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Where does the carbon footprint fall? Developing a carbon map of food production

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Executive Summary

The concept of local food is appealing to many consumers. However, difficulties remain with defining what actually constitutes local food. Given the globalised nature of agricultural markets, bread which is baked in a small village bakery in England may be made from grain grown in Canada. Similarly many of the inputs (e.g. tractors, fertilisers, diesel and concentrate feed) to a West Country dairy farm selling local ice cream may come from outside the UK.

One of the purported advantages of local food relates to reduced emissions of greenhouse gases from the food chain. This concept was initially encapsulated by measuring food miles, however more recently this simple concept has been replaced by the development of more comprehensive life cycle assessments and carbon footprints.

Carbon footprints report the total levels of greenhouse gas (GHG) emissions from food production, but do not document the actual geographic location of the emissions. If advocates of local food really wanted to differentiate local from non-local food in a quantifiable way, then one way to do this would be to utilise local stocks of carbon and to make GHG emissions locally.

This report advances the discussion about defining the local by examining the geographical location of GHG emissions along the supply chains upstream of two case study farms. The resulting carbon map illustrates the amount and location of the GHG emissions related to the provision of inputs and on-farm processes, and enables characterisation of the 'localness' of the two farm systems.

Inputs to the two case study dairy farms were documented and the origin of the constituent raw materials was identified. On-farm emissions were also estimated and through combining these sets of data the carbon footprint was calculated for each farm. Results are expressed per hectare and per litre of milk. Through combining the origin of the inputs with details of relative GHG emissions it was possible to develop a 'carbon map' which shows the spatial location of emissions at a global scale.

Both case study farms had very similar carbon maps. Less than 5 per cent of GHG emissions related to the provision and use of inputs are considered local (i.e. occur within 50 km of the farm). As the emissions of GHGs from soils and livestock occur on farm they are defined as being local. As a result their inclusion in the carbon footprint changed the carbon map considerably, and greater than 50 per cent of all total GHG emissions then occurred locally. Further analysis considered the emissions derived from soya in livestock meal, which may be grown in South America on land recently cleared from forest. Specific inclusion of emissions resulting from land use change for soya production in the carbon map increased the amount of non-local emissions for both case study farms.

This work was conducted over 10 days. Only two case study farms were considered, and there are considerable gaps in the analysis of the relevant supply chains. The knowledge-base on emissions for each input and process are incomplete. As a result the report does not represent a comprehensive analysis of the data and should be viewed more as proof of concept rather than a definitive analysis.

The data presented here pose serious questions about the validity of claiming that any food is truly local. All UK farms derive inputs from outside the UK, and consequently they are responsible for both the depletion of distant carbon stocks, and GHG emissions that occur outside their locality, and the UK. The concept of a carbon map offers a method to represent the level of localness for any production system. However, it is not known whether this information would be of benefit to consumers, food chain professionals and/or policy makers.

Further research may:

- develop more detailed analysis of supply chains and relevant emission factors (especially for livestock feed)
- obtain consumer feedback on the concept of the carbon map and document their perceptions of local and non-local emissions
- develop carbon maps for several different farming types, e.g. cereal, vegetable, poultry. These may have different distributions of local and non-local emissions to dairy farms as they would not include methane emissions from ruminant livestock
- consider how the results of a carbon map could be included in regional and national carbon accounts
- consider the variation in the carbon map between individual farms in a sector.
- expand the analysis beyond the farm gate.

If UK farms wanted to localise emissions then the most practical options are to:

- derive greater proportions of their energy needs from close by (e.g. renewable or bioenergy)
- alter the fertiliser strategy and seek substitutes for inputs of inorganic nitrogen
- reduce dependency on imported feed.

Contents

1. Introduction

The concept of local food has promoted considerable interest among consumers and politicians in recent years (Kelly 2004, Frith 2005, Smith *et al.* 2005, Hamilton 2006). While the basic concept of local food may seem appealing to many, quantifying some aspects of the concept remains problematic. Firstly, there are issues surrounding the definition of ‘local’. For example, 22 per cent of consumers who responded to an Institute of Grocery Distribution (IGD) survey expected local food to be produced within 30 miles of where they lived (IGD 2006), while others extended their notion of ‘local’ to country limits (e.g. England, Scotland or to Britain as a whole). For the majority of respondents, though, food was considered ‘local’ if it was produced in the same county as it was consumed.

Secondly are the issues relating to the environmental impact of local food. Initially proponents of local food were concerned about the emissions of greenhouse gases (GHG) from the transport of food. As a result the concept of food miles, which measures the distance food travels from farm to plate, was used as an indicator of the environmental impact of different food stuffs (Smith *et al.* 2005). However, recent analyses have questioned the value of this concept, and it is now accepted that food miles are not a good indicator or either greenhouse gas emissions or the overall environmental impact associated with food (Edwards-Jones *et al.* 2008). As a result, recent debates around the environmental benefit of local food have tended to focus on the overall level of GHG emissions from the entire food production and consumption process (e.g. Williams *et al.* 2006). This measure, termed the ‘carbon footprint’, is the total amount of GHGs emitted during its production, processing, retailing and consumption (N.B. the most important GHGs derived from agriculture and horticulture are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)). To date there are relatively few carbon footprints for food items published in the public domain (but see Edwards-Jones *et al*. 2008, Milà i Canals *et al.* 2007, Williams *et al.* 2006, Williams 2007). The calculation of carbon footprints is currently hampered by the lack of an agreed methodology and great uncertainty surrounding the amounts of GHGs emitted from different processes. Both of these problems may be reduced with time.

Advocates of local food are therefore in a difficult position. Politicians and scientists are seeking an evidence base which shows that local food is in some way different to non-local food. However, surveys repeatedly show that many consumers express a preference for local food, even in the absence of strong evidence in their favour (see IGD 2006, Nygard and Storstad 1998, La Trobe 2001, Draper and Green 2002, Weatherell *et al.* 2003, Winter 2003).

A further difficulty arises from deeper analysis of what actually constitutes local production. For example, so-called local bread may be baked in a small village bakery in England, but the flour may come from grain grown in Canada. Similarly, local ice cream may be made on a dairy farm using milk from that farm’s cows. However, many of the inputs to the dairy farm may come from outside the locality, e.g. tractors, fertilisers, diesel and concentrate feed. Not only are many of the physical inputs to farms derived from outside the locality, but the farm workers may come from Eastern Europe (Cross *et al.* 2008), much of the technological knowledge comes from an international scientific community and even the genes of the livestock may come from overseas (there is an active international trade in semen). These sorts of issues raise serious questions about what actually makes local food ‘local’.

The purpose of this report is to consider whether a more quantitative method can be found for defining the relative localness of different food systems, particularly in relation to the emission of GHGs. When considering the impacts of food production on climate change two factors are particularly important. These are the maintenance and use of carbon stores and the emission of GHGs. Carbon is typically stored in deposits of fossil fuels, in soils and in vegetation. Carbon dioxide is released through the use of fossil fuels, while land use change can also lead to the release of several greenhouse gases from soils and vegetation (e.g. nitrous oxide and carbon dioxide). If advocates of local food really wanted to differentiate it from non-local food in a quantifiable way, then one way to do this would be to utilise local stocks of carbon and to make GHG emissions locally. Such a system would have the added advantage that it allows international frameworks for GHG accounting to accurately account for emissions and stock depletions in national/regional accounts.

The analysis presented here will advance the discussion about the benefits of local by examining the geographical location of GHG emissions along the supply chain from raw materials and production of inputs to the farm gate. This will illustrate how geographically local GHG emissions from food production really are by decoupling the place of production of the food from the locality of origin of the various inputs that are used on farm during the production. In this way it is hoped to develop a potential methodology for comparing the relative localness of certain food systems. The basic concept is that if a high proportion of inputs and a high proportion of GHG emissions relating to the development and use of these inputs are derived close to the source of production then that system may be considered local. In the converse situation, a high proportion of the inputs to a farm, and the GHG emissions related to their production, may be made on a different continent to the farm itself. In this case the food system may not be classified as local.

1.1 Aims and report outline

In this report, we first estimate the carbon footprint of two case study dairy farms. We then assess the contribution of greenhouse gas emissions to the carbon footprint of these farms that arise locally and non-locally. The overall aim is to identify the extent to which any produce can be considered local in terms of carbon accounting.

The report is in four sections: Section 1 is the introduction. Section 2 presents the two case study farms and their carbon footprint. In Section 3 the various farm inputs and emissions are allocated to distance categories depending on where they are produced and where emissions occur. The results are then discussed in terms of how ‘local’ the milk produced on the case study farms is. Section 4 presents a discussion of the analysis.

The appendix discusses in more detail where raw materials and feedstocks used for the production of farm inputs originate.

It should be noted that this report is the product of 10 days work. It is by no means complete and should be viewed more as a proof of concept than as a comprehensive analysis.

2. Case studies

A carbon footprint was estimated for two case study dairy farms: a conventional dairy and a dairy farm in organic conversion. Dairy farms were chosen for this project because they can represent quite intensive systems that rely on a variety of inputs, especially concentrate animal feed. Both case study farms are located in South Wales, UK, and detailed data on farm inputs for an average year was obtained from both farms in early summer 2008. These farms were chosen at random from a list of farm contacts in Wales. The key factor in including them in this study was the willingness of the farmers to participate in the work and to answer the relevant questions about farm inputs. Although they are typical dairy farms in the region, two farms does not make a good sample and the results presented here should not be considered as representative of dairy farming in Wales or the UK, or of conventional and organic farms in general.

2.1 Methods

2.1.1 Definition of system boundaries

Estimates of the carbon footprint of a system will depend on how the system of concern is defined. System boundaries may be defined so that they include only certain elements of the food chain. For the purposes of this report, two system boundaries were defined:

System boundary 1 includes emissions arising from the manufacture and transportation of farm inputs such as fertilisers and concentrate feed as well as the use of energy (diesel, electricity, etc.) on farm. No emissions are considered for the transport and processing of food after it leaves the farm.

System boundary 2 includes the above plus the greenhouse gas emissions from livestock and their excreta, and emissions from soils related to fertiliser use and manure management. Again no emissions are considered for the transport and processing of food after it leaves the farm.

Several more system boundaries could be defined depending on the aim of a particular study. These become successively more complex and comprehensive as the system boundary is expanded to include the flow of greenhouse gases into and out of soils and plants in the productive and non-productive areas of the farm, e.g. woodlands, or to also include activities further down the food chain, e.g. transport off the farm, processing, retailing and consumption.

Non-productive areas of farms may form quite large areas in many agricultural systems, and these and the pastures themselves may have the potential to both release and lock up carbon (Castaldi *et al.* 2007, Chapuis-Lardy *et al.* 2007). Unfortunately, the flow of carbon into and out of agricultural plants and soils remains relatively poorly understood, and for this reason they are ignored in this report.

2.1.2 Calculation of the carbon footprint

The carbon footprint of the case study farms was estimated for the two system boundaries described above using published emission factors for GHG emissions associated with the extraction of raw material, the manufacture of inputs and their transport to the farms. In general, no Welsh data on emissions from inputs were available and UK data were also rare. Therefore, wherever available from the literature, a range of emissions reported was used for the calculations in order to define a minimum, maximum and mid range value of possible emissions.

Data and equations from the Intergovernmental Panel on Climate Change (IPCC) guidelines on national GHG reporting (IPCC 2006) were used to assess the GHG emissions arising from the grazing animals and their excreta, as well as from soils following nitrogen additions. These IPCC emission factors are default values, which may not always accurately reflect local conditions, but they were used in this study due to a lack of locally validated figures. Where emission factors defined by the IPCC were used, the uncertainty range surrounding these defaults was considered in order to reflect uncertainty in their estimation. For the calculations, the minimum, maximum and mid or default value of these ranges were used to represent a best case, worst case and average scenario. The reliability and robustness of the results should be enhanced by this explicit consideration of uncertainty and environmental variability.

Inputs and emissions are presented in several categories. Emissions from farm inputs include embodied emissions from the production and delivery as well as direct emissions from the use of the inputs on farm. Nitrous oxide emissions arise directly from soils as a result of nitrogen inputs (synthetic fertiliser, organic nitrogen, excreta of grazing livestock) and indirectly through volatilization and leaching of nitrogen applied. Methane emissions occur from enteric fermentation of livestock and from excreta, and the application of lime to soils leads to CO_2 emissions.

Case study farm 1 used 12t and case study farm 2 used 21t of sawdust as bedding material, which could not be considered due to a lack of emissions factors for sawdust. Both farms grow crops, however the GHG emissions arising from soils following ploughing or from residues after harvest are not included in the carbon footprint presented here. Carbon and nitrogen inputs in organic material such as bedding are not considered. To account for GHG emissions from the production and delivery of concentrate animal feed on the organic farm, the range of emission factors applied for the conventional farm was reduced by 5 per cent because the global warming potential of organic field crops is 2-7 per cent less than for conventional crops (Williams *et al.* 2006). One figure was available in the literature on emissions from the production of organic wheat feed and this represented the minimum figure used in the footprint calculation.

The carbon footprint is presented in kilograms of CO_2 equivalents per farm hectare per year (including grassland and arable areas but excluding woodlands). In addition, GHG emissions per litre milk sold are also presented. These calculations assume that the only output from the farm was milk, and no allocation of GHG between products has been attempted (i.e. calves, beef, cull cows). This lack of allocation would be a weakness in the context of a full life cycle assessment (LCA) (Guinée *et al*. 2002), but it does not impact on the main thrust of this report, which is largely concerned with the location of the GHG emissions. However, it does mean that the GHG emissions for each litre of milk are probably not precisely accurate and may be between 10 and 20 per cent lower than reported here

2.2 Farm descriptions

Case study farm 1 is a conventional lowland dairy farm; case study farm 2 is a dairy farm in organic conversion. The annual inputs and outputs of the two farms are shown in Table 1.

Table 1. Description of the case study farms

	Case study farm 1	Case study farm 2
FARM DESCRIPTION		
Total area of farm (ha)	96	223
Area of farm used for grazing (ha)	61	183
Area of improved grassland (ha)	61	142
Area of unimproved grassland (ha)	9	41
Area of woodland (ha)	6	8
Area of crops (ha)	20	32
Total number of cattle (all types)	270	395
Number of dairy cows	150	285
Number young stock	120	110
Milk sold per year (litres)	850,000	1,500,500
Silage used (t)	2,000	2,000
Number of weeks that cattle are housed per year	26	22
INPUTS per year		
Total diesel use per year, incl. contractors (litres)	8,000	9,000
Electricity use per year (kWh)	33,000	63,632
Nitrogen (kg)	17,500	0
Organic nitrogen (kg N)	5,923	8,614
Phosphorus (kg)	3,500	0
Potassium (kg)	7,500	0
Lime (kg)	60,000	250,000
Pesticides (litres)	18	0
Concentrates and other feed bought in (t)	338	470
Bedding bought in (straw) (t)	60	80

Data on organic nitrogen is an estimated mean (range: farm 1, 5,429-8,391 kg N year^{-1}; farm 2, 7,896-12,203 kg N year^{-1}).

2.3 Carbon footprint

Table 2 and Figure 1 present the results on GHG emissions from farm inputs (system boundary 1) plus GHG emissions from the grazing animals, their excreta and soils (system boundary 2).

On both farms methane (CH_4) emissions that are derived from the gut of the cattle (termed enteric fermentation) dominate GHG emissions. These emissions occur as bacteria and protozoa in the rumen of the cow break down the grass and are a perfectly natural part of rumen physiology. Other major GHG outputs include farm inputs and direct N_2O emissions from soils. Among the farm inputs, concentrate feed, nitrogen fertiliser and lime dominate emissions on case study farm 1. On the organic farm, concentrate feed is the greatest source of emissions from inputs, followed by lime. The conventional farm uses nitrogen (N), phosphorus (P) and and potassium (K) in the fertilisers, but only the N fertiliser is significant in terms of its contribution to the farm's carbon footprint. The contribution of fossil fuels to the carbon footprint is of minor importance on both farms.

Overall, the percentage contribution of the different components of the carbon footprint was similar for the two farming types for system boundary 2 (Figure 1). This was because of the great importance of methane and nitrous oxide emissions from the livestock and soils, which occurred equally on both farms and masked the fact that the organic farm had lower emissions from indirect inputs through the non-use of inorganic fertilisers and pesticides.

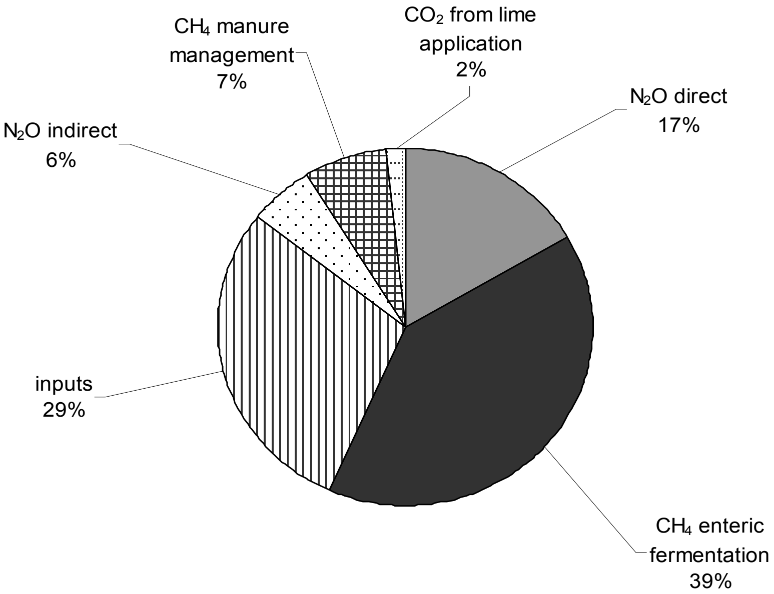
Table 2. Total GHG emissions in kg CO_2 equivalents ha^{-1} year^{-1} and kg CO_2 equivalents per litre milk produced on two case study dairy farms

	Case study farm 1 (conventional)			**Case study farm 2 (organic)**		
	min.	**max.**	**average**	**min.**	**max.**	**average**
EMISSIONS PER HECTARE (kg CO_2 equivalents ha^{-1} year^{-1}):						
Inputs						
diesel			243.6			114.7
electricity use			191.8			154.8
fertiliser – N	581.4	1,858.9	1,220.1	0	0	0
fertiliser – P	-7.1	31.4	12.1	0	0	0
fertiliser – K	25.0	60.0	42.5	0	0	0
fertiliser – lime	100.0	766.7	433.3	174.4	1,337.2	755.8
pesticides	0.3	2.7	1.5	0	0	0
concentrate feed	395.4	3,570.8	1,983.1	236.1	2,400.7	1,318.4
bedding	49.9	49.9	49.9	27.8	27.8	27.8
plastic for silage	64.6	94.2	79.4	27.0	39.4	33.2
total	**1,209.4**	**6,434.5**	**3,821.9**	**465.4**	**3,805.2**	**2,135.3**
TOTAL SYSTEM BOUNDARY 1	**1,644.7**	**6,869.8**	**4,257.3**	**734.9**	**4,074.7**	**2,404.8**
N_2O						
direct from soils	712.6	7,075.4	2,230.9	347.7	3,333.3	1,033.5
indirect from soils	21.8	7,412.8	640.9	8.9	3,094.0	259.2
direct from manure management	127.5	510.2	255.1	77.7	310.6	155.3
indirect from manure management	15.3	1,147.9	204.1	9.3	698.9	124.2
total N_2O	**877.3**	**16,146.3**	**3,330.9**	**443.6**	**7,436.8**	**1,572.2**
CH_4						
from enteric fermentation			5,926.3			3,994.0
from excreta			1,087.2			814.3
total CH_4			**7,013.5**			**4,808.3**
CO_2 from lime application	152.8	305.6	229.2	266.5	532.9	399.7
TOTAL SYSTEM BOUNDARY 2	**9,688.3**	**30,335.1**	**14,830.9**	**6,253.3**	**16,852.7**	**9,185.0**
EMISSIONS PER LITRE MILK SOLD (kg CO_2 equivalents l^{-1} milk):						
System boundary 1	**0.2**	**0.7**	**0.5**	**0.1**	**0.6**	**0.3**
System boundary 2	**1.0**	**3.2**	**1.6**	**0.9**	**2.4**	**1.3**

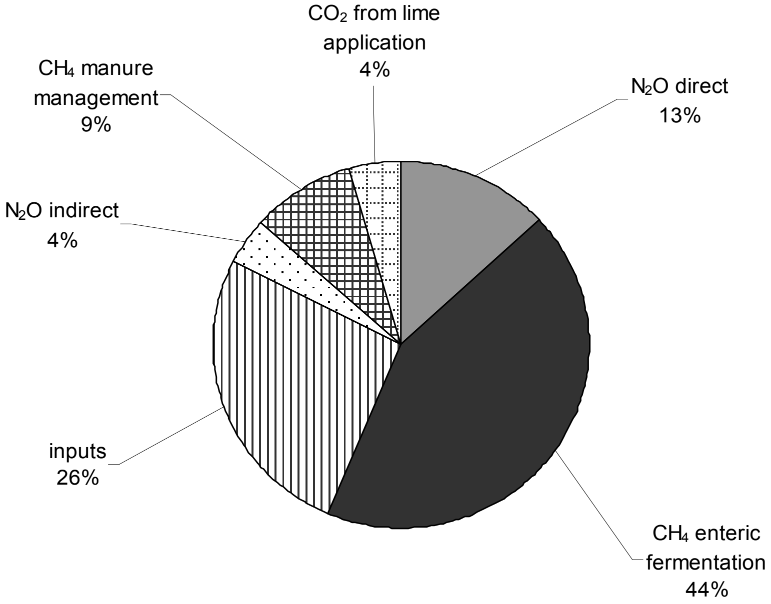
All emissions were calculated using a range of values reported in the literature. Values presented may not add up to the sum presented as total due to rounding errors. Figures for inputs include direct and embodied emissions.

Figure 1. Relative contribution to total GHG emissions (kg CO_2 equivalents) for a) case study farm 1, b) case study farm 2

a) Farm 1 (conventional)



b) Farm 2 (organic)



Emissions are the average for system boundary 2 and include embodied and direct emissions from inputs, direct and indirect N_2O emissions from soil and manure management and CH_4 emissions through enteric fermentation and from manure management..

The conventional farm had a slightly higher carbon footprint than the organic farm per litre of milk produced (Table 2). This may be due to the organic farm's lower use of inputs; but it could also be due to the organic farm, which has greater levels of output, working more efficiently than the conventional farm with a lower milk output ('ecology of scale'). This result is complicated by the lack of allocation between outputs undertaken on both farms. Before concluding that organic dairy farms had a lower carbon footprint than conventional farms it would be necessary to study more farms and make suitable allocation of GHGs between the outputs. Contrary to the results presented here, Williams *et al.* (2006) found that organic milk had a greater global warming potential than non-organic milk, and Haas *et al.* (2001) calculated the same value for both organic and intensive milk production.

3. Carbon map

3.1 Methods

The main purpose of this report was to consider the location of the GHG emissions from the two farms. In order to do this the origin of all inputs to the farms were determined (e.g. where did the fertiliser come from?). The emissions related to the production of the input were then allocated to the country of origin of the input. After completing this task, each farm input and their raw materials were allocated to one of five distance categories according to how far they were likely to have travelled to UK farms: distance category 1 = 0-50 km (local to the farm), 2 = 50-500 km (from within the UK), 3 = 500-1000 km (from the near continent), 4 = 1000-5000 km (international, e.g. Russia), 5 = >5000 km (international, e.g. South America). Emissions from cattle and the farm ecosystem (as included in system boundary 2) occurred on the farm and were considered as truly local system emissions. The following paragraphs and Table 3 sum up the reasoning for allocating distance bands. Transport emissions are allocated to the distance category of origin. Further details are presented in the Appendix.

Inputs

Electricity: all electricity was assumed to be produced in the UK using UK feedstock (distance band 2, 50-500 km).

Diesel: the majority of diesel used in the UK originates from the North Sea; this could fall into distance categories 1 (0-50 km), 2 (50-500km) and 3 (500-1000km) depending on where in the UK a farm is located. Considering that there will be several transport steps from the North Sea to refineries to storage to user, and that both case study farms are located in South Wales, here we assumed the worst case distance scenario and allocated all diesel to distance category 3.

Fertiliser – N: 47.3 per cent of N fertiliser used on the farms was assumed to have been produced in the UK. Because Russia is the largest importing country to the European Union and no more detailed data was found, it was assumed that the remaining 52.7 per cent of N fertiliser was imported from Russia.

Fertiliser – P: even though some processing occurs in the UK, all phosphate rock was assumed to be mined in countries in distance category 4 (1000-5000km) and distance category 5 (>5000km); an even split was assumed between those two distance categories.

Fertiliser – K: all K fertiliser input was allocated to distance band 2 (50-500km).

Fertiliser – lime: all lime was assumed to be derived from UK sources (distance category 2, 50-500km).

Pesticides: no information was found on production sites of pesticides; production was assumed to be in the UK and all emissions were allocated to distance category 2 (50-500km). Because the contribution of emissions from pesticides to the overall farm-scale carbon footprint was very low (see section 2), this assumption will only have a small impact on the results of the analysis.

Concentrate feed: using the figures in Casey and Holden (2005), 24.5 per cent of an average feed mix fall into the distance category 2 (50-500 km), 25 per cent into distance category 3 (500-1000 km) and 42 per cent into distance category 5 (>5000 km) (see Appendix 1.3). These figures exclude 8.5 per cent of the global warming potential per tonne of feed which are associated with shipping, trucking and processing; however, these figures are not available broken down by ingredient and can thus not be considered here. It was assumed that these percentages apply equally to conventional and organic feed although these might differ in their composition.

Straw used for bedding: this falls into the truly local distance category for case study farm 1 (in part bought in from a distance of 5 miles and in part home grown) and case study farm 2 (bought in from a distance of 6 miles).

Plastic used for wrapping silage: this was assumed to be produced in the UK using North Sea oil (distance band 3, 500-1000 km) (see under diesel).

Emissions from soils and livestock

All N_2O, CO_2 and CH_4 emissions following fertiliser and lime application to soils, from enteric fermentation and from manure management were considered truly local (distance category 1, 0-50 km).

Emissions from land use change

Two scenarios were developed to highlight the impact of expanding soya cultivation in countries such as Brazil and Argentina and how GHG emissions resulting from the conversion of native habitats in these countries might impact the carbon footprint of farms in the UK.

Scenario 1
Soya in concentrate feed was assumed to have been produced on long established arable land; no emissions in addition to those presented by Casey and Holden (2005) were considered.

Scenarios 2 and 3
Soya contained in concentrate feed was assumed to have been produced on recently converted native habitats in Brazil. We assumed that the soya proportion of compound animal feed varies between 8 per cent and 25 per cent based on the literature (Brookes 2001, Eriksson *et al.* 2005, van der Werf *et al.* 2005, Casey and Holden 2006, Ellingsen and Aanondsen 2006, Nemecek and Baumgartner 2006, Steinfeld *et al.* 2006, Garnett 2007). Using the data presented in Fargione *et al.* (2008), carbon emissions resulting from the conversion of Amazonian rainforest and woody and grassy savannah vegetation to produce the soya contained in 1t concentrate feed were calculated as shown below:

Average yield of soya beans in Brazil (FAO 2004): 2.6 t ha^{-1} year^{-1}
Percentage of soya in concentrate feed: 8-25% (average 16.5%)
Weight of soya per t of concentrate feed: 0.08-0.25 t (average 0.165 t)
Area needed to produce this amount of soya per t of feed:
Minimum: 0.08 t soya t^{-1} of feed / 2.6 t ha^{-1} year^{-1} = 0.031 ha year t^{-1} of feed
Maximum: 0.25 t soya t^{-1} of feed / 2.6 t ha^{-1} year^{-1} = 0.096 ha year t^{-1} of feed
Average: 0.165 t soya t^{-1} of feed / 2.6 t ha^{-1} year^{-1} = 0.063 ha year t^{-1} of feed

Emissions from land use change (first 50 years) (Fargione et al. *2008):*
Emissions from the conversion of rainforest: 737 t CO$_2$ ha^{-1}
Emissions from the conversion of woody savannah: 165 t CO$_2$ ha^{-1}
Emissions from the conversion of grassy savannah: 85 t CO$_2$ ha^{-1}

Emissions from land use change per ha per year (first 50 years):
Emissions from the conversion of rainforest: 14.7 t CO$_2$ ha^{-1} year^{-1}
Emissions from the conversion of woody savannah: 3.3 t CO$_2$ ha^{-1} year^{-1}
Emissions from the conversion of grassy savannah: 1.7 t CO$_2$ ha^{-1} year^{-1}

Emission from land use change to produce the soya in 1 t of concentrate feed:
Rainforest to soya:
minimum: 14.7 t CO$_2$ ha^{-1} year^{-1} * 0.031 ha year t^{-1} of feed = **0.45 t CO$_2$ t^{-1} of feed**
maximum: 14.7 t CO$_2$ ha^{-1} year^{-1} * 0.096 ha year t^{-1} of feed = **1.42 t CO$_2$ t^{-1} of feed**
average: 14.7 t CO$_2$ ha^{-1} year^{-1} * 0.063 ha year t^{-1} of feed = **0.94 t CO$_2$ t^{-1} of feed**

Woody savannah to soya:
minimum: 3.3 t CO$_2$ ha^{-1} year^{-1} * 0.031 ha year t^{-1} of feed = **0.10 t CO$_2$ t^{-1} of feed**
maximum: 3.3 t CO$_2$ ha^{-1} year^{-1} * 0.096 ha year t^{-1} of feed = **0.32 t CO$_2$ t^{-1} of feed**
average: 3.3 t CO$_2$ ha^{-1} year^{-1} * 0.063 ha year t^{-1} of feed = **0.21 t CO$_2$ t^{-1} of feed**

Grassy savannah to soya:
minimum: 1.7 t CO$_2$ ha^{-1} year^{-1} * 0.031 ha year t^{-1} of feed = **0.05 t CO$_2$ t^{-1} of feed**
maximum: 1.7 t CO$_2$ ha^{-1} year^{-1} * 0.096 ha year t^{-1} of feed = **0.16 t CO$_2$ t^{-1} of feed**
average: 1.7 t CO$_2$ ha^{-1} year^{-1} * 0.063 ha year t^{-1} of feed = **0.11 t CO$_2$ t^{-1} of feed**

Overall range for emissions from land use change across the three habitats and minimum to maximum inclusion rates of soya beans in feed: **0.05-1.42 (average 0.735) t CO$_2$ t^{-1} of feed**

In Scenario 2, the average value (for an average soya inclusion rate of 16.5 per cent) across the three natural habitats (735kg CO$_2$ t^{-1} feed) was multiplied by the tonnes of feed used and then divided by total farm hectares. This figure was then added to the carbon footprint of the case study farms as presented in section 2. All of these emissions fall into distance category 5 (>5000 km).

Scenario 3 represents the worst case: the assumptions used are that soya beans make up 25 per cent of the concentrate feed used and that the habitat converted for their cultivation is Brazilian rainforest (1.42 t CO$_2$ t^{-1} feed).

Scenarios 2 and 3 only apply to system boundary 2; system boundary 1 does not consider any ecosystem emissions.

Because most of Brazilian soya is GM soya, the concentrate feed used on the organic case study farm will not source its soya from Brazil. The main sources of organic soya are Argentina, China and Italy, with Italy accounting for less than a third of the total (Soil Association 2007). Both China and Argentina fall into distance category 5 (>5000 km), and here we assume the soya to have come from Argentina to enable direct comparison with the conventional farm. We also assume GHG emissions from land use change to be the same as for the conversion of native habitats in Brazil.

Table 3. Assumed distances for emissions from the production and delivery of farm inputs and emissions from soils and livestock

	distance category	
INPUTS		
Diesel	500-1000 km	3
Electricity	50-500 km	2
Fertiliser – N (produced in Russia)	1000-5000 km	4
Fertiliser – N (produced in UK)	50-500 km	2
Fertiliser – P (produced e.g. in the USA and China)	>5000 km	5
Fertiliser – P (produced e.g. in Morocco and Russia)	1000-5000 km	4
Fertiliser – K	50-500 km	2
Fertiliser – lime	50-500 km	2
Pesticides	50-500 km	2
Concentrates (wheat, barley, vegetable oil)	50-500 km	2
Concentrates (beet pulp)	500-1000 km	3
Concentrates (rapeseed, soya, oats, molasses)	>5000 km	5
Bedding	50-500 km	2
Silage plastic	500-1000 km	3
EMISSIONS FROM SOILS AND LIVESTOCK		
CO_2 from lime	0-50 km	1
N_2O	0-50 km	1
CH_4	0-50 km	1
CO_2 from land use change in South America	>5000 km	5

Data for inputs includes direct and embodied emissions.

3.2 Results

Table 4 and Figures 2-5 show the percentage contribution to the total farm scale carbon footprint of the case study farms for the five distance categories. Results are only presented for the average case carbon footprint as shown in section 2. In Figures 2-5, distance categories 1 and 2 are combined to show UK derived inputs and emissions.

Scenario 1 – system boundary 1 and 2

System boundary 1 considers GHG emissions from the production of farm inputs, but does not take into account ecosystem emissions from soils and livestock which are the truly local emissions occurring on farm. Because of this, the percentage contribution of truly local emissions (0-50 km) to the carbon footprint in system boundary 1 is negligible: 1.2 per cent for both case study farms. This means that the vast majority of emissions related to the milk produced on these farms occur non-locally. Emissions arising within the UK (0-500 km) account for 41.9 per cent of total emissions on the conventional farm and 52.5 per cent of total emissions on the organic farm, so even if the notion of ‘local’ were extended to country limits, only about half of the emissions of these farms could be called local in terms of carbon accounting.

Because the extended system boundary 2 considers ecosystem emissions in addition to those included in system boundary 1, the contribution of truly local emissions increases dramatically to 71.6 per cent for case study farm 1 and 74.1 per cent for case study farm 2. This is due to the overriding importance of CH_4 emissions from livestock through enteric fermentation which dominates the carbon footprint of both farms (see section 2) as well as N_2O emissions from soils and excreta. Thus, if GHG emissions from soils and livestock are taken into consideration, the majority of GHG emissions do occur truly locally on both farms. However, with 27.2 per cent and 24.7 per cent for farm 1 and farm 2 respectively, the remaining non-local emissions represent a significant portion of the total carbon footprint. Emissions that arise within the UK account for 83.3 per cent and 87.6 per cent respectively.

Scenario 2 – adding in emissions from land use change for soya production

In scenario 2, GHG emissions as a result of the conversion of natural habitats to soya bean cultivation were added to the farms' carbon footprint (system boundary 2 only). The average case assessed in scenario 2 considered an average inclusion rate of 16.5 per cent of soya beans in animal feed and an average figure for land use change emissions across three types of native habitats in Brazil. For organic soya beans produced in Argentina, the same emissions from land use change were assumed.

Emissions that arise within the UK were 2.7 times greater than emissions outside the UK for farm 1 and three times greater for farm 2.

The inclusion of emissions from land use change which occur over 5000 km away from the farms assessed decreased the percentage of emissions arising truly locally to 62.1 per cent on farm 1 and 63.1 per cent on farm 2, and the emissions arising within the UK to 72.3 per cent and 74.5 per cent on farm 1 and farm 2 respectively.

Emissions from land use change had a significant share in total emissions (farm 1: 13.3 per cent, farm 2: 14.9 per cent). These figures highlight the great importance of emissions resulting from the destruction of natural habitats in distant countries for the production of inputs to farms in Western Europe. In order to truly account for the environmental impact of UK and European farming practices, these emissions (and associated environmental and social costs) should be included in any assessment.

Scenario 3 – worst case scenario of land use change for soya production

Assuming the worst case scenario for emissions from land use change in Brazil and Argentina, i.e. the conversion of tropical rainforest and the maximum inclusion rate of soya beans in concentrate feed of 25 per cent, the percentage contribution of emissions arising locally decreased further. On both farms, truly local emissions and non-local emissions approached a 50:50 split, and emissions from outside the UK accounted for roughly one third of emissions.

Emissions from land use change accounted for 22.8 per cent and 25.3 per cent of total emissions on farm 1 and farm 2 respectively.

Conventional and organic dairy farming

In all scenarios, a greater percentage of emissions occurred locally and within the UK for the organic than the conventional farm. Emissions resulting from land use change in South America had a similar percentage share in total emissions for both farms in both scenario 2 and scenario 3. This is due to the fact that the two different farming systems use similar amounts of concentrate feed per cow, and both farming systems were assumed to source soya from South American countries.

No emissions from distance category 4 (1000-5000 km) occurred on the organic farm because no inorganic fertilisers were used.

Table 4. Percentage contribution of emissions from five distance categories to total farm carbon footprint for two system boundaries and three scenarios

System boundary		**1**	**2**	**2**	**2**
Scenario		**1**	**1**	**2**	**3**
Case study farm 1 (conventional dairy)					
Distance category 1 (0-50 km)	Straw	1.2	0.3	0.3	0.3
	CH_4	N/A	47.3	41.0	36.5
	N_2O	N/A	22.4	19.5	17.3
	CO_2 from lime	N/A	1.6	1.4	1.2
	Total	**1.2**	**71.6**	**62.1**	**55.3**
Distance category 2 (50-500 km)	Electricity	4.5	1.3	1.1	1.0
	N fertiliser	13.6	3.9	3.4	3.0
	K fertiliser	1.0	0.3	0.2	0.2
	Lime	10.2	2.9	2.5	2.3
	Pesticides	0.04	0.01	0.01	0.01
	Concentrate	11.4	3.3	2.8	2.5
	Total	**40.7**	**11.7**	**10.1**	**9.0**
Distance category 3 (500-1000 km)	Diesel	5.7	1.6	1.4	1.3
	Concentrates	11.6	3.3	2.9	2.6
	Plastic	1.9	0.5	0.5	0.4
	Total	**19.2**	**5.5**	**4.8**	**4.3**
Distance category 4 (1000-5000 km)	N fertiliser	15.1	4.3	3.8	3.3
	P fertiliser	0.1	0.04	0.04	0.03
	Total	**15.2**	**4.3**	**3.8**	**3.4**
Distance category 5 (>5000 km)	Concentrates	19.6	5.6	4.9	4.3
	P fertiliser	0.1	0.04	0.04	0.03
	Land-use change	N/A	N/A	13.3	22.8
	Total	**19.7**	**5.6**	**18.2**	**27.2**
Local	0-50 km	1.2	71.6	62.1	55.3
Not local	>50 km	94.9	27.2	36.9	43.8
UK	0-500 km	41.9	83.3	72.3	64.3
Non-UK	>500 km	54.2	15.5	26.8	34.8
Case study farm 2 (dairy in organic conversion)					
Distance category 1 (0-50 km)	Straw	1.2	0.3	0.3	0.2
	CH_4	N/A	52.3	44.6	39.1
	N_2O	N/A	17.1	14.6	12.8
	CO_2 from lime	N/A	4.4	3.7	3.3
	Total	**1.2**	**74.1**	**63.1**	**55.4**
Distance category 2 (50-500 km)	Electricity	6.4	1.7	1.4	1.3
	Lime	31.4	8.2	7.0	6.2
	Concentrate	13.4	3.5	3.0	2.6
	Total	**51.3**	**13.4**	**11.4**	**10.0**
Distance category 3 (500-1000 km)	Diesel	4.8	1.2	1.1	0.9
	Concentrates	13.7	3.6	3.1	2.7
	Plastic	1.4	0.4	0.3	0.3
	Total	**19.9**	**5.2**	**4.4**	**3.9**
Distance category 5 (>5000 km)	Concentrates	23.0	6.0	5.1	4.5
	Land-use change	N/A	N/A	14.9	25.3
	Total	**23.0**	**6.0**	**20.0**	**29.8**
Local	0-50 km	1.2	74.1	63.1	55.4
Not local	>50 km	94.2	24.7	35.9	43.7
UK	0-500 km	52.5	87.6	74.5	65.4
Non-UK	>500 km	42.9	11.2	24.4	33.7

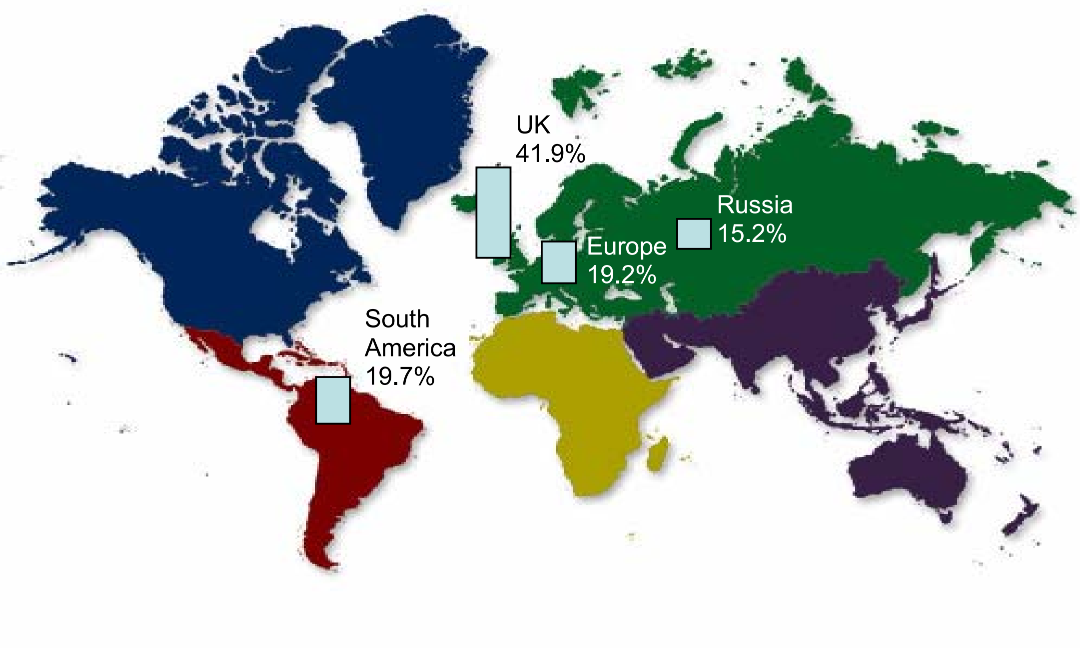
System boundaries: 1 = production of farm inputs; 2 = production of farm inputs plus emissions from soil and livestock.

Scenarios: 1 = excluding emissions from land use change for soya cultivation; 2 = including land use change emissions, average case; 3 = including land use change emissions, worst case.

Values presented in the table may not add up to the sum presented as total due to rounding errors and the 8.5 per cent of the emissions from concentrate feed that could not be allocated to a distance band

Figure 2. Location of greenhouse gas emissions from a dairy farm in the UK: Case study farm 1, a) system boundary 1, scenario 1, b) system boundary 2, scenario 1

a) Farm 1, system boundary 1, scenario 1

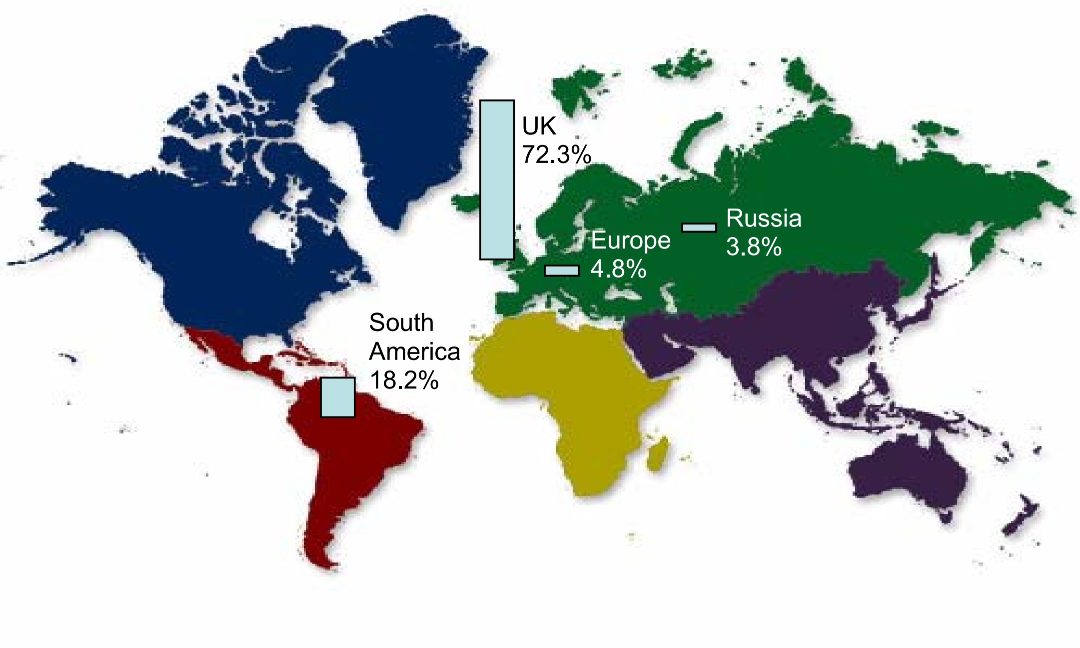


b) Farm 1, system boundary 2, scenario 1

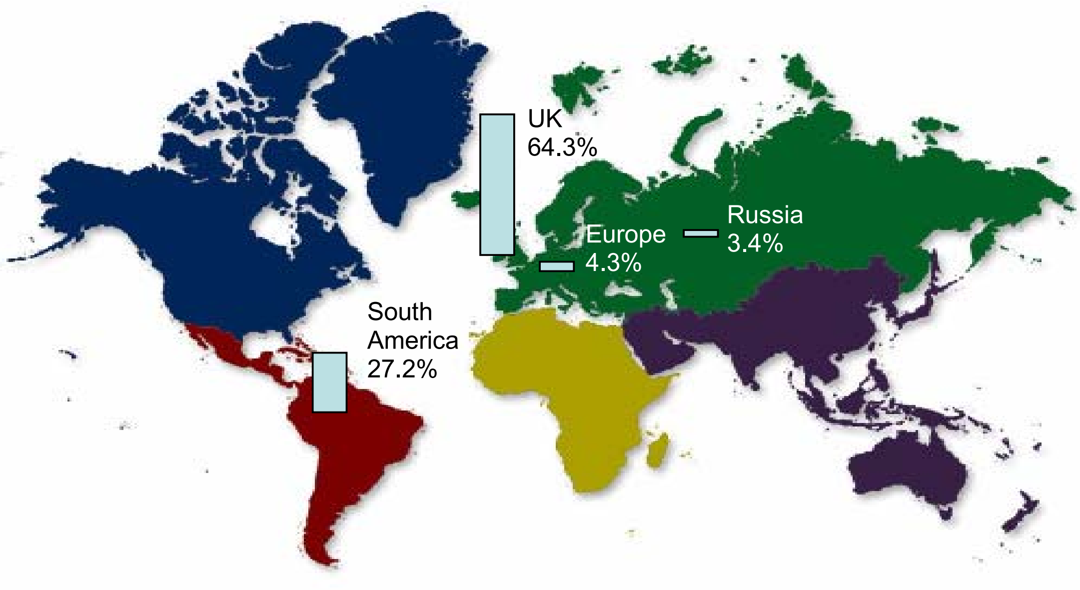
The bars illustrate where greenhouse gas emissions related to the production of farm inputs occur. Emissions in Russia are related to the production of nitrogen fertiliser, emissions in South America to the cultivation of soya beans used in concentrate feed.
Map downloaded from: http://www.winrock.org/programs/images/world_map-2.jpg.

Figure 3. Location of greenhouse gas emissions from a dairy farm in the UK: Case study farm 1, a) system boundary 2, scenario 2, b) system boundary 2, scenario 3

a) Farm 1, system boundary 2, scenario 2



b) Farm 1, system boundary 2, scenario 3

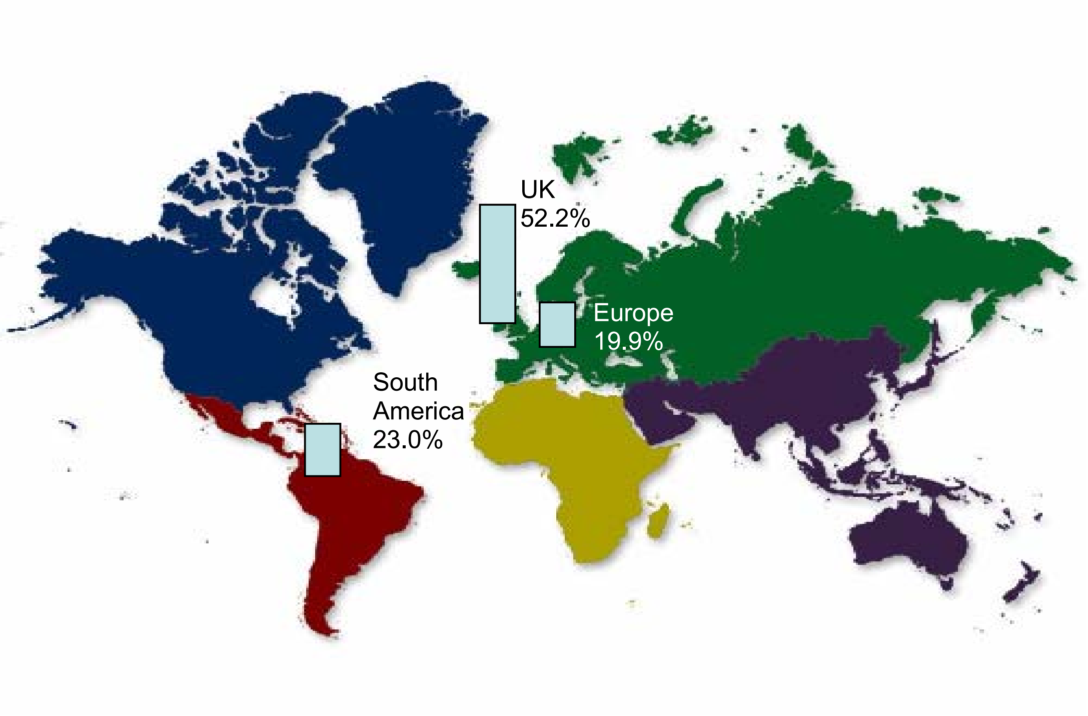


The bars illustrate where greenhouse gas emissions related to the production of farm inputs and from soil and livestock occur. Emissions in Russia are related to the production of nitrogen fertiliser, emissions in South America are related to the cultivation of soya beans used in concentrate feed and emissions from land use change.

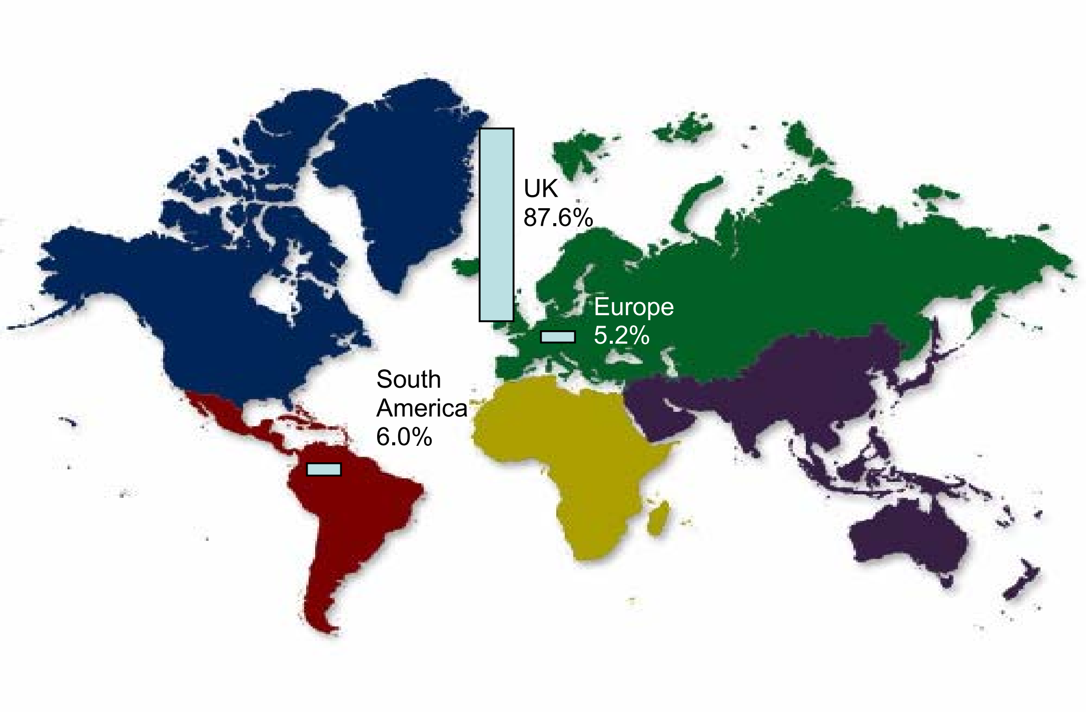
Map downloaded from: http://www.winrock.org/programs/images/world_map-2.jpg.

Figure 4. Location of greenhouse gas emissions from a dairy farm in the UK: Case study farm 2, a) system boundary 1, scenario 1, b) system boundary 2, scenario 1

a) Farm 2, system boundary 1, scenario 1



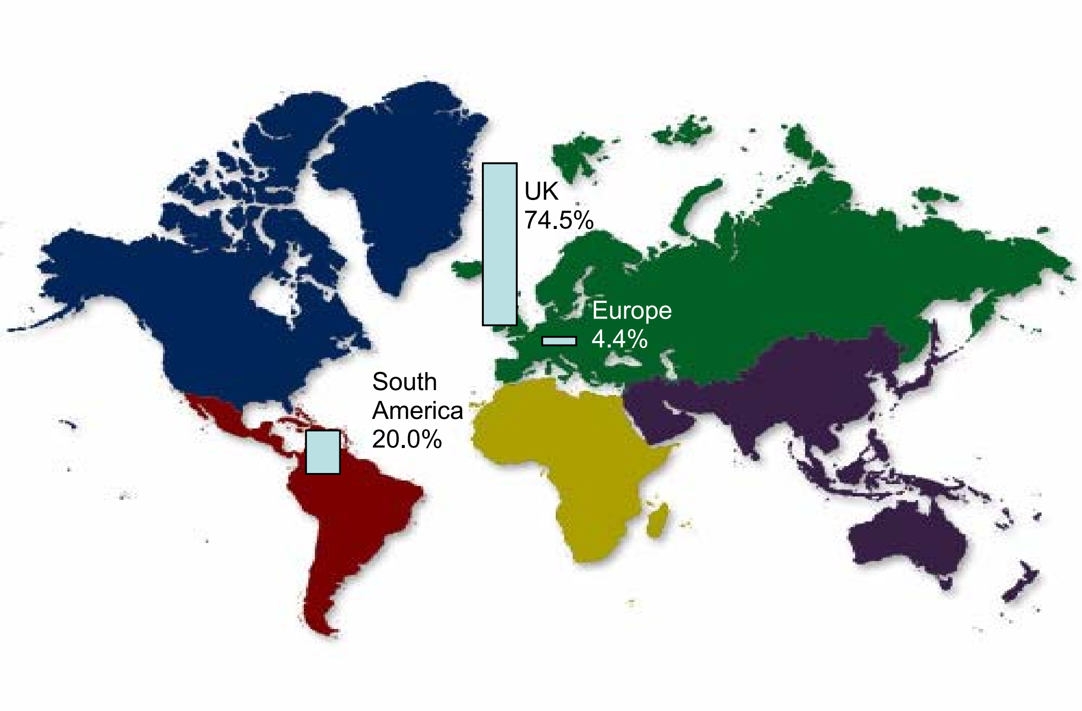
b) Farm 2, system boundary 2, scenario 1



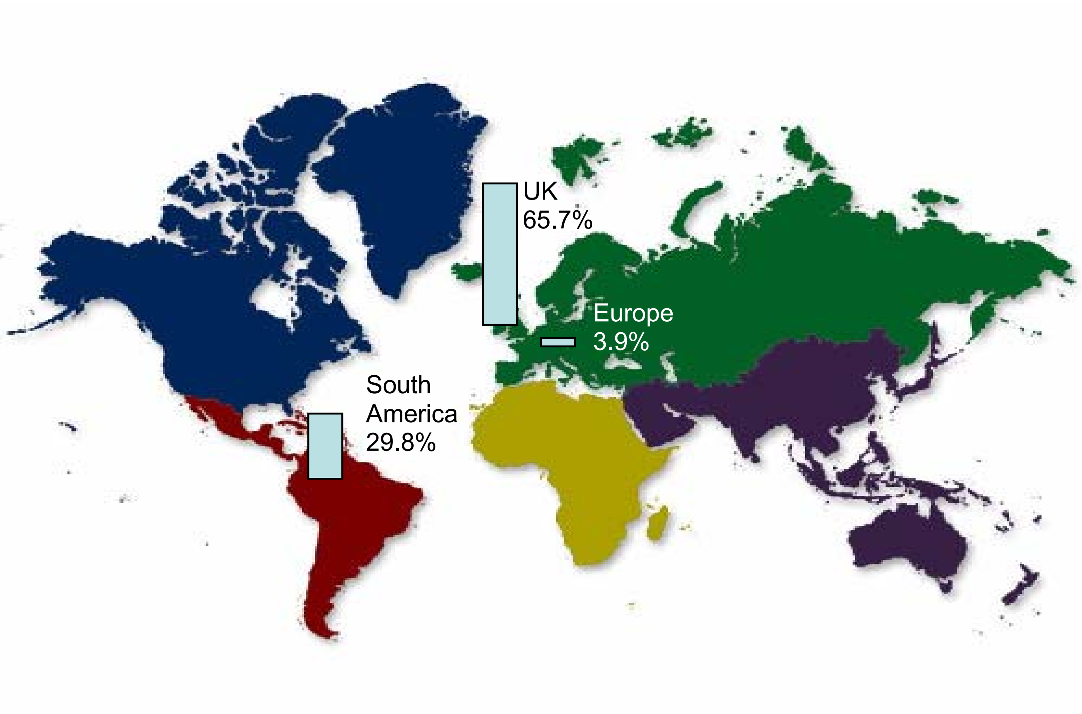
The bars illustrate where greenhouse gas emissions related to the production of farm inputs occur. Emissions in South America relate to the cultivation of soya beans used in concentrate feed.
Map downloaded from: http://www.winrock.org/programs/images/world_map-2.jpg.

Figure 5. Location of greenhouse gas emissions from a dairy farm in the UK: Case study farm 2, a) system boundary 2, scenario 2, b) system boundary 2, scenario 3

a) Farm 2, system boundary 2, scenario 2



b) Farm 2, system boundary 2, scenario 3



The bars illustrate where greenhouse gas emissions related to the production of farm inputs and from soil and livestock occur. Emissions in South America relate to the cultivation of soya beans used in concentrate feed and emissions from land use change. Map downloaded from: http://www.winrock.org/programs/images/world_map-2.jpg.

4. Discussion

Although the case study farms are different in terms of size and farming system (conventional and organic conversion), they show very similar carbon footprints per litre of milk. However, emissions per hectare are lower for case study farm 2 (in organic conversion). As stated earlier, the footprint analysis does not allocate emissions between different outputs from the farms, and therefore the estimated carbon footprints presented here for milk are almost certainly an overestimate of the real footprints. The footprint for the whole farm system, and for each hectare are however accurate. Interesting as these footprint results are, the analysis of the actual carbon footprint of milk is not the main purpose of this report, and these issues will not be discussed further here (they will, however, be discussed in future publications).

It is interesting to note that both farms show very similar carbon maps for their emissions. When only considering the direct and embodied emissions from inputs it is clear that less than 5 per cent of GHG emissions occur locally. Given the global nature of the supply chains for major farm inputs, this pattern of emissions was almost inevitable. When compared to other farm systems dairy farms tend to be quite intensive users of inputs, however the main classes of inputs to all farm systems are similar and include electricity, diesel, fertilisers and machinery. It is therefore highly probable that similar carbon maps would be derived for all farm types in the UK.

A complete analysis of the carbon footprints of food would not be restricted to considering only direct inputs, as in system boundary 1. Rather, it would consider all emissions from the farm system (as defined in system boundary 2). For dairy farms this requires consideration of the methane emissions from enteric fermentation in cattle and nitrous oxide emissions from livestock and soils. When these emissions were included in the analysis they represented the greatest part of the carbon footprint of both case study farms. Because these emissions occur directly on farm, they were classed as truly local emissions, and as a result in all scenarios analysed for system boundary 2, local emissions constituted more than 50 per cent of total GHG emissions. Of course, as the GHGs ultimately disperse in the atmosphere their impact is ultimately global. Indeed, it could be argued that as all GHG emissions ultimately have a global impact, they have no relevance to the concept of local food.

However, this is not true for the stocks of carbon that are depleted during the production of food and farm inputs. It is for this reason that the analysis considered the production of soya for use in animal feed. This is an issue of particular concern for animal production systems (including pigs and poultry), however it tends to remain relatively poorly analysed as it is difficult to access information on the exact nature of animal feed and the related levels of GHG emissions. Although some data on the make up of dairy feed were obtained from formal and informal sources, these data only enable rough estimates of the carbon footprint of animal feed, and they did not explicitly include emissions related to any land use change which occurred in order to enable production of the feed. For this reason it was necessary to develop three specific scenarios for the production of soya: one assumed soya was produced on land that had not previously been forested (scenario 1), and two scenarios assumed savannah and/or forest clearance occurred in South America to enable soya production (scenarios 2 and 3). In addition, the amount of soya in the animal feed varied from an average of 16.5 per cent in scenario 2 to a maximum of 25 per cent in scenario 3. As a result, the emissions from scenario 3 represent the worst case situation for soya production. In this scenario 55 per cent of total emissions were classed as local for both case study farms, and as noted above over 95 per cent of these would be related to the emission of methane from cattle and nitrous oxide from soils.

This analysis raises several questions about the concept of local food in a globalised market system. All UK farms derive inputs from outside the UK, and consequently they are responsible for both the depletion of distant carbon stocks, and GHG emissions that occur outside their locality. The concept of a carbon map offers a method to represent the level of localness for any production system. The maps presented here are very preliminary and tend to aggregate emissions at a large scale. More detailed maps could be derived from closer analysis of relevant supply chains. However, a detailed description of the supply chain would only provide part of the map. A full analysis would also require detailed emission factors for the inputs and their production processes. To date, much of the necessary data on both the supply chains and the emissions are lacking, and further research would be needed in order to operationalise the concept of the carbon map. If a carbon map could be developed for different food types it would provide a means of visualising the impacts of different food systems on the climate. Whether or not this information would be of benefit to consumers, food chain professionals and/or policy makers remains untested.

Further research

Further research is needed to develop this concept further in order to:

- develop more detailed analysis of supply chains and relevant emissions factors (especially for livestock feed)
- obtain consumer feedback on the concept of the carbon map and document perceptions of local and non-local emissions
- develop carbon maps for several different farming types, e.g. cereal, vegetable, poultry. These may have different distributions for local and non-local emissions as they would not include methane emissions from ruminant livestock
- consider how the results of a carbon map could be included in regional carbon accounts
- consider the variation in the carbon map between individual farms in a sector
- expand the analysis beyond the farm gate.

Conclusion

The data presented here pose serious questions about the validity of claiming that any food is truly local. Less than 5 per cent of GHG emissions from the production and use of inputs occur locally to the farm, and it is hard to conceive of a situation in modern UK agriculture where this would not be the case. Emissions from livestock and soils occur on farm, and are defined as local. Their inclusion in the analysis increased local emissions to more than 55 per cent. Further analysis of the specific emissions relating to the production of soya, which is a constituent of livestock feed, identified the emissions from land use as being important constituents of the farms' carbon footprints. Inclusion of these emissions in the analysis reduced the percentage of local emissions by up to 20 per cent. If UK farms want to localise emissions then the most practical options are to:

- derive greater proportions of their energy needs from close by (e.g. renewable or bioenergy)
- alter fertiliser strategy and seek substitutes for inputs of inorganic nitrogen
- reduce dependency on imported feed.

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Appendix: Origin of farm inputs

In this section we discuss the places of origin and manufacture of the main inputs into the dairy farms described in section 2. These are then allocated to five distance categories depending on the distance of the country of origin's capital to the UK (London). The distance categories were chosen to reflect local, regional, European and long-distance international origins: 1 = 0-50 km (local), 2 = 50-500 km (from within the UK), 3 = 500-1000 km (from the near continent), 4 = 1000-5000 km (international, e.g. Russia), 5 = >5000 km (international, e.g. South America).

1. Concentrate feed

Because of confidentiality issues, it is difficult to obtain an exact breakdown of ingredients used in compound feeds (Garnett 2007). Garnett (2007) estimated that cereals account for about 22 per cent in cattle feed and 60 per cent in pig and poultry feed used in the UK. Table 5 shows total compound feed production in the European Union and the percentages of each group of ingredient. Cereals are the main ingredients of animal feed as a primary source of energy, with wheat as the most important cereal (42 per cent of all cereals used in compound feed in the EU in 1999), followed by maize (29 per cent) and barley (20 per cent) (Brookes 2001). Oil meals and cakes are the second most important ingredient, providing a source of protein. Soya meal is the most important ingredient in this group due to its high protein content and represented 46 per cent of the total volume of protein material used in compound feed and feed mixed on-farm in the EU in 1999 (Brookes 2001).

Because of their importance as a protein ingredient in compound feed, their fast growth in market share and concerns about the environmental impacts resulting from their cultivation, the next section discusses soya beans in more detail.

Table 5. EU compound feed production in 1999 by main ingredient (from: Brookes 2001).

Ingredient	**Production (1000 t)**	**per cent of total ingredients used**
Cereals	48,536	39.6
Oilmeals and cakes	31,017	25.3
Co-products from the food industry (e.g. molasses)	17,130	14.0
Tapioca	4,469	3.6
Pulses	3,918	3.2
Minerals, additives, vitamins	3,894	3.2
Meat and bone meal	2,414	2.0
Dried forage	2,160	1.8
Oils/fats	1,998	1.6
Dairy products	1,606	1.3
Other ingredients	5,558	4.8
Total	**122,700**	**100**

1.1 Soya beans

Background

Soya beans can be cultivated in moderate, sub-tropical and tropical climates. Because they are an annual crop, global production can change quickly in response to changing world markets and prices. About 87 per cent of soya beans worldwide are crushed both in production and consumption countries, yielding soya oil (18 per cent of the soya bean), soya meal (79 per cent) and waste (3 per cent). Soya meal can then be further processed by toasting, drying and grinding. The end product is a high-protein meal which is used as an ingredient in livestock feed but also for other purposes. Because the main product from soya beans is the soya meal which is mainly used for livestock feeding (97 per cent, Steinfeld *et al.* 2006), world demand for soya beans is greatly driven by the compound feed and livestock industries. In 2002, global demand for soya meal for animal feed amounted to 130 million tonnes (Steinfeld *et al.* 2006).

Soya meal is blended with other ingredients such as wheat and barley as well as some soya oil to produce animal feed. Only about 3 per cent of the global soya bean harvest is fed directly to animals (Steinfeld *et al.* 2006). Due to its high protein content and low content of raw cellulose, soya meal is most suitable for non-ruminants such as poultry and pigs.

In 2004, the four main soya bean producing countries were the United States (43 per cent of global production), Brazil (35 per cent), Argentina (11 per cent) and Paraguay (4 per cent). The European Union accounted for 19 per cent of global imports (Defra 2006a). Global production increased by 47 per cent between 1995/96 and 2001/02, with the greatest increases in market share occurring in Brazil and Argentina. Soya bean crushing is also concentrated in these four countries, followed by the European Union (van Gelder & Dros 2003). Within the European Union, only 6 per cent of soya beans are produced domestically. Imports are mainly from Brazil (52 per cent in 2001). About 78 per cent of the total oil meal consumption in the European Union is by the animal feed industry, with soya meal from South America representing a large input.

Soybean productivity is growing faster in South America than anywhere else, and production is dominated by Brazil and Argentina. About 30 per cent of recent increases in production can be attributed to greater yields per hectare and 70 per cent to an increase in the area cultivated (van Gelder & Dros 2003). Table 6 illustrates the increase in the area under soya beans and production for one of Brazil's main growing regions. The European Union is the most important export market for South American soya beans and soya meal.

Table 6. Soy planted area, production and yield for the Mato Grosso region in Brazil from 1980 to 2003

Year	Area (1000 hectares)	Production (1000 t)	Productivity (t/ha)
1980	56	89	1.57
1985	823	1,611	1.96
1990	1,528	3,065	2.01
1994-1995	2,339	5,491	2.36
1996-1997	2,193	6,060	2.76
1999-2000	2,907	8,774	3.02
2001-2002	3,822	11,697	3.06
2002-2003	4,521	13,966	3.09

Source: Bickel and Dros (2003).

The UK is one the most important export markets for soya meal from Brazil, and feed producers will use large amounts of soya meal originating from Brazil (van Gelder and Dros 2003). UK imports of soya beans amounted to 732,177 t with a trade value of $239 billion in 2004 (Defra 2006a). In addition, the UK also imported soya oil (22,891 t) and soya meal (6,905 t) (Defra 2006a). The most important countries exporting soya beans to the UK in 2004 were Brazil (80 per cent of total imports), the

USA (9 per cent) and Canada (4 per cent). Soya oil was imported from the Netherlands (84 per cent of total imports) which acts as a staging, not producing, country. Soya meal was mainly imported from Belgium (35 per cent of total imports), Ireland (20 per cent) and the Netherlands (15 per cent) who all act as staging countries and also process soya they receive mainly from Brazil, Argentina, Paraguay and Bolivia (Defra 2006a). The main producers of animal feed in the UK are Mole Valley Farmers and Cherwell Valley Silos (Defra 2006a).

Greenhouse gas emissions from land conversion for soy cultivation

The conversion of native habitats to croplands leads to a release of carbon dioxide stored in soil and vegetation following land clearance and microbial decomposition of leaves and roots. This release of CO_2 is greatest immediately after land clearance; however, it can continue for decades after conversion (Fargione *et al.* 2008). Over the first 50 years after conversion, the amount of CO_2 released as calculated by Fargione *et al.* (2008) is shown in Table 7 for three different tropical habitats that might be converted for the cultivation of soya beans. Carbon dioxide losses are greatest for the conversion of tropical rainforest habitats, followed by the Brazilian savanna-woodland biomes called Cerrado.

Table 7. Carbon dioxide (t CO_2 ha^{-1}) released as a result of land conversion for the first 50 years after habitat conversion

Habitat	Total	Aboveground	Belowground	Roots	Soil
Amazonian rainforest	737	522	215	137	78
Woody Cerrado and Cerradão	165	59	106	85	21
Grassy Cerrado	85	16	69	48	21

Source: Fargione *et al.* (2008)

Other environmental impacts of land conversion for soya bean cultivation

The Brazilian rainforest and Cerrado vegetation are rich in biodiversity. The expansion of agriculture to produce soya, maize, rice and other products as well as the expansion of cattle ranching has led to the destruction of 35 per cent of the Cerrado (695,000 km^2) and 12-13 per cent of the Brazilian Amazonian rainforest (400,000 km^2) in the 25 years up to 1994 (Ratter *et al.* 1997) with an associated loss of biodiversity. In Brazil, the area under soya bean cultivation has grown by 3.2 per cent or 320,000 ha per year since 1995, while in Argentina, 5.6 million hectares have been converted to soya production in less than ten years (Altieri & Pengue 2006). This expansion in the area used for agriculture goes along with more destruction of natural vegetation for infrastructure needed to transport inputs and produce, such as industrial waterways, railway lines and road networks. Environmental problems relating to the land use itself include soil degradation and erosion, loss of soil organic matter, soil compaction, a lowering of the soil pH, nutrient depletion and pollution, landscape deterioration where native vegetation is converted to large-scale monocultures, and increased need for pesticides in monocultures (Mattsson *et al.* 2000, Altieri and Pengue 2006). There is also competition for land use between soya for export and other food crops, and social effects because soya farms are usually large and highly mechanised, impacting small farmers and displacing indigenous people (Defra 2006a, GRAIN 2007).

1.2 Greenhouse gas emissions from cultivation and processing of feed ingredients

Each European consumes agricultural products that equate to a land use of 0.237 ha per person in their own country. However, because of international trade in food and animal feed, each European also consumes 0.039 ha of arable land in other countries (Lehmann *et al.* 2005, cited in Mattsson *et al.* 2000).

Eriksson *et al.* (2005) compared the environmental impacts of three different pig feed mixtures: one in line with current practice containing about 12 per cent of soyabean meal; one without any soya products and low crude protein levels; and one organic feed mix. They found that soya meal had a greater global warming potential than all other feed ingredients except synthetic amino acids. They recommend the exclusion of soya bean products from animal feed in order to reduce negative environmental impacts, which could save about 7 per cent of the global warming potential of the feed. Another key conclusion from this study is that the global warming potential associated with the production of protein feeds and cereals is greater than that of the animal husbandry (emissions from manure, electricity and diesel use) in the system analysed.

Several studies reporting life cycle assessments of soya bean cultivation and soya bean meal were found in the literature. Table 8 shows the global warming potential associated with 1 kilogram of product calculated in these studies. Wheat and barley are examples of feed ingredients that are commonly produced locally or regionally and may represent a large proportion of feed mixtures. Table 9 presents the results of several LCA studies on wheat and barley.

Table 8. Greenhouse gas emissions (g CO_2 equ kg^{-1}) associated with soya bean cultivation, processing and transportation

	Country of origin	**Emissions up to farm gate (g CO_2 equ kg^{-1})**	**Emissions up to… (g CO_2 equ kg^{-1})**	**Reference**
Soya beans	Argentina	642		Dalgaard *et al.* (2007)
Soya beans	Argentina	620		Håkansson *et al.* (2005)
Soya bean meal[1]	Argentina		…Rotterdam: 721	Dalgaard *et al.* (2007)
Soya bean meal[2]	Argentina		…Rotterdam: 344	Dalgaard *et al.* (2007)
Soya bean meal	Brazil		…Swedish farm: 730	Eriksson *et al.* (2005)

[1] soya bean meal with palm oil as marginal oil, [2] soya bean meal with rapeseed oil as marginal oil

Table 9. Greenhouse gas emissions associated with the production of wheat and barley

	Greenhouse gas emissions	**Reference**
Bread wheat, non-organic	804 g CO_2 equ kg^{-1}	Williams *et al.* (2006)
Bread wheat, organic	786 g CO_2 equ kg^{-1}	Williams *et al.* (2006)
Bread wheat	381 g CO_2 equ kg^{-1}	Charles *et al.* (2006)
Barley	207 g CO_2 kg^{-1}	Saunders *et al.* (2006)

1.3 Origin of concentrate feed ingredients

For the purposes of this report we use the data presented in Casey and Holden (2005), who defined a standard mixture of feed ingredients after consultation with feed suppliers and calculated the percentage contribution of each of these to the total global warming potential of the feed mix. However, the authors did not disclose the inclusion rate of individual ingredients. Table 10 shows the results from this study as well as the countries of origin assumed for each ingredient. The greatest emissions relate to beet pulp imported from Germany, rapeseed from the USA or Uzbekistan, wheat from the UK and soya from Brazil. However, the issues of deforestation and subsequent release of greenhouse gases will apply mainly to the cultivation of soya beans. If the emissions resulting from the conversion of native vegetation in Brazil as discussed above were included in the calculation, the results would be different and might make soya the main contributor to the global warming potential of compound feed. Although not an ingredient in the feed mix defined by Casey and Holden (2005), maize derivatives can be an important part of animal feed, and are largely imported from the USA.

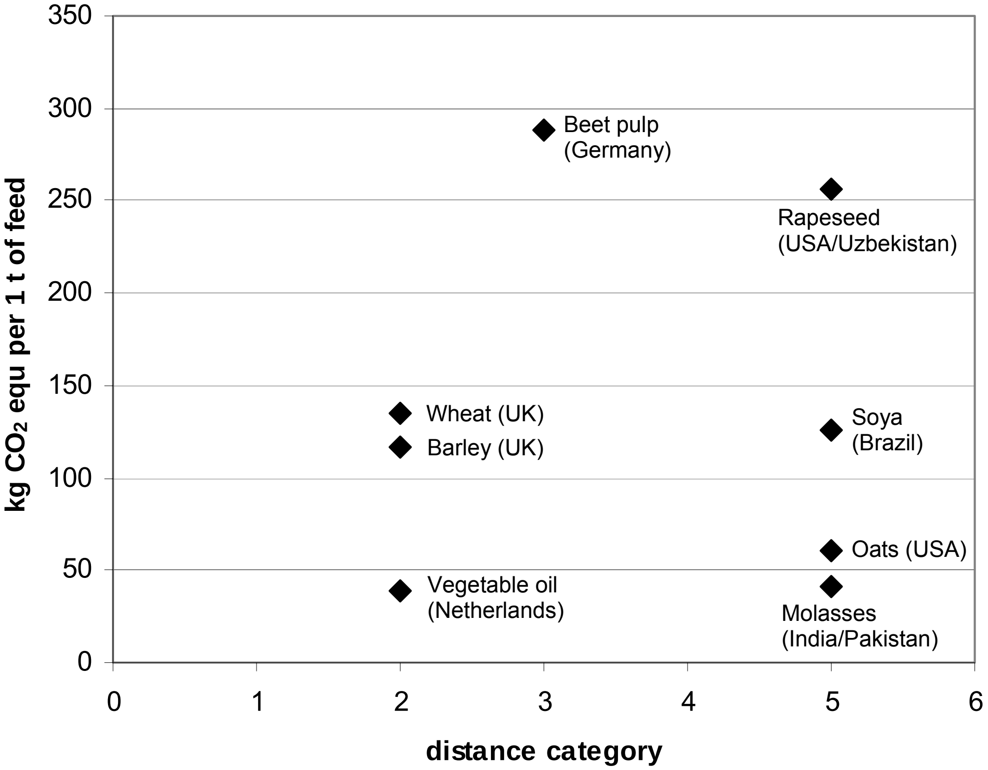
Using the Casey and Holden (2005) data, it is possible to allocate the contribution to GWP of each feed ingredient to a distance band (Figure 6). This highlights that the global warming impact of ingredients produced in the UK may be the same (e.g. soya from Brazil) or greater (oats from the USA, molasses from India/Pakistan) than for ingredients imported from overseas. The ingredients in this feed mixture with the greatest impact on global warming were beet pulp from Germany and rapeseed from the USA/Uzbekistan.

Table 10. Country of origin and global warming potential associated with the production of 1t of concentrate feed supplied to an average dairy unit in Ireland

Ingredients	Country of origin	kg CO_2 equ t^{-1}	% contribution	Distance (km)
Barley	UK	117	10	
Wheat	UK	135	11.5	
Beetpulp	Germany	288	25	918
Oats	USA	61	5	5,935
Soya	Brazil	126	11	8,729
Rapeseed	USA/Uzbekistan	256	22	5,935/5,236
Molasses	India/Pakistan	41	4	6,724/6,058
Vegetable oil	Netherlands	39	3	332
Minerals and vitamins		No data	No data	
Shipping		34	3	
Trucking		18	1.5	
Processing		42	4	
Total per t		**1,156**		

Source: Casey and Holden 2005). Also shown is the distance of the capital city of each of these countries of origin to London.

Figure 6. Global warming potential of different component parts of concentrate feed in kg CO_2 equivalents per t of feed



.Origin of ingredients in brackets. Distance bands indicate distance of country of origin from the UK: 1 = 0-50 km, 2 = 50-500 km, 3 = 500-1000 km, 4 = 1000-5000 km, 5 = >5000 km. Data on global warming potential and origin of ingredients from Casey and Holden (2005). Emissions from shipping, trucking and processing are not included.

2. Fertilisers

Total fertiliser consumption and production in the UK in 2002 are shown in Table 11 for nitrogenous, phosphate and potash fertilisers (from FAO Statistics). The table shows that nitrogenous fertiliser consumption in the UK exceeds production in the UK by a factor of more than 2, and phosphate fertiliser consumption is about 5.5 times greater than UK production.

Table 11. Total fertiliser consumption and production in the UK in 2002

	Production (1000 metric tons)	Consumption (1000 metric tons)	% produced in the UK
Nitrogenous fertilisers	540	1,142	47.3%
Phosphate fertilisers	50	283	17.7%
Potash fertilisers	540	376	100.0%

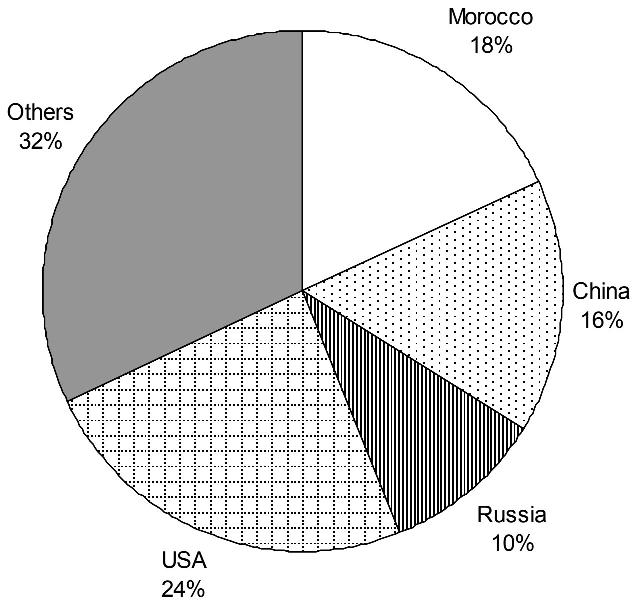
Source: http://faostat.fao.org.

No exact breakdown of the countries of origin for fertiliser imports into the UK was found; however, the Eurostat website (http://ec.europa.eu/eurostat) gives the amounts of fertiliser imports from countries outside the EU25. According to this data, in 2001 the most important importer of N fertilisers was Russia, accounting for 39 per cent of imports. Due to the size of Russia, the distance travelled from Russia to the UK can fall into the two distance bands 1000-5000 km and >5000 km. Based on the distance of the capital city Moscow to London (2494 km), we allocate this input to the distance band 1000-5000 km. The other countries importing to the EU25 are 1000-5000 km away.

Nitrogen fertilisers are synthetically produced using the Haber-Bosch process with natural gas as the main fuel used. Large amounts of fertiliser can be used for the production of animal feed in North America, Southeast Asia and Western Europe (Steinfeld *et al.* 2006).

The raw material for phosphate fertilisers, phosphate rock, is mined and processed mainly in North America, Russia, China and Africa (Figure 7). Although 17.7 per cent of phosphate fertilisers used in the UK is produced in the UK (Table 11), we assume all phosphate rock to have travelled from these countries to the production sites. These countries fall into the distance bands 1000-5000 km and >5000 km.

Figure 7. Phosphate rock production by country in 2001



Source: http://www.fertilizer.org/ifa/ statistics/indicators/ind_production.asp.

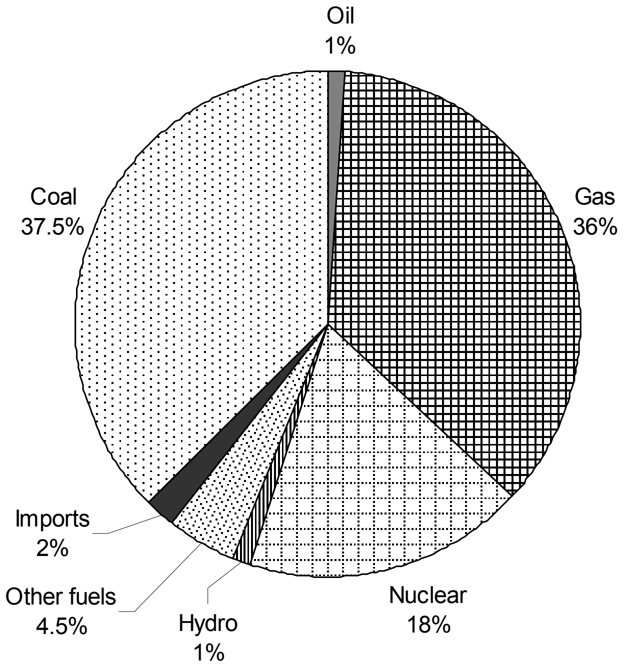
The main producers of potash are Canada, Russia, Belarus and Germany, followed by Israel, Jordan, the USA and the UK. The Boulby mine in north-east England is one of the world's major potash producers and provides 55 per cent of the UK market share of potassium chloride products plus export sales (http://www.mining-technology.com/projects/boulby). Although the UK import as well as export potash, because about 90 per cent of UK potash production is used for the production of fertilisers (Highley *et al.* 2006), for the purposes of this report, we allocate all emissions from the production of potash fertilisers to the distance band 50-500 km.

Imports of lime to the UK are historically low and all lime consumed in assumed to be UK derived (Defra 2006b).

3. Electricity

Figure 8 shows electricity supplied in the UK by fuel type. With 37.5 per cent, coal is the most important fuel type, followed by gas (36 per cent) and nuclear (18 per cent). Imports of fuel for electricity generation account for only 2 per cent which means that almost all electricity used in the UK will be produced from UK resources, thus falling into the distance category 0-500 km.

Figure 8. Electricity supplied by fuel type



Source: Department for Business, Enterprise & Regulatory Reform 2007.

4. Diesel

Over 80 per cent of the crude oil refined in the UK originates from the North Sea (UK and Norway) (UKPIA 2007). The remainder is imported from Russia (9 per cent), the Middle East (2 per cent), Africa (approx. 2 per cent) and other countries (unspecified) (UKPIA 2007). UK and Norwegian North Sea areas fall into the distance categories 0-50 km, 50-500 km and 500-1000 km, while Russia, Middle

Eastern and African oil producing countries fall into both the categories 1000-5000 km and >5000 km.

5. Tractors

According to the recommendations of the Carbon Trust (2007), emissions from the production of capital inputs are not included in the farm scale emissions presented in section 2. However, if emissions from the manufacture and maintenance of farm machinery were included, they would probably all be non-local. About 80 per cent of the metal ores consumed in Europe are imported (http://epaedia.eea.europa.eu). The main deposits of iron ore are located in Brazil (18 per cent of reserves) (>5000 km), Russia (18 per cent) (1000-5000 km) and Australia (14 per cent) (>5000 km). The main manufacturers of tractors (Massey Fergusson, John Deree, McCormick) have factories in the USA, Canada, Brazil and several European countries.

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