SCOTTISH DAIRY SUPPLY CHAIN GREENHOUSE GAS EMISSIONS

Dec 2010

Methodology report

Table of Contents

Tables

Figures

1 Introduction

1.1 Project

The objective of this research project was to estimate the life cycle GHG emissions associated with Scottish dairy products' in order to identify the main opportunities for reducing emissions while maintaining or improving economic productivity. The specific objectives are to:

1. Describe key inputs to and outputs from Scottish dairy products' supply chains
2. Summarise methodologies and data sources available to estimate life cycle GHG emissions
3. Assess life cycle GHG emissions associated with each Scottish dairy product supply chain
4. Identify opportunities for each Scottish supply chain to reduce GHG emissions

The original project tender – and more details of the project – can be accessed via the project website: http://www.dairyfootprint.org.

1.2 This document

This document details the methodological approach used in the footprint analysis and was the project output which was reviewed by The Carbon Trust as part of quality assurance. The aim of making this report available was to provide a useful resource of information for dairy industry and increase confidence in results.

A summary of the results are provided at the end of each sector – however the main results and interpretation document is separate.

2 Method summary

2.1 Model requirements

The methodology has been designed to enable total emissions associated with the production of Scottish dairy products to be expressed in two ways: A product-level breakdown of emissions per unit of Scottish dairy product; A sector-level estimate of total emissions from the production of dairy products. Additionally analysis needed to be sufficiently granular and Scotland-specific to enable mitigation options to be highlighted.

2.2 Summary of approach

The modelling approach draws heavily on four documents: PAS2050; the Guidelines for the Carbon Footprinting of UK Dairy Products (hereafter called the Dairy Guidelines); UK Greenhouse Gas Inventory 1990-2007 (AEA Technology, 2009); and a recent global assessment of dairy emissions by the FAO (Gerber, et al., 2010). These methodologies have already been widely consulted on by a range of stakeholders and the use of their boundaries and assumptions enables a degree of comparability with existing and future footprint studies (see limitations section below).

Significant conflicts between methods are explored within this text, however final decisions on which approach to take were decided in discussion with reviewers. The main differences regarded study boundaries (i.e. what emissions are included or excluded) and emissions allocation methods (e.g. how to apportion emissions between beef and milk outputs). Both these issues are explored in more detail in Section 6.

Because of the scope of the study and project time constraints the majority of data has been sourced from industry, governmental and academic publications – as opposed to collecting new primary data from individual companies. The latter approach is required for detailed product carbon footprinting but is very resource intensive.

2.3 Limitations

The objectives of the study mean that simplifications were necessary to achieve sector-wide estimates of a broad range of emissions sources and sinks. It is important to remember that it was not intended that the study deliver detailed product carbon footprints for the many 100s of dairy products which make up the Scottish supply chain, but rather guide industry efforts to focus in on emissions 'hot spots' and explore mitigation options. The method outlined in this document is consistent with these aims and constraints but would not be suitable for the following applications:

The results of this analysis **could not** be used to make an unqualified claim about the 'average emissions intensity' of all Scottish dairy products. This would require considerable primary data collection efforts, rather than reliance on secondary data. DairyCo have commissioned a very large study to do just this for cradle-to-gate emissions only. Similarly, the results of this study **could not** be used to say that, for instance, Scottish milk has lower/higher emissions than the UK average. Result uncertainty was not quantified as part of this work – and so a claim of better performance would be difficult to substantiate.

The results of this analysis **could not** be used for detailed tracking of sector emissions changes over time – again due to uncertainties inherent in such a high level assessment. Changes in emissions would be better tracked via different means e.g. individual product & company GHG reporting.

3 Unit of analysis

Emissions are expressed in the following:

3.1 Dairy products

The results of this analysis are presented at the following stages:

- $kgCO_2$-equivalent per litre of milk at farm gate
- $kgCO_2$-equiavlent per kg of dairy product (full life cycle)

3.1.1 Product groups

Based on dairy utilisation statistics for Scotland (by volume of milk)[1], emissions have been calculated for the following seven product groups:

- Liquid milk
- Cream
- Butter
- Cheese
- Yoghurt
- Ice cream

Due to time constraints most analytical and research effort was focused on product groups which are most significant for Scotland (i.e. liquid milk and cheese). Any limitations of calculations are fully documented in later sections.

3.2 Dairy sector

At the national level, emissions will be expressed in tCO_2-equivalent per year.

3.3 Data year

Data was sourced from 2007, 2008 and 2009 (due to availability constraints). Where possible 2007 data was preferred as this is the latest year for which a devolved national GHG inventory is available for Scotland (and so would enable the results to be expressed in the context of national GHG emissions).

[1] DairyCo

4 System boundary

This footprint study addresses all stages of the dairy supply chain – from farm production through to consumer use and disposal.

4.1.1 Imported & exported milk

Scotland's dairy supply chain relies almost exclusively on milk from Scottish dairy farms (Weir, 2009) (DTZ, 2007). It is understood that some milk is imported from Northern Ireland and England - and that year-to-year this will vary dependant on economic factors[1]. However no reliable data source was found on typical quantities and distances so the effect of this has not been modelled i.e. it is assumed that all milk used in Scottish dairy products is produced in Scotland. Based on the small volumes of milk involved and the relatively small contribution raw milk freight has on life cycle emissions, this was not seen as a major deficiency in the model.

4.1.2 Tertiary and further processing

This study only calculates the emissions associated with the production of primary and secondary dairy products – i.e. it does not address emissions associated with the many thousands of food products which use primary or secondary dairy products as an ingredient e.g. pizza, ready meals, confectionary, etc.

4.1.3 Imported & exported dairy products

This study does not quantify emissions associated with the production of final dairy products imported into Scotland (i.e. the purpose of this study is not to measure the footprint of Scotland's dairy consumption). The footprint study does, however, include non-Scottish emissions which occur as a result of Scottish dairy product distribution, use & disposal.

4.1.4 Dairy beef

A proportion of dairy farm emissions have been allocated to dairy beef production (see allocation method in Section 6), however this project does not provide lifecycle results for dairy beef (e.g. $kgCO_2e$/kg beef).

4.1.5 Organic milk

There are 31 organic farms in Scotland – their output represents 2% of milk production and farms achieve an average yield of approximately 6,500 litres per cow per year[2]. It had been originally proposed that the study would model organic milk production separately. However, during method development it was decided that creating an additional organic model was not the best use of project resources for four main reasons:

- It represents a small fraction of Scottish milk supply – and no other dairy farming system was being modelled explicitly
- There was limited industry-average data on organic systems
- The broad scope of this research was not the best forum for a detailed comparison between GHG impacts of different farming systems (for the reasons outlined in the section above on limitations)

[1] Karen Wonnacott, DairyCo – Personal communications

[2] Personal communications, Stuart Martin (Scottish Organic Milk)

- The division of dairy farming between organic or non-organic was over-simplistic, divisive and unhelpful: the messages for all farmers, regardless of system, are the same: e.g. reduce dependence on inputs, increase milk yield, etc.

So, instead, the analysis categorised Scottish farming by average yield (high, medium or low - see later sections for detailed explanation).

4.2 Boundary inclusions and exclusions

Original decisions on which emissions sources to include and exclude were based on an extensive literature review (see references in Section 12). The requirements of PAS2050 are to include all emissions sources (i.e. be complete), although in practice a significant proportion of small sources (i.e. <1%) are estimated. This section summarises the boundary inclusions and exclusions of this study. The rationale is provided for any exclusion decisions.

4.2.1 Cradle-to-farm gate

Published dairy life cycle studies consistently report that the majority of emissions are associated with agricultural production stages (see Table 1). As a result the main focus of this work will be the development of a Scottish milk production model.

Table 1: Summary of cradle-to-farm gate emissions source to be included in footprint

GHG source/sink	Description	Boundary	Exclusion rationale
Production of inputs	Fertiliser production	Included	
	Pesticides & herbicides	Included	
	Dairy farm electricity	Included	
	Veterinary products	Included	
	Cleaning products	Excluded	Insignificant
	Purchased seeds	Excluded	Insignificant
	Livestock feed	Included	
	Bedding straw	Excluded	No data
	Water	Included	
	Livestock transport	Excluded	Insignificant
	Production of machinery	Excluded	PAS2050 excludes
Fuel combustion on farm	Machinery & farm vehicles	Included	
	Buildings	Included	
Livestock, manure & soils emissions	Application of inorganic N	Included	
	Application of organic N	Included	
	Deposition of manures	Included	
	Enteric fermentation	Included	
	Manure management	Included	
	Nitrogen fixing crops	Included	
	Crop residues	Included	
	Soil carbon	Excluded	PAS2050 excludes
Land use change	During feed production	Included	
Waste management	Milk	Excluded	No data, insignificant
	Water	Included	
	Silage wrap	Included	
Other	Refrigerant gas leaks	Included	
	Staff commuting	Excluded	PAS2050 excludes

4.2.2 *Dairy processing*

Only primary and secondary processing has been considered. The emissions sources for dairy processing are summarised below.

Table 2: Summary of processing emissions to be included or excluded

GHG source/sink	Description	Boundary	Exclusion rationale
Production of inputs	Electricity use at processor	Included	
	Product packaging	Included	
	Refrigerant gas	Included	
	Cleaning products	Included	
	Water	Included	
	Major ingredients e.g. salt, sugar	Included	
	Production of machinery	Excluded	PAS2050 excludes
Fuel combustion	Raw milk freight from farms	Included	
	Inter-processor freight	Excluded	No data
	Buildings (e.g. steam creation)	Included	
Fugitive emissions	Inter-processor freight refrigerant	Excluded	No data
	Processing plant refrigerant	Included	
Waste management	Out-of-date products	Excluded	No data
	Other waste	Included	
	Waste water	Included	
Other	Business travel	Excluded	No data
	Staff commuting	Excluded	PAS2050 excludes

4.2.3 *Distribution, use & product end-of-life*

Distribution was modelled for products going via retail. The main emissions sources are summarised below.

Table 3: Summary of downstream emissions to be include/excluded

Life cycle stage	Emissions source	Boundary	Exclusion rationale
Distribution	Transport fuel	Included	
	Transport refrigerant gas leaks	Included	
	RDC[1] energy use	Included	
	RDC refrigerant leaks	Included	
	Retail/wholesale energy use	Included	
	Retail/wholesale refrigerant leaks	Included	
	Disposal of waste dairy products	Excluded	No data
Use	Refrigeration energy	Included	
	Refrigerant leaks	Included	
	Consumer transport to retail	Excluded	PAS2050 excludes
Product end-of-life	Waste food disposal	Included	
	Packaging disposal	Included	

[1] RDC: Regional distribution centre. Not considered in liquid milk product.

5 Greenhouse gases

5.1 Scope

The assessment will include all relevant greenhouses gases in IPCC 4th Assessment Report.

5.2 Global warming potential (GWP) factors

The UK's 2007 national greenhouse gas inventory (AEA Technology, 2009) uses IPCC Second Assessment Report (1995)[1] (SAR) global warming potential factors for the conversion of non-CO_2 gases into carbon dioxide equivalents (CO_2e). The use of these older GWP factors is a requirement of the Kyoto Protocol and the current UNFCCC Reporting Guidelines (UNFCCC, 2006)[2].

Unfortunately, this approach is currently at odds with product footprinting standards (e.g. PAS2050), which require that the latest GWPs are used (i.e. Fourth Assessment Report – AR4 (2007)). The implication being that sector-level emissions calculations which are comparable with national inventory reports and targets, would not be consistent with a product carbon footprint. The differences for some sectors – e.g. dairy – will be significant, as non-CO_2 gases are significant (see differences in GWP factors in Table 4).

Table 4: Global Warming Potentials (GWP) of GHGs in IPCC 2nd and 4th Assessment Reports

Greenhouse gas	SAR GWP	AR4 GWP	Difference
Carbon dioxide	1	1	n/a
Methane	21	25*	+19%
Nitrous oxide	310	298	-4%

Note*: See Section 5.2.1 below for discussion.

The decision was made to calculate product carbon footprints using AR4 global warming potential factors where possible[3].

5.2.1 Methane from biogenic sources

The Dairy Guidelines (Carbon Trust, 2010) note that CH_4 produced from a non-fossil biogenic carbon source has a lower effective GWP of 22.25. This is because it is originally derived from atmospheric carbon dioxide, and so results in the removal of CO_2 from the atmosphere. However, this adjusted GWP for biogenic methane is, to our knowledge, not used in any other product footprint method or standard (including the International Dairy Federation LCA guidelines (International Dairy Federation, 2010). The product footprint results therefore use the IPCC AR4 global warming potential factor for non-fossil biogenic methane. The authors would encourage wider discussions on this GHG accounting issue as it materially affects the results.

[1] http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm
[2] http://unfccc.int/national_reports/annex_i_ghg_inventories/reporting_requirements
[3] Some secondary sources of emissions factors used were themselves not derived using AR4 Global Warming Potential and so could not be updated

6 Allocation[1]

6.1 On farm - Beef, milk, leather

PAS2050 uses economic value to allocate emissions between co-products (including farm co-products in this project). This study will adhere to this method and use industry data of relative product values e.g. Economic Report on Scottish Agriculture (RERAD, 2009), SAC handbook (McBain, et al., 2009) (see Table 5).

Table 5: Economic share of dairy farm outputs

Yield	Calving period	Value of milk /cow/yr	Value of cull cow / yr	% Scottish cows[2]	Milk allocation	Cull cow allocation[3]
Low		£1,184	£150	28%	88.8%	11.2%
	All year	£1,217	£150	15%		
	Spring	£1,142	£150	9%		
	Autumn	£1,192	£150	4%		
Medium		£1,614	£150	60%	91.6%	8.4%
	All year	£1,659	£150	38%		
	Spring	£1,557	£150	16%		
	Autumn	£1,626	£150	6%		
High		£2,044	£150	11%	93.4%	6.7%
	All year	£2,101	£150	8%		
	Spring	£1,972	£150	2%		
	Autumn	£2,059	£150	1%		
Scotland average		**£1,614**	**£150**	**100%**	**91.1%**	**8.8%**

6.2 Draft power

This is not applicable to Scotland's dairy sector, and so is not considered.

6.3 Manure

6.3.1 Storage

Emissions from manure storage are fully allocated to the dairy system. This excludes an effective credit that a farmer would get for exporting manure (e.g. in that case emissions are allocated to the manure user not the farmer).

[1] "Dairy herds produce a mix of goods and services that cannot easily be disaggregated into individual processes. For example, a dairy cow produces milk, manure, capital services, and eventually meat when it is slaughtered. In LCA, we need to use specific techniques to attribute relative shares of GHG emissions to each of these goods and services." (Gerber, et al., 2010)
[2] For source of this data see Section 7.1.1 on assumptions on Scottish dairy herd structure
[3] Values sourced from SAC Farm Management Handbook 2009/10. Due to the way that this analysis is modelling livestock and feed emissions, the allocation is based on the relative value of 'milk' and 'cull cow' only (i.e. not including calves).

6.3.2 *Application to soils*

One of the challenges of undertaking a sector-level footprint assessment is the correct allocation of manure application emissions (mainly N_2O) to dairy system (as opposed to other products also produced on land receiving manure e.g. crops for human consumption).

To overcome this challenge, emissions from manure application have been calculated using feed production emissions factors that already include these emissions. For example, the Carbon Trust (2010) feed emissions factor for silage includes nitrous oxide (N_2O) emissions for the application of organic and inorganic nitrogen. As a result, emissions from fertiliser and manure application were not modelled explicitly and so there was no need for allocation.

6.4 Raw milk emissions to dairy products

This study uses methods and assumptions outlined in the Dairy Guidelines (Carbon Trust, 2010) to calculate the allocation of milk production emissions to dairy co-products on the basis of dry mass, and allocation of energy and water use emissions to co-products. These assumptions were themselves derived from (Generation of an Industry-Specific Physico-Chemical Allocation Matrix, 2007).

7 Cradle-to-farm gate model

7.1 Classification of farm types

To calculate cradle-to-farm gate emissions Scottish dairy farms were split into three groups based on the average milk yields achieved per cow per year. Yield was chosen as it is most closely related to the milk footprint. Other possible characteristics e.g. calving time, geographic location and organic status were initially considered but not pursued.

Average farm milk yields were classified as follows:

- Low (<6,500 litres per cow per year)
- Medium (6,500-8,500 litres per cow per year)
- High (>8,500 litres per cow per year)

Within each farming system, dairy livestock populations (all females and males for breeding) will be allocated to one of the groups below. This is consistent with the Dairy Guidelines:

- Dairy Cattle > 2 years
- Dairy Cattle 1-2 years
- Dairy Cattle < 1 year
- Bulls > 2 years
- Bulls 1-2 years

7.1.1 Dairy herd demography

These assumptions were developed by dairy experts at Laurence Gould based on typical replacement rates and local industry knowledge.

Table 6: Percentage of female dairy animals by age group for three yield classes

Herd yield type	<1yr	1-2yrs	>2yrs	All females
Low (<6,500)	16%	14%	70%	100%
Medium (>6,500,<8,500)	18%	16%	66%	100%
High (>8,500)	20%	18%	62%	100%

The number of males used for breeding was estimated based on the 2007 total Scotland dairy bull population (Scottish Government, 2008), allocated to milk yield class based on dairy cow (>2 years) numbers.

7.1.2 Dairy livestock numbers & milk production

The number of dairy cows[1] in Scotland was assumed to be 197,990[2]. Milk output was assumed to be 1,272.4 million litres[3]. This equates to an average yield of 6,626 litres of milk per dairy cow per year. These estimates were used to allocate total Scottish enteric and manure storage emissions to milk.

7.1.4 Raw milk properties

Assumptions on the characteristics of unprocessed milk are defined below. Fat, protein and dry mass assumptions are taken from the Dairy Guidelines (Carbon Trust, 2010). Density value was taken from the DairyCo Pocketbook 2009.

Table 7: Milk chemical properties by contract type (% w/w)

Product	Dry mass %	Fat %	Kg/litre
Raw milk	12.5	4	1.03

7.2 Farm inputs assumptions

7.2.1 Feed

The characteristics of a dairy farm's feeding regime are a significant driver of the farm's emissions profile[4], so it was important to develop a reasonably sophisticated model to quantify these impacts. This section summarises the assumptions used to quantify the types and quantities of feed used by Scottish dairy farms.

7.2.1.1 Feed quantities per litre milk

Adult cow feed intake was derived from the SAC Farm Handbook 2009/10 (see Table 8). These values were then combined with typical dry matter content assumptions to calculate feed intake per litre of milk (see

Table 9).

Table 8: Typical adult dairy cow feed intake – kg, as fed

Yield group	Yield (l/cow/yr)	Roughages (kg)	Concentrate (kg)	Grazing days	Grazing (kg)[5]	Total (kg)
Low	5,500	7,928	1,056	192	13,662	22,646
Medium	7,500	8,237	2,114	169	12,036	22,387
High	9,500	8,787	3,427	119	8,458	20,671
Dry matter	-	24%	88%[6]	-	18%	-

1 Dairy cow definition is same as June Census: Cows & heifers in milk + cows in calf but not in milk
2 June Census dairy cow numbers, 2007
3 Scottish Agriculture Input, Output and Incomes Statistics, 2007: 1,272.4 million litres (1,310 million kg).
4 Particularly in respect to the enteric CH_4 (methane) emissions.
5 Grazing days converted to mass (kg) of grass using assumption of 13kgDM/cow/day (source: Grass budgeting guidance "Grass challenge for dairy farmers Note 2a" from Northern Ireland Department of Agriculture and Rural Development
6 Derived from concentrate mix in Table 12

Table 9: Adult dairy cow feed intake – kg DM per kg milk

Yield group	Roughages (kg)	Concentrate (kg)	Grazing (kg)	Total (kg)
Low	0.371	0.174	0.460	1.006
Medium	0.283	0.256	0.297	0.836
High	0.238	0.328	0.165	0.731

Replacement feed intake was derived from SAC Farm Handbook 2009/10 (see Table 12). These values were then combined with Scottish dairy herd assumptions to calculate typical feed intake per kg of milk produced by herd (Table 13).

Table 10: Replacement heifer feed intake per animal per year – kg, as fed

	Hay (kg)	Silage (kg)	Concentrates (kg)	Grazing (kg)	Total (kg)
Typical feed intake	232	2,969	512	8,032	11,744
Typical dry matter	85%	25%	88%	18%	-

Table 11: Annual replacement feed intake (kg DM) per kg milk produced by herd

Yield group	Hay (kgDM)	Grass silage (kgDM)	Concentrates & other (kgDM)	Grazing (kgDM)	Total (kgDM)
Low	0.018	0.069	0.042	0.134	0.262
Medium	0.016	0.059	0.036	0.115	0.226
High	0.015	0.056	0.034	0.109	0.214

7.2.1.2 *Feed composition & emissions factors*

To assess the broad categories of 'grazing', 'forages' (mainly grass silage) and 'concentrates', a more detailed split of feed ingredients was required to adequately model the emissions associated with the production of concentrates and forages.

Regardless of the location of production (e.g. on farm or purchased), secondary sources of emissions factors were used to estimate emissions associated with the production of feeds. This is because the range of feeds used across the dairy industry makes the development of new Scotland-specific factors for each one prohibitive.

These cradle-to-farm gate emissions factors include all relevant farm emissions sources e.g. energy use, input production, soil emissions, and downstream processing (e.g. energy and other ingredients).

Emissions factors for these ingredients were sourced from the Carbon Trust Feed Database (Carbon Trust, 2010) and Cranfield agricultural LCA (Williams, et al., 2006) and adjusted to dry matter (see Table 15).

Concentrates

Assumptions for the composition of concentrates (dairy blends and compounds) fed to dairy cattle were derived from a questionnaire sent to a major feed manufacturer who provides a significant amount of feed to the Scottish dairy sector (Table 14). The questionnaire results were sense-checked against Defra livestock feed statistics[1] (which cover all feeds, not just dairy). The nutritional composition was not available from either source.

Table 12: Feed composition (by % wet mass) from questionnaire and Defra statistics (2007)

Ingredient	Project survey
Barley	10%
Wheat	14%
Wheat feed	13%
Distillers maize	9%
Biscuit meal	6%
Sugar beet pulp	9%
Soya meal	16%
Rapeseed	14%
Palm kernels	3%
Minerals	3%
Sunflower	2%
Molasses	4%
Fat	1%
Total	**100%**

[1] http://www.defra.gov.uk/evidence/statistics/foodfarm/food/animalfeed/index.htm

Concentrate feed emissions factors are for on farm production only – i.e. they do not include any further transport or processing. These additional emissions were estimated separately – see sections below.

Table 13: Concentrate ingredient assumptions

Group	Description	%DM	$kgCO_2e/kgDM$	Emissions factor source
Starch	**All**	**86**	**0.33**	**Derived from below & Table 12**
	Barley	86	0.46	Carbon Trust – average of all 5 barley factors
	Wheat	86	0.47	Carbon Trust – average of all 6 wheat factors
	Wheat feed	88	0.14	Carbon Trust – average of all 6 wheat factors
	Molasses	75	0.15	Carbon Trust – 'beet molasses'
Protein	**All**	**90**	**0.87**	**Derived from below & Table 12**
	Distillers maize	90	0.03	Carbon Trust – 'distillers grains'
	Biscuit meal	88	0.03	No data. Carbon Trust – 'brewers grains' proxy
	Soya	90	4.26	See section below
	Rapeseed	90	0.47	Carbon Trust – 'winter' & 'spring OSR meal'
	Sunflower	90	0.47	No data. Carbon Trust 'OSR meal' as proxy
Fibre	**All**	**90**	**0.08**	**Derived from below and Table 12**
	Sugar beet pulp	90	0.03	Carbon Trust – 'sugar beet'
	Soya hulls	90	0.10	Cranfield LCI[1] (Williams, et al., 2006)
	Palm kernels	90	0.10	No data. Cranfield LCI 'soya hull' as proxy

Soybean meal calculations

Land use change emissions associated with the production of soybean meal were estimated using the assumptions detailed in Table 16. These were derived from FAO[2] trade data and land use change emissions factors from Gerber *et al.* (2010). Scottish soybean meal imports were assumed to be similar to UK as no sub-national data was available.

[1] Derived from Cranfield LCI data 'soya meal (with hulls)' minus 'soya meal (no hulls)': http://www.cranfield.ac.uk/sas/naturalresources/research/projects/is0205.html

[2] http://faostat.fao.org/site/537/DesktopDefault.aspx?PageID=537

Table 14: UK soybean meal import assumptions (2007)[1]

Source	Tonnes imported into UK	Share (by mass)	Land use change assumptions[2]	LUC emissions $kgCO_2e/kg$	Production emissions kgCO2e/kg	Total emissions kgCO2e/kg	Total emissions kgCO2e/kgDM
Argentina	999,107	48%	Partially associated with the conversion of pasture and shrub land to cropland	0.93	0.21	1.14	1.27
Brazil	737,767	35%	Entirely associated with deforestation	7.69	0.22	7.91	8.79
Netherlands	226,572	11%	Assume 46% Argentina and 50% Brazil sourced[3]	4.25	0.21	4.51	5.01
Others	133,089	6%	No land use change	0	0.26	0.26	0.29
Total/Average	**2,096,535**	**100%**				**3.83**	**4.26**

[1] HMRC 2007 (https://www.uktradeinfo.com): "2304:Oil-cake and other solid residues, whether or not ground or in the form of pellets, resulting from the extraction of soya-bean oil"
[2] Gerber et al, 2010
[3] FAOSTAT, 2007 trade matrix

Feed processing
A feed processing energy overhead was applied to concentrate feeds using data from a Carbon Trust review of the sector (Carbon Trust, 2010): 85 kWh/tonne. The Carbon Trust study found 28% of this energy was in the form of electricity – and the rest by a combination of gas and oil (assumed to be 50:50 mix for the purposes of this analysis).

Using these assumptions, a processing 'emissions overhead' of 0.031 kgCO_2e per kg of processed feed was added to the model. Scotland-specific energy data was not used as the Scottish dairy sector uses feeds not only produced in Scotland.

Feed transport
Transport emissions are typically a small part of agricultural product footprints, so this emissions source was not modelled in detail. The table below sets out assumptions for distances and modes for the various concentrate ingredients. Imported feeds were modelled for routes from a single country which supplies the largest proportion of UK imports. It was assumed all goods were shipped in bulk and come from that country's major port to Southampton. Distances for internal trucking of feedstuffs in country of origin were based on Ecoinvent guidelines (Nemecek, et al., 2007).

Table 15: Concentrate feed ingredient transport assumptions

		Leg 1		Leg 2			Leg 3		
Ingredient	**From**	**Mode**	**Km**	**Mode**	**Km**	**Assumption**	**Mode**	**Km**	**Assumption**
Barley	UK	Artic	114						
Wheat	UK	Artic	114						
Wheat feed	UK	Artic	114						
Molasses	UK	Artic	114						
Distillers maize	UK	Artic	114						
Biscuit meal	UK	Artic	114						
Soya	South America	Artic	700	Ship	9,653	Santos to Southampton	Artic	803	Southampton to Central Scot.
Rapeseed	UK	Artic	114						
Sunflower	S Europe	Artic	800	Ship	3,391	Marseilles to Southampton	Artic	803	Southampton to Central Scot.
Sugar beet pulp	UK	Artic	114						
Soya hulls	South America	Artic	700	Ship	9,653	Santos to Southampton	Artic	803	Southampton to Central Scot.
Palm kernels	Asia	Artic	500	Ship	15,420	Jakarta to Southampton	Artic	803	Southampton to Central Scot.

Forages

Forage intake assumptions are summarised in Table 18. The vast majority of forages were assumed to be produced on farm or locally, so no additional transport burden was modelled.

Table 16: Forage composition assumptions

Description	% of mix (by mass)[1]	%DM	$kgCO_2e$/ kgDM	Emissions factor source
All	**100%**	**30%**	**0.28**	**Derived from below**
Barley straw	5%	86%	-0.06	Cranfield LCI – 'barley straw'
Grass silage	80%	25%	0.30	Cranfield LCI – 'dairy lowland silage'
Whole-crop wheat	15%	40%	0.29	Carbon Trust – 'wholecrop cereal'

Grazing

An emissions factor for the production of dairy grazing was sourced from Cranfield LCI: 0.33$kgCO_2e$/kgDM (assuming 18% dry matter content).

[1] Expert judgement, Laurence Gould Partnership

7.2.2 *Energy*

7.2.2.1 *Electricity*

Farm electricity consumption per kg of milk was estimated from spend data[1] extracted from the Scottish Farm Accounts Survey (2007) – see Table 19. As Farm Accounts Survey data is at farm not dairy enterprise level, dairy-related consumption was derived using financial allocation of farm outputs.

Electricity consumption figures were sense-checked against a survey of 100 dairy farms in Northern Ireland undertaken in 2007/8 by CAFRE[2] and a review of farm energy use conducted by Warwick HRI for Defra[3].

It is worth noting that the latter study used a per cow electricity consumption factor (910kWh) which was significantly higher than those used in this study. The Farm Account Survey was considered the best source as it was Scotland-specific and the basis for the Warwick assumption was unreferenced and not expressed per kg of milk.

Table 17: Farm electricity use assumptions

Source	Milk yield	kWh/cow	kWh/kg milk
FAS, 2007	Low	331	0.062
	Medium	383	0.051
	High	424	0.045
	Average	375	0.055
CAFRE, 2007	Average	330	0.049
Defra, 2007	Average	910	0.190

7.2.2.2 *Stationery fuel*

Farm heating fuel consumption per kg of milk was estimated from fuel spend data[4] extracted from the Scottish Farm Accounts Survey (2007) – see Table 18. It was assumed that oil is the dominant fuel used on farms. The Warwick HRI study for Defra quoted above excludes this source as insignificant.

Table 18: Farm heating fuel assumptions

Source	Milk yield	Litres oil/kg milk
FAS, 2007	Low	0.0069
	Medium	0.0045
	High	0.0051
	Average	0.0053

[1] Assumes £0.074/kWh (exVAT). Source: DECC energy price statistics - “Table 3.1.1 Prices of fuels purchased by manufacturing industry”. www.decc.gov.uk
[2] http://www.ruralni.gov.uk/dairy_energy_report.pdf
[3] http://www2.warwick.ac.uk/fac/sci/whri/research/climatechange/
[4] Assumes £0.334/litre of oil (exVAT). Source: DECC fuel price statistics – “Table 4.1.2 Average annual retail prices of petroleum products and a crude oil price index”. www.decc.gov.uk

7.2.2.3 Mobile fuel

Field machinery fuel use was not modelled explicitly – instead emissions from this source are included within the scope of Carbon Trust conversion factors used to model feed production. The Farm Accounts Survey had additional information of 'car fuel' spend[1]. This data was used to estimate additional business-related transport emissions.

Table 19: Farm heating fuel assumptions

Source	Milk yield	Litres diesel/ kg milk
FAS, 2007	Low	0.0019
	Medium	0.0018
	High	0.0015
	Weighted average	0.0018

7.2.3 Agrochemicals

The production and soil emissions that result from the use of fertilisers, pesticides and herbicides was not modelled explicitly – instead emissions from these sources are included within the scope of Carbon Trust conversion factors used to model feed production.

7.2.4 Livestock transport

Inter-farm movements of dairy replacements were excluded on the basis that it is not common practice to move young dairy animals around[2]. The onward transport of calves to the beef supply chain was also not included as these are out-of-scope (see Sections 4 *System boundary* and 4.1.4 *Dairy beef*).

7.2.5 Veterinary products

An emissions estimate was developed based on average spend on veterinary goods and services per kg milk (source: Farm Accounts Survey, 2007). These were sense-checked against the SAC Farm Management Handbook (McBain, et al., 2009) and a study of Scottish Dairy Enterprise (Laurence Gould Partnership, 2007).

Table 20: Veterinary spend assumptions[3]

Source	Milk yield	£(exVAT) per kg milk
FAS, 2007	Low	0.0054
	Medium	0.0068
	High	0.0058
SAC, 2009/10	Low	0.0097
	Medium	0.0097
	High	0.0097
LGP, 2006/7	Low	0.0067
	Medium	0.0074
	High	0.0073

[1] Assumed diesel at £0.97/litre. Source: DECC Fuel price statistics, 2007
[2] Laurence Gould Partnership expert judgement
[3] Method based on Defra GHG Reporting Guidelines 2009, Annex 8 (Defra, 2009)

7.2.6 Water

It was assumed that irrigation of pasture/crops is not practiced in Scotland. It was also assumed that water extracted on-site will be captured in dairy energy use data and so was not modelled separately.

Mains water consumption was estimated from Scottish Farm Accounts Survey water spend data (2007). The results were sense-checked against DairyCo publication on water use (DairyCo, 2007).

Table 21: Livestock water consumption

Source	Milk yield	kg mains water per kg milk
FAS, 2007	Low	1.84
	Medium	0.88
	High	0.68
	Average	1.06
DairyCo	Average	5.93

Table 22: Water use assumptions

Variable	Assumption	Source
Standing charge	£776/year	2008/09. Business Stream. 25-30mm supply
Supply charge	£0.74/m^3	2008/09. Business Stream. 1st 100,000 m^3
Sewerage charge	£1.26/m^3	2008/09. Business Stream. All m^3

7.2.7 Silage wrap

The consumption of silage wrap (kg plastic film) was estimated using the assumptions detailed in Table 25, and gave the results in Table 26.

Table 23: Silage wrap assumptions

Variable	Assumption	Source
Ratio of bale to clamp use in Scotland	70:30	Laurence Gould
Plastic use bale	1.3kg/tonne silage	Defra waste factsheet[1]
Plastic use clamp	0.16kg/tonne silage	Defra waste factsheet
Silage (kg) per kg milk	2.63 – Low yield 1.94 – Medium yield 1.58 – High yield	Adult and young
Plastic type	LDPE	
Recycled content	0%	
End-of-life	Landfill – no info on LDPE	

[1] http://www.defra.gov.uk/environment/waste/topics/farm/documents/waste-minimisation.pdf

Table 24: Silage wrap (kg plastic film) consumption per kg milk

Variable	Kg plastic film/kg milk
Low	0.0025
Medium	0.0019
High	0.0015

7.2.8 Wastes

7.2.8.1 Milk

No data was available on milk waste rates at farm.

7.2.8.2 Plastics

Derived from silage wrap assumptions in Table 25 and results given in Table 26.

7.2.9 Refrigerant for bulk tanks

Raw milk is stored on farm in bulk tanks prior to collection. These tanks are cooled using refrigerants, which can be potent global warming gases if they escape into the atmosphere. No references were found on these emissions sources in dairy farming and so an estimate of $8.4x10^{-8}$kg coolant per kg milk was developed based on the assumptions in Table 25. The production emissions of these refrigerants were excluded due to small quantities used and the assumption that use emissions dominate life cycle of these gases.

Table 25: Farm refrigerant leakage assumptions[1]

Variable	Assumption	Source
Scottish milk production	1,310,177,556 kg/year	Scottish Agriculture Output Input and Income Statistics (2009) - year 2007[2]
No. dairy enterprises	1,830	June Census, 2007
No. of tanks per enterprise	1	Assumption
Coolant capacity per tank	3kg	Defra 2009 GHG Reporting Guidelines "Stand alone commercial application"
Refrigerant leak rate (operation)	2%	
Mix of refrigerant gases used (by mass)	HFC 134a – 50% R404a – 50%	Assumption from literature review of common gases
Global warming potential of refrigerant mix	2,676 kgCO_2e/kg coolant	IPCC AR4 GWP factors (IPCC, 2007)

[1] Method based on Defra GHG Reporting Guidelines 2009, Annex 8 (Defra, 2009)
[2] http://www.scotland.gov.uk/Publications/2010/06/16144532/5

7.3 Enteric & manure storage (CH_4 & N_2O)

The study uses IPCC (IPCC, 2006) Tier 2 equations (AEA Technology, 2009) to calculate livestock-related emissions from enteric fermentation (methane) and manure storage (methane & direct and indirect N_2O).

The emissions from the application of manure and slurry (and inorganic nitrogen) were estimated as part of the feed production emissions model (see Section 7.2).

7.3.1 Livestock population and energy requirements

The first step in calculating methane and manure emissions is the calculation of the livestock population and energy requirements. The assumptions used in combination with IPCC (IPCC, 2006) equations are detailed below.

7.3.1.1 Assumptions

Unless otherwise stated, assumptions from UK National Inventory Report (UK NIR)[1] (AEA Technology, 2009) have been used in this study to calculate energy requirements. In the tables that follow, comparisons with UK NIR have been provided where possible. The assumptions are split into four main areas:

- **Environment** e.g. temperature
- **Animal & herd** e.g. live body weights
- **Feed** e.g. digestibility
- **Milk** e.g. fat content

Environment

The coefficient for calculating the Net Energy of Maintenance was adjusted in line with IPCC guidelines to take account of colder conditions in Scotland. The average winter temperature in dairy farming areas in Scotland was estimated from Met Office seasonal temperature charts to be 3.6°C. The UK average used in National Inventory Report is 5.9°C.

Animal & herd

Animal and herd assumptions were derived from a variety of sources including the SAC Farm Management Handbook, Laurence Gould Partnership (LGP) collated data and expert judgement and June Agricultural Census for Scotland. It was assumed that 85% of females are pregnant in any one year[2].

Table 26: Live body weights (kg) for different yield and age classes

Milk yield	< 1 year	1-2 years	> 2 years (mature)
Low	150	370	650
Medium	160	385	700
High	200	420	750
UK NIR	*180*	*400-500*	*652*

[1] http://www.naei.org.uk/reports.php

[2] Derived from Scottish June 2007 census of total dairy cows and heifers in calf divided by total mature females (Scottish Government, 2008).

Table 27: Average dairy weight gain (kg/animal/day) (McBain, et al., 2009)

Animal age	SAC	*UK NIR*
< 1 year	0.63	*0.6*
1-2 years	0.62	*0.3*
> 2 years	0	*0*

Table 28: Percentage of time spent grazing[1]

Yield	< 1 year	1-2 years	> 2 years
Low	38%	53%	53%
Medium	38%	53%	46%
High	38%	53%	33%
NIR	*46%*	*43%*	*46%*

Feed

Average feed digestibility was derived from assumptions on the digestibility of feed constituents and typical feed profiles for different ages and yields (see Section 7.2.1).

Table 29: Average digestibility of different feed types: following **(Gerber, et al., 2010)**

Feed type	Digestibility (DE%)
Hay[2]	71%
Silage[3]	71%
Concentrates[3]	84%
Grazing[4]	75%

Table 30: Average digestibility of diets

Animal age	Low	Medium	High
> 2 year	74.02%	74.38%	74.75%
1-2 years		73.72%	
< 1 year		76.87%	
UK NIR		*73.59%*	

[1] Developed using expert judgement (Laurence Gould Partnership) and SAC Management Handbook
[2] Gerber et al (2010). Table A2.5. Western Europe conserved grass value
[3] Derived from Gerber et al (2010) Table A2.6 using project-specific concentrate mix
[4] Gerber et al (2010). Table A2.5. Western Europe fresh grass value

Milk

Table 31: Average milk yields per dairy cow[1], following **(McBain, et al., 2009)**

Yield group	Litres/year	Kg/day
Low	5,500	15.52
Medium	7,500	21.16
High	9,500	26.80
UK NIR	-	*19.40*

Table 32: Fat content of milk **(Carbon Trust, 2010)**

	Fat %
All yields	4.00
UK NIR	*4.06*

7.3.1.2 Gross energy results

Table 33: Gross energy results (MJ/day)

Age	Animal type	Low	Medium	High
< 1 year	Cattle (non-lactating cows)	62.74	64.76	75.43
1- 2 year	Cattle (non-lactating cows)	132.56	134.36	141.34
	Cattle (lactating cows)	270.56	316.57	368.47
	Cattle (bulls)	89.18	90.24	94.79
> 2 years	Cattle (non-lactating cows)	140.88	146.55	150.02
	Cattle (lactating cows)	297.42	347.14	393.75
	Cattle (bulls)	90.94	94.04	94.80
UK NIR	Dairy Cattle	266.86		

[1] Dairy cow census definition: Cows & heifers in milk + cows in calf but not in milk

7.3.2 Emissions factors

7.3.2.1 Enteric fermentation

Methane conversion factor

The IPCC methane conversion factor (Ym) is the percent of gross energy in feed converted to methane. Ym was calculated for each age group using project specific feed digestibility assumptions[1].

Table 34: Methane conversion factors: following **(Gerber, et al., 2010)**

Age	Yield	Ym
< 1 year	All	5.84
1 - 2 years	All	5.99
> 2 years	Low	5.98
	Medium	5.96
	High	5.94
UK NIR	All	6.00

Table 35: Enteric methane emissions ($kgCH_4$) per animal per year, by yield **(IPCC, 2006)**

		Milk yield class		
Animal age	Animal type	Low	Medium	High
< 1 year	Cattle (non-lactating cows)	24.02	24.80	28.88
1- 2 year	Cattle (non-lactating cows)	52.11	52.82	55.56
	Cattle (lactating cows)	106.36	124.45	144.84
	Cattle (bulls)	35.06	35.47	37.26
> 2 years	Cattle (non-lactating cows)	55.24	57.29	58.47
	Cattle (lactating cows)	116.63	135.72	153.47
	Cattle (bulls)	35.66	36.76	36.95
UK NIR	Dairy cattle - All	105.02		
	Non-dairy cattle - All	42.95		

[1] Ym = 9.75 – 0.05 * Digestibility Rate

7.3.2.2 *Manure storage – methane (CH_4)*

Methane emissions from manure storage were calculated based on the assumption in Table 38 and the IPCC (IPCC, 2006) default conversion factors.

Table 36: Prevalence of manure management systems in Scotland[1]

Milk yield	Pasture	Liquid	Solid	Daily spread	Anaerobic digestion
Low	49%	39%	12%	0%	0%
Medium	44%	43%	12%	0%	0%
High	39%	48%	12%	0%	0%
UK NIR	*45.50%*	*30.60%*	*9.80%*	*14.10%*	*0%*

Table 37: Methane emissions ($kgCH_4$) from manure storage, per animal per year

		Milk yield class		
Age	Animal type	Low	Medium	High
< 1 year	Cattle (non-lactating cows)	6.06	6.86	8.86
1-2 years	Cattle (non-lactating cows)	14.29	15.89	18.53
	Cattle (lactating cows)	29.17	37.44	48.30
	Cattle (bulls)	9.62	10.67	12.43
> 2 years	Cattle (non-lactating cows)	15.04	16.95	19.00
	Cattle (lactating cows)	31.75	40.16	49.87
	Cattle (bulls)	9.71	10.88	12.01
NIR	Dairy cattle - All	25.79		
	Non-dairy cattle - All	4.18		

7.3.2.3 *Manure storage – nitrous oxide (N_2O)*

Nitrous oxide emissions from manure storage were calculated based on the methodology[2] and IPCC (IPCC, 2006) default conversion factors.

Table 38: Direct nitrous oxide emissions (kgN_2O) from manure storage, per animal per year

		Milk yield class		
Age	Animal type	Low	Medium	High
< 1 year	Cattle (females)	0.39	0.40	0.35
1-2 years	Cattle (females)	0.92	0.95	1.18
	Cattle (bulls)	0.12	0.12	0.16

[1] Derived using expert judgement (Laurence Gould Partnership). No publicly available information was found on typical management practices in Scotland. A number of organisations were approached e.g. Scottish Agricultural College, Scottish Environmental Protection Agency, DairyCo

[2] (IPCC, 2006) N_2O emissions methodology accounts the pasture manure management system (Table 38) under Agricultural Soils section of the GHG Inventory. This section was not calculated for this project due to the PAS2050 exclusion of soil emissions.

> 2 years	Cattle (females)	0.88	0.88	0.97
	Cattle (bulls)	0.15	0.16	0.20

Table 39: Indirect nitrous oxide emissions (kgN_2O) from manure storage, per animal per year

		Milk yield class		
Age	Animal type	Low	Medium	High
< 1 year	Cattle (females)	0.29	0.30	0.26
1-2 years	Cattle (females)	0.69	0.72	0.90
	Cattle (bulls)	0.09	0.09	0.12
> 2 years	Cattle (females)	0.66	0.66	0.73
	Cattle (bulls)	0.12	0.12	0.15

7.3.3 Soil carbon changes in existing agricultural land

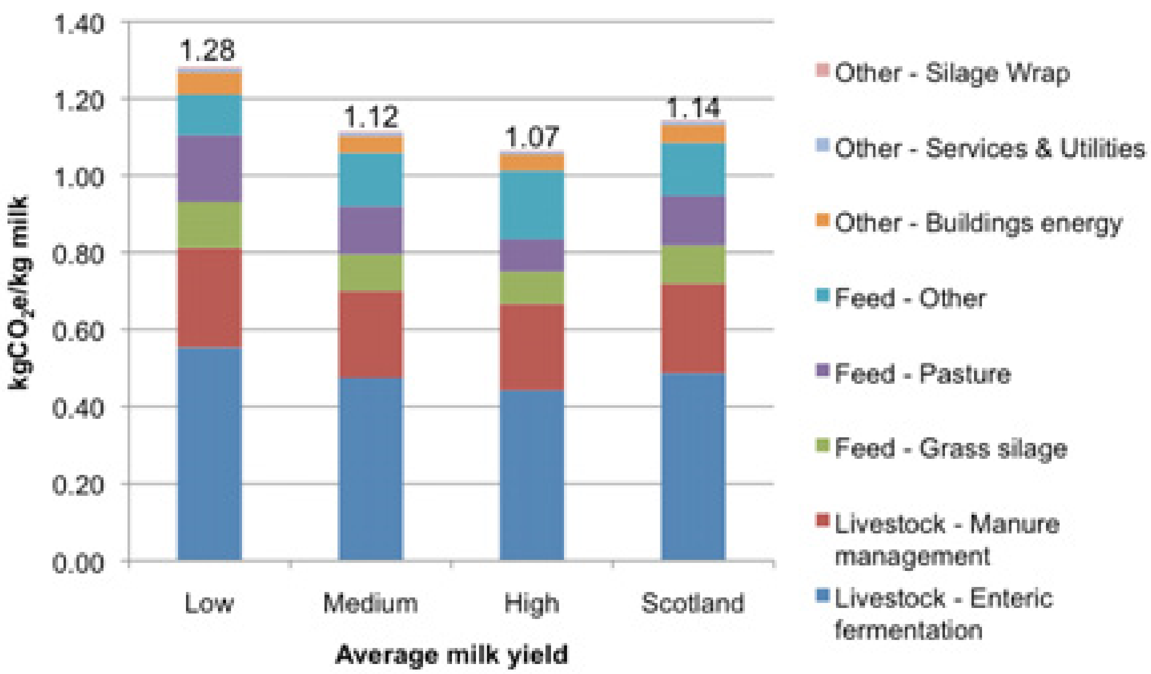
Due to data availability and scientific uncertainties, changes in soil carbon in existing agricultural systems are currently excluded from the Dairy Guidelines and UK National Inventory (AEA Technology, 2009).

7.4 Summary of results

Table 40: Summary of milk emissions ($kgCO_2e/kg$), by herd yield & Scottish average

Emissions source	Description	Low	Medium	High	Scotland
Livestock	Enteric fermentation	0.55	0.47	0.44	0.49
	Manure storage	0.26	0.23	0.22	0.23
Feed production	Grass silage	0.12	0.10	0.08	0.10
	Pasture	0.17	0.12	0.08	0.13
	Other feeds	0.11	0.14	0.18	0.14
Other	Building energy	0.06	0.04	0.04	0.05
	Services & water	0.01	0.01	0.01	0.01
	Silage wrap	<0.01	<0.01	<0.01	<0.01
TOTAL		**1.28**	**1.11**	**1.06**	**1.14**

Figure 1: Summary of cradle-to-gate milk emissions ($kgCO_2e/kg$), by yield group



8 Dairy processor models

This section outlines the assumptions used in developing footprints for the six products under examination. First of all, assumptions on product packaging and the allocation of raw milk emissions is discussed then additional assumptions are presented by product type.

8.1 Raw milk allocation

All six dairy products modelled in this study used raw milk as the major ingredient. As such an important step was the allocation of raw milk production emissions (i.e. those that occur at farm stage). For most products this project followed procedures outlined in the Dairy Guidelines, where-by incoming milk footprint is normalised according to its dry mass (see tables below). An exception was made for cheese production – where economic allocation was used to allocate emissions between cheese and whey co-product. This is explored in more detail below.

Table 41: Dry mass assumptions for liquid milk

Milk	Scottish utilisation	Dry mass %
Full fat	66%	13
Skimmed	30%	11[1]
Cream	4%	48
Scotland	100%	14

Table 42: Dry mass assumptions for all dairy products (Feitz et al. 2007)

Product	DM%
Liquid milk	13.4%
Butter	84.4%
Cheese	63.9%
Cream	48.1%
Yoghurt	14.2%
Ice cream	21.9%

Table 43: Milk emissions (to farm gate) per kg of final dairy products

Product	$kgCO_2e/kg$
Liquid milk	1.18
Butter	7.42
Cheese	9.89
Cream	4.23
Yoghurt	1.25
Ice cream	1.93

[1] Assume semi-skimmed

8.1.1 *Accounting for whey co-product*

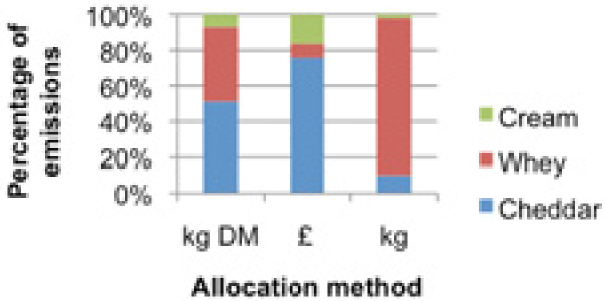
In dairy footprinting studies this is important as co-products occur on farm and during processing stages e.g. a significant Scottish dairy co-product is liquid whey from cheese manufacture (see Figure 2).

Figure 2: Simplified cheese production inputs and outputs (in wet and dry mass - DM)[1]

At processing stage, dairy footprinting guidelines (both from the Carbon Trust and IDF) recommend that emissions are allocated on a dry mass basis (the assumption being that this is a proxy for economic value). While this simplifies calculations and works with most dairy products, the authors of this study think that this proxy does not currently hold true in the cheese situation (where whey is often disposed of as a waste or as low/no value products). When the current footprint guidelines were applied to the whole industry in this study, a significant proportion of milk emissions were allocated to whey, regardless of end use (even if disposed of down public sewers). This is because, even though whey is dilute, it contains a significant quantity of dry matter in total. The net result is that, per kg, cheese had a lower footprint than might be reasonable (especially given that whey utilisation is an acknowledged waste issue[2]).

If emissions were to be allocated along the lines of economic value, however, this would incentivise the full utilisation of co-products (i.e. those companies that dispose of whey as waste would have a much higher cheese footprint). The existing system provides no such incentive and is open to criticism.

Figure 3: How allocation decisions (by dry mass, value or mass) influence results



For this reason (and with the agreement of The Carbon Trust), this analysis allocated cheese/whey emissions on the basis of economic value. As no data was available at an industry-level on whey utilisation, estimates were used (and so is an area for data improvement).

[1] Arla foods via Danish Food LCA: http://www.lcafood.dk/processes/industry/cheeseproduction.htm

[2] See Box 8 in main report for details of forthcoming Scottish Enterprise study into whey valorisation

8.1.2 Packaging

This section summarises assumptions used to estimate packaging emissions factors. Estimates were derived using the methods set out in PAS2050 Annex D.1. A variety of emissions factors sources for the production, recycling and disposal of materials were used (documented in footnotes). Recycling 'credit' was not calculated at end-of-life as it was included in packaging material production (see dairy processing section). This is in line for Carbon Trust Footprint Expert methodology.

The study did not model transport of raw materials or bottle production & transport due to time constraints (i.e. it was assumed that material production/recycling is main source of emissions across life cycle).

Table 44: Relative GWP impact and EOL recycling rates of different packaging materials

Material	Virgin $kgCO_2e/kg$[1]	GHG saving recycling (%)	Recycling $kgCO_2e/kg$[2]	Average EOL $kgCO_2e$[3]	EOL recycling rate (UK)[4]
Glass	0.84	37%[5]	0.53	0.00	47%
Plastic (HDPE)	2.83	80%[6]	0.50	0.02	3%
Plastic film (LDPE)	2.166	81%[6]	0.44	0.02	3%
Cartonboard	3.49	43%[7]	1.98	0.19	3%[8]
Aluminium	12.86	86%[9]	1.74	0.00	10%
Paper	2.00	57%[10]	0.85	0.29	33%
Polypropylene	4.41	88%[11]	0.53	0.02	3%

Table 45: Average recycled content of packaging materials

Product	Av. recycled content[12]
Milk	1.9%
Cheese	4.4%
All industry[13]	2.9%

[1] Source: Carbon Trust
[2] Carbon Trust do not publish recycled factors for most materials so these figures were derived from published sources which detail GHG savings from recycling
[3] Source: Average EOL factors, Carbon Trust. This covers average disposal emissions (e.g. landfill)
[4] Household recycling rates from Carbon Trust
[5] Derived from WRAP (2007): Assessment of the International Trading Markets for Recycled Container Glass and their Environmental Implications
[6] Derived from US EPA (2006): Solid Waste Management and Greenhouse Gases A Life-Cycle Assessment of Emissions and Sinks
[7] No Cartonboard data was available so assumed corrugate board and used Carbon Trust virgin/recycled factors
[8] Assumed plastic as no carton board rate available
[9] Derived from Bath Inventory of Carbon and Energy, version 1.6a
[10] Derived from Ecoinvent v 2.0
[11] Derived from RECOUP (2002): Recycling Plastic Bottles - The Energy Equation
[12] Dairy UK packaging benchmark data. Recycled content assumptions were applied across all materials as no disaggregation was available.
[13] This rate was applied across all other products: cream, ice cream, yoghurt & butter

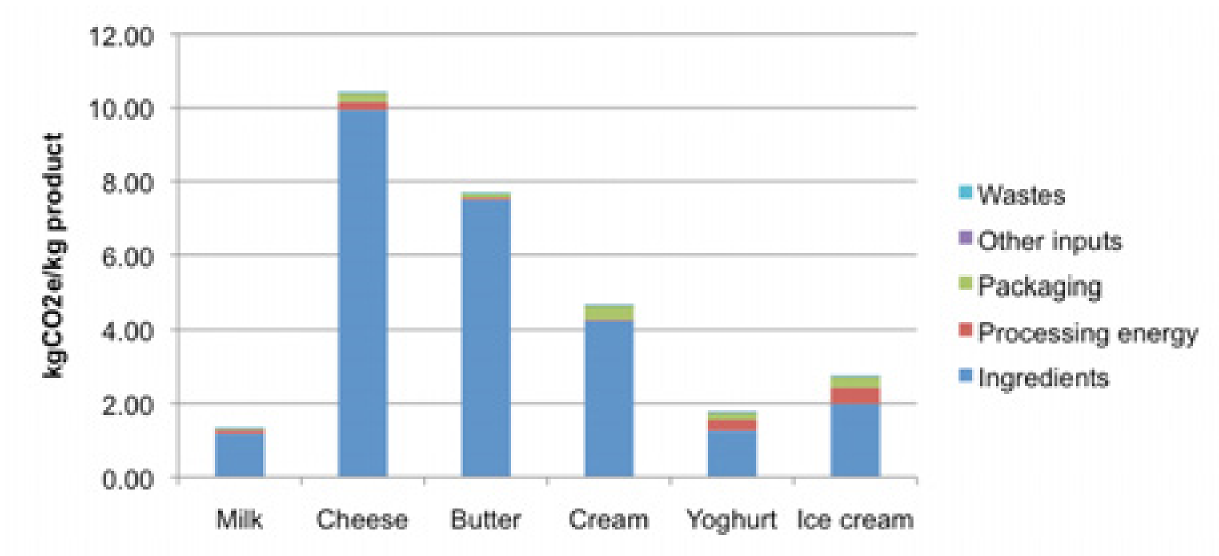
8.2 Summary of inputs and cradle-to-gate results

This section details processing inputs, outputs and assumptions. It also provides cradle-to-gate emissions for the six products being studied[1] (see table and figure below).

Table 46: Cradle-to-gate GHG emissions

Input/output	Milk	Cheese	Butter	Cream	Yoghurt	Ice cream
Ingredients	1.19	9.94	7.49	4.27	1.26	1.99
Processing energy	0.09	0.22	0.06	0.00	0.29	0.44
Packaging	0.06	0.26	0.14	0.41	0.22	0.33
Other inputs	0.00	0.00	0.00	0.00	0.00	0.00
Wastes	0.00	0.00	0.00	0.00	0.00	0.01
Total	**1.35**	**10.43**	**7.70**	**4.68**	**1.77**	**2.76**

Figure 4: Cradle-to-processor gate GHG emissions totals ($kgCO_2e/kg$) for six products



Emissions sources in subsequent sections have been colour coded to highlight hotspots:

- 1% or less = Green, low priority
- >1% < 10% = Amber, medium priority
- 10% or greater = Red, high priority

[1] Footprint results given to two decimal places

8.2.1 *Liquid milk*

Table 47: Liquid milk processing assumptions & results to processor gate

Input/output	Description	per kg milk	Units	$kgCO_2e/kg$	%	Footnotes
Raw milk				1.18	87%	1
Processing energy	Electricity	0.08	kWh	0.05	4%	2
	Fuel	0.21	kWh	0.05	3%	
Transport	Raw milk freight	0.00	litres diesel	0.01	1%	3
Refrigerant	HCFC	5.83E-07	kg	0.00	0%	4, 5
	HFC	4.18E-08	kg	0.00	0%	
Packaging	Total, *of which …*	22.8	g	0.06	5%	6
	Plastic	17.8	*g*	0.05	4%	
	Glass	2.5	*g*	0.00	0%	
	Carton	2.5	*g*	0.01	1%	
Other inputs	Water	0.95	litres	0.00	0%	7
	Process chemicals	2.0	g	0.00	[illegible]	8
Waste	Trade effluent	0.95	litre	0.00	0%	9
	Landfill waste	4.0	g	0.00	0%	9
TOTAL				1.35	100%	

[1] See Section 13.1 on raw milk emissions allocation

[2] Total energy data from Dairy UK benchmark data (2008) – Fergus McReynolds, Personal communications. Energy split based on UNEP "Cleaner Production Assessment in Dairy Processing". 'Fuel' assumed to be natural gas.

[3] Derived from Dairy UK, Milk Road Map data – Fergus McReynolds, Personal communications

[4] F-Gas Support, Information Sheet RAC 2: "Guidance for Stationary Refrigeration & Air-Conditioning". HCFC assumed to be R22 (GWP 1,810); HFC assumed to be 50:50 blend of R134a and R404a (GWP 2676)

[5] Derived from Dairy UK, Milk Road Map data – Fergus McReynolds, Personal communications

[6] Average packaging burden per kg of milk was estimated using Dairy UK packaging benchmarks data (total mass) and WRAP milk LCA report which includes assumptions on market share by packaging type: glass 11%; plastic: 78%; carton: 11% (WRAP 'Life cycle assessment of example packaging systems for milk'). Packaging results include end-of-life disposal.

[7] Dairy UK benchmark data (2008). Assumed to be all mains water.

[8] Derived from Dairy UK, Milk Road Map data – Fergus McReynolds, Personal communications. Assumed to be 'average chemical'

[9] Dairy UK benchmark data (2008). Assumed to be mixed paper/card commercial waste

8.2.2 Cheese

Cheese was assumed to be cheddar as this makes up majority of Scottish production.

Table 48: Cheese processing assumptions and results summary (cradle-to-processor gate)

Item	Description	per kg cheese	Units	$kgCO_2e/kg$	GHG %	Footnotes
Raw milk				9.89	95%	1
Energy	Electricity (processing)	0.093	kWh	0.06	1%	2, 3
	Fuel (processing)	0.598	kWh	0.13	1%	3, 4
	Electricity (maturing)	0.058	kWh	0.03	0%	5
Transport	Bulk milk freight	0.017	litres diesel	0.05	0%	6
Packaging	Total, of which …	64	g	0.26	2%	7
	Plastic	23	*g*	0.05	0%	
	Metal	12	*g*	0.15	1%	
	Paper	30	*g*	0.06	1%	
Other inputs	Water	1.4	litres	0.00	0%	8
	Salt	20	g	0.01	0%	9
Waste	Trade effluent	1.3	litres	0.00	0%	3
	Landfill waste	4.7	g	0.00	0%	3, 10
Total				10.43	100%	

[1] See Section 13.1 on raw milk emissions allocation
[2] Dairy UK benchmark data (2008) – Fergus McReynolds, Personal communications
[3] Electricity/fuel split from UNEP "Cleaner Production Assessment in Dairy Processing". Fuel assumed to by natural gas.
[4] No data available. Cheeses can be matured up to 12 months in cool.
[5] From discussions with Scottish dairy processor who provided annual electricity and cheese tonnage for large store facility
[6] Derived from Dairy UK, Milk Road Map data – Fergus McReynolds, Personal communications
[7] Total packaging mass from Dairy UK benchmarking (2008). Assumption on material split from WRAP "UK Packaging Benchmark product analysis" (2005)
[8] Assumed to be all mains water. Quantity from Dairy UK benchmarking (2008)
[9] Assumed to be pure, vacuum dried salt. Estimated that salt added at up to 2% by mass of product.
[10] Assumed to be mixed paper/card commercial waste

8.2.3 Butter (salted)

Table 49: Butter processing assumptions and results summary (cradle-to-processor gate)

Input/waste	Description	per kg butter	Units	$kgCO_2e/kg$	% GHGs	Footnotes
Raw milk				7.42	96%	1
Energy	Electricity	0.064	kWh	0.04	0%	2
	Fuel	0.086	kWh	0.02	0%	
Transport	Bulk milk freight	0.022	litres diesel	0.07	1%	3
Packaging	Total, *of which …*	13.1	g	0.14	2%	4
	Aluminium	11.0	*g*	0.14	2%	
	Paper	2.2	*g*	0.00	0%	
Other inputs	Water	1.0	litres	0.00	0%	5
	Salt	13	g	0.00	0%	6
Waste	Trade effluent	1.3	litres	0.00	0%	7
	Landfill	4.7	g	0.00	0%	8
Total				7.70	100%	

[1] See Section 13.1 on raw milk emissions allocation
[2] Energy total and splits derived from Danish Food LCA and Dairy Guidelines resource use allocation methods
[3] Dairy UK, Milk Road Map data – Fergus McReynolds, Personal communications
[4] Assumptions on total mass and material split derived from "UK Packaging Benchmark product analysis", WRAP (2005)
[5] Assumed to be all mains water
[6] Assumed to be pure, vacuum dried salt. Quantity estimated from review of typical salting levels (% by mass)
[7] No data, so used same assumption as cheese (conservative assumption)
[8] No data, so used same assumption as cheese (conservative assumption)

8.2.4 Yoghurt (natural)

Table 50: Yoghurt processing assumptions and results summary (cradle-to-processor gate)

Input/waste	Description	Value	per kg yoghurt	kgCO2e/kg	% GHGs	Footnote
Raw milk				1.25	70%	1
Energy	Electricity	0.325	kWh	0.19	11%	2
	Fuel	0.447	kWh	0.10	6%	3
Transport	Bulk milk freight	0.0037	litres diesel	0.01	1%	4
Packaging	Total, *of which …*	53.9	g	0.22	ls%	5
	Plastic	38.2	*g*	0.16	9%	6
	Metal	1.9	*g*	0.02	1%	7
	Paper	13.9	*g*	0.03	2%	
Other inputs	Water	1.9	litres	0.00	0%	8
Waste	Trade effluent	1.3	g	0.00	0%	9
	Landfill	4.7	g	0.00	0%	10
Total				1.77	100%	

•No data was available on refrigerant emissions or chemical use. Excluded as likely to be insignificant

•Added sweeteners, fruits, etc were not included due to lack of data

1 See Section 13.1 on raw milk emissions allocation
2 Derived from milk energy requirements and assumptions outlined in Defra (2007) 'Impacts of food production and consumption' Pg 68
3 Derived from milk energy requirements and assumptions outlined in Defra (2007) 'Impacts of food production and consumption' Pg 68
4 Derived from Dairy UK, Milk Road Map data – Fergus McReynolds, Personal communications
5 Assumption from "UK Packaging Benchmark product analysis", WRAP (2005)
6 Assume polypropylene
7 Assume aluminium
8 Assumed to be all mains water
9 No data, so used same assumption as cheese (conservative assumption)
10 No data, so used same assumption as cheese (conservative assumption)

8.2.5 Cream

Table 51: Cream processing assumptions and results summary (cradle-to-processor gate)

Input/waste	Description	Value	per kg cream	kgCO_2e/kg	GHGs %	Footnote
Raw milk				4.23	90%	1
Energy	Electricity	0.0062	kWh	0.00	0%	2
	Fuel	0.0036	kWh	0.00	0%	3
Transport	Bulk milk freight	0.0127	litres diesel	0.04	ng	4
Packaging	Plastic	94.7	g	0.41	9%	5
Other inputs	Water	0.2	litres	0.00	0%	6
Waste	Trade effluent	1.3	litre	0.00	0%	7
	Landfill	4.7	g	0.00	0%	8
Total				4.68	100%	

[1] See Section 13.1 on raw milk emissions allocation
[2] Derived from Danish Food LCA and Dairy Guidelines resource allocation factors
[3] Derived from Danish Food LCA and Dairy Guidelines resource allocation factors
[4] Derived from Dairy UK, Milk Road Map data – Fergus McReynolds, Personal communications
[5] No data available, therefore used same assumption as ice cream
[6] Assumed to be all mains water
[7] No data, so used same assumption as cheese (conservative assumption)
[8] No data, so used same assumption as cheese (conservative assumption)

8.2.6 Ice cream

Table 52: Ice cream processing assumptions and results summary (cradle-to-processor gate)

Input/waste	Description	Value	Unit per kg ice cream	$kgCO_2e/kg$	% GHGs	Footnote
Raw milk				1.93	70%	1
Energy	Electricity	0.726	kWh	0.43	16%	2
	Fuel	0.016	kWh	0.00	0%	3
Transport	Bulk milk freight	0.0058	litres diesel	0.02	1%	4
Packaging	Plastic	76.4	g	0.33	12%	5
Other inputs	Water	4.5	litres	0.00	0%	6
	Sugar	150	g	0.05	2%	7
Waste	Trade effluent	3.4	litres	0.00	0%	8
	Landfill waste	45.2	g	0.01	0%	9, 10
Total				2.76	100%	

•No additional ingredients (e.g. fruit or trace ingredients) were modelled.

[1] See Section 13.1 on raw milk emissions allocation
[2] Derived from Feitz et al (2007)
[3] Derived from Feitz et al (2007)
[4] Derived from Dairy UK, Milk Road Map data – Fergus McReynolds, Personal communications
[5] Assumed to by polypropylene. Mass is estimate from research of packaging specifications e.g. http://www.lianfu.cc/display.asp?id=53
[6] Assumed to be all mains water. Quantity from International Finance Corporation 'Environmental, Health, and Safety Guidelines for Dairy Processing'
[7] Derived from University of Delph data http://www.foodsci.uoguelph.ca/dairyedu/iccalc.html
[8] International Finance Corporation 'Environmental, Health, and Safety Guidelines for Dairy Processing'
[9] International Finance Corporation 'Environmental, Health, and Safety Guidelines for Dairy Processing'
[10] Assumed to be mixed paper/card commercial waste

9 Distribution, use & end-of-life

The Carbon Trust's Footprint Expert tool was used to model distribution and use emissions. Product packaging and food disposal were modelled separately (see packaging assumptions section (8.1.1) for details of former).

9.1 Distribution & retail

Distribution emissions sources include: vehicle fuel during transport from processor to point-of-sale; refrigerant leakage from chilled vehicles; regional Distribution Centre energy use; retail/wholesale store energy use and refrigerant leaks. For the purposes of this study it was assumed all products were consumed in the UK.

Doorstep delivery was not modelled separately as it makes up a small and declining percentage of total sales (7%)[1]. Additionally it was assumed that all products went via retail and regional distribution centres (RDCs).

Table 53: Key distribution assumptions & summary of results

Variable	Milk	Butter	Cheese	Cream	Yoghurt	Ice cream
Total emissions, $kgCO_2e/kg$	**0.06**	**1.01**	**0.59**	**0.84**	**0.05**	**1.02**
Road freight, $kgCO_2e/kg$	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**
Proportion of product via RDC	0%	100%	100%	100%	100%	100%
Outbound distance (km)[1]	185	185	185	185	185	185
Empty backhaul distance (km) [2]	185	185	185	185	185	185
Lorry type	33t	33t	33t	33t	33t	33t
Lorry fuel	Diesel	Diesel	Diesel	Diesel	Diesel	Diesel
Frozen (F), chill (C), ambient (A)	C	C	C	C	C	F
Pallet type	Euro	Euro	Euro	Euro	Euro	Euro
Load per pallet (kg)[3]	818	1,000	1,000	800	1,000	800
Average load utilisation (%)[4]	71%	71%	71%	71%	71%	71%
RDC, $kgCO_2e/kg$	**0.00**	**0.01**	**0.01**	**0.01**	**0.01**	**0.02**
Frozen, chilled or ambient?	n/a	C	C	C	C	F
Retail, $kgCO_2e/kg$	**0.04**	**0.98**	**0.56**	**0.80**	**0.02**	**0.97**
Frozen, chilled or ambient?	C	C	C	C	C	F
Days in shop chiller/freezer[5]	1	5	5	5	5	10
... % time in open door unit	100	100	100	100	100	50
... % time in closed door unit	0	0	0	0	0	50

[1] "Life cycle assessment of example packaging systems for milk", WRAP (2010)
[2] BFF conservative assumptions – no references found
[3] Estimated using assumptions on product volume, product mass & pallet volume
[4] Carbon Trust default assumption for 33t articulated lorry
[5] Best Foot Forward assumptions – no references found

9.2 Use

Use phase addresses only electricity use and refrigerant leaks (i.e. not cooking). For the calculation of electricity emissions is assumed all products are consumed in United Kingdom (i.e. UK grid average electricity). No industry-standard assumptions were found for typical storage times so these were estimated and sense-checked by Carbon Trust.

Table 54: Product use assumptions

Variable	Milk	Butter	Cheese	Cream	Yoghurt	Ice cream
Total emissions, kgCO2e/kg	**0.01**	**0.15**	**0.07**	**0.04**	**0.04**	**0.13**
Frozen, chilled or ambient?	C	C	C	C	C	F
Product in fridge/freezer (days)	4	11	11	4	7.5	11
Portion size (g)[2]	250	5	30	15	150	75

[1] Best Foot Forward estimate from shelf life information for typical product

[3] From a variety of sources including http://www.milk.co.uk

9.3 End-of-life

Disposal emissions of dairy food waste were estimated using assumptions on average wastage rates (see table below). For assumptions on product packaging end-of-life see Section 8.1.1.

Table 55: Food wastage assumptions

Variable	Milk	Butter	Cheese	Cream	Yoghurt	Ice cream
Food wastage rate [4]	9%	9%	9%	9%	9%	9%
Disposal route	Sewer	Landfill	Landfill	Sewer	Sewer	Landfill

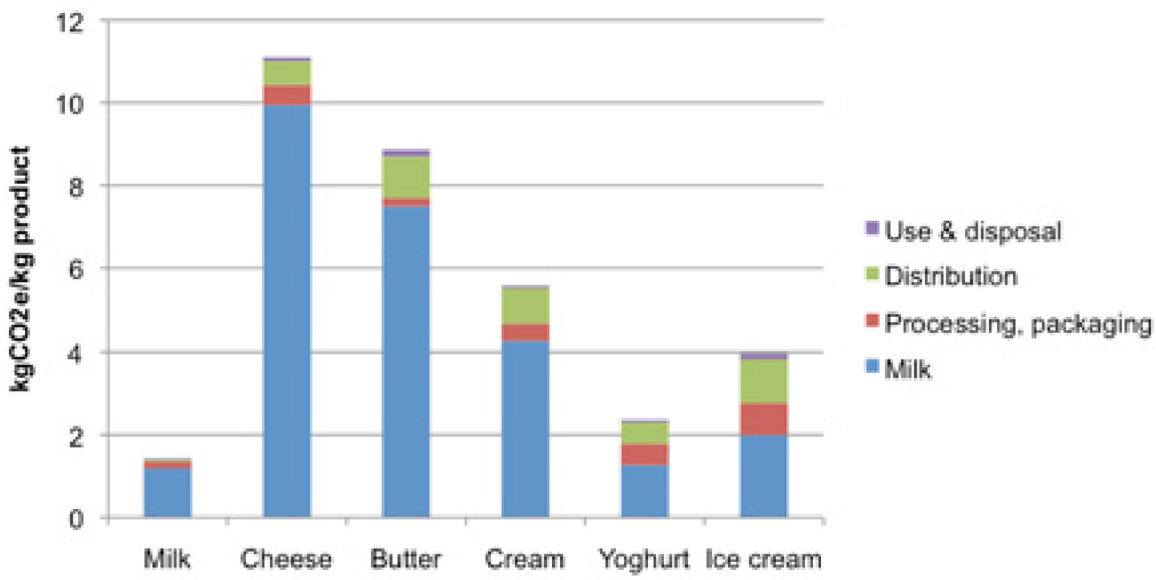
[4] 'Waste arisings in the supply of food and drink to households in the UK' – WRAP (2010)

10 Summary of cradle-to-grave results

Table 56: Summary of cradle-to-grave emissions (kgCO_2e/kg) for six products

Life cycle stage	Milk	Cheese	Butter	Cream	Yoghurt	Ice cream
Ingredient production	1.19	9.94	7.49	4.27	1.26	1.99
Processing & packaging	0.16	0.49	0.20	0.41	0.51	0.78
Distribution	0.06	0.59	1.01	0.84	0.52	1.06
Use & EOL	0.01	0.08	0.16	0.05	0.06	0.15
Total	1.4	11.1	8.9	5.6	2.4	4.0

Figure 5: Summary of cradle-to-grave emissions for six products



11 Quality assurance

11.1 Internal quality assurance

Best Foot Forward will undertake standard analysis and report quality assurance procedures – e.g. cell-by-cell checking of spreadsheet model, references, assumptions, data sources, etc.

11.2 External review

The Carbon Trust reviewed overall model approach, key assumptions, data sources and GHG accounting to ensure consistency with the draft Dairy Guidelines as far as is possible. The Carbon Trust also provided valuable insight during model development based on their significant experiences of carbon accounting in the UK dairy sector

The Carbon Trust did not undertake a cell-by-cell check of spreadsheet model – this was undertaken by Best Foot Forward as part of normal Quality Assurance checks. Nor was the model certified e.g. to PAS2050 or Carbon Label.

The Carbon Trust provided 7.5 days of support to the project. This amount of time provided an adequate level of review considering the overall aims of the project (i.e. to target hotspots and estimate supply-chain level emissions).

12 Appendix 1 - Works Cited

ADAS. 2004. *An evaluation of organic farming system research needs for Scotland.* s.l. : Scottish Executive, 2004.

ADAS Consulting Ltd. 1999. *Energy use in organic farming systems.* s.l. : Defra, 1999.

ADAS. 2007. *The Environmental Impact of Livestock Production.* s.l. : Defra, 2007.

AEA Technology. 2010. *Climate Change Agreements - Results of the Fourth Target Period Assessment.* s.l. : DECC, 2010.

—. 2009. *Climate Change Agreements: Results of Fourth Target Period Assessment.* 2009.

—. 2009. *End User GHG Inventories for England, Scotland, Wales and Northern Ireland:1990, 2003 to 2007.* s.l. : DECC, 2009.

—. 2009. *Greenhouse Gas Inventories for England, Scotland, Wales and Northern Ireland:1990 - 2007.* s.l. : DECC, 2009.

—. 2009. *UK Greenhouse Gas Inventory, 1990 to 2007 Annual Report for submission under the Framework Convention on Climate Change.* s.l. : DECC, 2009.

—. 2010. *UK Greenhouse Gas Inventory, 1990 to 2008 Annual Report for submission under the Framework Convention on Climate Change.* s.l. : DECC, 2010.

ATTRA. 2009. *Comparing Energy Use in Conventional and Organic Cropping Systems.* s.l. : National Sustainable Agriculture Information Service, 2009.

Audsley, E, et al. 2009. *An assessment of GHG emissions from the UK food system and the scope for reduction by 2050.* s.l. : WWF, 2009.

Azeez, G. 2009. *Soil carbon and organic farming.* s.l. : Soil Association, 2009.

Bosworth, M E, Hummelmose, B and Christiansen, K. 2000. *Cleaner Production Assessment of Dairy Processing.* s.l. : UNEP, Danish EPA, 2000.

British Standards Institute. 2009. *Publicly available specification on assessing the life cycle greenhouse gas emissions of goods and services (PAS2050).* 2009.

Brunel University. 2008. *Greenhouse Gas Impacts of Food Retailing.* s.l. : Defra, 2008.

Carbon footprinting - The science, challenges and benefits. **Aumônier, S. 2008.** 2008. Oxford Farming Conference.

Carbon Trust. 2010. *Footprint Expert Product Footprinting Tool.* [Excel] s.l. : Carbon Trust, 2010. http://www.footprintexpert.com/Pages/default.aspx. v3.1.

—. 2010. *Guidelines for the Carbon Footprinting of Dairy Products in the UK.* s.l. : Dairy UK & DairyCo, 2010.

—. 2010. *Industrial Energy Efficiency Accelerator - A guide to the animal feed milling sector.* s.l. : Carbon Trust, 2010.

College of Agriculture, Food & Rural Enterprise. 2005. *Challenge Note 2A: Grass budgeting for dairy farmers.* s.l. : Department of Agriculture and Rural Development, Northern Ireland, 2005.

Confederation, Agricultural Industries. 2010. Industry structure. [Online] 2010. [Cited: 30 April 2010.] http://www.agindustries.org.uk.

Dairy Energy Savings Ltd. *Climate Change Agreement data.* Fergus McReynolds, Personal communication.

Dairy Supply Chain Forum. 2008. *The Milk Roadmap.* s.l. : Dairy Supply Chain Forum, 2008.

—. 2009. *The milk roadmap: One year down the road.* s.l. : Dairy Supply Chain Forum, 2009.

Dairy UK. *Environmental benchmarking data.* Fergus McReynolds, Personal communication.

—. 2009. *Sustainability Report.* 2009.

DairyCo. 2009. *Dairy statistics - An insider's guide.* s.l. : DairyCo, 2009.

—. 2010. DairyCo - Datum. [Online] 2010. http://www.dairyco.co.uk.

—. 2008. *Distribution of Cows by Herd Size, Scotland.* s.l. : DairyCo, 2008.

—. 2007. *Effective Use of Water on Dairy Farms.* s.l. : MDC, 2007.

—. 2009. *Ensuring a sustainable dairy supply chain.* s.l. : DairyCo, 2009.
—. 2008. *Milk flow diagram.* 2008. http://www.dairyco.net/datum/milk-supply/uk-milk-flow-diagram/uk-milk-flow-diagram.aspx.
Defra. 2009. *Energy Use on Farms; Results from the Farm Business Survey, 2007/08.* s.l. : Defra, 2009.
—. 2009. *Farm practices survey. England farm size, type and regional results.* s.l. : Defra, 2009.
—. 2009. *Feedingstuff prices.* s.l. : Defra, 2009.
—. 2010. *GB Animal Feed Statistical Note.* s.l. : Defra, 2010.
—. 2002/3. *Grain fed to livestock (England and Wales).* s.l. : Defra, 2002/3.
—. 2009. *Guidance on how to measure and report your greenhouse gas emissions.* 2009.
—. 2008. *Organic statistics UK.* s.l. : Defra, 2008.
—. 2010. *Production of compounds, blends and other processed feedingstuffs in Great Britain.* s.l. : Defra, 2010.
—. 2010. *Surveys of milk utilisation by dairies in England and Wales, Scotland and Northern Ireland.* s.l. : Defra, 2010.
—. 2010. *The British Survey of Fertiliser Practice.* s.l. : Defra, 2010.
—. 2010. *UK Availability, Disposals and Production of Milk and Milk Products 2009.* s.l. : Defra, 2010.
Department of Energy & Climate Change. 2009. *UK Greenhouse Gas Inventory 1990 to 2007: Annual Report for submission under the Framework Convention on Climate Change.* 2009.
Dick, J., Smith, P., Smith, R., Lilly, A., Moxey,A., Booth, J., Campbell, C., Coulter, D. 2008. *Calculating farm scale greenhouse gas emissions.* 2008.
Dragosits, U., et al. 2008. *) Implications of farm-scale methane mitigation measures for national methane emissions.* s.l. : SAC and SEPA, 2008.
DTZ. 2007. *Scottish Primary Food and Drink Produce Processed in Scotland.* s.l. : Scottish Executive, 2007.
EPA Ireland. 2008. *BAT Guidance Note on Best Available Techniques for the Dairy Processing Sector.* 2008.
ERM. 2010. *Life cycle assessment of example packaging systems for milk.* s.l. : WRAP, 2010.
—. 2010. *Life cycle assessment of example packaging systems for milk (doorstep).* s.l. : WRAP, 2010.
FCRN. 2010. *Soil carbon sequestration workshop: Summary of discussion.* s.l. : FCRN, 2010.
Flysjöa, A, Cederberg, C and Dalsgaard, J. 2009. *Carbon Footprint and Labelling of Dairy Products – Challenges and opportunities.* s.l. : Joint Actions on Climate Chang, 2009.
Food Standards Agency. 2010. Approved dairy premises in Scotland. [Online] 2010. http://www.food.gov.uk/foodindustry/farmingfood/milkandairy.
Garnett, T. 2007. *Meat and dairy production and consumption.* s.l. : Centre for Environmental Strategy, 2007.
Generation of an Industry-Specific Physico-Chemical Allocation Matrix. **Feitz, A J, et al. 2007.** 12 (2) 109 – 117, s.l. : Int J LCA , 2007.
—. **Lundie, S, et al. 2007.** 2, s.l. : Int Journal of LCA, 2007, Vol. 12, pp. 109-117.
Gerber, Pierre, et al. 2010. *Greenhouse Gas Emissions from the Dairy Sector - A Life Cycle Assessment.* s.l. : Food and Agriculture Organisation, 2010.
Greenpeace. 2004. *GM and dairy cowfeed.* 2004.
HGCA. 2010. *UK Cereal Supply and Demand.* s.l. : HGCA, 2010.
Hopkins, A and Lobley, M. 2009. *A Scientific Review of the Impact of UK Ruminant Livestock on Greenhouse Gas Emissions.* s.l. : Centre for Rural Policy Research, 2009.
IFC. 2007. *Environmental, Health, and Safety Guidelines for Dairy Processing.* s.l. : International Finance Corporation, 2007.

International Dairy Federation. 2010. *A common carbon footprint approach for dairy (445/2010).* s.l. : IDF, 2010.
—. 2009. *Environmental/Ecological impact of dairy sector: Literature review.* s.l. : IDF, 2009.
—. 2005. *Guide on Life Cycle Assessment Towards Sustainability in the Dairy Chain.* s.l. : IDF, 2005.
International Organization for Standardization. *ISO14067 - Standard for measuring and communicating the carbon footprint of products (draft). .*
Internet-based tools for behaviour change. **Bottrill, C. 2007.** 2007. European Council for Energy Efficient Economies.
IPCC. 2007. *Fourth Assessment Report: Climate Change.* s.l. : IPCC, 2007.
—. 2006. *Guidelines for National Greenhouse Gas Inventories. Chapter 10: Emissions from livestock and manure management. National Greenhouse Gas Inventories Programme, Intergovernmental Panel on Climate Change.* s.l. : http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html, 2006.
—. 2006. *Guidelines for National Greenhouse Gas Inventories. Chapter 11: N2O Emissions from Managed Soils. National Greenhouse Gas Inventories Programme, Intergovernmental Panel on Climate Change.* s.l. : http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html, 2006.
Land Use and Climate Change Group. 2010. *Land Use Climate Change Report to Welsh Assembly Government.* s.l. : Welsh Assembly Government, 2010.
Laurence Gould Partnership. 2007. *Dairy enterprise cost study for year ending.* s.l. : Scottish Government, 2007.
Lundie, S, hias Schulz, M and Peters, G. 2009. *Fonterra carbon footprint measurement - Methodology report.* s.l. : Fonterra, 2009.
Lyne, A, et al. 2009. *"Product Origin – Scotland": A Review of Industry Practice & Evidence.* s.l. : RERAD, 2009.
Manchester University. 2007. *The Environmental, Social and Economic Impacts Associated with Liquid Milk Consumption in the UK and its Production.* s.l. : Defra, 2007.
McBain, C and Curry, J. 2009. *The Farm Management Handbook 2009/10.* s.l. : SAC Consulting, 2009.
Nemecek, T, Kägi, T and Blaser, S. 2007. *Life Cycle Inventories of Agricultural Production Systems. Final report ecoinvent v2.0 No.15.* Dübendorf, CH : Swiss Centre for Life Cycle Inventories, 2007.
New Zealand Institute of Chemistry. *Environmental issues in dairy processing.*
—. *Manufacture and use of cheese products.*
—. *Milkfat products.*
Nix, J. 2010. *Farm Management Pocketbook.* s.l. : The Andersons Centre, 2010.
Reay, G. 2008. *Pesticide usage in Scotland - Arable crops.* s.l. : Scottish Agricultural Science Agency, 2008.
RERAD. 2010. *Abstract of Scottish agricultural statistics 1982-2009.* s.l. : Scottish Government, 2010.
—. 2009. *Economic report on Scottish agriculture.* s.l. : Scottish Government, 2009.
—. 2009. *Farm incomes in Scotland 2007/8.* s.l. : Scottish Government, 2009.
—. 2009. *Local Versus Global Markets for Scottish Food: Producers and Consumers What Difference Does it Make?* s.l. : RERAD, 2009.
—. 2008. *Review into the Profitability of the Scottish Dairy Farm Sector.* s.l. : RERAD, 2008.
SAC Commercial Ltd. 2008. *UK Marginal Abatement Cost Curves for the Agriculture and Land Use, Land-Use Change and Forestry Sectors out to 2022, with Qualitative Analysis of Options to 2050.* 2008.
SAC. 2008. *The Impact of Increased Feed Costs on Scottish Agriculture.* s.l. : SAC, 2008. Agriculture & Rural Development Factsheet.

SAI Platform. 2009. *Discussion paper: Calculating GHG emissions in the dairy sector.* s.l. : SAI Platform, 2009.
Scottish Government. 2008. *Climate change and Scottish agriculture: Report and recommendations of stakeholder group.* 2008.
—. 2009. *Final results of the 2009 June Agricultural Census.* s.l. : Scottish Government, 2009.
—. *Milk utilisation statistics, Scotland.* Alistair McGregor, Personal communication.
—. 2008. *Scottish agricultural census summary sheets by geographic area, June 2007.* s.l. : Scottish Government, 2008.
—. 2010. *Scottish agricultural census summary sheets by geographic area, June 2009.* s.l. : Scottish Government, 2010.
—. 2009. *Scottish agriculture output, input and income statistics.* 2009.
Smith, H and Thanassoulis, J. 2008. *The Milk Supply Chain Project.* s.l. : University of Oxford, 2008.
Soil Association. 2009. *Organic Beef and Dairy Production: An introductory guide.* s.l. : Soil Association, 2009.
Struthers, G. 2009. *Pesticide usage in Scotland - Grass and fodder.* s.l. : Scottish Agricultural Science Agency, 2009.
Thomassen, M, et al. 2008. *Attributional and consequential LCA of milk production.* s.l. : Int J Life Cycle Assess, 2008.
UNFCCC. 2006. *Updated UNFCCC reporting guidelines on annual inventories following incorporation of the provisions of decision 14/CP.11.* 2006.
University of Aberdeen. 2007. *ECOSSE: Estimating Carbon in Organic Soils - Sequestration and Emissions: Final Report.* s.l. : Scottish Executive, 2007.
Warwick HRI. 2007. *AC0401: Direct energy use in agriculture: opportunities for reducing fossil fuel inputs.* s.l. : Defra, 2007.
WBCSD/WRI. 2004. *The Greenhouse Gas Protocol – A Corporate Accounting and Reporting Standard (Revised Edition).* s.l. : WBCSD/WRI, 2004.
—. 2010. *The Greenhouse Gas Protocol – Product Life Cycle Accounting and Reporting Standard (draft).* s.l. : WBCSD/WRI, 2010.
—. 2010. *The Greenhouse Gas Protocol – Scope 3 Accounting and Reporting Standard (draft).* s.l. : WBCSD/WRI, 2010.
Weidema, B, et al. 2008. *Environmental Improvement Potentials of Meat and Dairy Products.* s.l. : European Comission JRC, 2008.
Weir, R. 2009. *Mapping and Analysis of the Resilience of the Food Supply Chain in Scotland.* s.l. : Scottish Government, 2009.
Williams, A, Audsley, E and Sandars, D. 2006. *Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities.* s.l. : Defra, 2006.
World Resources Institute. 2006. *The Land Use, Land-Use Change, and Forestry Guidance for GHG Project Accounting.* 2006.
WRAP. UK Packaging Benchmark Database. *WRAP.* [Online] WRAP. http://www.wrap.org.uk/retail/tools_for_change/uk_best_in_class/index.html.

The Scottish Government

ISBN: 978-0-7559-9989-7 (web only)

APS Group Scotland
DPPAS11243 (11/10)

w w w . s c o t l a n d . g o v . u k