much land needs to be grazed and at what stocking density in order to promote biodiversity?
- What volume of genuine by-products have we available to use, balancing the advantages of feeding them to livestock against their possible use as a feedstock in anaerobic digestion systems?

Our level of dairy and meat consumption would then be limited by this overall quantity and policy strategies would need to be put in place to influence consumer demand for livestock products.

In this scenario policies would also seek to encourage a shift towards ‘nose to tail eating’ including the consumption of offal and other edible parts that currently go for rendering.

Table 22: Scenario: Marginal livestock rearing

Area of concern	Impact of reduction
GHGs	Methane emissions would increase; nitrogen use efficiency might also decrease and hence nitrous oxide per kg of milk or meat would increase. Feed production related impacts would be eliminated. Negative second order impacts would be reduced. There would be an overall reduction in emissions owing to radical cuts in population numbers
Human nutrition	Consumption would decline substantially – although a return to nose-to-tail eating would offset this very slightly. The dietary consequences of this would generally be good but interventions would be needed to maintain calcium and iron levels among vulnerable groups. Cattle and sheep would be the main meat sources since pig and poultry production would decline.
Non-food goods	Slight reduction in availability
Rural economy	Overall potentially very damaging (although good for hill farmers) unless measures are put in place to raise the cost of livestock products and increase the value of returns to farmers. Also there is potential for diversification into other agricultural sectors such as biocrops
Soil fertility	Possibly beneficial as there is a nutrient surplus at present. There would be less manure available for spreading on arable land although the amount of arable land needed would decline (since so much is currently fed to livestock). Nutrient shortfalls could in part be met from anaerobic digestion digestate and compost.
Biodiversity	This depends on management; reductions in overgrazed areas will be beneficial but livestock numbers will need to be maintained/increased in undergrazed areas
Aesthetics	This depends on management. If upland/undergrazed areas are stocked appropriately then the impacts will be favourable. Some changes may be perceived to be negative such as an overall decline in the livestock we see on rural land.
Animal welfare	Impacts on welfare may be beneficial although care is needed to maintain good nutritional health.
Land opportunity cost	The effects will be positive with less lost carbon sequestration from overseas feedstuff production. Land in the UK could be used for arable or other food production and for biofuels.

SECTION 8: DISCUSSION AND CONCLUSIONS

This paper has explored the contribution that the UK meat and dairy sector makes to the emission of greenhouse gases and the complexities associated both with efforts to quantify this contribution and with attempts at mitigating greenhouse gas impacts.

From the studies we have reviewed, it is clear that the livestock sector makes a very significant contribution to the UK's greenhouse gas emissions. But it also supplies us with a great many benefits. We conclude that a certain level of livestock production is actively beneficial for the environment, particularly for soil quality and biodiversity, and perhaps for our health too. At current levels, however, and with current methods of production, the negative impacts on the environment very much outweigh the benefits.

Livestock contribute to the emission of all the three major greenhouse gases, nitrous oxide, methane and carbon dioxide. The relative importance of these greenhouse gases will vary by livestock type: For ruminants, methane and nitrous oxide dominate, for pigs carbon dioxide, with the remainder shared between methane and nitrous oxide. For poultry, impacts are fairly evenly split between nitrous oxide and carbon dioxide. Given the overwhelming contribution made by ruminants to total livestock related contributions, one might argue that methane and nitrous oxide emissions represent the key areas for concern in any strategy to tackle livestock related greenhouse gases.

This said, the indirect carbon dioxide losses resulting from livestock farming in the UK, while less studied, may be very significant. By these we mean the lost opportunity for carbon sequestration that results when land that was previously forest or grassland, is transformed for soy and other fodder cultivation. These are the second order impacts that we have highlighted repeatedly during the course of this paper.

Livestock systems are fantastically complicated. This paper has studied a fairly extensive range of literature and we have found, as often as not, that where mitigation strategies have been proposed in one study, another one comes along that overturns or at least casts doubt on its conclusions. Tackling one type of greenhouse gas emission may lead to increases in another; similarly reductions in one part of the farm ecosystem can prompt increases in another. As with hanging wallpaper, it seems that whatever we do, a little bubble of gas will pop up somewhere. Moreover even where absolute reductions can be achieved, there will inevitably be clashes with other social, economic, environmental or ethical priorities.

Bearing all this in mind, what possible courses of action might UK policy makers wish to consider? These will very much depend on the policy standpoint. Are current trends in consumption (and hence production) to be assumed as a given, and if so how can emissions be reduced within the context of that 'given'? Or will policy makers actually question and perhaps seek to alter the direction of these trends?

Additionally, it will be necessary to decide whether to take an atomised or a synthetic approach to tackling the problems we face. Do we target individual areas of concern – greenhouse gases, unhealthy eating habits, biodiversity losses – separately? Or do we adopt a more utilitarian 'greatest good for the greatest number' stance? In the latter case we would explore a range of problems in tandem and try to work out an

approach that addresses all of them, accepting that for no one particular area will this represent an optimal approach.

Of course the options for mitigation depend not only on what area has the greatest impact but also on where the greatest scope for achieving savings (economically and practically) might lie. To take an example, methane emissions from ruminant enteric fermentation are far greater than those from manure. However at present, we know more about managing methane from manure (through anaerobic digestion, for instance) than we do about enteric fermentation. This could of course change in future years as new technologies develop.

When it comes to mitigation it is important also to think not just one move ahead but several. Land use provides a salient example. We need to consider not just how to reduce emissions from land allocated to livestock production (be it pasture or land put to fodder) but how to do so such a way that the opportunities for greenhouse gas savings on other areas of land (unrelated to livestock production) are maximised.

Thus, while livestock fed a diet high in concentrates produce less methane (and possibly fewer overall emissions per unit of output) than those left simply to graze on upland areas, those grazing on the uplands are using land that can be put to no other use apart from woodland planting. The concentrates fed to the other livestock on the other hand, could be used for non-livestock purposes, perhaps as a feedstock for biofuels production or directly for human consumption.

A third possibility might of course be to use the upland areas for carbon-sequestering biomass production; to use arable land hitherto used for feed cultivation to grow crops for human consumption; and to abandon livestock farming altogether. In which case we will need to think about how much land might be needed to furnish us with the other outputs of livestock rearing, such as non-food product, soil fertilisation and so forth. And these are just three of a potentially vast range of moves in this rather crucial game of chess.

Our thinking needs to be done too with global population growth in mind. By 2050 the number of people on this planet is projected to top 9 billion.[613] Demand for land, food and energy will grow. If land is used for livestock, however, efficiently, it means that there will be less available to grow other food or biofuels. As a result, hungry people may be forced to farm on ever more marginal lands with – among other things – damaging consequences for carbon storage.

Bearing in mind the multiple pressures on land use, global increases in population, the importance of other non-climate related environmental issues, the ethical obligation to care well for the animals we use and the limitation of technological-managerial solutions, a key conclusion we would draw is that if we are serious about tackling food related greenhouse gas emissions, we need to consider making significant reductions in our overall production of livestock products, while seeking to maximise the benefits that livestock can bring. An inherently linked priority is to investigate how the British public might be encouraged to reduce substantially their consumption of meat and dairy products.

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[613] Earthtrends, July 2006 Monthly Update: *World Population Growth - Past, Present, and Future*, World Resources Institute August 1, 2006 http://earthtrends.wri.org/updates/node/61 accessed 10 June 2007

At current profit levels, a decline in production and consumption could terminally damage the UK farmers and so a demand reduction scenario needs to be considered very carefully. But in our view it *does* need to be considered. Serious efforts to tackle climate change mean that we may be forced to consider options that we now find unthinkable. Such options may include reassessing current economic systems and ways of doing business.

Unfortunately economics are beyond the scope of this paper, although in future work we intend to explore this very fundamental area in detail. We simply note for now that we have a situation today where meat has never been cheaper and more plentiful – and yet farmers are struggling. While limits on production within this economic framework could clearly be fatal to farmers, even current levels of production are hardly helping. We may need to explore policies that trigger actions along the whole of the supply chain – the supermarkets in particular – to ensure that the external costs of livestock products are internalised and that farmers receive a fair return for their efforts.

In short, we may need to eat fewer livestock products, and – if farming is to survive – pay more for them.

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