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The Environmental, Social and Economic Impacts Associated with Liquid Milk Consumption in the UK and its Production

A Review of Literature and Evidence

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The Environmental, Social and Economic Impacts Associated with Liquid Milk Consumption in the UK and its Production

A Review of Literature and Evidence

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1. Executive summary

1.1 Background and objectives

This report documents a review of evidence concerning the impacts of liquid milk production, processing, retailing and consumption on the environment and to a lesser extent, society and the economy (the economics of the dairy industry are extensively covered by other work). Its primary objective is to inform the "roadmap" being developed by the dairy industry and Defra to improve the sustainability performance of UK liquid milk.

The project sought to answer the following questions regarding the sustainable development impacts that occur in the life cycle of liquid milk consumed by individual consumers[1]:

1. what evidence exists for these impacts, and how robust and relevant to the UK is it?
2. to what extent can this evidence be related to functional units of 1 litre of raw milk produced and 1 litre of milk consumed?
3. what evidence exists about the potential for these impacts to be affected (positively or negatively) by innovations, interventions or system changes?
4. to what extent does the existing evidence highlight a need for further work, and what should be the focus of such work?

1.2 Method

The project primarily comprised a literature review focused on finding material that quantifies impacts arising from the production, processing, distribution and consumption of liquid milk in the different forms available to the consumer. A significant part of the relevant literature reports environmental life cycle assessment (LCA) studies. These generally treat production-consumption systems as comprising a series of stages (for food products, these might be production, processing, distribution, preparation and use) and such an approach has been adopted here. The brief required that the LCA practice of relating all impacts to a set amount of product (the “functional unit”) was also followed: in this case, the amount of product was 1 litre of milk consumed.

Importantly, this project has sought to incorporate evidence about environmental and social themes not normally considered in LCA alongside LCA results. The project went beyond pure literature review by using the Cranfield University agricultural LCA model (for the farm stage) and Life Cycle Impact Assessment calculations combined with data provided by the Dairy Roadmap Taskforce (for later stages), to explore the implications for environmental impacts of the range of UK practice identified. This exercise has been particularly important to answering the third question listed above.

[1] Liquid milk for further processing (e.g. into confectionery) was not considered. However it has not been possible to exclude some consideration of liquid milk used to produce cooked food in retail outlets such as restaurants.

The quality of the evidence concerning different impacts at each stage of the system has been assessed, and where quantitative values were available these have been related to 1 litre of milk consumed.

1.3 Results

The UK milk system

Figure A 1 (pviii) characterises the UK milk system as considered in this project[2].

Impacts associated with liquid milk

The impacts arising in the liquid milk system have been described for the following stages:

- dairy farming
- transport to the dairy
- milk processing
- milk packaging
- milk transport to the “retail distributor”
- milk retailing and transport to the consumer
- milk utilisation.

For those impacts that can be both quantified and related to one litre of milk, the values at each stage are shown in Table A 2 (pxii).

In agreement with previous studies, this research concludes that agricultural production contributes the largest proportion of environmental impacts for most environmental themes. The social impacts of employment, which is greatest in the dairy farming stage, and of nutrition, which arise at the point of utilisation, are of course not comparable.

Both dairy farming and arable farming to produce dairy farm inputs have impacts on the soil, the landscape and affect biodiversity in the areas they occupy. Evidence about these has been reviewed, but no basis was found for relating such impacts to milk volume, whether of milk produced or milk consumed. Nor was sufficient evidence found to quantify the difference between different products or modes of milk production for these impacts.

Table A 1 (pix) shows how different inputs of dairy farming account for different proportions of the environmental impacts covered by LCA.

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[2] Figure A1 draws on a number of sources so the numbers in it are not fully internally-consistent, and it does not constitute a mass balance of the UK milk industry

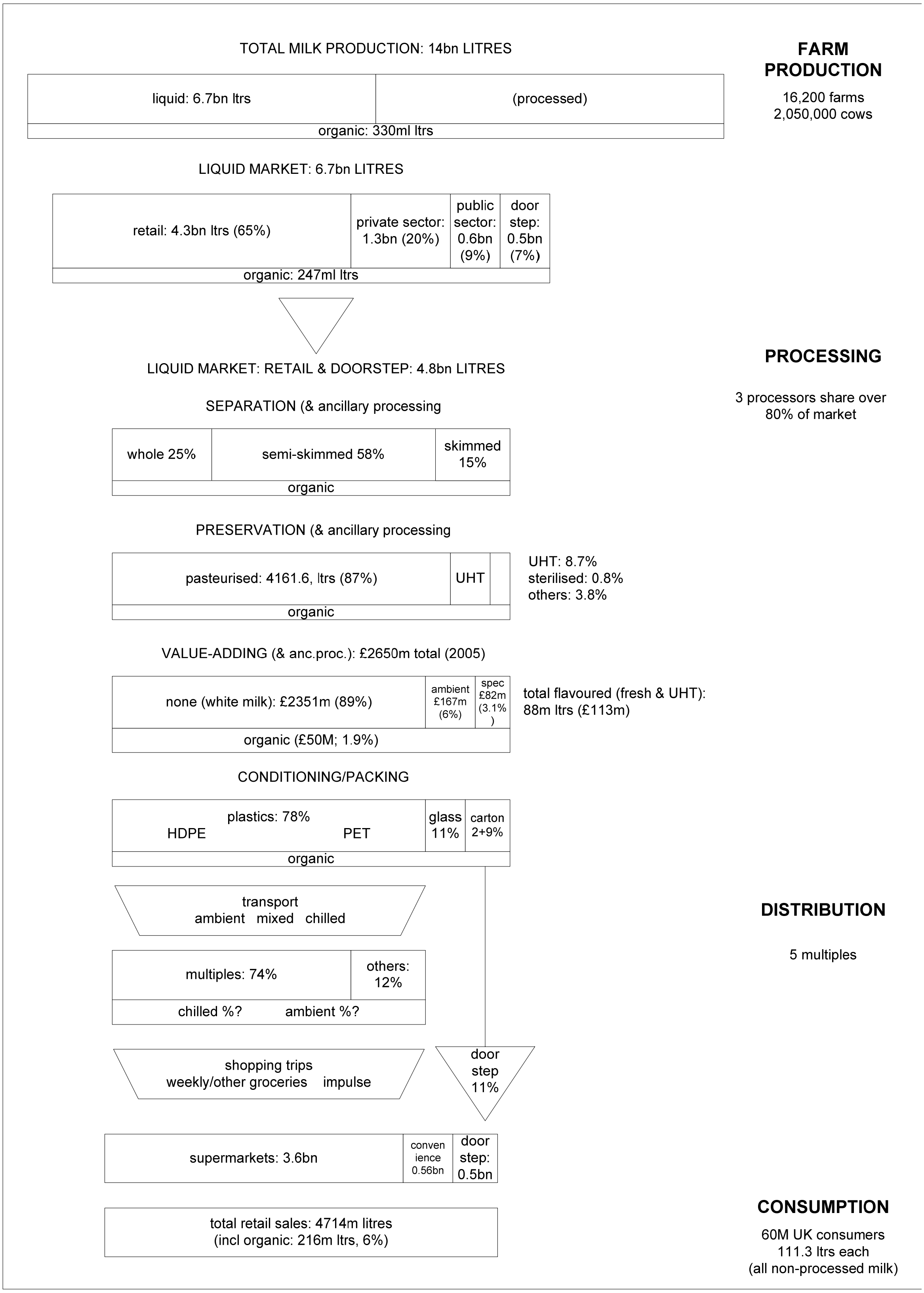

Figure A 1: Milk in the UK

After agricultural production, processing and packaging are found to make the next most significant contributions to overall impacts on the basis of the available evidence. These impacts are largely associated with consumption of fossil energy resources, whether directly or indirectly.

Milk wastage by users is potentially a significant cause of impacts – because the associated production, processing and transport fails to provide function, but there is very little quantitative evidence about the extent of this.

	Primary energy used	**GWP_{100}**	**Eutrophication potential**	**Acidification potential**	**Abiotic resource use**	**Land use**
	MJ	kg CO_2 eq.	kg PO_4 eq.	kg SO_2 eq.	kg Sb eq.	ha
Concentrates	1001	234	0.8	1.3	1.9	0.04
Grass	884	242	2.9	6.3	0.6	0.09
Forage maize	125	36	0.1	0.1	0.1	0.01
Manure	-34	62	1.7	6.2	0.0	-0.01
Direct energy	839	50	0.0	0.3	0.9	0.00
Direct emissions	0	516	0	2	0	0
TOTAL	2816	1141	6	17	3	0

Table A 1: LCA values for the production of 1,000 litres liquid milk, by farm input
(no allocation to beef)

1.4 Conclusions

Evidence quality

For agricultural systems, evidence is best for primary energy and land use associated with the production of arable crops for feed, and for acidification and eutrophication arising directly from dairy farm operations. Evidence for other impacts from this stage is weakened by underlying scientific uncertainties, such as those relating to nitrous oxide (N_2O) releases.

For the transport stages of the system, evidence is strongest for transport to the dairy, becoming weaker as milk moves closer to the consumer and its transport becomes increasingly mixed with the transport of other foods. Evidence about some impacts to which transport is generally a more significant contributor (those in which particulate emissions play a major part, for example) is weaker, being difficult to collect on a product-specific basis.

For processing, evidence about modern, larger plants (which account for most liquid milk processing) is good. However, evidence linking impacts to different products is weaker.

The impacts of packaging are well-understood; work is in progress (by WRAP) to examine these as they relate to liquid milk delivered to final consumers in the UK.

For milk retailing and utilisation, quantitative evidence for milk-specific impacts is sparse. As with transport impacts at the retail and consumer ends of the system, tying impacts to individual products presents significant challenges.

Factors influencing impacts

Dairy farming is closely connected to beef production by the transfer of animals from the former to the latter. The effective sharing of animal-rearing burdens between the two systems is an important influence on the impacts associated with each.

Important variables in dairy farming that have a significant affect on the impacts associated with milk production are:

- the annual milk yield of individual cows
- whether farm practice is organic or non-organic
- the time of year at which calves are born
- the level of fertiliser application to grassland
- the proportion of forage maize in cows' diet
- the proportion of clover in cows' diet

The influence of each of these variables on individual impacts is different, both in magnitude and – in some instances – in direction. For example, increasing fertiliser application reduces the land used to produce a given volume of milk while increasing the associated primary energy demand and global warming potential (GWP), while moving from non-organic to organic farming reduces primary energy demand while increasing land use and GWP.

It is clear that many of these significant variables are the subject of current research and development.

While there is limited evidence that organic farming brings benefits in terms of biodiversity, neither this nor the evidence about other impacts is extensive or strong enough to allow a detailed analysis of influencing factors.

In processing, the scale of operations strongly affects impacts, with economies to scale being identifiable for both energy and water consumption. Heat treatment and cooling appear to be the principal aspects of processing that drive impacts. The trend towards product diversification generally works against the achievement of resource efficiency through larger scale in processing.

For packaging, pack weight and the fate of packaging after use are key influences on environmental impacts. For reusable containers, the number of uses (the "trippage rate") is a critical factor. These influences are, of course, common across all products and not particular to milk.

Refrigeration occurs at most stages of the system (for fresh milk, it is only absent from transport to the dairy and transport from retailer to home). The effectiveness of refrigeration systems and the efficiency with which they are operated are believed to have a significant cumulative effect on impacts across the system.

Potential for change

The following are suggested as opportunities for change at various points in the system that could reduce environmental impacts in the relatively short term:

- promoting the necessity of matching feed to yield to maximise efficiency (as output per cow)
- continuing and/or developing initiatives to benchmark on-farm energy and water use / water management and adopting the means to reduce usage across the sector
- examining how fertiliser application and use might be made more effective at the farm-level, through the greater use of support tools designed for this process, and through the use of new technologies
- encouraging the application of “best available techniques” in all milk processing
- encouraging the uptake of best practice in the operation of refrigeration systems, and of new refrigeration technologies.

Pursuing some potentially beneficial changes in farm practice (e.g. moving towards a bias for calving to occur in the spring) is likely to require change by processors, retailers and perhaps consumers, notably:

- addressing the demand for milk (particularly fresh milk) in periods when production is ‘least environmentally efficient’ and reviewing the price incentives for autumn calving
- addressing the market-pull for lower-impact milk, and (with processors and farmers) how this might be incentivised at farm-level.

Other changes are identified that could take place and that would lead to significant changes in the impacts arising from milk production and consumption, such as the development of low-environmental-impact food distribution systems, or the replacement of natural gas by a more sustainable source of hydrogen for the production of ammonia. These changes are beyond the direct control of the actors within the liquid milk system, although their implementation would probably require change on the part of those actors.

Table A 2: LCA impacts of liquid milk

L-C stage	Volume leaving the stage to provide 1 litre consumed	Impact	Units (all per litre milk consumed)	Value (blank if unknown, N/A if not likely to be accessible)	Comments
Raw milk production	1.30l	*Primary energy*	MJ	3	Average impacts for UK milk from Cranfield LCA
	1.5% adjustment for on-farm milk use ex MDC data	*GWP*	kg CO_2 eq	1	
		Acidification	kg SO_2 eq	2 $\times10^{-2}$	12% of raw milk production impacts allocated
		Eutrophication	kg PO_4^{3-} eq	6×10^{-3}	
		Abiotic resource	kg Sb eq	3×10^{-3}	
		POCP	kg C_2H_4 eq	1 $\times10^{-2}$	
		Water use	litre	8	
		Biodiversity		N/A	
		Land use	ha	1×10^{-3}	
		Soil quality			
		Landscape impact		N/A	
		Employment	jobs	3×10^{-6}	
		Vehicle movements	vehicle km	N/A	
Transport to the dairy	1.28l	*Primary energy*	MJ	2 $\times10^{-1}$	
	Allowing for cream removal and processing loss	*GWP*	kg CO_2 eq	1 $\times10^{-2}$	
		Acidification	kg SO_2 eq	6×10^{-5}	
		Eutrophication	kg PO_4^{3-} eq		
		Abiotic resource	kg Sb eq		
		POCP	kg C_2H_4 eq	5×10^{-6}	
		Water use	litre		
		Biodiversity		N/A	
		Land use (direct)		N/A	
		Soil quality		N/A	
		Landscape impact		N/A	
		Employment	jobs		
		Vehicle movements	vehicle km	1 $\times10^{-2}$	

L-C stage (cont'd)	Volume leaving the stage to provide 1 litre consumed	Impact	Units (all per litre milk consumed)	Value (blank if unknown, N/A if not likely to be accessible)	Comments
Milk processing	1.2l Including material lost & becoming waste	*Primary energy*	MJ	1	Expected to be higher for UHT, µ-filtered variants
		GWP	kg CO_2 eq	6 x10^{-2}	
		Acidification	kg SO_2 eq	1 x10^{-4}	
		Eutrophication	kg PO_4^{3-} eq	2x10^{-5}	
		Abiotic resource	kg Sb eq		
		POCP	kg C_2H_4 eq	1x10^{-4}	
		Water use	litre	1	
		Biodiversity		N/A	
		Land use (direct)		N/A	
		Soil quality		N/A	
		Landscape impact		N/A	
		Employment	jobs	2 x10^{-6}	
		Vehicle movements	vehicle km	N/A	
Packaging	packaging for 1.18l	*Primary energy*	MJ	2	4-pint HDPE bottles, production only. No allowance for recovery, reuse etc.
		GWP	kg CO_2 eq	6 x10^{-2}	
		Acidification	kg SO_2 eq		
		Eutrophication	kg PO_4^{3-} eq		
		Abiotic resource	kg Sb eq		
		POCP	kg C_2H_4 eq		
		Water use	litre		
		Biodiversity			
		Land use (direct)			
		Soil quality		N/A	
		Landscape impact		N/A	
		Employment	jobs		
		Vehicle movements	vehicle km		

L-C stage (cont'd)	Volume leaving the stage to provide 1 litre consumed	Impact	Units (all per litre milk consumed)	Value (blank if unknown, N/A if not likely to be accessible)	Comments
Transport to retailer	1.18l	*Primary energy*	MJ	3 x10^{-1}	
		GWP	kg CO_2 eq	2 x10^{-2}	
		Acidification	kg SO_2 eq	1x10^{-4}	
		Eutrophication	kg PO_4^{3-} eq		
		Abiotic resource	kg Sb eq		
		POCP	kg C_2H_4 eq		
		Water use	litre	N/A	
		Biodiversity		N/A	
		Land use (direct)		N/A	
		Soil quality		N/A	
		Landscape impact		N/A	
		Employment	jobs		
		Vehicle movements	vehicle km	5 x10^{-2}	
Retailing	1.18l Application of WRAP 15% factor for wastage by the consumer	*Primary energy*	MJ	7 x10^{-2}	Storage in large
		GWP	kg CO_2 eq	1 x10^{-2}	
		Acidification	kg SO_2 eq	4 x10^{-5}	
		Eutrophication	kg PO_4^{3-} eq	3 x10^{-5}	
		Abiotic resource	kg Sb eq	1x10^{-3}	
		POCP	kg C_2H_4 eq	2 x10^{-8}	
		Water use	litre		
		Biodiversity		N/A	
		Land use (direct)		N/A	
		Soil quality		N/A	
		Landscape impact		N/A	
		Employment	jobs	N/A	
		Vehicle movements	vehicle km	N/A	

L-C stage (cont'd)	Volume leaving the stage to provide 1 litre consumed	Impact	Units (all per litre milk consumed)	Value (blank if unknown, N/A if not likely to be accessible)	Comments
Utilisation	1.0l	*Primary energy*	MJ	3 x10^{-1}	Storage for milk consumed only. No allowance for transport
		GWP	kg CO_2 eq	2 x10^{-2}	
		Acidification	kg SO_2 eq	6x10^{-5}	
		Eutrophication	kg PO_4^{3-} eq	4 x10^{-6}	
		Abiotic resource	kg Sb eq	2 x10^{-4}	
		POCP	kg C_2H_4 eq	3 x10^{-8}	
		Water use	litre	N/A	
		Biodiversity		N/A	
		Land use (direct)		N/A	
		Soil quality		N/A	
		Landscape impact		N/A	
		Employment	jobs	N/A	
		Vehicle movements	vehicle km		

Notes:
POCP is Photochemical Ozone Creation Potential. A measure of the propensity of releases to contribute to low-level ozone creation.
GWP stands for Global Warming Potential

Further work

Throughout the report, current research is identified that may facilitate future improvements in the sustainability of the milk production-consumption system. A number of areas for further work are identified, however. These are of particular relevance to the liquid milk roadmapping exercise. They fall broadly into 3 groups:

- evidence gathering work: some of the gaps and weaknesses in the evidence base deserve attention, for example those concerning utilisation of milk by consumers and the foodservice sector
- work aimed at understanding which incentives would best promote uptake of best practice in resource efficiency and pursuit of “environmental excellence” by dairy farmers to build on progress already made through agri-environment schemes
- methodological development to enable impacts such as biodiversity or landscape quality, which arise on the farm scale or greater, to be more readily considered alongside resource-efficiency and emissions-driven impacts. Such work would have value for other “roadmapping” projects concerned with food products.

2. Introduction

This report documents a review of evidence concerning the impacts of liquid milk production, processing, retailing and consumption on the environment, society and, to a lesser extent since the economics of the dairy industry are covered by other work, the economy. Its primary objective is to inform the "roadmap" being developed by the dairy industry and Defra to improve the sustainability performance of UK liquid milk.

The review's emphasis is on evidence about environmental impacts. It is well-recognised that while industries need to be environmentally sustainable to survive in the long term, this is not a sufficient condition for them to continue to exist: social and economic sustainability are also important. This review therefore also seeks to identify evidence about the social and economic impacts of milk production and consumption, and more particularly the social and economic implications of change in this production-consumption system.

3. Method

3.1 Objectives

This short project sought to answer the following questions regarding the sustainable development impacts that occur in the life cycle of liquid milk consumed by individual consumers[3]:

1. what evidence exists for these impacts; how robust and relevant to the UK is it?
2. to what extent can this evidence be related to functional units of 1 litre of raw milk produced, and 1 litre of milk consumed?
3. what evidence exists about the potential for these impacts to be affected (positively or negatively) by innovations, interventions or system changes?
4. to what extent does the existing evidence highlight a need for further work, and what should be the focus of such work?

3.2 Research techniques

The method has been that of a literature review focused on finding material that quantifies impacts arising from the production, processing, distribution and consumption of liquid milk in several forms available to the consumer:

- semi-skimmed pasteurised, semi-skimmed UHT, semi-skimmed organic
- skimmed pasteurised
- standardised whole milk, pasteurised

[3] Liquid milk for further processing (e.g. into confectionery) was not considered. However it has not been possible to exclude some consideration of liquid milk used to produce cooked food in retail outlets such as restaurants.

Underlying the method used in this project are the principles of Life Cycle Assessment (LCA). LCA analyses production systems systematically to account for all inputs and outputs that cross the specified boundaries of the “product system” (Figure 1 p2). The mass and energy flows at the system boundary must balance. The useful output is termed the functional unit, which must be of a defined quantity and quality, for example 1,000 litres fat-corrected milk. The function of the milk is to provide us with high quality nutrition. There may be co-products like manure (which is waste product as far as the animal is concerned, but is treated as a co-product in the LCA that is credited with its fertiliser content, but debited with its management burdens) or waste products that are of no use (e.g. unrecyclable packaging), together with emissions to the environment, for example nitrate (NO_3^-) to water or nitrous oxide (N_2O) to the air. All inputs are traced back to primary resources, for example electricity is generated from primary fuels like coal, oil and uranium (and their burdens of refining). Ammonium based fertilisers use methane as a feedstock and source of energy. Phosphate (P) and potassium (K) fertilisers require energy for extraction from the ground, processing, packing and delivery. Tractors and other machinery require steel, plastic, and other materials for their manufacture, all of which incur energy costs, in addition to their direct use of diesel. The minerals, energy and other natural resources so used are all included in an LCA. Allowance is also made for making the plant used in industrial processes (factory or power station) as well as the energy used directly.

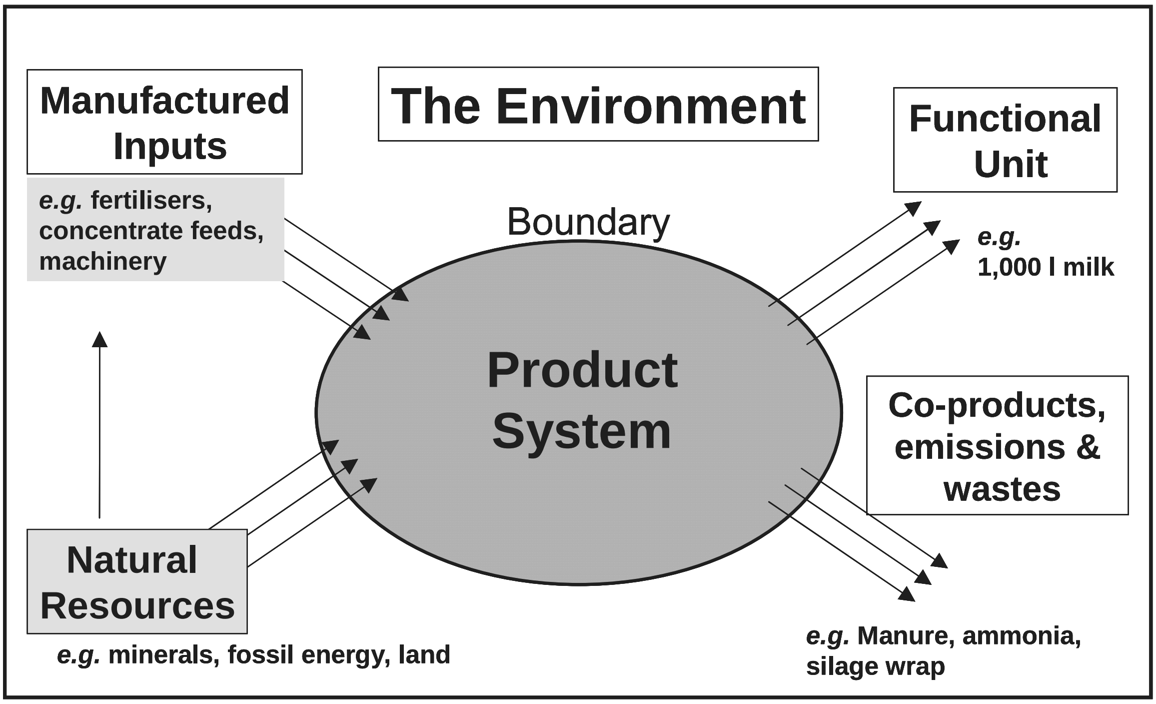

Figure 1: The LCA concept

The application of LCA to agricultural products is discussed in Williams, Audsley & Sandars (2007) and Williams et al., 2006, while its application to entire food product life cycles is considered in Foster, Green et al. (2006), Berlin 2003 and Jungbluth, Tietje & Scholz (2000).

In the Cranfield agricultural LCA of milk production (Williams, Audsley & Sandars, 2007), all inputs (except veterinary ones) are included, e.g. the overheads of followers, growing and conserving forage, growing grains and their processing into concentrates. Some grains are assumed to be grown overseas, e.g. maize and soya. Burdens of producing feeds like soya or rape meal or wheatfeed are allocated between the primary product (oils or flour) and the co-product (animal feeds) using economic valuation. There is also a credit for cull cows entering the beef supply. Changing input parameter values, such as calving index, thus affects the whole production system and the consequences are reflected in the burdens of producing the functional unit of 1,000 litres milk. This method thus goes considerably beyond other approaches that may consider only effects of changes in practice on, for example, a per hectare basis.

To be exact, the UK liquid milk life cycle being considered by the Liquid Milk Roadmapping Project constitutes several "product systems": the function delivered to consumers by each of the products listed above is slightly different, and there is more than one "system" for production and delivery to the dairy of raw milk (see next Section). This project is not an LCA entailing strict application of the ISO standards that apply to LCA (ISO 14040, 2006 & ISO14044, 2006), but applies LCA principles. It draws heavily on the LCA of milk carried out by Cranfield University and reported in Williams *et al*. (2006) for the basic analysis of environmental impacts arising from raw milk production. The functional output of the product systems is milk consumed by individuals which entered the retail outlet as liquid. It should be noted that milk consumed is not the same as milk purchased, although data that is supposedly about "consumption" appears to neglect the difference more often than not.

Setting a boundary around the liquid milk product system is less straightforward than it first appears. Of the milk that leaves the dairy as liquid, not all goes to retail outlets, since some is used in further processing. Of that which enters foodservice-type retail outlets[4], some may be used for cooking the same foods as milk taken into industrial food processing, while some will be presented to consumers in its liquid form. But milk purchased from a shop by the individual may also be divided in the home between the same cooking uses and consumption as liquid. On the basis of discussions about the issues and impacts of interest to the roadmap project team, the boundary noted above has been used.

The original project specification stated that this project would seek to describe in some detail an individual product system for each of the products listed earlier for the UK, and that consolidated data from the review would be linked to a single litre of each one. It is apparent that, for some stages of the chain, published data to quantify the impacts associated with particular liquid milk products barely exist. In some cases, there is a stronger basis for a discussion of the consequences of changing practice, or changing from one product to another. So as well as trying to describe the single product systems to the extent possible, this report also considers the consequences of changing the relative importance of the different liquid milk product systems within the wider UK liquid milk life cycle.

This project deviates from conventional LCA practice in another significant manner. It includes environmental impacts which are not conventionally covered in LCA, such

[4] Which include food service outlets

as biodiversity, and certain socio-economic consequences (also termed impacts here) of the production, processing, distribution and consumption of milk. LCA typically covers the following environmental impacts: primary energy use, climate change (as global warming potential, GWP), eutrophication, acidification, impact on low-level air quality (as Photochemical Ozone Creation Potential, POCP), toxicity (both as human toxicity and ecotoxicity) and abiotic resource depletion. Cranfield's LCA of agricultural commodities also encompasses land use, water use and pesticide use (in lieu of toxicity). The additional impacts considered in this project are:

- soil properties, including carbon content
- biodiversity
- landscape value and recreational use value
- employment
- animal welfare
- vehicle movements
- human health & nutrition

It is important to note that for some impacts at certain stages of the life cycle, the relationship between throughput and impact is not well-established, while for others there is no obvious link. Exploring the evidence that might demonstrate or clarify such relationships has been an important component of the research.

We have considered commercial aspects of the liquid milk life cycle to a limited extent, since the economics of the dairy industry are explored in detail in much recent research (e.g. Colman *et al.* (2002), MDC (2005), Frontier Economics (2005), Moss *et al.* (2007), Defra (2007a)).

3.3 The UK liquid milk life cycle

The life cycle of UK milk can broadly be divided into the following parts, discussed in more detail in the bulk of the report:

- production of farm inputs (pre-production)
- dairy farming (production)
- transport to the dairy
- dairy processing
- milk packaging
- milk transport to the retail distributor
- milk retailing and transport to the consumer
- milk utilisation

This life cycle is summarised in Figure 2 (p5).

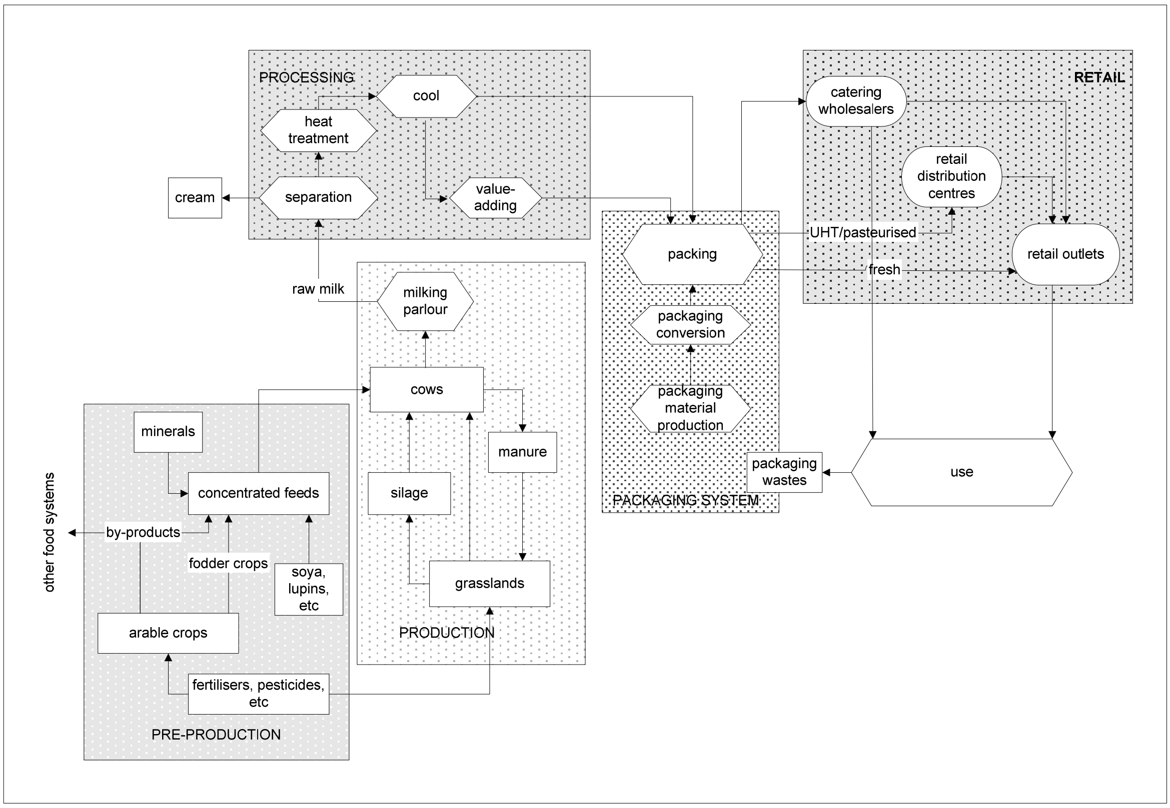

Figure 2: Milk LCA summary

Production of farm inputs (pre-production)

The range and volume of inputs used on individual dairy farms varies considerably. Farms that produce most of the food for their cows in situ require different inputs from those that make more use of purchased feeds. Agricultural machinery, fuels, and inorganic chemical fertilisers are brought in by all who use them. Manures (organic fertilisers) and forage crops can be brought to the farm or produced on it.

Dairy farming (production)

On the farm, cows are raised, fed and milked. As well as differences in farming practice between organic and non-organic farms, there are major differences between farms in many other areas, including calving patterns, feed regimes and genetics. Farm operations include the maintenance of grazing, provision of winter housing and feed, animal husbandry (especially managing cow pregnancy), manure management, operation of milking parlour machinery (which includes milk chilling) and the management of non-productive land (hedgerows, set-aside).

Dairy farming is closely connected with beef production. Forty percent or more of beef production in the UK utilises the progeny of the dairy herd, while cull cows are used as lower-grade meat (in fact for the year 2006, 51% of beef animals emanated from the dairy herd on a headage (rather than weight) basis, made up of 43% ‘clean cattle’ and 8% cull cows (MLC 2007)).

Dairy farming is also connected with arable crop production, through animal feed. In this context, dairy farming uses products such as feed wheat directly, while indirectly it is a major user of by-products from the food industry, such as oilseed meal, brewers' grains and wheatfeed. It also uses imported arable crops and their by-products such as maize and soyabean. LCA also takes into account the inputs and burdens of these and their land use.

Transport to the dairy

Milk is collected from the farm by the milk purchaser to which the farm is contracted. Bulk milk tankers transport chilled milk either directly from the farm to the dairy or via a 'transhipment depot' (the tankers themselves are insulated, but not refrigerated). Raw milk may pass through transhipment depots on its way to the processing plant. Imports account for a relatively small proportion of all liquid milk, although imports of organic milk are reported to be rising (Defra 2007a). Organic milk produced in the UK is collected separately: a dedicated co-operative for organic milk suppliers[5] handles about half, while other dairy processors handle the rest. Some farmers are contracted to supply milk for sale by particular retailers: we refer to this as "source-specified milk"[6]. The collection system must ensure that this material is tracked and kept separate for subsequent dedicated processing and packaging.

Dairy processing

Milk for sale as liquid is processed separately from milk destined for cheese. At the dairy, cream is separated from the milk and the three familiar liquid milk variants are generated: standardised whole milk, semi-skimmed milk and skimmed milk. Cream leaves the liquid milk system at this point; since it has economic value, some of the burdens of raw milk production are allocated to it.

Different degrees of heat treatment are applied to produce pasteurised, UHT and sterilised milk. Some pasteurised milk is subject to an additional micro-filtration step. Some milk is further processed to produce flavoured milk drinks. Organic and source-specified milk are treated in the same ways, but separately. After packing, pasteurised milk is kept in refrigerated storage for the short time before its despatch to the retailer, while UHT and sterilised milk can be kept at ambient temperatures, and for longer periods.

Milk packaging

High-density polyethylene (HDPE) bottles are the most popular form of milk packaging, in 1-, 2-, 4- and 6-pint variants. Board and laminated-board cartons, polyethylene terephthalate (PET) and glass bottles are also significant in the range of packaging used for liquid milk. Some larger containers are used to distribute milk, mainly to industrial customers, and linear low-density polyethylene (LLDPE) pouches are being tested. The foodservice sector is supplied with milk in a variety of small packs holding about 5 ml. We have no detailed information about the material composition of these; most are polymer mouldings with foil or laminate covers, although the "Dairystix" pack also appears to be a PE film.

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[5] The Organic Milk Suppliers' Co-operative, OMSCo

[6] The common industry terminology for this is "dedicated supply-chain" milk

Milk transport to the retail distributor

Pasteurised milk remains in the “cold chain” and is delivered directly from the dairy to major retail outlets and many convenience stores[7] in dairy processors’ own vehicles. UHT and sterilised milk are distributed to retailers via the latter’s main regional distribution centres (RDCs). The distribution route for milk sold to the foodservice industry is unclear, but probably parallels that for other foods. Smaller foodservice outlets also obtain liquid milk from large retailers.

Milk retailing and transport to the consumer

Milk “retailing” encompasses numerous points at which the consumer takes possession of milk. Supermarkets, petrol-stations and newsagents all sell liquid milk in differing levels of variety. But coffee shops, restaurants and buffet-cars on trains are also milk retailers, often providing liquid in single-portion packs to avoid contamination and limit the potential for spillage. They also take in liquid milk and transform it into cooked products just as individuals do in their homes.

The traditional doorstep milk delivery service and the online stores of major multiples constitute milk retailers that the consumer doesn’t visit physically. Milk is collected from the other outlets mentioned either alone, or with other goods. As one of the shorter-life products in the kitchen, its purchase may have been the initial impetus for the trip to the shops, even if it was not the only item that ended up in the shopping basket.

Within the retail outlet, fresh milk is stored in refrigerated areas, while UHT products are generally kept at ambient temperatures (certainly in larger shops).

Milk utilisation

Household purchases of milk account for around 1/3 of raw milk produced in the UK and around 3/4 of the liquid milk market. Milk is consumed with cereal, drunk on its own and – of course - in tea and coffee and a smaller proportion is used in cooking; some is simply discarded without being consumed. Consumption with cereals is reported to be the biggest single use, accounting for some 40% of uncooked milk use in households (TNS, 2007). Children account for around 60% of milk (and 80% of whole milk) that is drunk. Note that because cooking is not one of the most popular uses for milk, it is considered to be beyond the remit of this study.

While obviously similar, the mix of nutrients provided differs slightly between whole milk, semi-skimmed milk and skimmed milk.

Fresh milk is stored in a refrigerator by almost all consumers. UHT and sterilised milk can be stored at ambient temperature but require refrigeration once opened.

Milk packaging becomes waste at the point of use; it may be recovered or recycled if the infrastructure exists and is used. In the body of this report, the management of packaging waste and the associated impacts are considered under the heading “Milk packaging” (p56).

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[7] Exact details of distribution routes for milk to the entire range of retail outlets that sell it are not clear

3.4 UK liquid milk in figures

One objective of this work was to understand the potential significance of various changes. To do that, it is necessary to understand the way the system is constituted now. Figure 3 (p9) provides some detail about the liquid milk system in the UK. The underlying data used to produce this analysis come from several sources, so some discrepancies remain. Producing a detailed mass balance for the UK liquid milk system was not within the remit of this project.

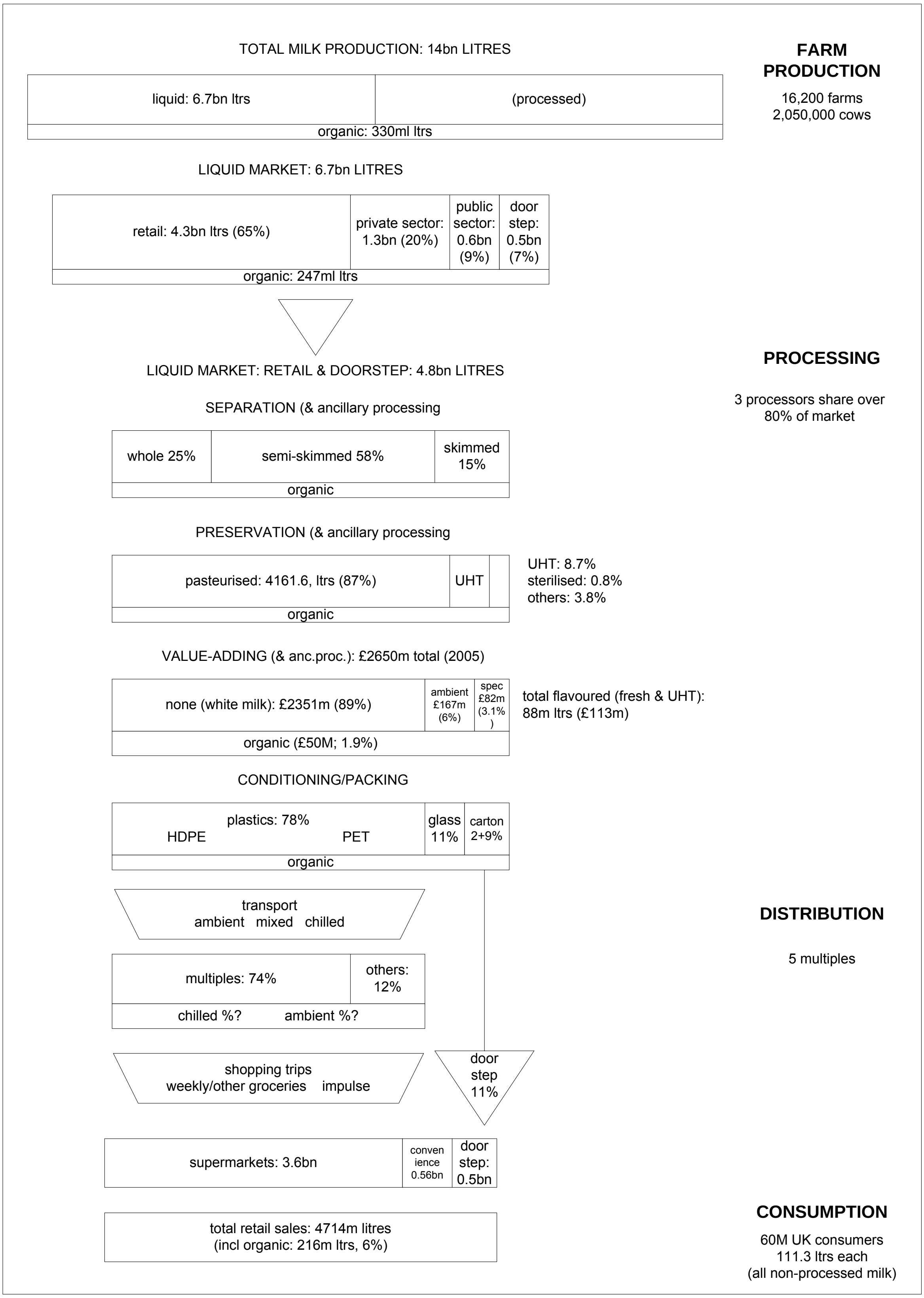

Figure 3: Milk in the UK

4. Results

4.1 Milk production - introduction

Milk production may be conceptualised in a series of stages, each with its own inputs and outputs. Many of these stages and inputs/outputs are used by the dairy industries as a means of measuring and monitoring performance. For example, farm level inputs such as purchased feed, fertiliser, straw, energy and water, together with labour, capital-investment and depreciation have been balanced against milk outputs to produce industry key performance indicators such as 'margin over purchased feeds'.

Other inputs and outputs have been of relatively low importance to the sector as a whole, or have proved more difficult to quantify, and as such have little in the way of good quality data attached to them. Such impacts are for the most part external to the financial exchanges by which inputs and outputs are allocated. Previous authors have described (e.g. Pretty, 2001; Eftec, 2004) and attempted to provide figures for the overall financial value (e.g. O'Neill, 2007) of the positive and negative 'externalities' of UK agriculture. Thus diffuse pollution from dairy farming may present a cost to the water industry, just as the improvement, by farming practices, of countryside biodiversity and landscape value of hedges, stone walls and pasture might present a benefit to the public. However, for a sector such as dairy farming which consists of many thousands of micro-businesses, the relevance of estimated and hypothetical financial values is limited. Neither are directly included in the costs of farm inputs or in the farm gate price of milk. What matters here is the scale of the externalities of milk production and the potential for the sector to reduce the negative and increase the positive impacts of their industry without threatening its commercial viability.

Pre-production	**Production**	**"Externalities"**
Inputs Fertliser Water Energy Feed Buildings Machinery	Dairy system Cows Herd replacement Fields Staff	Social consequences Employment Land management
	Outputs Milk Cull cows Calves Manure	Emissions CO_2 CH_4 N_2O NO_3^- NH_3 Silt/sediment

Table 1: Simplified inputs and outputs for dairy farming

Cranfield's 'environmental burdens report' (Williams *et al.*, 2006) modelled the environmental burdens involved in a range of commodities, including milk, using the principles of Life Cycle Assessment. A series of models of milk production were used in order to estimate the relative environmental burdens of organic and non-organic systems operating at high, medium and low levels of milk yield.

The model provides a means to assess how changes in on-farm dairy practice would reduce the negative and increase the positive environmental impacts of milk production, and in particular how changes in farm practice might affect primary energy use, land-use, global warming potential, nitrate leaching, ammonia and N_2O outputs (e.g. Williams *et al*., 2007).

4.2 An introduction to UK farm systems

Herd size and structure

The UK dairy herd consists of approximately 2,066,000 cows (MDC, 2007, based on the 2006 June Agricultural Census), producing around 14 billion litres of raw milk per year. Year-on-year trends are for a decreasing number of cattle, on fewer farms, producing a roughly equivalent output of milk.

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

Table 2: The UK dairy herd (data from 2006)

Sources: Defra, Dardni, SEERAD, WDA, MDC (2007)

These data shows that in addition to the cow herd (i.e. cows on their first or subsequent lactations) we can assume an additional 21%-22% (as a proportion of the cow herd) to be in-calf heifers and an additional 19% to be dairy replacements over 1 year old but not in calf. Based on data for England, it can be assumed that a further number of juvenile cows less than 1 year old must also be taken into account, amounting to 33% for the milking-cow herd.

Dairy farms are generally situated to the west of the country; the predominant dairy regions in England being the North West, West Midlands and South West. In terms of numbers of farms, of the 19,011 identified in the 2006 June Agricultural Census (MDC 2007), 13,778 (72.5%) were in England & Wales, 3,761 (19.8%) were in Northern Ireland and 1,472 (7.7%) in Scotland. A better picture of the relative importance of different regions in dairying terms is gained by looking at the location of quota. Approximately 33% of England's quota is held in the South West, 24% in the North West and 17% in the West Midlands. Welsh production is concentrated in Dyfed and Clwyd, Scottish production is dominated by Dumfries and Galloway and Strathclyde, and Northern Irish production is dominated by Antrim, Down and Tyrone.

Within these areas, the average quota per holding varies widely, so that, for example, in Cheshire this stands at 1.04 million litres and in Lancashire it is 0.75

million litres. However, in general the size of dairy farms in terms of head of cattle / unit has been increasing (the UK average herd size rising from 72 to 95 between 1996 and 2006 (MDC, 2007)); the 2006 distribution within England is shown in Figure 4 (p13) and Figure 5 (p13).

	Quota	% Country quota	% UK quota
England	**9509**	**100**	**66.7**
North West	2248	23.6	15.8
West Midlands	1620	17.0	11.4
South West	3226	33.9	22.7
Also: N. Yorks	482	5.1	3.4
Also: Derbyshire	343	3.6	2.4
Wales	**1573**	**100**	**11.1**
Dyfed	918	58.3	6.5
Clwyd	263	16.7	1.8
Scotland	**1286**	**100**	**9.0**
D&G	507	39.4	3.6
Strathclyde	489	38.0	3.4
Northern Ireland	**1853**	**100**	**13.0**
Antrim	488	26.3	3.4
Down	420	22.6	3.0
Tyrone	452	24.4	3.1

Table 3: Distribution of quota within the UK

Source: MDC datum

The proportion of holdings of different herd sizes does not differ by region as we travel from the North West to the West Midlands to the South West. However, using Defra data on holding sizes for dairy farms of different herd sizes, two trends are apparent[8]:

1. increasing area/cow as we travel from the North West to the South West, indicating either decreasing stocking rates or increasing areas given over to non-dairy activities
2. decreasing area/cow as herd size increases. i.e. increasing herd sizes do not appear to be simply taking advantage of a greater availability of land, but are becoming more ‘intensive’ or ‘efficient’ in their use of the land

Farm Business Survey data (Robertson & Wilson, 2007) indicates that dairy farms operated as smaller units (by area) produce greater output/ha than either medium or large units. That is, farms which are constrained by the area of land available to them appear to increase the output per cow to compensate. A corollary to this is that smaller farm sizes (by area) also have higher concentrate costs and higher fertilizer inputs per hectare.

[8] Actual area/cow cannot be truly estimated since farms may include other livestock – hence these data may be used to assess trends but not actual stocking rates

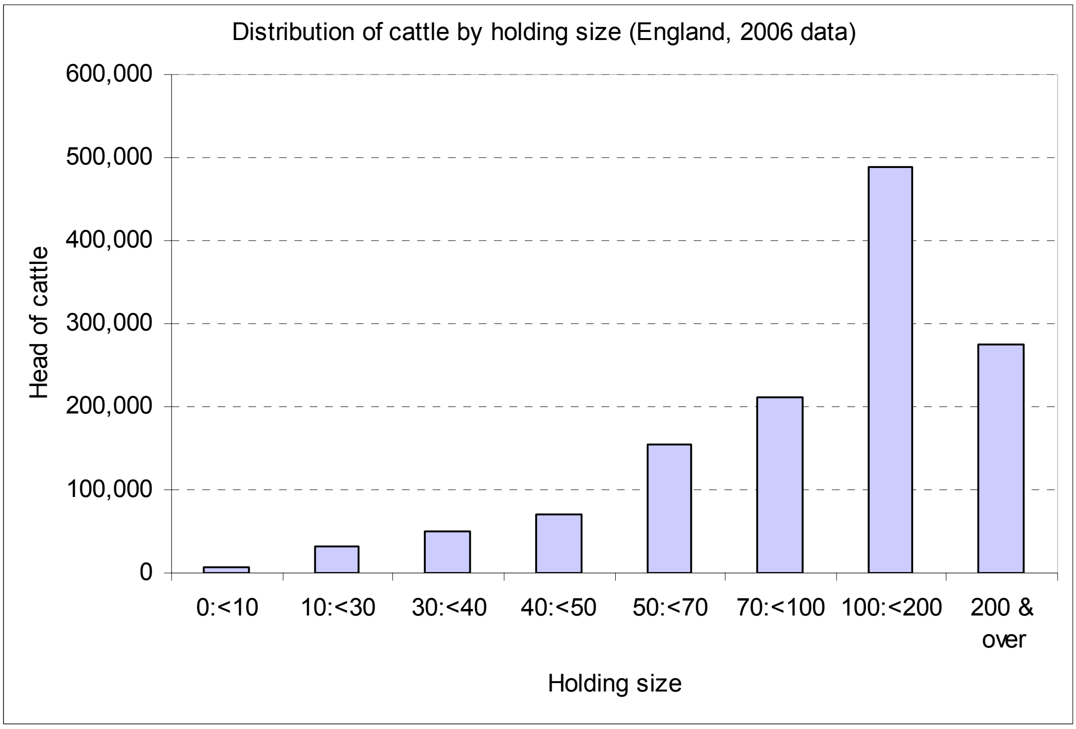

Figure 4: Cattle distribution

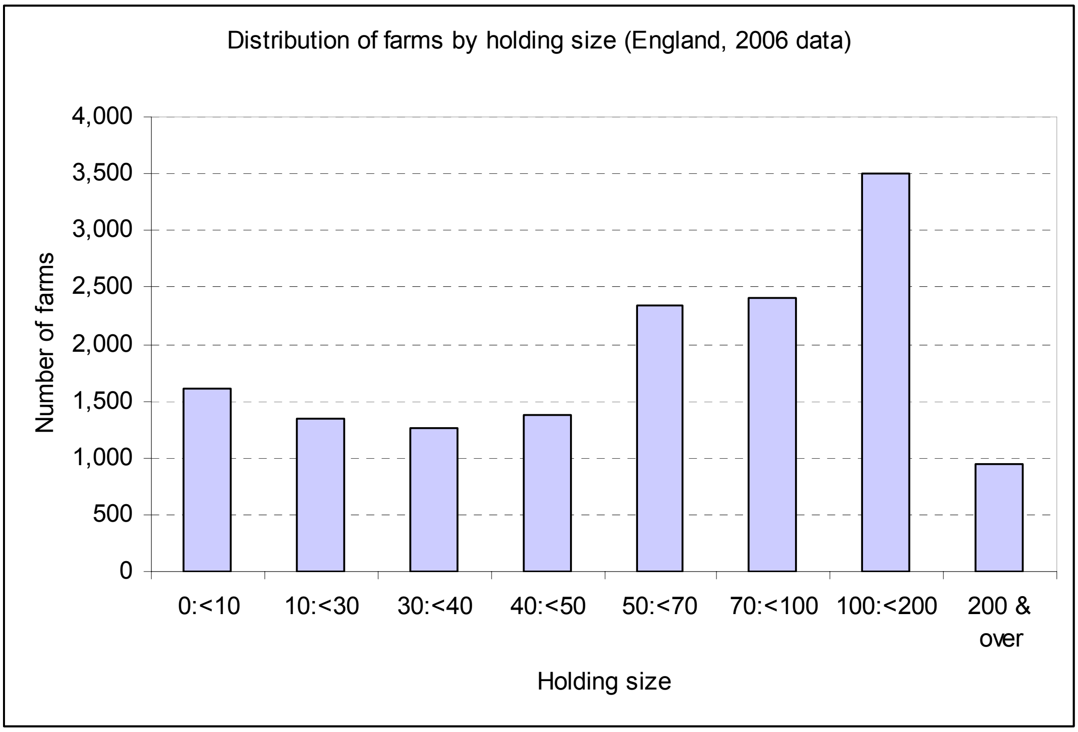

Figure 5: Farm distribution

4.3 Impacts of dairy farming (LCA)

Whilst many of the impacts of dairy farming fall within the LCA model, others do not. This chapter examines first the impacts that are factored into the LCA model, before looking at impacts which are not, such as employment and biodiversity.

Table 4 (below) shows the standard LCA values for the production of 1,000 litres of the national commodity liquid milk using the Cranfield University LCA model. The description of the model, the sources of data and the model itself can be obtained from www.agrilca.com. This is based on the current structure of the industry and includes conventional and organic milk production. Results are based on national levels of production and national data on inputs. These results are compared with similar studies from Denmark, New Zealand and Sweden. They are all clearly of a similar order.

	Primary energy used	**GWP_{100}**	**Eutroph. potential**	**Acidific. potential**	**Abiotic resource use**	**Land use**	**NO_3-N to water**	**NH_3-N to air**	**N_2O-N to air**	**CO_2 (total) to air**	**CH_4 to air**
	MJ	kg CO_2	kg PO_4 eqv.	kg SO_2 eqv.	kg Sb eqv.	ha	kg	kg	kg	kg	kg
Cranfield	2614	1039	5.1	14.5	3.1	0.10	5.2	3.5	0.6	249	22
DK (9)	-	-	-	-	-	-	13.0	5.4	1.1	-	22
NZ (10,11)	1928	-	-	-	-	-	-	-	-	-	-
S (12)	3550	-	-	-	-	non-org.	3.6	7	0.4	-	20
	2511	-	-	-	-	organic	4.9	6.1	0.3	-	24

Table 4: LCA values for the production of 1,000 litres liquid milk
based on UK, Danish, New Zealand and Swedish studies

A recent study by Kite Consulting (Allen, Davis & McCombe, 2007) modelled emissions related to on farm milk production and found similar, although marginally lower figures for GWP of 907g CO_2 equivalent / litre milk, based on conventionally farmed (i.e. non-organic) average performing UK dairy farms.

Williams *et al.*, (2006) and Cederberg & Mattsson (2000) both consider organic and non-organic milk production within the same study. Both groups found the primary energy demand for production of organic milk to be lower by similar amounts - the difference being approximately 1GJ per thousand litres milk in each case. Cederberg and Mattsson, (2000) found that organic milk has lower global warming potential

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[9] Randi Dalgaard; Niels Halberg; S. Kristensen; Inger Larsen. Modelling representative and coherent Danish farm types based on farm accountancy data for use in environmental assessments. Agriculture, Ecosystems and Environment 117 (2006) 223–237

[10] Colin Wells. Total Energy Indicators of Agricultural Sustainability: Dairy Farming Case Study Technical Paper 2001/3, Dept of Physics University of Otago ISBN: 0-478-07968-0 ISSN: 1171-4662 August 2001

[11] Caroline Saunders & Andrew Barber, Comparative Energy and Greenhouse Gas Emissions of New Zealand's and the UK's Dairy Industry, Lincoln University, 2007

[12] Christel Cederberg, Berit Mattsson. Life cycle assessment of milk production — a comparison of conventional and organic farming. Journal of Cleaner Production 8 (2000) 49–60

(13.6% less CO_2 equivalent per tonne energy corrected milk (ECM) and lower acidification potential (12% less SO_2 equivalent per tonne) than conventional production. On the other hand, because of the type of feed used they found that organic production contributes more than conventional to eutrophication (9% more O_2 equivalent per tonne ECM associated with higher nitrate leaching[13]), while photo-oxidant formation is higher for organic production than for conventional because of the less productive use of tractor diesel (i.e. the lower yield per unit area). Finally, Swedish organic production was estimated to require 80% more land to produce a unit of milk than conventional dairying. Williams *et al.* (2006) found all calculated impacts to be higher for organically-produced milk than they for the conventional product, as Table 5 below shows:

Environmental theme & units	**Value per litre milk at the farm gate**	
	Conventional	**Organic**
GWP_{100}, g 100 year CO_2 equiv.	1,060	1,230
EP, g PO_4^{3-} equiv.	6.3	10.3
AP, g SO_2 equiv.	16.2	26.4
Land use, ha	0.001	0.002

Table 5: Averaged environmental burdens from organic and conventional milk production
Source Williams *et al*. (2006)

It is important to note that the apparently contrasting conclusions of the two studies concerning the relative global warming impacts of organic and conventional milk arise from relatively small differences (certainly in LCA terms) between the calculated impacts in each case.

The Cranfield model calculates the LCA for 10 commodities, including cereals, meats and eggs. Each has very different properties as well as their primary contents of protein, fat, and carbohydrate. They are therefore very difficult to compare. However as an example, when expressed as per tonne of protein, rather than on a unit weight or volume basis, milk appears to be produced very efficiently compared to eggs, poultry meat and pig meat, as shown in Table 6, below.

	Milk	**Poultry meat**	**Eggs**	**Pig**
GJ/t protein	75	83	95	153

Table 6: Primary energy consumption associated with production of different protein foods

This comparison highlights the disproportionate effect that isolating certain elements of the product can have.

Before any of the impacts of dairy farming are allocated to beef production, the breakdown of LCA impacts by farm inputs are as shown in Table 7 (p16).

The model also allows for more detailed disaggregation of impacts. While Table 7 shows the relative significance of concentrates, grass and direct energy within

[13] Notwithstanding the greater nitrate leaching, Cederberg and Mattsson (2000) argue that it is difficult to estimate whether organic or conventional farming is more damaging in terms of eutrophication

overall primary energy consumption, Figure 6 (p17) shows the relative importance of different energy-bearing inputs across the system[14].

	Primary energy used	GWP 100	Eutro. pot'l	Acid. pot'l	Abiotic resrce use	Land Use	NO_3-N to water	NH_3-N to air	N_2O-N to air	CO_2 (total) to air	CH_4 to air
	MJ	kg CO_2 eq.	kg PO_4 eq.	kg SO_2 eq.	kg Sb eq.	ha	kg	kg	kg	kg	kg
Concentrates	1001	234	0.8	1.3	1.9	0.04	1.0	0.2	0.2	152	0.3
Grass	884	242	2.9	6.3	0.6	0.09	3.9	1.3	0.4	66	0.2
Forage maize	125	36	0.1	0.1	0.1	0.01	0.1	0.0	0.1	8	0.0
Manure[(1)]	-34	62	1.7	6.2	0.0	-0.01	1.2	1.4	0.0	-3	2.0
Direct energy	839	50	0.0	0.3	0.9	0.00	0.0	0.0	0.0	49	0.1
Direct emissions	0	516	0	2	0	0	0	1	0	0	22
TOTAL	2816	1141	6	17	3	0	6	4	1	271	24

Table 7: LCA values for the production of 1,000 litres liquid milk, by farm input

(no allocation to beef)

(1) Note that manure receives credits for fertiliser value and debits for emissions and the effort needed for its management.

The energy-bearing inputs shown in Figure 6 (p17) are:

- fertiliser N is the energy embodied in nitrogen fertilisers. This makes up just over a quarter of total primary energy inputs.
- fuel includes diesel used in machinery operations, including field-work, as well as electricity, and accounts for just under one-half of primary energy used in on-farm milk production.
- capital equipment includes buildings and machinery construction and maintenance. Fuel combines such items as diesel used for farm operations, electricity (as primary energy) used in the dairy parlour, and energy used in processing and milling concentrates (in the UK).
- other inputs (P,K, pesticides) make up only 4% of the total
- overseas refers to the energy used in producing crops such as maize and soya and their processing and delivery to the UK, for example as soyameal or maize gluten. In these cases economic allocation is used to divide the energy burden between the products.

Note also that the benefits associated with manure have been subtracted in this analysis.

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[14] Capital equipment is "energy-bearing" in the sense that its production requires energy to produce, and this energy may be considered to be embodied, or embedded within the equipment

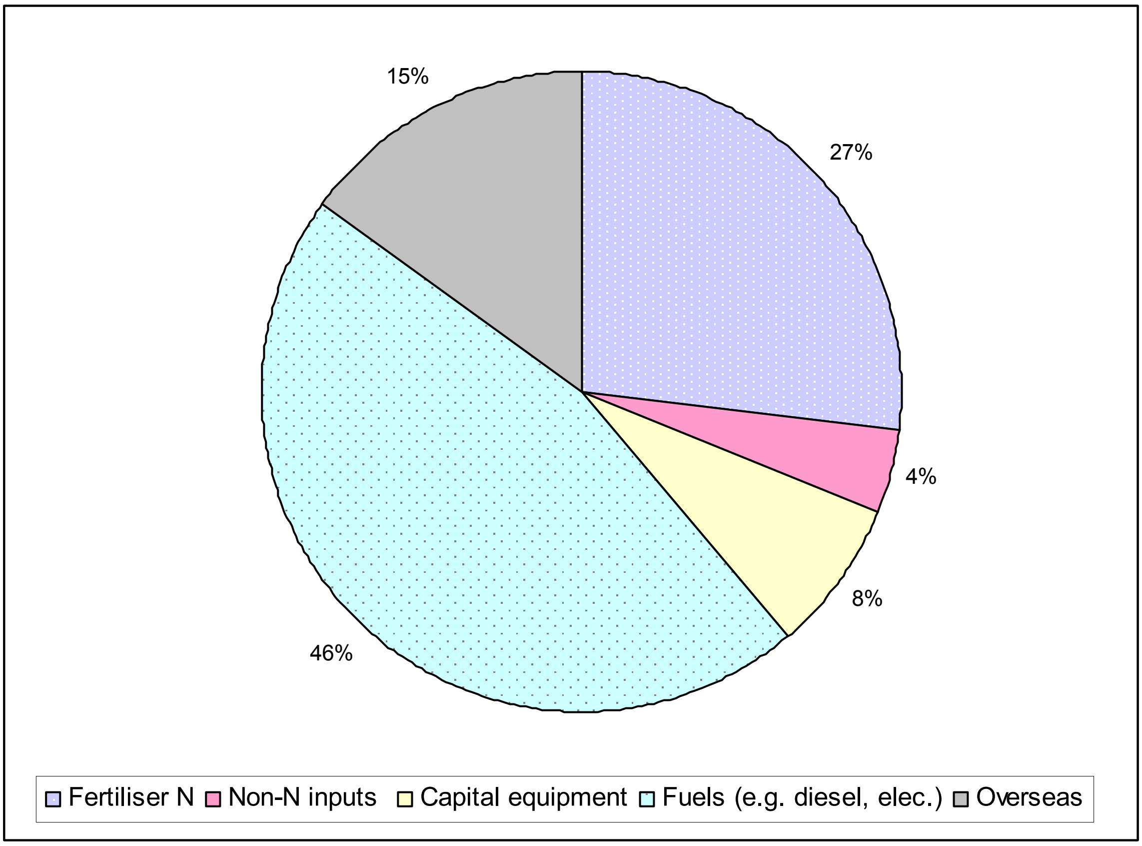

Figure 6: Primary energy for milk production

Significant factors

It is possible, within Cranfield's LCA model, to alter values that characterise key factors by which dairy farming systems may be defined, and the results of a regression analysis indicating the significance of each of these factors is given in Table 8 (p18). Each of these parameters is considered in more detail in the sub-sections that follow.

Yield

As Table 8 shows, modelling indicates that the yield given by individual cows has a significant effect on land use, GWP and ammonia emissions.

Figures on yield are provided in a number of ways. At the simplest level the total UK annual production is divided by the total UK cows, to give an average annual yield per cow of 6,815 litres. On a county basis, correcting 'quota held' data for over- or under- production (MDC datum) and using Defra's statistics on numbers of cattle, the variation in yield is more clearly observed. For example, the East Midlands and South East of England present average yields per cow of 6,620 and 6,719 litres respectively whereas in Cornwall the average yield is 7,031 litres and in Cumbria it is 7,727 litres.

The average annual yields per cow for England, Wales, Scotland and Northern Ireland are as follows:

- England – 7,010 litres
- Wales – 5,283 litres
- Scotland – 6,676 litres
- NI – 6,514 litres

Factor (Figures in brackets indicate unit of change)	**Primary energy**	**Land use**	**GWP_{100}**	**Nitrate leaching**	**Ammonia**	**N_2O**
Units	MJ	ha	kg CO_2 eq.	kg	kg	kg
Starting value	**2462**	**0.132**	**1019**	**3.3**	**3.6**	**0.52**
Low, medium, high yielding cows (0,1,2)	-21	**-0.013**	**-33**	-0.2	**-0.2**	-0.01
Organic dairying (0,1)	**-705**	**0.044**	**204**	**1.1**	**1.1**	-0.04
Spring calving v autumn (0,1)	**-354**	0.004	**-42**	**0.4**	0.0	**-0.08**
Forage maize proportion (0,0.2,0.4)	75	**0.060**	**137**	**2.4**	**1.0**	**0.34**
Level of fertilizer on grass (0,1)	**350**	**-0.032**	**60**	**1.4**	0.1	**0.08**
With clover versus no clover (0,1)	**-248**	**0.008**	**-29**	**0.9**	0.1	-0.02
Life of cow, lactations (0,1; 1 = +1 yr)	-13	0.002	-4	0.3	0.0	0.00
Interval between calving (0,1; 1 = +35 days)	12	0.003	2	0.4	0.0	0.01
Site class of grassland (1 v 3)	47	**-0.039**	14	0.1	0.0	0.02
ME value of grass and silage (0,1; 1 = +5%)	-36	0.015	-5	0.2	0.0	0.02

Table 8: Impacts of changes to dairy system on burdens/1,000 litres milk

Notes:
*- figures in **bold** show significant effects.*
- the scale of the impact is the unit of change multiplied by the impact. So, for example, moving from no clover (0) to all clover (1) will present a difference in primary energy use of 1(-248) MJ = -248 MJ per 1,000 litres; increasing the number of lactations by 1 will present a difference in primary energy use 1*(-13) MJ = -13 MJ per 1,000 litres; and increasing the interval between calving by 35 days will present a difference in primary energy use 1*12 MJ =12 MJ per 1,000 litres*
- 'with clover' does not exclude fertiliser, so the amount of actual clover is limited since it is discouraged by the fertiliser, unlike organic which uses clover and no fertiliser.

More accurate (and generally higher) figures are obtained from national milk recording (NMR). These figures take into account on-farm usage of milk. NMR data, based on 636,350 lactating cattle (i.e. over 30% of the national herd) presents an average annual yield per cow of 7,044 litres for all cattle combined, but of 7,187 litres for Holsteins alone and 4,964 litres for Jerseys. Channel Island breeds averaged 5,518 litres ‘rolling annual yield’ according to Kingshay data (cited within MDC datum). It is of particular note that yield per cow, even under apparently identical circumstances, can vary widely according to genetic, dietary, social and other factors. Within a single farm, yield per cow may range from a 3,500 litres for poor producing cows to over 10,000 cows for more highly productive animals (Webster, 1993).

Average annual yields from organic dairy systems are given by MDC datum (quoting Kingshay data to July 2007) as 6,509 litres. This is close to the average yields reported in a Defra funded, SAC study (Project AW1020, Langford personal communication) using pair-wise comparisons of farms, and in which the organic yield was 6,281 litres, compared to a conventional yield of 7,538 litres.

The Cranfield LCA model shows that, moving from low-yielding to high-yielding breeds of cows (fed optimally) made significant, if slight, reductions in the impacts of land use, GWP and ammonia emissions. As yield per cow increases the total area of land required for a unit of output decreases but only very slightly, since most land is required for feed production (whether grass or concentrates) which is in proportion to yield. The impacts on GWP may be a result of fewer cows being necessary to produce a given output of milk, since a proportion of methane emissions are relative to the numbers of animals in the system.

Variation in yield within the model was based on an average yield of 6,500 litres, with high-yield being classed as 8,000 litres and low yield as 5,500 litres per year. What if the annual yield was 10,000 litres? Table 9 below gives an insight into such changes.

Milk yield of cow	**Primary energy used**	**Land use**	**GWP_{100}**	**NO_3-N to water**	**NH_3-N to air**	**N_2O-N to air**
litres cow^{-1} $year^{-1}$	MJ	ha	kg CO_2	kg	kg	kg
standard 8000	2471	0.10	1014	5.3	3.5	0.6
10,000	2451	0.09	940	4.5	2.9	0.5
3500	2825	0.16	1339	9.8	6.8	0.9
10000+ constant cow size	2580	0.09	828	4.2	2.7	0.5
6500+ constant cow size	2344	0.12	1231	6.5	4.4	0.7

Table 9: Impacts per 1,000 litres milk produced for differently-yielding spring calving cows

From this, it can be seen that there are disbenefits if the yield is increased to 10,000 litres, and again there were no other changes to the cow – suggesting that very high intensity feeding is not a good idea. On the other hand, the model also shows disbenefits if the yield level is reduced to extremely low levels and other factors including the size and breed of the cow remain constant. (This is not the same as smaller low yielding cows).

The proportion of feed energy used for milk, maintenance and replacements is shown in Figure 7 (p20), which shows that as we move from low to high yielding animals, the proportion of feed energy used for maintenance decreases only slightly (figures are based on per unit output calculations cf. per cow calculations). The assumption has been made in this calculation that 20% of energy is used for replacements.

Consider a cow of fixed size. To increase yield we must increase the proportion of (energy-expensive) protein in the ration. To decrease yield we decrease the proportion of protein in the ration. This mirrors the effect of reducing fertiliser applied to arable crops, where we also see that the 'economic' optimum level is higher than the 'environmental' optimum.

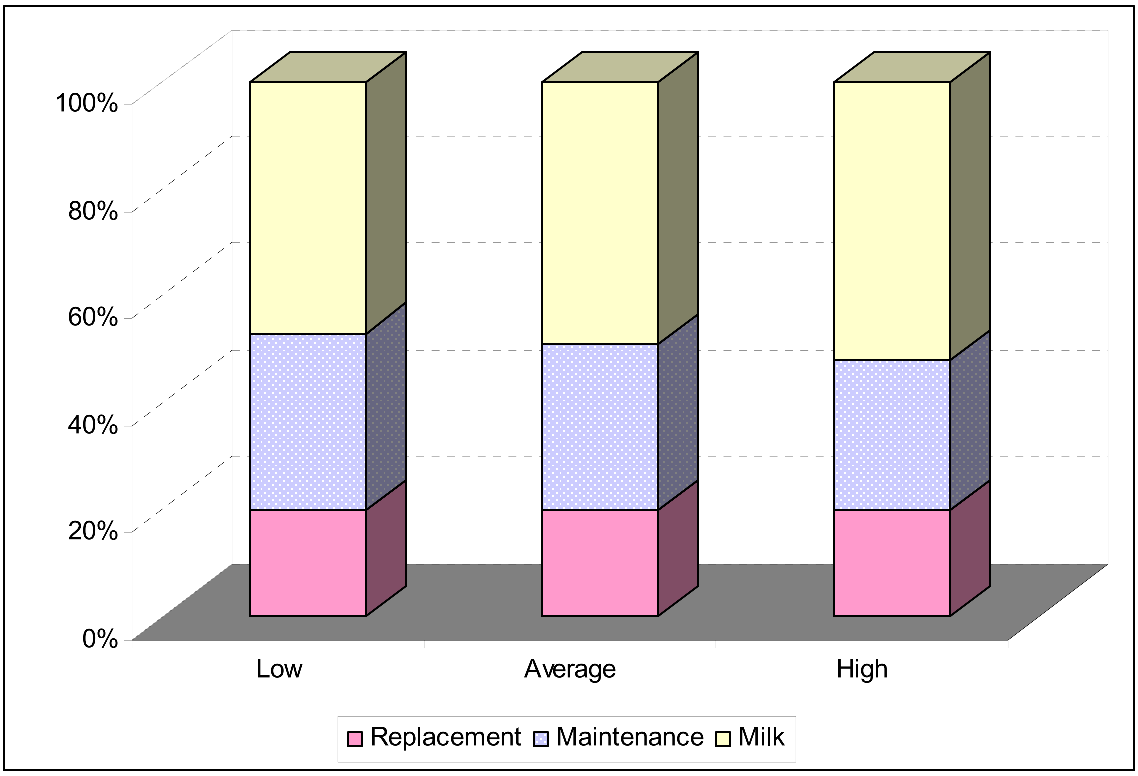

Figure 7: Proportion of energy in feed used for milk production, maintenance and replacements

Note that the 20% of energy used for replacements is a proportion of all energy used and does not imply a 20% replacement rate.

Even though, in the Cranfield model, they are smaller in size, there is also a considerable disbenefit associated with very low yielding (3,500 litres) cows. Such low yields require significantly more animals per unit of production, with concomitant increases in dietary maintenance, primary energy use for management and so on.

It should be noted that the model is based on national data and reflects national levels of production. While the model incorporates different size ranges of cow within this national herd, the results reflect the functioning of the predominant breed of dairy cow used in the UK (the Friesian-Holstein) and the most common dairy systems used in the UK for liquid milk production. Although organic practice is incorporated separately, other systems that represent small components of national production are not. Therefore, the assumptions used in the model may need to be re-addressed if it were to be applied to breeds and systems for which inputs, and outputs differ significantly from prevailing practice involving Friesian-Holsteins. Care should be therefore taken when applying the results of the analysis to such breeds (Channel Island breeds, for example, which constituted around 3% of the national herd in 2000, according to Nix, 2006) and systems.

In addressing yield it is important not to ignore concomitant welfare problems that can arise with high yielding cattle, such as nutritional and locomotive problems, and increased difficulties with fertility (Webster (2004)). These are known to be more prevalent in cattle which are genetically predisposed to be high yielding However, such problems are taken into account in developing the genetic potential of a herd and in the management of feeding and herd-health regimes.

Potential for change

There would obviously be a benefit to achieving a higher average yield from the same amount of feed, such as might be obtained by reducing the range of yields obtained within a typical herd. The LCA model has not been used to consider this, as it merely considers the feed and yield of the average performing cow. In achieving higher average yield from the same amount of feed, environmental gains might be considered to run in tandem with sound commercial practice and to be driven by commercial pressure. However, increasing the efficiency of production in this manner should not be confused with increasing the intensity of production. The examination above also showed that feeding excessive quantities of concentrates so as to increase yield in otherwise average-yielding animals increases the energy burdens of milk production.

Selection for increases in yield from the 1970s to today has been at the expense of other traits, in particular fertility, and this has reduced the commercial benefits of high yielding cows. The use of genomic markers and Single Nucleotide Polymorphisms to select sires for specific traits may now allow further increases in yield with a lower risk of loss of other desired traits.

Addressing environmental effects **on** yield may become necessary if climate trends follow predictions in future years. For example, when the Temperature Humidity index (THI) exceeds 72 (related to actual climate), high producing dairy cows become affected by heat stress. When an animal becomes heat stressed, her feed intake will decline and so will her milk yield. There will be a reduction in fertility and an increase in embryonic loss. There is often an increase in cases of clinical mastitis in heat stressed animals (MDC project report, ‘Housing the 21st Century Cow’ 2007). The current impact of heat stress on the yield of the UK herd has not been quantified. However, higher temperatures and heavier summer rainfall can lead to high THI values. Research is under way in the USA and in the EU to design housing systems that incorporate water sprays and effective forced ventilation to cool animals under conditions of high THI. Such systems need to take into consideration requirements to keep energy usage and water losses to a minimum, so the type and size of ceiling fans, and incorporation of water recycling systems, are important considerations.

Spring vs. autumn calving

As Table 8 (p18) shows, modelling indicates that the time of year at which calving takes place has a significant effect on primary energy demand, GWP, nitrate leaching and N_2O emissions (which contribute to GWP). This is in part the conclusion of the Lincoln University study from New Zealand (Saunders & Barber 2007) where cows for cheese are all spring calving.

Whilst the Cranfield LCA used to produce the values in Table 8 (p18) modelled the milk production system as a whole, it is worth considering the farm-level influences on when calves are born – most simply categorised as all-year-round or block-calving. Milk production curves indicate that there are significant numbers of spring calving cows within the UK. However, contracts with dairies have provided incentives for farmers to move away from spring or autumn calving (or disincentives for them to remain as block-calving herds) and to move towards all-year-round calving herds. The benefits to the dairy processing companies lie in an even supply of milk throughout the year.

Within block-calving systems the herd as a whole calves within a relatively short time-frame, and the herd as a whole will need to be in the right condition for conception. This is very different from the all-year-round calving system, in which the cow that is being dried off is the odd one out, and individual feeding protocols should be more important. Spring calving is not without difficulties, such as insufficient grass during dry summers, but it makes most use of grazed grass whilst autumn calving herds rely on a greater use of concentrates following calving and on silage rather than grazed grass. In any block-calving system the levels of culling may be increased in order to maintain the herd's tight calving period. Moving to all-year-round systems has the effect of reducing some of the penalties of poor fertility (other than the cost of maintaining cows whilst not in calf or lactating), and may therefore present the better option for high yielding cows where fertility can pose particular problems.

Spring or autumn calving in the Cranfield University LCA analysis indicates the proportion of the cow's annual feed which comes from grazed grass (i.e. it is not used to indicate block calving *per se*), but to indicate the period over which calves are born. Within this model, moving from spring to autumn calving has significant impacts upon primary energy use, GWP, nitrate leaching and N_2O. Autumn calving results in:

- higher primary energy use
- slightly lower GWP_{100}
- lower nitrate leaching
- higher N_2O emissions

The LCA impacts of medium yield dairy production, utilising 20% silage as maize, under an autumn calving and a spring calving system are shown in Table 10 and Table 11 (p23). The major difference between the systems arises from the higher levels of concentrates used in the autumn calving system. Spring calving herds are less reliant on concentrates, thereby using less primary energy and reduced N_2O associated with concentrate production, and silage and more reliant upon grazed grass, thereby increasing methane emissions and nitrate leaching .

Potential for change

Dairy farmers opt for block-calving or all year round calving systems because of a number of factors, including management considerations, labour availability, system preferences, economic and lifestyle choices and tradition; and not least because of the requirements of dairy processors for a relatively even milk supply. The Cranfield LCA model demonstrates the differences in environmental impact that result from the time of year at which calves are born; this determines the proportion of feed that comes from grazed grass and the proportion from silage and additional protein.

An alternative to spring calving as a means to increasing the proportion of the cow's annual feed which comes from grazed grass is to extend the grazing season. However the utility of this depends on the late (or early) grass having good feeding properties, which seems unlikely as the sun and hence radiation input is low in the UK, since otherwise it will be necessary to increase the concentrate feeds in the same way as for conserved forage. Whilst there is a significant body of farmers in the UK who practise extended grazing, this is not an option that would suit all farm systems.

	Primary energy used	GWP 100	Eutro. pot'l	Acid. pot'l	Abiotic resrce use	Land Use	NO_3-N to water	NH_3-N to air	N_2O-N to air	CO_2 (total) to air	CH_4 to air
	MJ	kg CO_2 eq.	kg PO_4 eq.	kg SO_2 eq.	kg Sb eq.	ha	kg	kg	kg	kg	kg
Concentrates	1138	270	0.8	1.5	2.2	0.04	1.1	0.2	0.2	179	0.3
Grass	901	242	2.5	5.2	0.6	0.08	3.4	1.1	0.4	67	0.2
Forage maize	133	38	0.1	0.1	0.1	0.01	0.1	0.0	0.1	9	0.0
Manure	-34	72	2.0	7.3	0.0	-0.01	1.4	1.6	0.1	-4	2.2
Direct energy	841	50	0.0	0.3	0.9	0.0	0.0	0.0	0.0	49	0.1
Direct emissions	0.8	480	0.5	2.2	0.0	0.8	0.8	1.2	0.8	0.8	20.2
TOTAL	2978	1152	5.9	16.6	3.7	0.12	6.0	4.1	0.7	300	23.0

Table 10: LCA impacts of dairy production per 1,000 litres: autumn calving

Medium yield, 20% silage as maize

	Primary energy used	GWP 100	Eutro. pot'l	Acid. pot'l	Abiotic resrce use	Land Use	NO_3-N to water	NH_3-N to air	N_2O-N to air	CO_2 (total) to air	CH_4 to air
	MJ	kg CO_2 eq.	kg PO_4 eq.	kg SO_2 eq.	kg Sb eq.	ha	kg	kg	kg	kg	kg
Concentrates	837	192	0.6	1.1	1.5	0.03	0.8	0.2	0.1	124	0.2
Grass	925	252	3.3	7.3	0.6	0.10	4.4	1.5	0.4	69	0.2
Forage maize	102	29	0.1	0.1	0.1	0.01	0.1	0.0	0.0	7	0.0
Manure	-30	66	1.8	6.5	0.0	0.00	1.3	1.4	0.0	-3	2.0
Direct energy	839	50	0.0	0.3	0.9	0.00	0.0	0.0	0.0	49	0.1
Direct emissions	0.0	543	0.6	2.3	0.0	0.0	0.0	1.3	0.2	0.0	23.0
TOTAL	2673	1133	6.4	17.6	3.1	0.13	6.6	4.4	0.7	245	25.5

Table 11: LCA impacts of dairy production per 1,000 litres: spring calving

Medium yield, 20% silage as maize

Increasing the proportion of the herd which calves in Spring is no doubt technically feasible from a farming perspective. However, if this were to be encouraged the impacts on the dairy processing sector would need to be taken into account; processors' needs are currently reflected in milk-pricing mechanisms which encourage all-year-round production. Further, the advantages (and disadvantages) of an all-year-round system, in particular the reduced costs associated with poor fertility, would need to be set against the costs and benefits of increasing the proportion of animals which were spring calving.

To be resolved this issue would benefit from further analysis of the impacts of calving, by month rather than by broad season. This would provide a more detailed understanding of the effects of calving pattern on LCA impacts (which are clearly significant), and from this a preferred calving pattern for the population as a whole might be developed. Such an analysis would allow dairy processors and retailers to alter the pricing mechanisms which they apply, and should also clarify the extent to which a an increase in the proportion of longer-lived UHT milk in total milk purchases might, by allowing processors more flexibility in meeting overall demand, bring environmental gains[15].

Life of cow / lactations

As Table 8 (p18) shows, modelling indicates that extending the average life of milking cows from 3.8 to 4.8 lactations has a relatively small effect on the environmental impacts associated with producing a unit of raw milk.

Data from NMR indicates an increasing rate of reduction in the population over the course of lactations, a fact that is recognised in the academic and veterinary literature. The average lactations per cow (based on NMR's Holstein records this is approximately 2.9, whilst figures of 3.5 – 3.8 are also quoted with reference to dairy genetic evaluations) belies the fact that between the first and second parity there is only slight reduction in population, whereas between the second and third and subsequent lactations this reduction is marked – and close to 40% between the third and fourth parities. This is shown in Figure 8 (p25). There are two principal reasons why cattle are culled early: the farmer is unable to get them into calf (typical with high yielding animals which can lose condition throughout the lactation), or there are underlying health issues – typically being lameness and mastitis.

Perhaps surprisingly, increasing the number of lactations of milking cows from 3.8 to 4.8 has only a very minor (and not significant) effect on fertiliser use, GWP_{100} or any of the other measures on a per 1,000 litre basis. This may be due to the following reasons:

1. the energy requirements for maintenance are generally far lower than those for milk production, so any decrease in the numbers of followers will have only a minor impact on the overall energy use of the herd
2. dairy cows would still be required to produce offspring even if the average lactations per cow rose. The impacts of increased proportions of dairy x beef offspring would be rightly allocated to the beef sector. Counter to this would

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[15] It is recognised that such a shift would run counter to the trend towards lowest-possible stock holdings and the implementation of "lean" techniques throughout the food chain

be a reduced number of cull cows from the dairy herd entering the beef system, so that the overall allocation would not differ significantly from the current allocation.

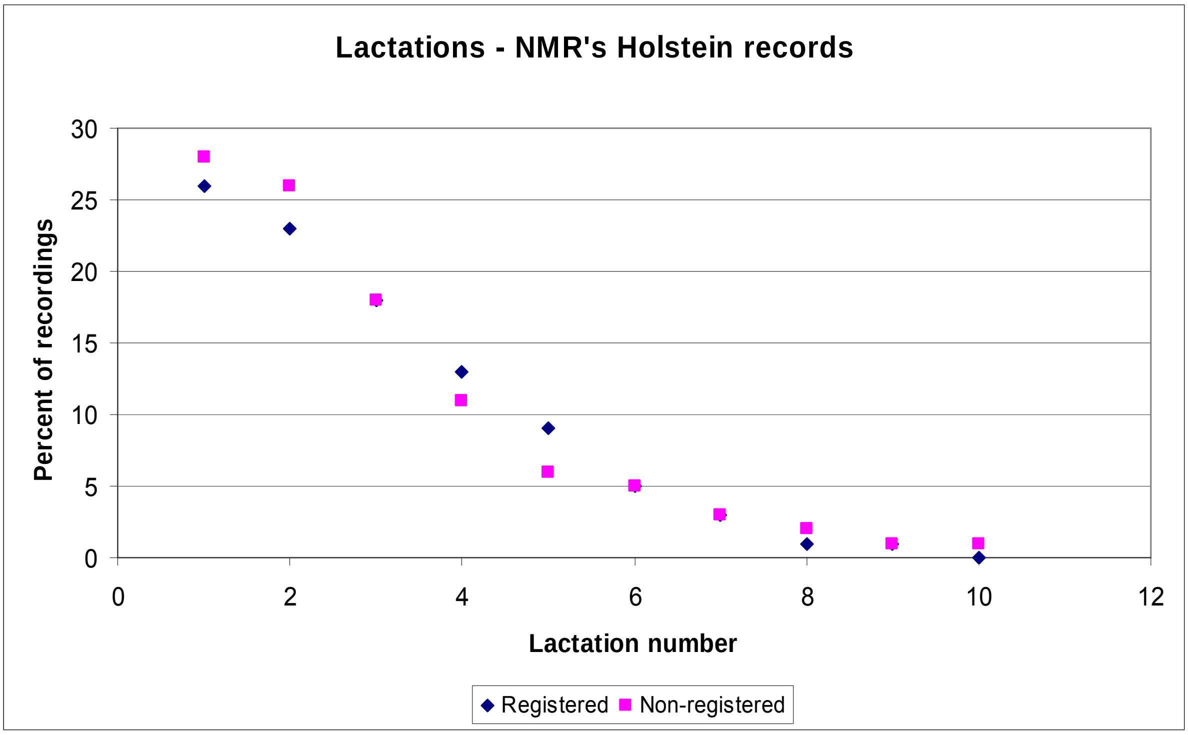

Figure 8: Lactations

On examination of the energy requirements of farmed animal systems and how they are partitioned between breeding on the one hand and production/finishing on the other, two factors are clear. Firstly, the vast majority of energy in the dairy system is within milk production. The second is the positive impact that dairy farming has on the beef sector, by dint of supplying it with dairy cross calves which are reared as beef animals. This is shown in Figure 9 (p26). In this figure, the three left-hand columns show energy distributed between different activities, the three right-hand bars show it distributed between different functions.

Potential for change

Whilst neither of these factors would seem to have significant impact upon LCA measures, they are nevertheless cause for concern from two separate viewpoints: they cost farmers money and they may be perceived by the wider public as demonstrating waste or a disregard for the life of animals within the dairy industry. This is especially so because most members of the public could not be assumed to be fully aware of the interactions between the dairy and beef sectors.

Improved selection for yield without the loss of fertility traits is dealt with above (in the Yield Section, p17). Further options here include, quite simply, allowing cows longer to get back into calf – a strategy reported by Kingshay (2007) as being increasingly popular. Such an option is not of course best suited to block-calving systems.

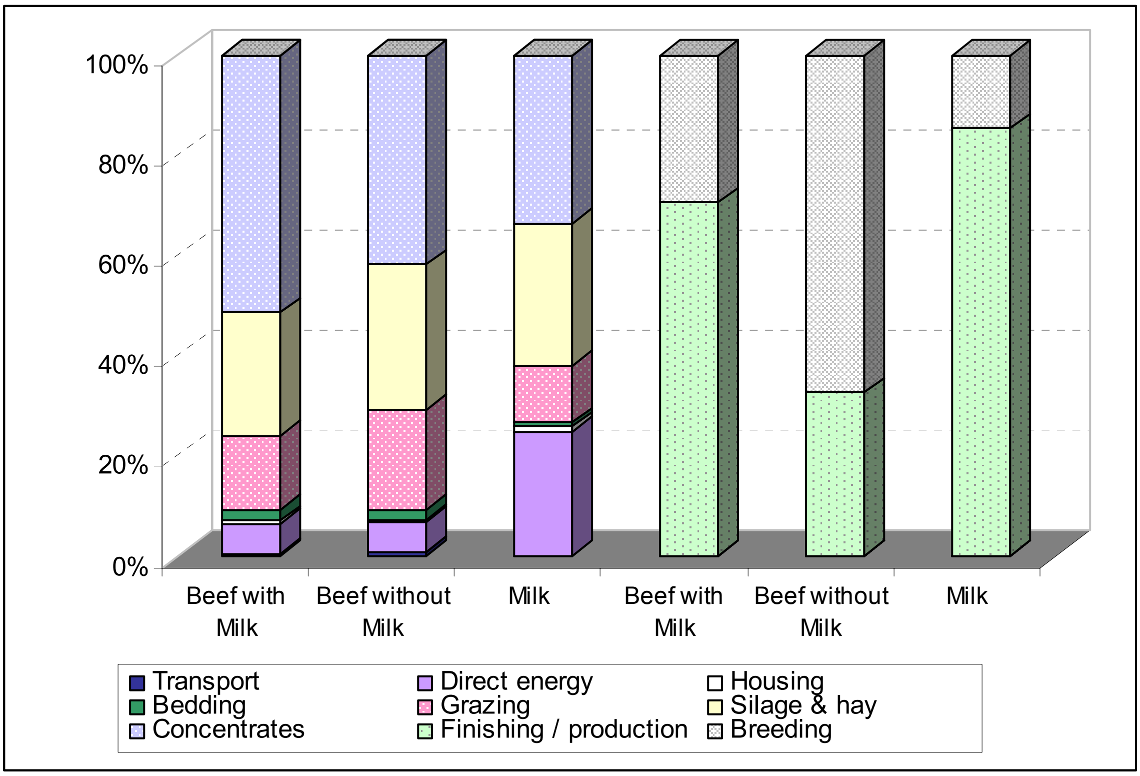

Figure 9: Distributions of energy by activity (LHS) and function (RHS)

Since a major factor in infertility is the high demand for energy and protein during peak lactation, when ovulation resumes, a recent study examined the ways that cattle manage their body energy reserves during lactation (the Robust Cow LINK project at SAC Edinburgh). This resulted in a new selection index that can identify sires whose daughters maintain their body condition during lactation and have longer, more productive lives. Since this additional selection term tends to reduce the rate of gain of the productivity traits in the index, the robustness traits are being presented to farmers as a customised index that can be used alongside the standard £PLI[16] for those farmers who wish to extend the lives of their high yielding stock.

Identification of heat and the correct time to serve heifers and cows was traditionally judged by animal behaviour and was very inefficient. This results in delays in getting animals pregnant and even culling pregnant cows believing them to be infertile. Many farmers have therefore chosen to use automated systems for heat detection, including visual recoding of mounting behaviour and monitoring progesterone levels in milk. Progesterone monitoring not only identifies heat but also provides information on fertility problems that can be treated. At present, progesterone is measured in an off-farm laboratory assay but new developments of automated bio-sensing assays that are conducted in the milking parlour will make heat detection more reliable.

A recent study by Edinburgh University (MDC) demonstrated that when dairy cattle are fed concentrates and are less reliant on season for forage availability, it is more efficient to extend the calving interval beyond 12 months. Since annual calving

[16] £PLI stands for 'Profitable Lifetime Index' - a figure based on the assessment of a variety of heritable traits that is used to aid selection for economic merit

requires high fertility, it is the main reason for culling. There is genetic variation in the shape of lactation curves, with some cows having a flatter curve with lower peak lactation levels but extending for a longer period. The milk records are now being examined to test whether long flat lactation curves can be selected for.

Calving interval

Regression analysis (Table 8, p18) also demonstrated that changing the calving interval in the range of 385 (average value for non-organic cows used in the Cranfield model) to 420 days (average 2005/06 value for Holstein dairy cows in NMR's Annual Production Report) did not have a significant effect on any of the LCA impacts. The same reasoning applies here as in the analysis of lactation numbers on LCA impacts:

1. decreasing calving intervals only impact upon the time spent by dairy cows in maintenance (cf milk production), but this period of time is relatively short in the overall life of a cow
2. the major impacts of milk production are proportional to milk output, with approximately 80% of energy utilised for this function. Increasing or decreasing the calving interval will have a negligible impact on the overall energy utilised in maintenance or breeding.

Animal genetics

Animal breeding has the potential to reduce emissions through increased performance. In Defra-funded project AC0204, Jones *et al.* (2007), calculated that animal performance attributable to genetic improvement over the last 20 years ran at about 1% each year, resulting for example in changes of: milk yield - 107 litres, longevity - 0.012 years and calving interval - 0.27 days. It was considered that this rate of improvement was likely to continue for the next 15 years or so. The rate of improvement after that is open to speculation.

The effects of these improvements were tested with the Cranfield LCA model, but with results that depend on various possibilities. The main factor is the interaction between body size and diet. With a larger body size, more energy needs can be met from forage than can be with a smaller size, thus the methanogenic fraction of the diet is higher that with a more concentrate biased diet. Various scenarios were investigated (in which all factors were held constant except those under test, so that other managerial factors have not been changed). The results show that genetic improvement has the capacity to reduce emissions of ammonia and methane by 2% to 12% in 2022. The actual degree of benefit obtained would depend on the feed mixtures consumed by the cows. Different management systems also vary in what control is placed upon the cow's diet (e.g. summer grazing and concentrate supplements vs. total mixed rations in housed stock).

Fertiliser inputs

As Table 8 (p18) shows, modelling indicates that changing the fertiliser application rates to grass has a significant effect on all impacts except ammonia emissions.

Fertiliser use on dairy farms is measured or estimated by the British Survey of Fertiliser Practice (BSFP, Defra, 2007b). Figures given for mean use per hectare for dairy farms are shown in Table 12 (p28). Average field application rates in 2006 for all grazed grass were 72 kg/ha (where grazed) and 113 kg (where mown) for silage (Defra 2007b, Table GB2.1).

	England and Wales			Scotland		
	N	**P_2O_5**	**K_2O**	**N**	**P_2O_5**	**K_2O**
Grass under 5 years old	153	30	53	160	37	58
Grass 5 years and over	127	28	37	167	39	70
All grass	132	28	41	166	38	68

Table 12: Average field rates (kg/ha)

Source: Tables EW5.1 and SC5.2, British Survey of Fertiliser Practice 2007 (Defra 2007b)

Calculation of fertiliser requirements is an area in which farmers may seek professional advice and use formal tools, but also one in which they rely heavily on their own knowledge (appearance of the crop) and farm experience (normal practice) – with 78.6% of farms opting for the latter (Farm Practice Survey, Defra/National Statistics 2007). Similar figures apply to the calculations of nutrients supplied from manure. Thus the actual fertiliser application rates used across the dairy sector are likely to vary quite significantly around the mean figures provided within the BSFP. The ranges of application reported in the BSFP for all grazing grassland and all grassland cut for silage are shown below (Figure 10).

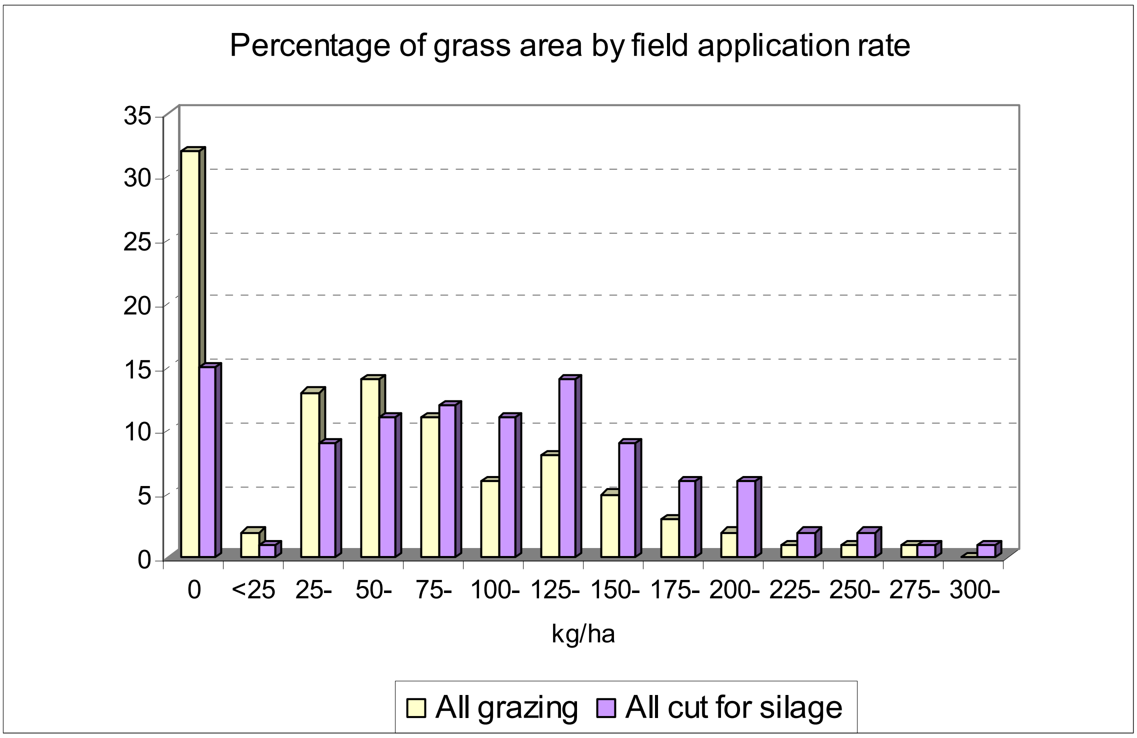

Figure 10: Grass area and field application

That there is such variation does not in itself indicate that fertilisers are being over or under used; the fact that many farmers continue to use ‘rules of thumb’ such as the appearance of the crop in determining appropriate levels of fertiliser application would indicate that application rates will vary above as well as below the economic optimum.

The 2006 British Survey of Fertiliser Practice shows that over the last 10 years there has been a substantial fall in the use of fertiliser on grass (see Figure 11, p29).

This trend may well reflect better use of manures and a reduction in nitrate leaching. There is some possibility that greater use of maize for silage and more use of clover are influences on it.

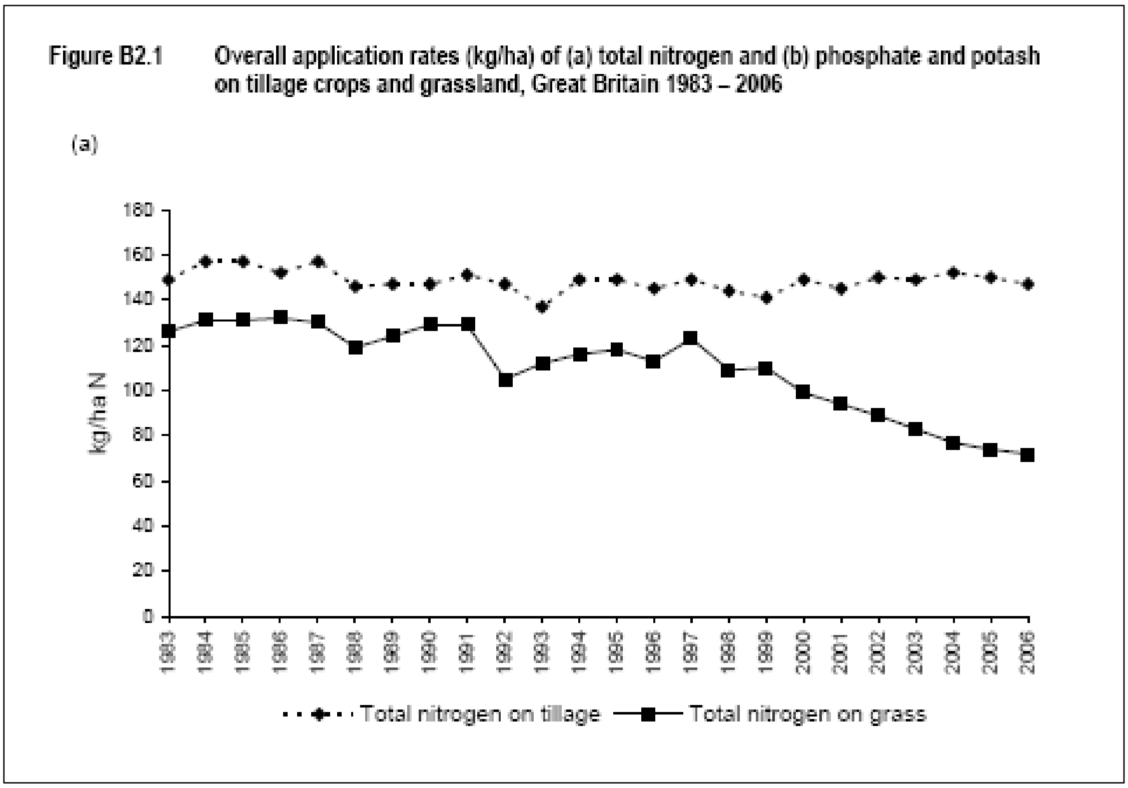

Figure 11: Fertiliser application rates on grass and tillage

Source (BFSP2006)

The effect on milk production impacts of adjusting fertiliser application rates around the economic optimum level[17] in the Cranfield University LCA model is shown in Figure 12 (p30) (changing only N on grassland).

The impact on grassland productivity of reducing fertiliser inputs is reflected in 'land use', the value of which increases as fertiliser use decreases; on a per unit output basis, fertiliser inputs allow for greater productivity per hectare. Counter to the effects on land use, two major impacts (NO_3^-N to water and N_2O to air), are significantly reduced as fertiliser use decreases. However, primary energy use is less strongly

[17] The economic optimum is the point at which the marginal cost of a unit increase in input becomes less than the marginal return in output. It is of course fixed at a point in time, as it depends on the relative costs of inputs and prices received for outputs. However, the trends shown would be the same across a range of input costs and output prices

affected. Only 25% of primary energy is associated with N-fertilisers, and field work (which also accounts for a significant proportion of primary energy use) will remain the same at all levels of fertiliser input, hence a 40% reduction in N-fertilisers will only lead to a 10% reduction in primary energy. Similarly, GWP_{100} is little changed by reductions in fertiliser use, reflecting the contribution made to this impact by emissions of GHGs other than N_2O, notably methane, which is unaffected by fertiliser inputs.

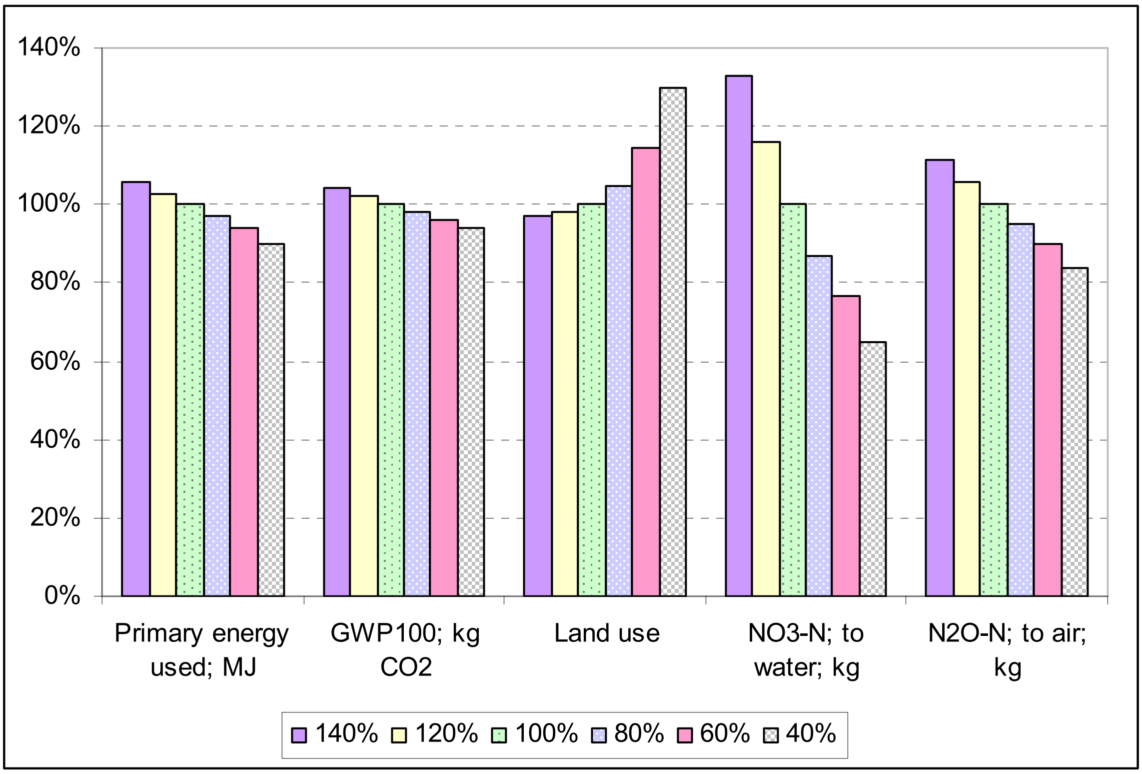

Figure 12: Effects of fertiliser rate changes

Potential for change

Considerable effort has been made by Defra and others to encourage farmers to apply the recommended levels (i.e. not excessive) fertiliser in all areas of agricultural production, and these efforts appear to be having a positive effect in terms of year-on-year reductions in fertiliser applications (see the British Survey of Fertiliser Practice 2007 for trends in application rates) by farmers.

The techniques of precision farming widely used in arable farming and horticulture have not as yet translated well to pasture management. Technologies have been developed, however, for tractor-mounted sensors to assess nitrogen requirements of areas of pasture, and these would be expected to markedly reduce excess fertiliser use.

In order to reduce the fertiliser requirements of on-farm milk production, it is also worth considering the fate of feeds produced using such fertiliser and to examine the efficiency with which they are used. In effect, this addresses feed efficiency as a means to reduce demand for fodder crops, so as to reduce the demand for fertiliser.

Residual feed intake (RFI) is the difference between the *ad libitum* feed intake and the expected feed requirements for maintenance and production. Reducing the value of RFI should reduce the environmental impact of milk production and studies are underway to assess the value of including RFI in selection indices and to investigate how this could be achieved.

It is also worth considering the efficiency of nutrient uptake by forage plants. The grass and clover breeding programme at IGER has focused in the past 10 years on breeding for varieties that require less nitrogen and phosphorus and are more disease tolerant. These varieties are more effective at capturing nutrients from the soil and require much less fertiliser, thereby reducing the environmental footprint. Varieties of clover have been developed having root nodules that are more stable, particularly after cutting or grazing, which results in reduced nitrogen loss into the soil and from there to air and water courses.

Research at IGER has led to the breeding of high sugar rye-grasses[18]. These have typically 15-30% more sugars than conventional grasses, although the difference is more apparent at the start than end of the growing season (Theodorou, 2007). Breed development continues and the effectiveness of high sugar grasses has been investigated at IGER[19] and in a Sustainable Livestock Production LINK project - LK0638 “High sugar ryegrass for improved production efficiency of ruminant livestock and reduced environmental N pollution”[20]. The extra sugars in these rye-grasses (fructans) help dietary protein to be more effectively used so resulting in better performance in some circumstances.

Intake, digestibility and milk yields		
	High sugar grass	**Control grass**
Grass intake, kg DM/d	15	13
DM digestibility, %	75	72
Milk yield, kg/d	33	30
Milk protein yield, kg/d	870	760

Table 13: Milk production using high sugar and conventional grasses

Source: www.iger.bbsrc.ac.uk/Publications/Annual_Report/AnnRep2000/arasciadv.htm#Sweet

By making better use of protein, the nitrogen utilisation efficiency of milk production can be increased from 23% to 35% along with lower losses of N to the environment in urine and faeces. This should reduce emissions of ammonia, nitrous oxide and nitrate. When sufficient results are available, an LCA covering agronomy, nutritional properties, balancing concentrates, animal performance and emissions to the environment would enable the overall benefits of these grasses to be established.

Fertiliser production is not within the milk sector, but any change in the impacts associated with it would clearly affect the impacts associated with milk (for example, as Figure 9 (p26) shows, nitrogen fertiliser accounts for more than one quarter of primary energy used in the milk production system – so any change in the energy required to produce fertiliser will feed through strongly to the impacts of milk

[18] e.g. Aberdart: www.iger.bbsrc.ac.uk/Research/Departments/PGB/Teams/GTV/varieties/plant-aberdart.html
[19] www.iger.bbsrc.ac.uk/Publications/Annual_Report/AnnRep2000/arasciadv.htm#Sweet
[20] www2.defra.gov.uk/research/project_data/More.asp?I=LK0638&M=CFO&V=IGER

production. The environmental impacts associated with fertiliser production, and the potential for them to change, are therefore discussed briefly in Appendix 1 of this report.

Forage maize

Figures for maize production are available from Defra and SEERAD websites and can be mapped against cow numbers on a regional basis for England, as shown in Table 14 (p32).

Maize production is most suited to the warmer climate of southern England, and this is reflected in the area grown across the English regions. That said, the increasing quantities of maize grown in the north, arising from changes in husbandry, genetics and climate demonstrate that increases in total maize proportion in the UK herd are increasingly feasible.

It should also be noted that the relatively low levels of maize production in the North-West of England are counter to the higher levels of yield. This perhaps reflects the traditionally greater reliance upon purchased feeds and relatively intensive grassland use in this region. As such, additional modelling of high yielding dairy production with little or no maize in use within the system might more accurately reflect the situation in many parts of the North-West of England.

	Maize (hectares)	**Number of cows**	**Maize area/head (ha)**
North East	201	18,558	0.01
Yorks and Humber	3,634	104,966	0.03
North West	11,351	291,898	0.04
East Midland	8,598	95,603	0.09
West Midlands	18,035	196,694	0.09
South West	55,276	464,180	0.12
South East	20,028	91,089	0.22
Eastern	7,123	26,370	0.27
TOTAL	124,431	1,290,230	0.10

Table 14: Areas of maize grown in the English regions

In the Cranfield model, an increase in the proportion of forage maize included in the diet had very little impact on primary energy use, but increased GWP, nitrate leaching, ammonia emissions and N_2O (Table 8 p18). This is due to higher levels of soya meal being used within forage maize diets, for which - due to its low yield - a higher level of leaching[21] per tonne of dry matter, is incorporated in the Cranfield model.

There are further impacts of maize production that should be taken into account, relating, in particular, to compaction and run-off. Maize is normally harvested later than cereals so that soils tend to be wetter than for cereal harvests (note that this

[21] Others claim that soya has very little leaching (R. Dalgaard, 2007, personal communication)

year had very unusual weather). Maize also has a wider spacing than cereals, so making it more susceptible to erosion, and hence run-off before adequate crop cover has developed. Harvesting in wet conditions leads to soil compaction, while poor stubble management leads to soil and nutrient loss to water courses (GFA Race, from Defra 2006). If manure is applied in excessive quantities, this can lead to additional nitrate leaching, de-nitrification and under-utilisation of resources. Using decision support tools (such as Defra's RB209, ADAS's MANNER and Rothamsted's SUNDIAL) to calculate the crops needs and farm waste management plans to make better use of manure can reduce these problems.

Concentrate production

Concentrates constitute approximately one-third of primary energy requirements and one-fifth of GWP_{100} impacts of on-farm milk production and it is therefore worth considering how these impacts might be reduced. Table 15 (p33) presents the burdens for feed wheat production under three different scenarios; as-is, using 50% of the economic optimum fertiliser rate, and with an increased yield of 50% achieved through technological (*cf.* fertiliser) advances.

Using 50% of the fertiliser rate only reduces energy burdens from 2.2 to 2.1 GJ/t because of the lower yield, although it thus changes the balance of sources of burdens. As it reduces N_2O emissions it reduces global warming more, but not by 50%.

Increasing the average yield of feed wheat due to technology by 50% (12t/ha) reduces the burdens, even though there is a proportionate increase in fertiliser use.

	Primary energy used	**GWP_{100}**	**Eutrophic. potential**	**Acidific. potential**	**Pesticide use**	**Abiotic resource use**	**Land use**
	MJ	$kgCO_2$	$kgPO_4$ eq.	$kgSO_2$ eq.	dose per ha	kgSb eq.	grade 3 ha
as-is	2,194	629	2.89	2.89	0.49	1.39	0.13
-50% fertiliser	2,132	487	2.21	2.64	0.65	1.35	0.17
+50% yield	1,776	529	1.91	2.35	0.32	1.18	0.08

Table 15: Burdens for feed wheat production, per tonne

	Field diesel	**Machinery manufacture**	**Crop storage & processing**	**Pesticide manufacture**	**Fertiliser manufacture**
standard	24%	12%	6%	7%	52%
50% fertiliser	32%	16%	6%	10%	36%

Table 16: Allocation of primary energy use to activities

Proteins for use in dairy cow diets include those from home grown sources, such as field beans, as well as imported products such as soya bean meal. The burdens from these alternative protein sources are given in Table 17 (p34). For field beans, 50% of the primary energy use is due to field diesel.

	Primary energy used	GWP_{100}	Eutroph. potential	Acidific. potential	Pesticide use	Abiotic resource use	Land use
	MJ	$kgCO_2$	$kgPO_4$ eq.	$kgSO_2$ eq.	dose per ha	kgSb eq.	grade 3 ha
Field beans	**2,470**	**1,010**	**5.9**	**4.8**	**2.9**	**1.4**	**0.30**
Soya beans	3,010	**1,300**	**7.3**	**6.4**	**4.4**	**1.7**	0.42

Table 17: Burdens for protein production, per tonne of crop

Source: Williams *et al*. 2006

The majority of very high protein sources are grown abroad and, for example, transport from the Americas makes a significant contribution to the primary energy burden of soya used in concentrate (28%, in Cranfield's LCA model). Home-grown lupins have been proposed as an alternative to imported soya and it is worth comparing the burdens of their production on the burdens of producing milk. Whereas field beans require 2.5 GJ/t primary energy input, lupins are estimated to require 2.8 GJ/t, but are grown on lighter land. It was assumed that they can replace all of the soya meal input to concentrate feeds. Even allowing for the lower processing energy requirement of lupins (just local milling), compared with oil extraction and milling for soya, primary energy requirements for 1,000 l milk were reduced by only 3% as a result of this substitution, whilst GWP_{100} and other burdens were hardly changed.

Potential for change

Soya beans have the best amino acid profile of all plant sources so are the crop of choice for inclusion in concentrates. However, soya cannot grow to maturity in the UK climate and the protein is imported. Considerable effort has gone into studying home grown protein sources that will replace soya beans and new formulations are being developed. Field lupins are not used to a great extent at present but research comparing different varieties for their feeding value in dairy herds is ongoing.

Clover

Clover is used as a means of introducing nitrogen without the requirements for purchased synthetic N and is used in both conventional and organic dairying, albeit to a greater extent in the latter. The impact of clover in the absence of additional fertiliser is a significant reduction in the energy burden of milk production, coupled with a slight increase in land use, a decrease in GWP_{100} and a slight increase in nitrate leaching. In contrast, organic dairy farming requires one third more land for an equivalent yield from conventional farming. This includes both the additional grassland and the additional area of arable land. Put another way, organic farming will yield approximately three quarters the volume of milk for an equivalent area of conventionally farmed land. Since it is generally farms rather than milk yields that convert from conventional to organic, it would be expected that any significant increases in organic production will be accompanied by a commensurate decline in overall milk yield.

Organic dairying

Organic dairying is still a relatively minor part of total UK dairy production, totalling 330 million litres per year during 06/07 (OMSCo Market Report 2007). OMSCo, the organic milk sales cooperative, reports a membership of 300 and a demand for raw organic milk for the liquid sector of 201 million litres in 2005/06, forecast to rise to 247 million litres for 2006/07. Estimates of organic milk sales are given as 6% of total liquid milk sold through major multiples (TNS data, cited in OMSCo), or the rather lower level of 2% of total liquid milk sales by value (£50M) (Mintel, 2006); feedback from the Milk Roadmapping Taskforce suggests that the current level is approximately 3%.

Organic dairy farming standards (Compendium of UK Organic Standard, Defra, 2006a) specify a series of feeding and husbandry elements which together differentiate it from conventional farming, for example:

1. feedstuffs for organic dairy cows must be organically produced. In terms of LCA measures, this reduces many of the impacts associated with conventional cereal production and relating to the use of compound fertilisers
2. feeding regimes are based on the maximum use of pasturage, with at least 60% of dry matter in daily rations to consist of roughage, fresh or dried fodder or silage
3. grassland (and crop) production is reliant on legumes, green manures, deep rooting plants and livestock manures rather than compound fertilisers. Stocking rates are limited so that a maximum of 170kg N/ha agriculture area is applied through animal manures[22].
4. limitations on pesticide use, and in particular on the range of pesticides that may be applied. Organic assurance schemes (e.g. the Soil Association's certification scheme) may also promote alternative husbandry practices that are intended to reduce the need for pesticides, such as crop rotations, timing of cultivations and variety choice.

There is little evidence that organic dairy cattle are systematically housed differently from non-organic cows. It is noticeable, however, that the majority of organic livestock producers in England are located in the South-West, where dairy housing for all types of farm is most frequently on straw bedded systems (Defra/National Statistics 2007). This results in organic dairy cattle having somewhat greater levels of straw as bedding or as feed overall in England. It is not clear what overall differences there may be in Wales or Scotland.

Using the Cranfield model, moving from non-organic to organic farming has a quite different effect on primary energy use than it does on nitrate leaching, ammonia emissions and GWP. Primary energy use in organic systems is much reduced – due to decreased inorganic fertiliser inputs and increased dependence on clover to fix atmospheric nitrogen (see Table 18, p36), and on the use of organic concentrates

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[22] Maximum application rate according to the Compendium of UK Organic Standards, September 2006, www.defra.gov.uk/farm/organic/standards/pdf/compendium.pdf

which have lower energy costs. However, nitrate leaching, ammonia emissions and GWP are increased (on a per unit output basis). The following factors are at work:

- the reduced yield per cow in organic systems means that more cows are required per unit of production, increasing that proportion of methane output which is driven by cow numbers and increasing the proportion of the total diet that is required for maintenance. Further to this, forage-based feeding systems are believed to result in greater levels of methane production, whilst increasing the proportion of concentrates in the diet is thought to decrease methane emissions
- nitrate leaching is increased due to a greater reliance on grazing and a reduced reliance on silage and concentrate feeds
- ammonia losses are increased in the organic system through a greater dependence on farmyard manures throughout the production chain (i.e. for cereal crops used in concentrate production as well as in grass crops used as cattle fodder) and through urine excreted during grazing

Organic milk production also has a greater requirement of land per unit of output, due to the greater reliance upon organic fertilisers and clover. This is discussed in more detail under the section on land use (see p40).

Item	Non-organic lowland grazing	Organic lowland grazing	Non-organic lowland silage	Organic lowland silage
Primary energy used, GJ	0.67	0.14	1.4	0.3
GWP_{100}, t CO_2 equiv.	0.19	0.12	0.38	0.2
EP, kg PO_4 equiv	4.8	5.7	1.3	0.6
AP., kg SO_2 equiv.	12	13	1.2	1.6
Pesticides used, Dose-ha	0	0	0	0
Abiotic resource use, kg Sb equiv.	0.45	0.16	0.88	0.27

Table 18: Burdens of producing 1t DM of representative forages

Other studies into the impacts of organic systems have produced conflicting results. For example, Shepherd *et al*. (2003) concluded that on balance there is little evidence for differences between conventional and organic systems in the ammonia losses per unit of yield, but highlighted that very little work had been done to test this in practice, and Haas *et al.* (2001) calculated that GWP_{100} was equivalent per unit output for both organic and intensive grassland farming, although in this study the impact of diet on methane emissions were not taken into account.

A further factor to be taken into account in the comparison of organic with non-organic milk is that of biodiversity. Shepherd *et al.* (2003) examined the evidence for ‘positive biodiversity impacts’ on organic farms and reported evidence of greater sward species diversity in grassland systems. However, Shepherd also reports that the evidence for differences in species abundance or diversity in the non-cropped habitat is mixed, with some data showing no differences between organic and conventional.

Differences in pesticide use as well as differences in fertiliser inputs may result in further benefits to organic farming, and studies demonstrate a greater diversity and abundance of invertebrates in organic as compared to conventional systems. These differences are supported by studies on bird populations in organic farming, which have generally shown higher bird densities in comparison to conventional farms (Shepherd *et al*. (2003); MacDonald (2006)).

In their assessment of the evidence about the benefits for biodiversity of organic farming, Hole *et al.* (2005) examined 76 studies that had specifically compared organic and conventional systems and which identified a wide range of taxa (including invertebrates, birds and mammals) that benefited from organic farming, and three management practices which were particularly beneficial to wildlife: limits on pesticides and N-fertiliser, sympathetic management of non-cropped habitats and mixed farming. However, they also noted that "our knowledge of the impacts of organic farming in pastoral and upland farming is limited".

4.4 Impacts of dairy farming (non-LCA)

Biodiversity

Recent work by the European Environment Agency indicates that the decline in biodiversity and loss of ecosystem services continue to be "of major concern across the pan-European region", and highlights the fact that the target of halting global biodiversity loss by 2010 is "unlikely to be met" (European Environment Agency, 2007). The EEA identifies several broad causes of biodiversity loss, among them environmental impacts like eutrophication to which dairy farming contributes and which have been discussed elsewhere in this report. Here, we consider the extent to which direct actions associated with dairy farm practice can be linked to changes in biodiversity.

Defra's 2007 Observatory report no. 8 (Defra 2007e) showed 2% of dairy farming land to be either set-aside or fallow. To be eligible for set-aside, land must be classed as temporary grazing (sown in the last 5 years), and only 20% of dairy land falls into this category. Given the likely scenario in the current year of a 0% figure for set-aside payments, this is likely to reduce further.

Hedgerows are often the most species-rich part of the farmed landscape (English Nature, 2001, "Wildlife gain from agri-environment schemes"). English Nature estimates that there are 278,000 km of ancient/species-rich hedgerow in England (English Nature, 2004 "State of Nature"). Defra's Countryside Survey (2000) estimated that a total of 468,000 km of hedge and further 58,000 km of remnant hedge existed in Great Britain. Hedgerow planting and maintenance has been encouraged and supported through agri-environment schemes. Jones *et al.* (2006) mention that, of dairy farmers included within a survey of NFU and CPRE members, 42% reported that they managed hedge laying and 73% that they managed hedge trimming. Farmers in the principal dairying regions of England reported average annual commitments to hedgerow maintenance of 122 hours (South-West), 87 hours (North-West) and 68.5 hours (West Midlands), reflecting the differences in topography of these regions. The average dairy farm input to hedgerow maintenance was 115 hours, of which 84 hours was uncompensated.

Studies on earthworms indicate that the highest densities and species diversity are found under permanent pasture, due to the continuous supply of plant matter on which earthworms feed. The addition of fertiliser in general increases the supply of plant matter and thereby increases earthworm populations (Toal *et al.*, 2002). There is evidence that earthworms prefer organic over conventional soils, and that populations are greater under the former (*ibid*) which may be indicative of higher levels of overall soil organic matter under such systems, in turn indicating higher levels of soil carbon (see next section).

Many impacts of farming upon biodiversity are indirect, and therefore difficult to measure in the way that hedgerows, ponds and other landscape features are. Some of these are effectively included within other measures, so that the negative impacts of nitrate leaching can be expected to include a reduction in biodiversity of farm flora and consequently of fauna. MacDonald (2007) relates high fertiliser use in conventional grassland systems to a greater sward density, which is believed to have negative consequences for ground nesting birds. Less intensive use of fertilisers also results in later cutting dates for mown swards, reducing damage to nesting sites, and lower stocking densities reduce the likelihood of nests being destroyed by trampling.

In part to ameliorate the impacts of dairy farming on farmland biodiversity, the Entry Level Scheme requirements include measures such as the "use of 2,4 or 6m uncut buffer strips on intensive grassland, which do not receive any fertiliser or manure application and which are not poached or overgrazed". The Single Payment Scheme (SPS) has been quite universally adopted by dairy farmers within England (Defra Observatory Report no. 5, Defra 2007c), indicating the successful uptake of cross-compliance measures. However, cross-compliance effectively measures the extent to which farmers undertake the bare-minimum requirements of good agricultural practice. A more sensitive measure of the environmental performance of dairy farming would be given by the uptake of the Entry Level Scheme and the measures included by those who are within the ELS. Data on uptake of the ELS are compiled by Defra and, at mid-June 2007, showed that 41% of the dairy agricultural area in England was entered into the ELS. Further analysis of the actual measures included has not been possible within the timescale of this project.

So while a considerable amount of activity aimed at implementing measures to mitigate biodiversity loss can be identified, published evidence for the impact of that activity in the specific context of dairy farming seems to be scarce at this stage. Given that many of these initiatives are recent, this should perhaps not be unexpected.

Soil organic matter and carbon

Stocks of organic carbon in soils represent a major term in carbon balances. Soil C is generally in a dynamic state with inputs from materials like plant residues, exudates and manures. Losses are mainly from soil bacteria that degrade organic matter in the essential soil processes that allow manure and arable residues to be broken down and so release nutrients etc. All studies of C turnover in soil agree that the quantity of C in soil moves towards an equilibrium over time as the supply and losses tend to the same rate (e.g. Coleman *et al*., 1997; Dawson and Smith, 2007; Smith P., 1996; Smith P., 2004; Soussana *et al*., 2004). The equilibrium depends on factors like the soil texture, temperature, drainage, management and, particularly, land use. The main types of land use that need to be considered are arable, grassland and forestry. The soil C levels at equilibrium generally increase from arable to grassland and reach maximum with forestry. This is recognised by the IPCC in its provision of methodology for evaluating changes in soil C through changes in land management (IPCC, 2006). The time taken to reach equilibrium following a change from one land use to another is typically 50-100 years.

Given that grassland undoubtedly stores more C than arable soils, should dairying receive a “carbon credit” of some kind? The sources cited essentially agree that changes in practice cause the largest change in soil C stocks and would not give a credit merely for maintaining an existing practice. Credits for a change in practice are only accounted for over fixed periods until a new equilibrium is approached. The rates of change of soil C are asymmetric; Soussana *et al*. (2004), for example, calculated that the loss rate of soil C after ploughing grassland is about twice that of establishing grassland after arable and suggested that no more C would be sequestrated after 20 years. One consequence of this is that calculating the starting position for any possible C sequestration using grassland depends highly on the history of any field.

Changes in grassland management have been predicted to increase carbon sequestration (Soussana *et al*., 2004; Dawson and Smith, 2007). Those cited by Dawson and Smith are mainly positive, and the positive values ranged from 0.2 to 3 t C ha^{-1} yr^{-1}, with a minority of options causing losses of up to -0.9 t C ha^{-1} yr^{-1}. Methods for increasing C sequestration included extending the length of grass leys, converting leys to permanent pasture, changing fertiliser input, conversion to grass-legume mixtures. Some will be more suitable for various dairying systems than others.

Dairy cows (and followers) do not, however, exist just on grassland, but also eat arable crops and by-products. Any assessment of the soil C balance associated with dairying should thus include soil C changes in arable land used to supply crops for concentrate feeds. These include crops in the Americas where soil C losses, both in the North American prairies and much more so in Brazil, have been considerable in the last 5-150 years. Brazilian soya is probably the crop associated with the highest soil C loss. Of course, the massive changes in land use driving these losses occurred many hundreds of years ago in Britain as our forebears deforested the country to provide them and their descendents with agricultural land – and indeed a landscape that we now value. Furthermore, historic practices such as drainage of grassland will have resulted in losses of soil C (while improving productivity), and such practices were widespread during the post-war years as agricultural productivity increased radically. Despite this major historic change, soil organic matter in UK soils overall was still decreasing quite recently: the Environment Agency (n.d) notes a reduction of 0.5% in the average organic matter content of soils in England and Wales between 1979-91 and 1995.

To summarise, the desire for a soil C credit from grassland is quite reasonable, but is not supportable simply for maintaining current practice. Any such credit would have to be based on an evaluation of the soil C balance across all land relevant to the dairy system in question, including that producing arable feed crops. That said there seem to be opportunities for changing grassland management to increase sequestration and it seems rational to pursue those that fit in with dairying systems but do not compromise their survival for other reasons.

Other aspects of soil quality

The structural integrity of soil, and the prevention of soil erosion (which also entails nutrient loss), are further important considerations in the quest for more sustainable land management practices. An Environment Agency report (n.d.) on the state of UK soils points to compaction by heavy machinery and trampling by livestock as important causes of structural soil damage and erosion. Soil erosion risk is identified as being higher in the west of the UK, although dairy farming practice is clearly not the only reason for this (slope, for example, is another factor influencing erosion risk and the land with the highest degrees of slope is also found in the west of the UK). Some factors associated with maize cultivation that lead to higher risks of soil compaction and erosion have been noted in the discussion of forage maize above. The same Environment Agency document reports the piloting of some agri-environment schemes aimed at reducing soil erosion risk, while dairy farming systems using smaller, lighter cows may have some advantage in this respect, but no publicly reported studies recording such effects have been encountered by the project team.

Land use

Regression analysis of the impacts of changing dairy practice on land use is shown in Table 19 (p40) which reprises values from Table 8 (p18) with some additional detail. Three factors have a significant and sizable effect on land use, these being the level of fertiliser, site class and organic/conventional practice. Improved site class and increased fertiliser inputs both reduce the land required to produce a given output of milk. Increased yield per cow also decreases land requirements, although to a lesser extent.

In contrast, organic dairy farming requires one third more land for an equivalent yield from conventional farming. Put another way, organic farming will yield approximately three quarters the volume of milk for an equivalent area of conventionally farmed land. Since it is generally farms rather than milk yields that convert from conventional to organic, it would be expected that any significant increases in organic production will be accompanied by a commensurate decline in overall milk yield.

	Coefficients	**Standard Error**	**t Stat**
Intercept	132	8	17.60
Low, medium, high yielding cows	-13	2	-5.40
Organic dairying	44	10	4.43
Spring calving v autumn	4	4	0.97
Forage maize proportion	6	1	4.70
Level of fertilizer on grass	-32	7	-4.54
Clover versus none	8	4	2.10
Life of cow, lactations (3.8 v 4.8)	2	9	0.27
Interval between calving (385 v 420)	3	9	0.28
Site class of grassland (1 v 3)	-39	6	-6.54
ME value of grass and silage +5%	15	9	1.71

Table 19: Impact of changes to dairy system on land use

'000ha/ 1000litre milk

Landscape

Landscape value is typically assessed using econometric methods, such as willingness-to-pay studies, applied to specific geographic areas. Thus a study may enquire of the willingness-to-pay to maintain landscape features of a national park or area of outstanding natural beauty. However, assessing the value that might be attributed to the landscape of a farming sector presents a series of rather difficult issues to be addressed. First of all there is the problem of placing boundaries on what it is that people would be asked about their willingness to pay for. For a sector as a whole this might be at the level of the 'knowledge of existence' of aspects of that sector (e.g. hedgerows, cattle, rural scenery) which may not be physically accessible to the interviewee, or it may relate to a percentage change in these aspects or in the sector as a whole. Secondly, there would be some difficulty in defining the landscape character that is typified by the sector. This may be overcome at a local level, but would be more difficult at a national level. Thirdly, the relative value of any alternative landscapes that would be present in the absence of, or following reduction in, one particular farming sector could be at least as important as the value attributed to the farming sector in isolation. No significant evidence has been found regarding the valuation of landscapes presented by dairy farming; placing values on these landscapes is therefore an area for future study.

Water use

Water use in dairy systems was estimated by Thompson *et al.* (2006) based on previous studies relating water intake to dry matter intake and milk yield, and studies on the use of water for washing. The latter studies have shown wide variation in water use (15-63 l cow day), although average daily use was 23 l with low volume hoses, and 28 l with high volume hoses (Survey of Slurry Management Practices, 2004 – cited in Thompson 2006). A mean figure of 25 l day is therefore chosen as representative to allow a calculation of a reasonable range for water use in dairy farms – see Table 20 (p41).

Milking dairy cow	91.8l/day for drinking	2066089*91.8	= 189,666,970
	25.0l/day washing	2066089*25.0	= 51,652,225
Replacements	20.0l/day drinking	846419*20.0	= 16,928,380
Calves	5.0l/day drinking	681809*5.0	= 3,409,045
Total daily water use			**261,656,620**
Total annual water use			95,504,666,373

Water use per 1,000 litres milk: 6,867 litres

Water use if washing used 15.0 l/ day: 6,325 litres

Water use if washing used 35.0 l/ day: 7,409 litres

Table 20: Water use on dairy farms

If the intake figures above are correct, and assuming that there is only little seasonal variation in water intake, the amount of water consumed by the dairy herd, including replacements and followers, is approximately 7 litres per litre of milk. When considering the impact of this water use, account needs to be taken of the high levels of rainfall in those areas of the UK where most dairy farms are based. Figure 13 (p42) shows average annual rainfall in the UK for the period 1971-2000, clearly demonstrating the fact that the major dairy regions lie in the wetter parts of the country.

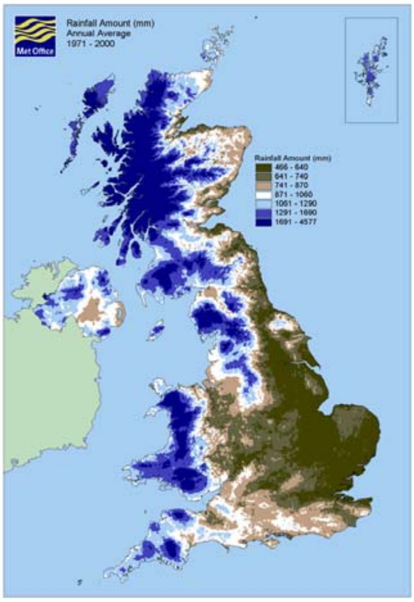

Figure 13: Rainfall in the United Kingdom 1971-2000

Further, 42.8% of dairy farms have a private water supply (Defra/National Statistics, 2007). Whilst just under 5% of dairy farms receive un-metered mains water, the majority of dairy farms are on a metered supply, indicating a price-incentive to reduce consumption. Approximately 38% of farms currently monitor water use and the MDC have a campaign to increase this level. Opportunities to reduce the consumption of mains water (which carries the burdens of energy used in cleaning and pumping) lie in the greater use of collected rainwater and in the specification of equipment in the parlour.

Some of the environmental impacts associated with mains water use are linked to the energy required to treat and deliver it. On the basis of 57% of water use on dairy farms being sourced via a mains supply (i.e. assuming that farms with private supplies will use these in preference to metered mains supplies), the total quantity of water used in on-farm production of milk is 6,867 l H_2O * 57% = 3,914 l mains water / 1,000 l milk.

Data from Water UK (2006) indicate that 1 million litres of mains water in the UK in 2005/6 requires on average 586kWh of energy and leads to emissions of 289kg CO_2.

Based on these figures, mains water use in milk production adds 1.13 kg CO_2 to the LCA impacts of producing 1,000 l milk. Reducing the volume of water used in washing to 15 l/day would reduce this burden to 1.04 kg and increasing the volume of water to 35 l/day increases this burden to 1.22 kg CO_2 per 1,000 l milk produced.

Private water supply will also carry an energy burden, although it might be assumed that this would be less than that for mains water, and this is not included in the above calculation.

Water pollution

As well as diffuse pollution, which is dealt with within the LCA (e.g. through eutrophication potential), dairy farming also has direct impact on water courses through point-source pollution incidents. Data collected by the Environment Agency show that approximately one half of agriculture's Category 1 and Category 2 point source pollution incidents result from dairy farming. If incidents were in proportion to numbers of animals, then we would expect dairy farming to result in around 40% more incidents than beef farming. However, the dairy sector regularly experiences between 3 and 5 times as many Category 1 & 2 incidents as the beef sector.

According to Environment Agency definitions, Category 1 incidents are regarded as the most serious, and result in 'persistent and extensive effects on water quality' and 'major damage to the ecosystem'. Category 2 incidents, although less severe than Category 1, result in 'significant effects on quality' and 'significant damage to the ecosystem'.

	2002	**2003**	**2004**	**2005**	**2006**
Arable	17	14	12	7	5
Beef	20	13	15	10	9
Dairy	**88**	**51**	**43**	**53**	**31**
Pigs	10	6	4	7	4
Poultry	2	2	3	2	3
Sheep	4	2	23	18	2
Horticulture	0	2	3	4	4
Other	7	7	10	9	7
Fish	0	0	0	1	0
Forestry	0	0	2	1	0
Stables	2	1	0	0	0
Total	**150**	**98**	**115**	**112**	**65**
Dairy as propn. total	**59%**	**52%**	**37%**	**47%**	**47%**

Table 21: Category 1 and 2 incidents in agriculture

Source: Environment Agency Pollution Incident Statistics 2006

A small number of these incidents relate to dairy washings, but the vast majority relate to slurry, dilute slurry and silage liquor and may therefore be considered a result of the housing and silage storage structures on dairy farms. This relates back to issues of water use, since the proper separation of clean (e.g. from roofs and gutters) and dirty (e.g. from parlour cleaning) water on farm not only provides for free drinking water and the reduction of energy burdens from the mains water supply, but it also reduces the volume of water which is contained within slurry tanks and lagoons. This win-win situation has not gone un-noticed, and organisations including the EA, RABDF, Defra and the MDC have all worked towards better water management on dairy farms; for example, the Environmental Plan for Dairy Farming, published jointly by the Environment Agency, Dairy UK, NFU, MDC and RABDF, highlighted water wastage and dirty water from farms as issues to be addressed. The MDC has subsequently developed a booklet entitled 'Effective Use of Water on Dairy Farms' (MDC, 2007) and a downloadable 'DIY full water audit', which is available from the MDC website.

Employment

The NFU (2006) estimate that 50,000 farmers and farm workers are employed on dairy farms in the UK. The EU census reports that there are 16,200 dairy farms in the UK (Dairy UK, 2007). From the 2007 DEFRA Statistics Digest we know that there are 12,289 farms in England and a further 2,934 in Wales. We know also that there are 9,605 permanent and 2,404 non-permanent workers in England and a further 1,651 permanent and 744 non-permanent workers in Wales. Assuming one farmer/manager to each of the farms, there are 29,627 employed on farms in England and Wales. Previous research (RABDF) indicated the levels of family labour (which is not normally fully remunerated) on dairy farms to be high, with 64% of farms involving the spouse of the farmer, 42% involving offspring and 33% involving a parent; Defra (2007d) calculate that unpaid labour contributes a further 16% (3,888 for England, 853 for Wales), which takes the figure to 34,368. To calculate an approximate figure for Northern Ireland and Scotland, we can take the regional output and divide it by an average labour productivity for Wales (rather than the more efficient English farms).[23] Applying this factor to the output in Scotland and Northern Ireland (1.286bn litres + 1.853bn litres/0.00254) gives us 12,336 employed and non-employed workers; overall, the total employed is 46,704, close to the 50,000 NFU figure.

We note, in passing that the cost of labour is a high proportion of total dairy farming costs: 25% of total dairy farming costs in England according to Robertson and Wilson (2007). Colman and Harvey (2004) calculated imputed average hourly labour costs of £8.15 (milking) or £7.66 (forage production) on dairy farms. Absolute costs can be expected to rise over time in line with, or slightly faster than, the rate of inflation. In this area, there are economies of scale available to dairy farmers. In relation to the average total cost of milk production of 18.33 pence per litre in 2002/3, Colman and Harvey estimated that, as herd size increases from less than 40 to over 150, labour costs fall from over 11ppl to under 4ppl.

The production of farm inputs also generates employment, of course. No data has been found that links employment in the feed and fertiliser industries, for example, explicitly to dairy farming, while detailed work to assemble such information has been outside the remit of this project.

[23] Labour productivity (output/employed and non-employed workers) on Welsh farms is 0.00254 (1.573bn litres/6182).

4.5 Transport to the dairy

Milk processing is dominated by three large processors[24]. A typical farm produces 2,000 litres of milk a day and the milk is tested (weekly or daily), collected daily (or every other day) by a haulier (whose lorries carry about 15,000 litres milk) and transported to a local processor (if the milk travels further, the lorry capacity typically increases to 30,000 litres milk) (Komorowski, 2005). Transport is either direct from the farm to the dairy or via a 'transhipment depot'. Tankers are not refrigerated but are insulated and the milk purchasers' guarantee delivery at less than 6°C (*ibid*.).

Impacts

The impacts of transportation on the environment are those arising from fossil fuel use (resource depletion, climate change impacts linked mainly to CO_2 emissions, contributions to acidification and eutrophication linked mainly to NOx emissions, affects on low-level air quality arising from emissions of photochemical smog precursors – importantly NOx and volatile organic substances) and from vehicle movements themselves (noise and disturbance). There is of course employment in this part of the life cycle.

So the environmental impact of transport from the farm to the dairy depends on the relative locations of producer and processor, and on the operating parameters of vehicles[25]. Milk production in the UK is concentrated in Shropshire, Cheshire, Lancashire and the West Country (DEFRA, 2001) and most milk is processed by dairies located near urban areas (Competition Commission, 1999; Komorowski, 2005).

Foster *et al*., (2006) calculated average energy consumption at this stage from transport data in Competition Commission 1999. Energy consumption for milk consumption across the UK was found to be approximately 96MJ/1,000 l milk, which corresponds - since this is in the form of diesel – to GWP of approximately 8 kg CO_2 eq./1,000 l milk for fuel production and combustion.

Dairy UK data indicate that milk collection for a 'generic' dairy processing 250,000 tonnes [sic] of milk per year involves approximately 2,760,000 vehicle km and uses 984,000 litres diesel fuel (i.e. 11 vehicle km/tonne at an average fuel consumption of 35 l/100 km). Taking the specific gravity of milk as 1,000 kg m^{-3}, and applying widely-used conversion factors for CO_2 emissions from diesel production and combustion, the GWP associated with this fuel use (production and combustion) is around 12 kg CO_2 eq./1,000 l milk.

[24] Dairy Crest and Robert Wiseman Dairies (both UK plcs) and Arla Foods (owned by Scandinavian Co-op Arla) provide around 90% of milk to grocery multiples (Competition Commission, 2007b). Other significant processors are First Milk, Milk Link, United Dairy Farmers and Dairy Farmers of Britain, all of which are processing operations of UK dairy farming co-operatives. Co-op producer processing has been increasing since deregulation in 1994: 30% of processing is now owned by UK producer co-ops (Dairy UK, 2007)

[25] Since we know how much milk is produced (14.2bn litres in 2004), the size and proportionate use of tankers (operating at optimum capacity) and the litres transported per vehicle kilometre, with data on the fuel consumption of tankers and global warming coefficients we could calculate the fuel consumption and associated environmental impact of the average farm to processor journey (notwithstanding improvements in vehicle efficiency).

The emissions driving other impacts covered in LCAs vary more with vehicle operating conditions than do CO_2 emissions. Some conversion factors from fuel energy content are provided in de Beaufort-Langeveld *et al*. (2003). Applying those for NOx only to Dairy UK's data (and taking a value of 36.1 MJ/litre for the net energy content of diesel as per DTI 2006) a very approximate value of 0.05kg SO_2 eq./1,000 litres of milk for the acidification potential arising from this stage of the life cycle.

Vehicle exhaust emissions are relatively important sources of substances contributing to photochemical smog formation, measured in LCA as Photochemical Ozone Creation Potential (POCP). From one LCA dataset describing the operation of a 'medium' truck (14t payload, Euro II standard engine) in rural driving conditions, a factor for POCP impact of 5.2×10^{-5} kg eq ethene per tonne km can be derived. If we assume that the collection truck delivering to the generic processing site fills up at an even rate throughout its round and contains 150,00litres (i.e. 15 tonnes) on its return to the processing site[26], then we can estimate impact on the basis that each vehicle km represents 7.5 tonne km. The total POCP arising from the collection of the 250k tonnes of milk entering the generic plant would then be 108kg ethene equivalent. This works out at 0.004kg eq. ethene per thousand litres.

Water and chemicals are used to clean milk tankers. There is no specific data published about the amount of water used for this activity, although it is believed that it often takes place at dairy processing plants following offloading, so that the water involved may well be included within consumption at the processing stage. Losses from milk transport (whether between farm and dairy or between dairy and retailer) might reasonably be assumed to arise almost entirely from incidents. The road transport sector overall contributed around one-third of all Category 1 & 2 water pollution incidents in 2006, according to Environment Agency (2006). The extent to which these involved milk as the polluting substance is unknown.

Significance

The GWP figures noted above are around 2 orders of magnitude less than the GWP associated with primary milk production, so this part of the life cycle has relatively low significance in terms of this impact. For acidification, the picture is similar: even if the approximate acidification potential calculated above were half of the total when all acidifying emissions from vehicle exhausts were allowed for, acidification potential arising from milk collection would be less than 1/100th of the average acidification potential associated with the primary production of milk calculated by Williams *et al*. (2006).

Of course, milk collection is much more significant within the milk life cycle in terms of the transport-dedicated impact, 'vehicle movements'. Dairy UK's data for a generic processing plant shows that onward distribution is more significant in this respect, involving 48 vehicle km per tonne.

For POCP, no figures are reported for primary production or for other stages of the life cycle in published LCAs of milk. However, apart from NO_2 (which has a characterisation factor of approximately 0.03kg ethene eq./ kg), all substances contributing to this environmental impact are volatile organic materials.

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[26] Dairy UK members report that tankers are normally 90-95% full (Dairy UK, pers. communication)

Williams *et al*. (2006) did not report it, but have a value of 0.09 kg ethene eq. per 1,000 l milk in their working model. Production of liquid hydrocarbon fuels and their combustion in vehicle engines is a significant source of such substances, and distribution is generally found to have higher significance for this environmental impact than for others. Sonesson & Berlin (2003) note that the production of polymers for plastic packaging is also a significant source of POCP in the milk processing and consumption system.

How do impacts change if production increases/decreases?

All produced milk must be collected, so if more milk is produced, impacts will eventually rise. However, the relationship is unlikely to be linear. If tankers are not fully utilised in the existing system, increased production might allow better utilisation of tankers and so reductions in per litre impacts. Competition Commission (1999) did suggest that utilisation improved in the 1990's (average volume carried per trip increased from 9,700 litres to 11,100 litres between 1995 and 1997, with vehicle km per tonne falling from 9.1 to 8.3)[27]. This information is clearly somewhat dated now, and we have no data to allow a comparison with the current situation.

Increased production of organic milk from dispersed locations, which cannot be transported with non-organic milk, may add further complexity and inefficiency into the collection system, particularly while a relatively small proportion of farmers operate on organic principles.

Potential for change

Figures for vehicle km per tonne milk and calculated values for GWP from this transport element suggest that there may have been some increase in the impacts associated with it. However, there is very limited evidence to support a strong assertion that performance is deteriorating. Logistics within the milk value chain have been the subject of study by the Food Chain Centre; we understand that this work identified some scope for improvements in the transport efficiency of milk collection within the current market arrangements.

These arrangements themselves also influence the impact of milk collection. An important aspect of the liquid milk value chain that may be pushing milk collection away from operating in a manner that minimises impacts is the tie between farm and particular collector or processor.

To be as efficient as possible (in transport terms), the milk collection system would involve all milk being treated as equal, so that collection from all farms in a given area was organised as a single logistics exercise bringing milk in to the nearest processing (or transhipment) location. The more individual sources are distinguished (whether on the basis of contractual arrangements that they have in place, or by virtue of the characteristics of the milk itself) the more this pursuit of logistical efficiency must be compromised. So the very existence of multiple milk purchasers (which are not geographically constrained) and of ties between individual farms and particular processors or retailers suggests that milk collection involves more than the minimum possible impacts on the environment (but perhaps more than the minimum level of employment). Given the relatively low significance of these impacts in the life

[27] Although this increase could also reflect increased use of larger tankers

cycle, some may consider this to be a price worth paying for the economic advantages that the present arrangements bring when compared to a single-purchaser/collector system.

Of course, the distribution of farms affects the extent to which the impacts of milk collection can be reduced, whatever market arrangements exist. The Competition Commission (1999) noted that milk production is more densely clustered in Ireland and Holland so that collection can be more efficiently organised in those countries. An article on the German dairy industry (Milk & Market 2007[28]) states that collection on alternate days is more efficient than every day collection. It is understood that the former has become common practice in the UK over the past 5 years.

It is plausible, but unquantified, that outlying producers will incur larger transport burdens than producers in more concentrated areas. This effect is likely to be yet larger for organic producing, given its niche position.

4.6 Milk processing

There are more than 100 dairies in the UK that vary widely in size, most are small (taking between 1 and 10 million litres of raw milk per year). However, three large firms (Arla, Dairy Crest and Robert Wiseman) dominate liquid milk processing in the UK.

The elements of milk processing are shown in Figure 14 (p49).

A number of variants are possible:

Pasteurisation (which normally involves raising the temperature of the milk to 72°C for 15 seconds) can be replaced by ultra-heat treatment (UHT, a continuous process in which milk attains a minimum temperature of 135°C for 1 second) or sterilisation (in which pasteurisation or UHT is typically followed by autoclave heat treatment of milk in its final container at 110-125°C for 20 to 40 minutes). These changes lead to familiar liquid milk product variants. Sterilised milk accounts for a very small proportion of the UK liquid milk market and is not discussed further here.

Separation can be used to create either three milk streams (standardised whole milk, semi-skimmed milk and skimmed milk) with different fat contents which are then processed separately to provide the three forms of liquid milk familiar to consumers, or two streams (skimmed milk and a high-fat content milk) which can be recombined at the packing stage to give products of any desired intermediate fat content.

A microfiltration step can be added prior to heat treatment to remove residual bacteria from the milk. Some branded milk products (for example Cravendale) derived from this process have been introduced to the UK market relatively recently.

[28] www.milch-markt.de/en/dairy_data/logistik2/collection last viewed 18/09/2007

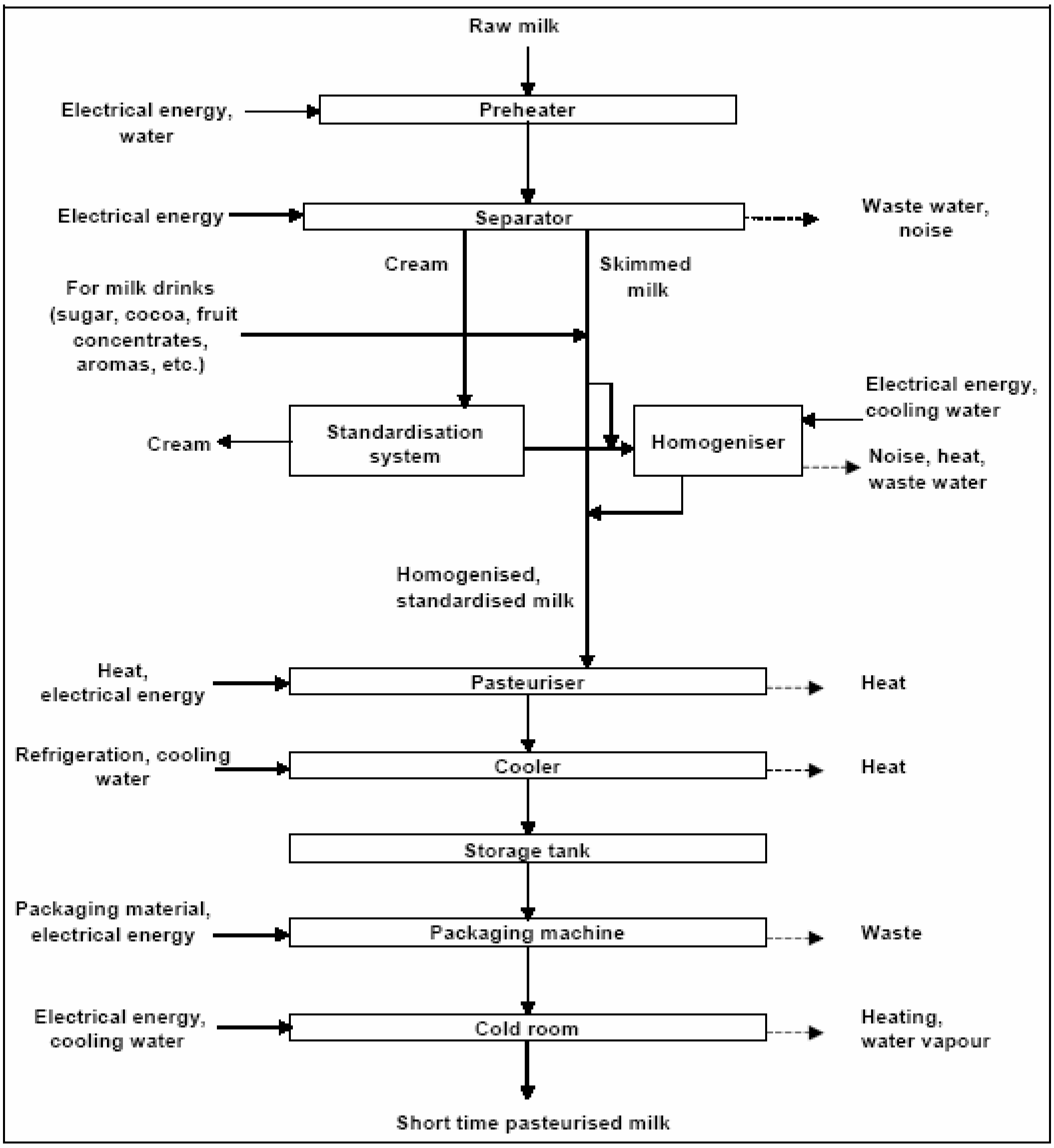

Figure 14: Short time pasteurised milk process

Source: European Commission 2006

Cream, once separated, is handled in distinct process equipment within the liquid milk facility. According to Dairy UK's figures, useable cream accounts for 6% of the raw milk delivered to a generic dairy plant (6.5% of products despatched). The cream yield can vary somewhat; data from regulatory submissions for milk processing installations regulated under the PPC regime suggests that cream can account for 4% to 9% of products. This report concerns liquid milk, not cream, so there is no further discussion here of its processing and the impacts associated with it. It should be noted, however, that since cream has economic value, it is normal LCA practice to allocate a proportion of the burdens of raw milk production to it. The common conventions used are allocation on the basis of economic value or of physico-chemical properties. Relative economic value can be used as the basis for allocation by drawing on MDC Datum's historical price information about the value of cream to processors (2003-5) and liquid milk wholesale prices, in conjunction with UK average butterfat levels for raw milk, cream, skimmed, semi-skimmed and whole milk. This approach results in allocation of 12.2% of raw milk production impacts to cream in a situation where the dairy is producing an 'average' mix of finished liquid milk (i.e. the mix of these products produced in the generic plant described by Dairy UK's generic plant data). If physico-chemical properties are used as the basis for allocation, then the relative volumes of cream and milk produced in Dairy UK's generic processing plant can be used. This would lead to the allocation of 6.5% of the burdens associated with raw milk production to the cream produced in the dairy (with the product mix as before). The difference can be attributed to the different values of the products on a per-litre basis. Neither attribution is more 'correct' than the other. For the purposes of relating impacts to 1 litre of milk consumed, we use the value reached by economic allocation, since that is consistent with the approach used for allocation between different outputs of agricultural systems in Cranfield's model.

Impacts

Energy consumption is the main source of environmental impacts associated with milk processing. Energy is used for running electric motors on process equipment, for creating steam for heating processes, evaporating and drying, for cooling and refrigeration and for generating compressed air. Heat treatment and subsequent cooling account for a large proportion of direct energy use.

Dairies use energy in the form of delivered electricity and fossil fuels (mostly gas, but some facilities don't have access to gas supplies so use heavy fuel oil (HFO) or gasoil). The impacts associated with energy consumption are well-known, linked to fossil fuel combustion, nuclear electricity generation and electricity distribution.

Data was provided by members of the SCP taskforce for a generic dairy producing liquid-milk products. Pasteurised milk constitutes 88% of the output of this generic plant, while UHT/sterilised milk account for around 5%, as does cream. This data indicates that energy use is approximately 200MJ (delivered) electricity per thousand litres milk produced, while other fossil fuels - >80% gas, with HFO and gasoil – account for a further 300MJ (delivered) per thousand litres. These values can be compared with figures of 200MJ/1,000 l for electricity and 500MJ/1,000l for 'fuels' in UNEP (2000), for which the source is a 1980's survey of energy use in Australian dairies, and with 500MJ/1,000 l electricity and 600MJ/1,000 l 'fuel' given in European Commission (2006) as indicative figures from the European Dairy Association for energy consumption in market milk production[29]. Using recognised impact factors for delivered electricity in the UK, together with figures for combustion-gas emissions from the generic plant, we can calculate the following impacts per thousand litres milk leaving the dairy associated with energy use in processing:

- primary energy (MJ): 820
- GWP_{100}, kg CO_2 eq.: 50

Some other GHGs are released from dairies if the refrigeration systems in place use certain HFCs or HCFCs. Dairy UK's generic processing site releases 0.6g HFC and 0.043gHCFC per thousand litres milk. However, since the GWPs of HFCs vary from below 100 to 12,000 kg CO_2 eq. per kg, and those of HCFCs from 120 to 2,400, it is

[29] In comparing these with UK figures, differences in the relative importance of different forms of heat treatment in different countries may well need to be considered. The term "market milk" is not precisely defined in European Commission (2006)

not possible to estimate how much these add to the GWP arising from milk processing.

Other air pollutants, including oxides of nitrogen and sulphur, and suspended particulate matter are by-products of energy consumption for milk processing. Using the same original data from the Taskforce, further, rather more approximate, values can be calculated for the environmental impacts arising from these emissions – see Table 22 (p51) (all values per thousand litres milk).

Eutrophication potential kg PO43- eq.	**Acidification potential kg SO2 eq.**	**Abiotic resource kg Sb eq.,**	**POCP kg ethene**
0.018	0.12	n/a	0.081

Table 22: Other emissions

These values somewhat understate the impacts that would be found in a thorough LCA because they exclude impacts arising from the extraction and production of liquid hydrocarbon fuels. They also exclude packaging production (which often takes place on the milk processing site).

Dairies also use large volumes of water for cleaning and steam generation. Water consumption also gives rise to energy consumption, since mains water is pumped to its destination.

An estimate of the environmental impact of water consumption can be made on the basis of the average energy cost of delivering mains water, and associated emissions. Water UK (2006) indicates that on average, delivery 1M l of mains water in the UK in 2005/6 required 586kWh of energy[30] and led to emission of 289kgCO_2. Dairy UK's figure for water consumption in a generic dairy is 1,130 l water per thousand litres milk produced. From that, water delivery would add a further 0.3kg CO_2/1000 l to the GWP associated with milk processing; the primary energy value cannot be calculated as the delivered energy mix is not reported in Water UK (2006). While this figure ignores the fact that some dairies use borehole water for part of their water requirements, the supply of which is likely to be less energy-intensive than the supply of mains water, the Dairy UK figure is at the lower end of observed water:milk ratios (see Figure 16 on page 55).

The resource implications of water consumption in dairy processing are not discussed in detail in any of the literature reviewed. However, a general principle of environmental protection has long been that reducing water use is desirable. With growing pressure on water resources, in many parts of the UK there is increasing interest in reducing abstraction. Liquid milk processing is predominantly carried out in a band east of the milk-producing areas in the west of the UK; this band is still to the west of the more highly water-stressed parts of the UK.

[30] We assume this refers to delivered, rather than primary energy.

Dairies discharge impure water, either into the sewers as untreated or partially-treated effluent, or into a watercourse as fully-treated effluent. In the former case, further indirect energy consumption arises to operate the treatment works where the effluent is mixed with other wastewaters and the total loading reduced to a dischargeable level, while in the latter this energy consumption will be identifiable within the dairy site. In both cases, direct environmental impacts arise from the final discharge of substances other than water into the aquatic environment. The energy and GHG implications of effluent treatment are similar in magnitude to those of mains water delivery. Water UK (2006) states that treating 1 M l of sewage requires 634kWh energy and leads to the release of 406 kg CO_2, while Dairy UK's figure for effluent production in processing is 1,052 litres waste water per thousand litres milk (it is fairly safe to assume that discharge volumes will be more or less equivalent to intake volumes, since milk passes through the dairy largely unchanged, so the same comment must apply to this value's relationship to average performance as was made about water consumption).

These approximate calculations suggest that water use and wastewater management add a minimum of 2%, but probably seldom more than 5%, to the GWP arising from energy use in agricultural production given in Table 7 (p16). Other milk LCAs reviewed for this study have not considered the environmental burdens arising from dairy effluent treatment. It is important to note that the environmental burdens of treating effluent are influenced by its strength and characteristics. The approximate calculations above suggest that this is not, however, a topic that merits detailed further analysis.

Cleaning operations in dairies also utilise a range of chemicals, notably sodium hydroxide (a product of the chlor-alkali industry, which begins with the electrolysis of sodium chloride brine) and detergents.

Point source pollution incidents cause relative large environmental impacts on a local basis. The food and drink industry accounted for 19% of Category 1 & 2 incidents in 2006 according to Environment Agency (2007). The sector has the third-highest number of incidents (after construction & demolition, and 'other manufacturing'). The extent to which the milk industry is responsible for these incidents is unclear.

In terms of employment, of the 34,000 people who work in the milk industry driving tankers, pasteurising milk and packing and distributing dairy products (NFU, 2006), the majority work in milk processing. According to United Nations Industrial Development Organization (UNIDO) data, in 2003, dairy product processing employed 29,319 people[31]. There is no evidence indicating how this employment is divided between milk processing for liquid products and other milk processing. Labour costs account for 12.2% of total dairy processing costs in the UK (London Economics, 2003); average gross annual wages in 2006 were £26,628 according to the Annual Survey of Hours and Earnings (Office for National Statistics, 2007).[32]

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[31] From UNIDO data, UK Employment, wages and related indicators by industry, at current prices, selected years. See www.unido.org/data/country/Stats/StaTableE.cfm?ShowAll=Yes&c=UK, last accessed 24/09/07

[32] For Annual Survey of Hours and Earnings data see www.statistics.gov.uk/StatBase/Product.asp?vlnk=13101, last accessed 24/09/07

Significance

In terms of energy use in the system, processing is relatively significant, with primary energy per litre around one-third of that associated with milk production. Because of the contribution from non-CO_2 GHGs in farm and pre-farm activities, the importance of processing in the overall GWP associated with 1 litre milk is much less: around 1/20.

Employment at the processing stage of milk products is not as high as at the dairy farming stage: total employment is lower in absolute terms and labour is a smaller proportion of total costs. However, wage rates are high compared to the farming or wholesale stages of milk production and consumption.

Milk processing in the UK represents a relatively concentrated industry sector. The largest UK milk processors are Arla UK, Dairy Crest and Robert Wiseman and these are the main suppliers to the UK grocery retailers. They account for over 90% of total processed liquid milk sold to grocery retailers in the UK (Competition Commission, 2007b). Despite faring better than the farmers, the processors share of milk's retail price has decreased in relative terms since 1995: MDC data tells us that in 1995, of the 74.1p per litre retail price, processors received 28.7p (39%); in 2005, of the 89.6 per pint retail price, processors received 29.6p (33%). The retailers have gained relative to the farmers and processors, seeing their share of the retail price increase from 2.3p in 1995 (3%) to 27.5p in 2005 (31%) (Dairy UK, 2007).

How do impacts vary for the different types of liquid milk available to the consumer?

No published literature considers how the environmental impacts described above differ for different milk products.

From literature (particularly European Commission 2006) and plant data published in the form of regulatory submissions, it is possible to identify certain changes in operating parameters that accompany shifts in production, as follows:

- production of UHT requires higher energy inputs to achieve higher temperatures required. There are few UHT-dedicated producing dairies; drawing on performance data for one (small) one for which HFO is an important fuel, specific CO_2 emissions (CO_2/litre) for conversion of raw milk to UHT products can be calculated as approximately – 0.08kgCO_2eq./litre. In view of the nature and source of the data, this should not be taken as a fully representative figure for all UHT production, however. A very approximate value for the additional energy per litre required to produce UHT is energy needed to raise the milk's temperature sufficiently beyond the pasteurisation temperature, which is the specific heat capacity of water multiplied by this temperature difference. Since (according to European Commission 2006) UHT milk is raised to a temperature 63K higher than pasteurised, this amounts to an additional 0.3MJ/litre. FAO (1977) data, though dated, also indicate that water and steam requirements are high for sterilised milk and UHT compared to pasteurised milk.
- microfiltration also adds to the energy demand of milk processing. No exact figures are available but it is reported that energy demand for the overall processing stage may be increased by much as 30% when microfiltration is introduced (Dairy UK, personal communication)

Data on labour and capital productivity provided by FAO (1977) is dated and differences across types of milk are related to different product packaging. There is no recent evidence giving a breakdown of employment for production of different types of liquid milk.

How do impacts change if production increases/decreases?

There is evidence that, at least up to a certain point, larger-scale processing reduces per litre emissions. Figure 15 (p54) draws on published data to show how specific CO_2 emissions vary across a number of UK milk-processing dairies[33] with different annual throughput levels, while Figure 16 (p55) shows the variation of water consumption across a larger number of UK sites (effectively in water used per 1,000 litres milk, taking the specific gravity of milk to be 1,000 kgm^{-3}, as we have throughout this work).

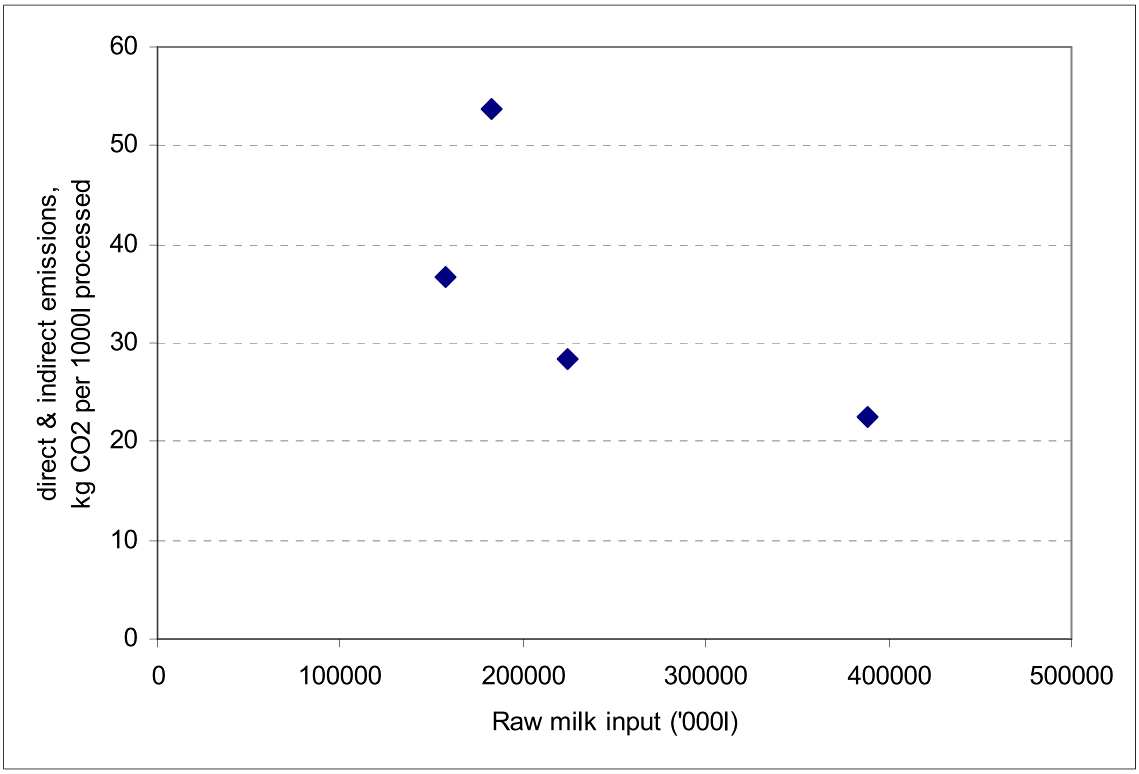

Figure 15: Specific CO_2 from energy use in 4 milk processing plants
Source: Dewick & Foster 2007

[33] The data used relate to dairies for which no UHT production is declared in the sources used.

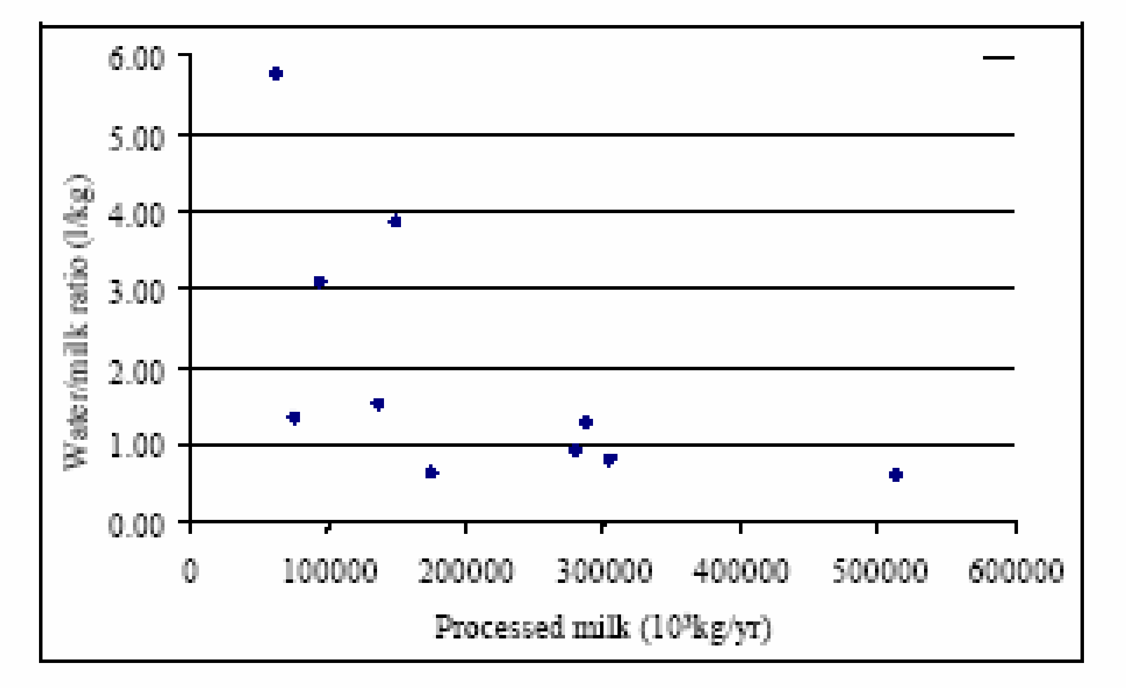

Figure 16: Water use for milk processing
Source: European Commission 2006

Both economies of scale, and limits to them, have been found by analysts considering milk-processing economics. Seven companies process over 100 million litres of milk per year in England and Wales, accounting for over 90% of all milk processed (MDC Datum). London Economics found that plants processing over 3 million litres of milk annually are more productive. However, after a point, further production does not significantly reduce average costs (FAO, 1977). These diminishing returns to scale in milk processing were also found more recently; London Economics (2003) showing that industry productivity would be highest if all dairies produced between 50 million and 100 million litres of milk (*c.f.* all small dairies or all large dairies). FAO (1977) states that the optimal production levels for different types of milk (UHT, sterilised, pasteurised) differ according to labour, equipment, energy and packaging considerations, but this information may be less relevant now.

Potential for change

European Commission (2006) provides benchmarks for what is achievable in terms of energy, water use and wastewater production:

- energy consumption: 250 – 700MJ/'000l
- water consumption: 0.6 – 1.8m^3/'000l
- waste water discharge: 0.8 – 1.5 m^3/'000l

The food trade 'press' recently reported that pasteurisation using ozone is being tried in a Scandinavian dairy – a process that is said to lower energy costs since it removes the need for heat treatment (El Amin, 2007). It is also reported that micro-filtration alone can achieve the same microbiological contamination levels as pasteurisation (Arla Foods, personal communication). However, there are also reported to be disadvantages associated with all alternatives to pasteurisation so far developed (Dairy UK, personal communication).

Data on the numbers of processors are difficult to interpret given that the later data is based on survey response, so the extent to which the industry is operating at 'optimum scale' is hard to assess. It is likely that the number of processors has fallen since 1997 and we know that an increased proportion of total milk is produced by fewer processors (see Table 23, p56).

	Number of enterprises (% of total)		**Annual production (litres milk) (% of total)**	
	1997	**2005**	**1997**	**2005**
1m litres or less	796	6	15	2.2
	(90)	(14.7)	(0.02)	(0.0)
Between 1m and 10m litres	47	9	190	33
	(5.3)	(26.5)	(2.8)	(0.6)
Between 10m litres and 30m litres	20	6	409	102
	(2.3)	(17.6)	(6)	(1.9)
Between 30m litres and 100m litres	6	7	219	381
	(0.7)	(20.6)	(3.1)	(7.1)
More than 100m litres	11	7	6051	4869
	(1.25)	(20.6)	(87.8)	(90.4)
Total	880	34	6884	5388

Table 23: Number and scale of UK milk processors

Source: Eurostat (1997 figures) for the UK annual production of drinking milk. MDC Datum data for England and Wales liquid milk output. The difference between the 5388 figure and the 6726 figure is accounted for by Scotland (where 605M litres of whole and skimmed milk was processed in 2004 according to MDC datum)[34] and Northern Ireland (for which we do not have figures). Note that the 2005 figures are based on DEFRA survey data and underestimate the numbers, particularly among small dairy processors.

4.7 Milk packaging

According to Mintel (2006), HDPE and PET bottles are used to pack 78% of all milk sold through shops and doorstep delivery (clearly, HDPE is more important than PET, with the 4-pint[35] HDPE container being the most popular). Glass bottles are still used for 11% of retail liquid milk, while the remainder is packed in cartons. Of the carton-packed milk, around 90% is UHT. Some retailers have recently experimented with flexible pouches for milk packaging, while the trade press bears witness to the efforts of PET-based packaging to extend its use for milk.

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[34] MDC Datum: Scotland milk utilisation at www.mdcdatum.org.uk/ProcessorDataPrices/ukmilkutilisation.html, last accessed 5/10/07

[35] Milk is still sold in containers sized in multiples of imperial pints (US pints in the USA); for convenience we use these units in referring to container sizes, although impacts are quoted per thousand litres milk. 1 imperial pint is 0.568l. 1 US pint is 0.472l

The packaging used for milk going to other 'retail' outlets (institutions, restaurants) is not covered by survey or statistical information. Most people will have encountered various single-portion packs in restaurants, cafes or trains. The extent to which milk is delivered to large 'catering' users in containers larger than 6 pints is unknown.

Impacts

It is useful, in discussing the environmental impacts associated with packaging, to distinguish between the impacts of package production and the impacts associated with packaging systems. Evaluating the latter takes into account the extent to which packaging re-use, recovery and/or recycling allows the impacts arising from the initial production steps to be spread over several uses (which can be the same or different). Where recycling takes packaging material into other applications, the 'benefit# of recycling is often taken as the impact associated with some displaced 'virgin' material production that would have occurred had the recyclate not been available[36]. Since re-use rates, recycling rates and the options available for reprocessing vary from country to country (and even from region to region), it is no surprise that assessments of the relative environmental performance of packaging systems produce different answers. Employment in the packaging industry is beyond the scope of this work, although since polymer bottles are often produced from polymer granules within the dairy, the boundary between the packaging industry and the dairy processing industry is unclear.

A significant body of work studying the environmental impacts of packaging exists, much of it relating to beverage containers and some directly relating to milk packaging. WRAP has recently commissioned a LCA of milk packaging in the UK; this is planned to reach its conclusion in Spring 2008, and is in its early stages at the time of writing.

Most complete LCAs of packaging consider packaging systems and the reporting of results seldom allows production impacts to be disaggregated (there are several life cycle inventories, notably the "BUWAL 250" report (SAEFL 1998), Plastics Europe datasets and data in the "ecoinvent" database, that allow the calculation of production impacts for containers if container weights are known). However, for single-trip HDPE bottles, the most important milk packaging in the UK, Keoleian and Spitzley (1999) found that material energy accounted for 84% of total life cycle energy for milk delivered in the USA in 0.5 US-gal (i.e. 1.89-litre) single-trip HDPE containers, an amount equivalent to 3.8MJ/litre.

A Plastics Europe LCA dataset describes the production of blow-moulded HDPE bottles, and could be used to calculate impacts for bottle production under all environmental themes covered in LCA. A complete LCA is beyond the remit of this project, but reference to Boustead (2005) and Dairy UK data on the weight of 4-pint HDPE bottles used in the UK provides the following approximate values for primary energy and global warming potential per thousand litres milk arising from packaging production:

- primary energy (MJ): 1700
- GWP_{100}, kg CO_2 eq.: 50

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[36] In the case of recovery through combustion in Energy-from-Waste plants, it is other forms of energy production that are displaced

Note that the primary energy figure here is considerably lower than the 'material energy' figure found by Keoleian & Spitzley (1999). As well as differences between US-relevant and European data, differences in pack weight account for some of the discrepancy: the single-trip HDPE container in Keoleian & Spitzley's analysis weighed 45.2g (i.e.24kg per 1000 l), whereas Dairy UK figures indicate that the weight of HDPE containers used in the UK is about 17kg/1,000 l

We have identified no published studies of milk packaging used in the UK from which comparable figures for the production of alternative packs could be disaggregated. Studies of packaging systems in other countries give some indication of how impacts **differ** between different packs, however.

Keoleian and Spitzley's (1999) work considered several forms of milk packaging in the context of practice in the US, and appears to be the only published LCA dedicated to this. Their values for life-cycle energy use (Figure 17 below) show clearly how the number of times containers are used[37] affects the calculated impact of refillable containers, as well as the principal differences between pack types using this measure. Note that these figures also incorporate the energy requirements for transporting containers by road when full, for 200km from dairy to retail outlet.

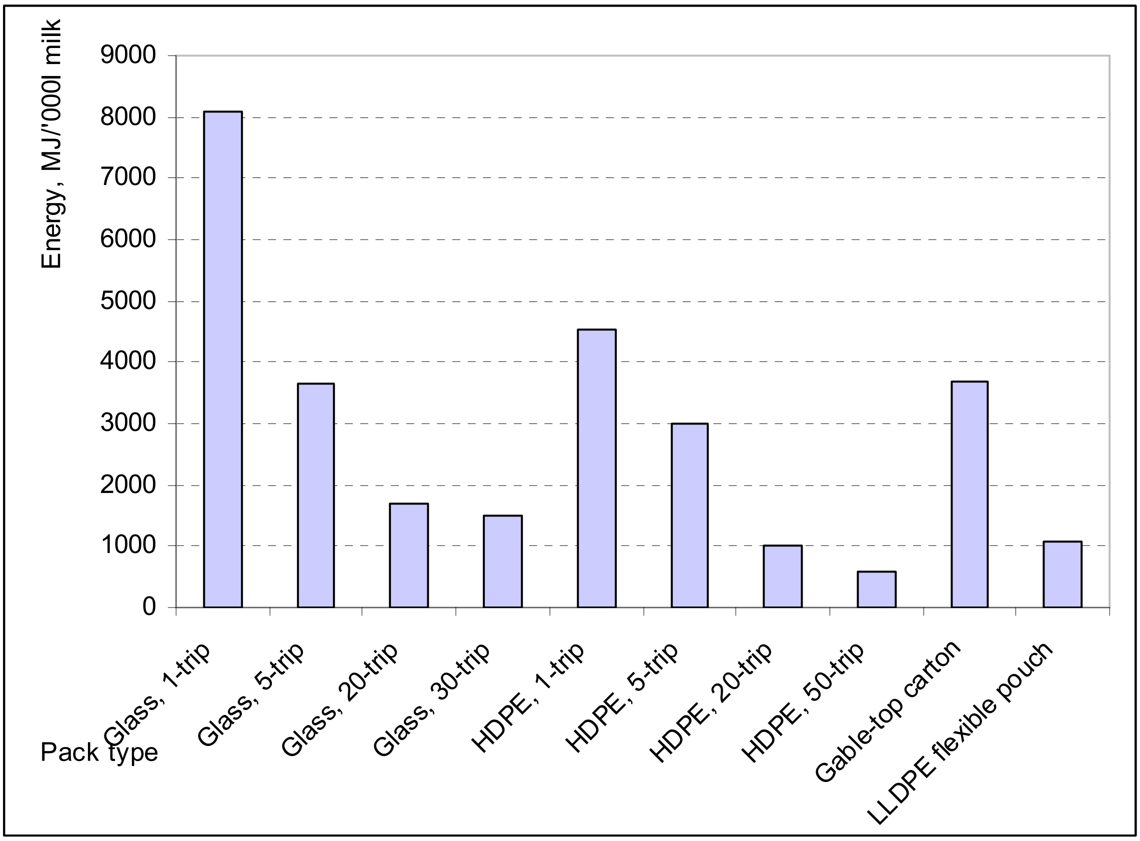

Figure 17: Life cycle energy for 4-pt (US) milk packs
Source, Keoleian & Spitzley, 1999

[37] This is generally referred to as the trippage rate. The number of trips refers to the number of times a container is refilled before it becomes waste – whatever happens to that waste

This evaluation is based on modelling that incorporates post-consumer recycling rates for the various containers reported for the USA in the mid-1990s, which were approximately 30% for HDPE bottles, 22% for glass and 0% for cartons. Changing the recycling rate changes the burdens associated with the different packs. Figure 18 below shows the life cycle quantities of solid waste calculated by Keoleian & Spiztley (1999) for two conditions, US average recycling and zero recycling (this still incorporates a 16% recovery-by-incineration rate). Scott Wilson and SWAP (2002) reported that only around 3% of plastic bottles entering the UK waste stream were collected for recycling in 2002, while more recent WRAP data (RECOUP 2006) shows this to have risen to 13% in 2005. According to RECOUP's 2007 survey the recycling rate for HDPE milk bottles is now 37% (Nampak, personal communication).

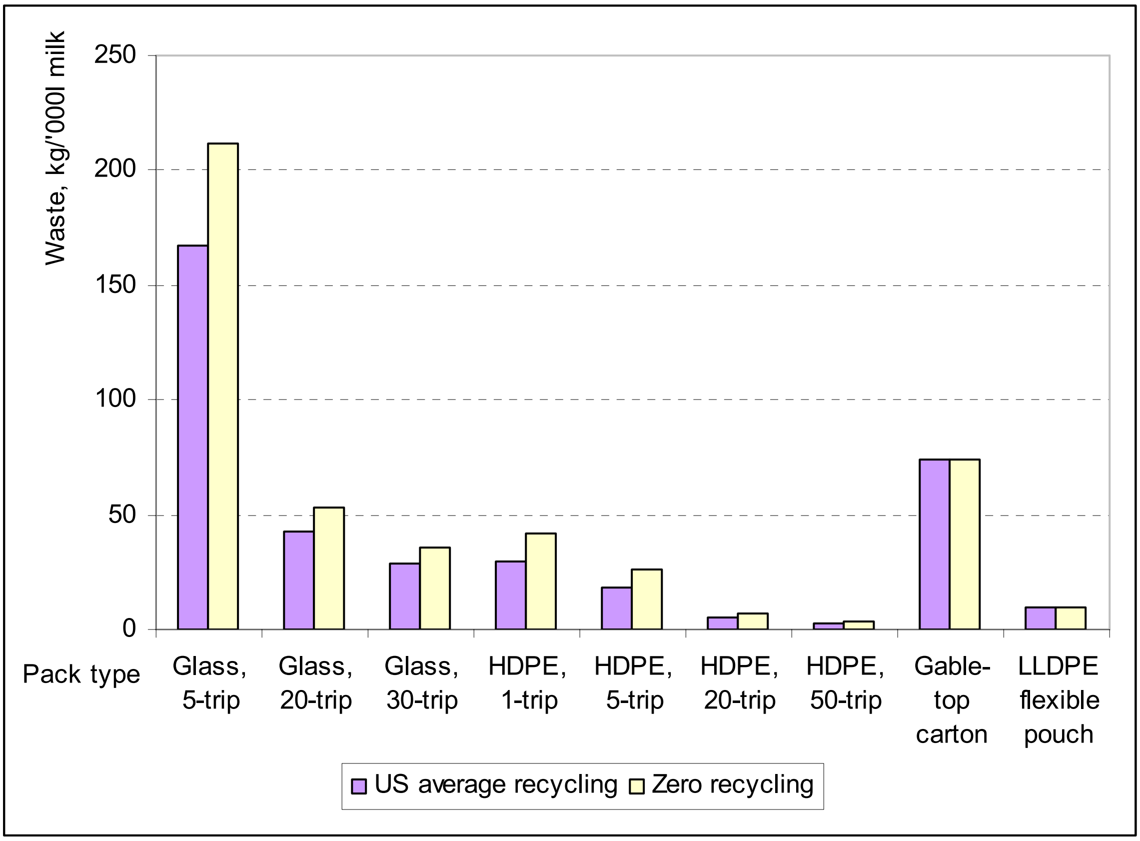

Figure 18: Life cycle solid waste for 4-pt (US) milk packs

Source, Keoleian & Spitzley, 1999

(values for single trip glass are 500 & 630 kg/'000 l milk, omitted from chart for clarity).

Note that average recycling rates for gable-top containers and LLDPE pouches were 0 in this work.

Detzel *et al*. (2004) conducted a comparative LCA of PET-based and glass-based beverage packaging systems in Germany. This attempted to take into account all the 'benefits' delivered by different packaging systems used for home and out-of–home consumption of soft drinks. The home consumption systems included 0.7l refillable glass containers re-used 50 times and larger (1.5l and 2l) one-way PET containers with high levels of collection and recovery. The overall results of this study found that the re-usable glass system had somewhat lower impacts than the PET system in terms of fossil resources and global warming potential, but somewhat higher impacts in terms of eutrophication and photochemical ozone creation potentials, with smaller differences for other LCA impact categories.

RDC/PIRA (2003) in a study of both internal and external (environmental and social) costs of different packaging systems also compared refillable glass and PET (both refillable and non-refillable) containers. This work found that distance to market was a key parameter in determining the balance of external costs between packaging systems and concluded that "neither refillable nor non-refillable [containers] may be considered generally preferable for beverage packaging". However, it did find single-trip PET packaging systems to have lower total costs than refillable glass ones; but here, in contrast to the IFEU study, the 'trippage' rate for glass containers was set at 20. The external costs associated with the different systems were more finely-balanced than the total costs. For these, refillable glass performed better than single-trip PET containers for distribution distances less than approximately 200km (although refillable PET containers performed better still), while the situation was reversed for greater distances to market. This situation is, of course, the consequence of the higher fuel costs associated with transporting heavier glass containers.

Significance

If the primary energy and global warming potential figures for production of HDPE bottles are taken as indicators of the 'significance' of packaging in the absence of recycling or recovery, then the contribution of packaging to overall life-cycle environmental impacts is similar to, and possibly greater than, that of processing.

If we consider the environmental impacts of initial packaging production to be 'diluted' by reuse, recycling or recovery then it is reasonable to assert that the current environmental impact of milk packaging is somewhat lower than this maximum, while not forgetting that the nature of milk packaging influences the impacts that arise in transporting the milk to the retailer and the consumer.

How do impacts vary for the different types of liquid milk available to the consumer?

There is limited information on the exact packaging mix used for the different liquid milk products. It is clear from the figures in Figure 3 (Milk in the UK, p9) that a higher proportion of UHT milk than of fresh milk is packed in laminated board containers. The work of Keoleian & Spitzley (1999) suggests that these are associated with higher environmental impacts than single-trip HDPE containers. Single-trip glass containers, which perform very poorly in Keoleian & Spitzley's analysis, may be more common as packaging for sterilised milk (where the choice of container is constrained by the need for heat tolerance in the process); fresh milk is not packed in glass containers intended to make only a single trip. Secondary packaging is likely to differ for other types of milk and container size also.

The impacts of packaging per litre are somewhat sensitive to the size of the container used; broadly speaking, because of the relationship between a volume and the area of the surface enclosing it, the higher the container volume, the lower the container:contents ratio. Keoleian & Spitzley found that life cycle energy use for milk delivered in 1-US gallon containers was approximately 75% of life cycle energy use for the same volume of milk delivered in 0.5 US-gal containers. So while it is reasonable to assume that impacts per unit volume of milk will be considerably higher for individual portion packs than for 4-pint HDPE bottles, and lower for 10-litre 'Pergall' packs, quantification of the range is impossible. Such information is unlikely to be an output of WRAP's current research, however, since its remit is confined to "the most used container sizes" and "domestic consumers" only (WRAP, personal communication).

Potential for change

Some potential for reducing the environmental impacts of milk packaging is recognised, and is being pursued by signatories to the Courtauld Commitment. New trials of LLDPE pouches in the UK were widely reported in the press earlier in 2007 (e.g. Guardian Unlimited, 2007).

It will be clear from the preceding discussion that reducing pack weight is not the only way in which the environmental impact of milk packaging can be reduced: effective material recycling is an important factor, and material selection should be carried out with recycling capacity in mind. At present, single-material HDPE packaging can be recycled back into milk bottles at up to 50%. The difference in price between virgin material and recyclate is a critical factor in determining the extent of recycling that takes place; the current price for virgin HDPE is reported to be £900 per tonne, whereas the price for baled post-consumer HDPE milk bottles is £330 per tonne. The latter, of course, need further processing before they represent a raw material for moulding; Scott Wilson/Swap (2002) quoted reprocessing costs for polymer from plastic bottles in general as being in the order of £150-200 per tonne. While much attention focuses on packaging for milk sold through multiples, it is possible to speculate on the scope for wider use of larger containers for provision of milk to institutions or catering establishments. Sales of milk to, and its use in, these 'retail' outlets are so little-reported that no estimate can be made of the scope such change might offer.

4.8 Milk transport to the 'retail distributor'

Most (4.16 bn litres) fresh milk is transported direct from the dairy to the retailer: each lorry may make four to five 'drops' to stores in a vicinity. Every day, sometimes more than once a day, milk, already packaged, arrives at the supermarkets. Fresh milk is kept in large refrigerators in the warehouse or in refrigerated display cabinets.

UHT and sterilised milk (~0.4 bn litres) are transported via retailers' Regional Distribution Centres (RDCs). These products are stored at ambient temperatures. Some fresh milk (0.5 bn litres) is delivered direct to customers' doorsteps.

We have no data on how milk is delivered to the private foodservice sector (1.3 bn litres), but it is likely to be via an intermediary, be it a supermarket or wholesaler. We have no data either on how milk is delivered to public institutions (0.6 bn); however, we know that many local authorities specify that milk should be sourced locally.

Impacts

As discussed above (Section 4.5 'Transport to the dairy'), the impacts of transportation on the environment are those arising from fossil fuel use and from vehicle movements themselves. DEFRA (2007e) list the main environmental and social impacts as congestion, impact on the infrastructure, accidents, air quality, climate change and noise; when quantified in economic terms, congestion has the largest impact. There is employment at this stage too of course. The environmental impacts thus depend directly on the distance the milk travels from the dairies to the retailers, the type of packaging and the efficiency of the vehicles (both in terms of storage and fuel efficiency). Keoleian and Spitzley (1999) estimated the energy consumption (MJ per 1,000 l energy corrected milk) for transportation in the USA at between 37 to 406 MJ per 1,000 l milk depending on the type of packaging (paperboard and HDPE bottles respectively). In the form of diesel this corresponds to a GWP of between 2.8 and 31 kg CO2 eq per thousand litres of milk for fuel production and combustion.

For a generic UK dairy producing 250m litres of milk, milk travels 7.55m miles, using 1.822m litres of diesel, equivalent to 5,727 tonnes of CO_2 (Dairy UK data). Applying widely-used conversion factors, the GWP associated with this fuel use (production and combustion) is around 19 kg CO_2 eq./1,000 litres milk – within the (albeit wide) range given by Keoleian & Spitzley.

Taking a similar approach to that described in 'Transport to the Dairy', NOx emissions at this stage are very approximately 0.1kg SO_2 eq./1,000 litres milk, which gives a coarse estimate for the acidification potential arising from this stage of the life cycle. There is insufficient data available to calculate other impacts.

Significance

All sources (Competition Commission (1999); Keoleian and Spitzley (1999), Dairy UK generic processing data) indicate that transport from the dairy to the retailer generates higher impacts than milk collection. According to Keoleian and Spitzley (1999), energy consumption can be four times greater at this stage if the heaviest packaging is used. Dairy UK data for a generic dairy producing 250 million litres of milk attach 11.2km per 1,000 l of milk between farm and dairy and 48km per 1,000 l of milk between dairy and retail. Evidence from a case study of the milk supply chain for Spar (Food Chain Centre, 2005) suggests that from a dairy processing 60,000 litres of milk, 1,000 litres of milk travels an average of 48 km between farm and dairy but travels 90km between dairy and retailer.

These impacts remain very much lower than those arising from primary production, however.

Different products

Higher transport-related environmental and social impacts might be expected for UHT/sterilised milk than with fresh milk since they go to the retail outlet via an RDC or other intermediate location, rather than directly from the processing site. But the fact that UHT and sterilised milk can be transported in ambient, rather than refrigerated vehicles means that the position – with regard to energy and emissions at least – is unclear.

How do impacts change if production increases/decreases?

More milk produced would lead to more milk processed and more milk going on to the retailer. Notwithstanding increases in production, there is a long-term trend toward more milk being sold through retailers and other convenience outlets (vis-à-vis doorstep delivery). Environmental impacts will eventually rise but, as argued above, the relationship is unlikely to be linear and there may be economies of scale that can be exploited. DEFRA (2007e) shows us that the economic costs of environmental impacts decrease as lorries increase in size to a certain load (up to 33 tonnes, after which the costs increase significantly). Environmental impacts in this report include congestion, impact on the infrastructure, accidents, air quality, climate change and noise (Defra, 2007 – FISS).

Potential for change

The report of FISS group on food transport (DEFRA, 2007e) identified a number of ways in which impacts at the transport stage can be reduced, some of which are applicable to milk. For instance, local sourcing of milk can avoid milk being transported great distances. This strategy is already being followed by Waitrose ('Select Farm') and Tesco ('Local choice') amongst others who sell milk under various different labels. The location of dairy farming in the UK relative to where most people live and work imposes some limits on the extent to which this strategy can be pursued. In addition, transporting packaged milk from dairies located in milk fields brings additional energy costs.

Alternatively, DEFRA (2007e) suggests that a review of the location of RDCs could offer savings, though strong capital investments would be required to change the location or size of RDCs.

The non-linear relationship between increased production and increased environmental impacts can be exploited by greater capacity vehicles and collaboration between the retailers. The use of greater capacity vehicles and transport collaboration have been estimated to be the two most effective means of reducing CO_2 emissions by the FISS transport group, offering the potential to lower food transport CO_2 emissions by over 10% (DEFRA, 2007e). Collaboration is perhaps more difficult to implement, and effective management is required to avoid conflicts of interest.

From a technological perspective, general improvements in engine specifications will improve efficiency with fleet replacement, usually on a 3-5 year cycle. Faster replacement would lead to improvements sooner, but there is a major cost associated with this. The introduction of new technology into fleets, for instance 'vehicle telematics' (maximising route planning and fleet utilisation), has been shown to reduce fuel consumption by between 5 and 10% (DEFRA, 2007e). Combining improvements in engine specifications and vehicle telematics could lead to an estimated reduction in food transport CO_2 emissions of 2.7%. In addition, lower vehicle-related emissions at all levels of production can be achieved by improving driver performance; a 6.5% improvement in fuel efficiency has been achieved for instance in a confectionary manufacturer (DEFRA, 2007e). A Safe and Fuel Efficient Driving (SAFED) standard has been developed and is aimed at improving the safe and fuel-efficient driving techniques of heavy goods vehicle (HGV) drivers. Further details are available from www.safed.org.uk/index.htm (last accessed 14/11/07).

4.9 Milk retailing and transport to the consumer

It is important to remember that milk 'retailing' encompasses numerous points at which the consumer takes possession of liquid milk. Supermarkets, petrol-stations and newsagents all sell liquid milk in differing levels of variety. But coffee shops, restaurants and buffet-cars on trains are also milk retailers, often providing single-portion packs to avoid contamination and limit the potential for spillage. The traditional doorstep milk delivery service and the online stores of major multiples constitute milk retailers that the consumer doesn't visit physically. Some idea of the relative importance of these different outlets has been provided earlier in this report.

Within the retail outlet, fresh milk is stored in refrigerated areas, while UHT products are generally kept at ambient temperatures (certainly in larger shops).

Given the range of retail outlets for milk, it's clear that milk is transported to the consumer in many ways, and seldom alone. Setting aside the foodservice sector, since it would be ridiculous to characterise a visit to the restaurant as a trip to collect liquid milk, still leaves a complex picture. Online retailers and "milkmen" deliver from vans, but both may bring other products. An individual's trip to supermarket or newsagent might be prompted by a need to replenish the fresh milk supply, but whether the return trip involves solely the transport of milk to the home is another matter.

Impacts

At the retail level, and confining the discussion to shops, it is possible to link some of the environmental impacts of store operation to milk, by allocating part of shops' energy use to milk storage.

Elsayed et al. (2002), in their survey of energy use and CO_2 emissions in the UK's non-domestic building stock, report that refrigeration and catering combined account for 37% of electricity use in supermarkets. From other data in the same source, mean electricity consumption in a supermarket can be estimated at 3,000 GJ/yr[38], making mean electricity consumption for refrigeration approximately 1,100GJ/yr. Information supplied to the project team by the Roadmap Taskforce indicates that milk typically accounts for 5% of refrigerated goods in a supermarket. On that basis, milk storage accounts for around 55GJ/yr (15.2MWh/yr) electricity consumption in an average UK supermarket. Using the same characterisation factors as applied in Cranfield's LCA model, this electricity use gives rise to the following impacts:

GWP_{100}	**Eutrophication potential**	**Acidification potential**	**Abiotic resource**	**ODP**	**POCP**
kg CO_2 eq.	kg PO_4^{3-} eq.	kg SO_2 eq.	kg Sb eq.,	kg	kg ethene
9800	2.7	36	110	0.003	0.16

Table 24: Milk retailing impacts (1)

[38] The source reports mean area and mean specific energy consumption. Both are distributed widely about the mean values quoted.

Average milk volume sold through a supermarket is not reported, so these annual impacts cannot be related to individual litres of milk. A more rigorous approach to calculating these impacts might also allocate some of the energy ‘overhead’ associated with operating a supermarket (energy for space heating, space cooling and lighting, for example) to milk – probably based on the proportion of sales volume or value the product represents.

The data in Elsayed *et al.* (2002) for smaller retail outlets indicates that these are less energy intense (in terms of annual energy consumption per unit area) than supermarkets, and does not include identifiable fractions of energy use associated with refrigeration. It has already been noted (Garnett, 2006) that this may reflect shorter opening hours as much as more efficient use of energy.

Another way of estimating energy used for fresh milk storage is to draw on data relating to the operation of refrigeration equipment. Carlsson-Kanyama and Faist (2000) quote electricity consumption of retail refrigerated displays at 0.12MJ/litre net volume/day, and that of ‘cool rooms’ at 0.0025MJ/litre/day. It is understood from information supplied by the Roadmap Taskforce that milk is typically retained in supermarkets for 24-48 hours. If we take 36 hours as a working figure, and assume that the product is in a cold room for 2/3 of this period, and a refrigerated display for the other 1/3, energy consumption per thousand litres of milk would be 62.5MJ. The impacts associated with this would be those shown below:

GWP_{100}	**Eutrophication potential**	**Acidification potential**	**Abiotic resource**	**ODP**	**POCP**
kg CO_2 eq.	kg PO_4^{3-} eq.	kg SO_2 eq.	kg Sb eq.,	kg	kg ethene
10	$3x10^{-3}$	$4x10^{-2}$	0.1	0.003	$2x10^{-5}$

Table 25: Milk retailing impacts (2)

It appears that the refrigeration units used to hold the trolleys on which milk botlles are shipped from dairy to supermarket generally incorporate fewer features promoting efficient refrigeration than other units, because of the form required for convenience in use (it is for example, difficult to incorporate a closed front or even a ‘lip’ to retain cold air).

In terms of transporting food home from the retailer, we have no milk-specific data. From Mintel (2006) we know that in 2004, 92% of shoppers bought groceries at the supermarket (the next most popular, 21%, were convenience stores). A large proportion (35%) drive to out-of-town supermarkets but tend to spend more (and thus might be supposed to be relatively more efficient in transport terms) in these larger stores. Most (59%) shop once a week but we know that since the demise of the doorstep delivery, milk is a staple purchase, bought regularly from various different outlets (petrol forecourts, smaller grocery stores, newsagents, etc) at consumers’ convenience. The environmental impacts associated with consumers’ transport of food to the home have been considered by Pretty et al (2005). Those people who walk or cycle to and from the shops where they buy their food impose no adverse impact on the environment. But this is not the most common behaviour: Figure 19 (p66) shows the relative importance of the main modes of transport used by shoppers.

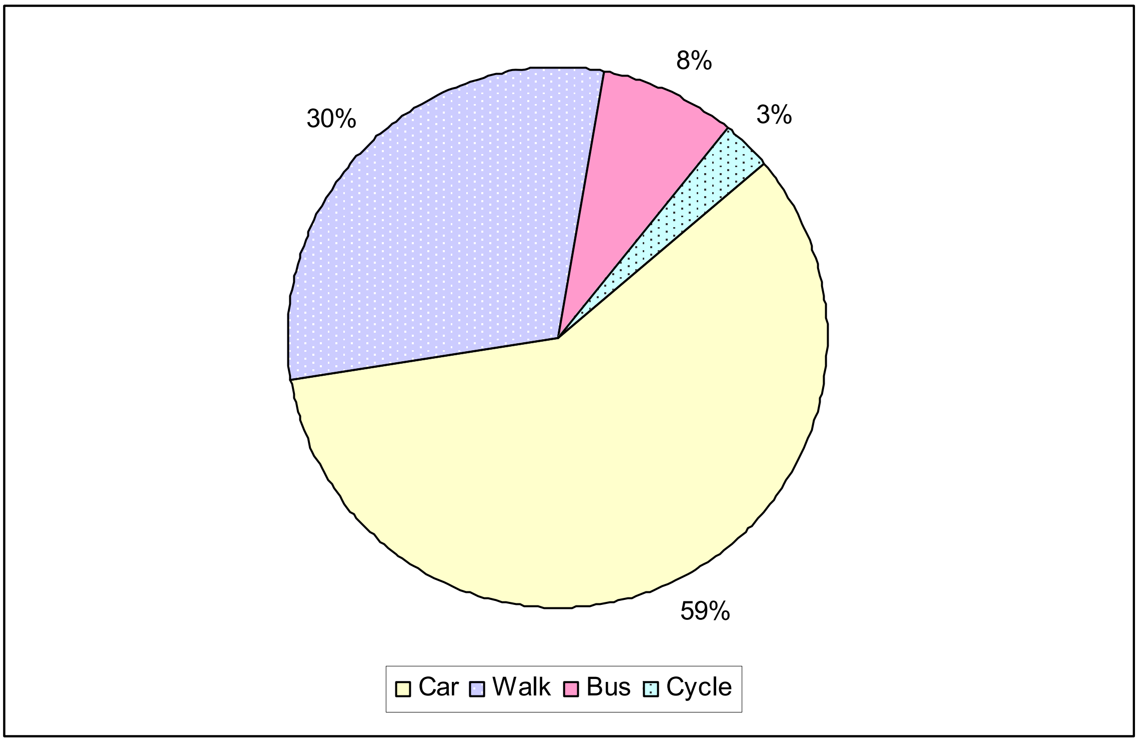

Figure 19: Shopping transport
Source: Pretty et al (2005)

According to Pretty *et al.* (2005), on average, each person in the UK made 221 shopping trips in 2000, travelling an average of 6.4km for each. Using the car involves burning petrol or diesel fuel, resulting in emissions of carbon dioxide (CO_2) and carbon monoxide (CO), nitrogen oxides (NOx), particles and unburnt volatile organic compounds (VOCs). Each of these contributes to environmental damage: the CO_2 to climate change, the NOx to acidification and the NOx, particles and VOCs to local deteriorations in air quality. Pretty *et al*. (2005) tried to calculate the environmental and health costs of food transport at different points in the food chain. The authors' calculations suggest that transporting food from retail outlets to the home involves around 10 billion car kilometres per year. Assuming that a medium-sized car uses less than 0.1litre fuel to travel 1km, emitting around 240gm CO_2, this equates to total emissions of CO_2 from that are around 240,000tonnes.

We have no detailed description or analysis of the impacts associated with doorstep delivery of milk. We know that it is a declining channel by which consumers buy their milk, some of which can be attributed to price. The price of milk sold in supermarkets was 27p per pint in 2007 compared to an average doorstep delivery rate of 43p per pint, but the trend is underpinned by changing social habits (e.g. growth in people eating out). Despite declining sales, doorstep deliveries still account for 7.5% of total drinking milk sold to customers. Dairy Crest, the largest doorstep delivery business in England and Wales have 3,000 milk rounds, 180 depots and deliver to 1.6 million households. More than half of their delivery vehicles are electric, so, although we do not have any specific data we can assume that the contributions to environmental impacts will be lower for at least this proportion of milk delivered. Load capabilities of milk floats average between 1.5 – 3.5 tonnes (including batteries). Re-charging the batteries of the vehicles – said to take about 8 hours – involves some electricity use and thus has impacts at the energy generation stage.

Losses at the retail stage, as elsewhere, generate waste and inflate the production rate necessary to provide a given function to consumers. There is little published data on product wastage rates in retailers. One member of the Dairy Roadmap Taskforce indicated that losses of 0.1% are achieved in large multiples (Reynolds, personal communication). Losses from retailers through pollution incidents might also be expected to be relatively low: Environment Agency (2006) statistics indicate that wholesalers and retailers accounted for 11 Category 1 & 2 water pollution incidents in 2006, whereas agriculture (in total) accounted for 65 and road transport (of all goods) 212. The extent to which these involved milk is unknown.

In terms of employment, the Milk Task Force report in 2002 reported that the impact of declining doorstep sales had been a fall in the number of milk rounds, from 19,786 in 1994 to 11,081 in 2000, with a corresponding loss of milkmen employed. It is not possible to calculate the net effect associated with increased employment in supermarkets and convenience stores as a result of increased milk sales through those channels, though it is unlikely to offset the fall in the more labour intensive doorstep delivery channel.

Significance

If we take the GWP figures in Table 24 (p64) and Table 25 (p65) as at least indicative of retail-stage impacts, then for GWP this part of the life cycle is of similar significance to milk collection.

FISS (2006) state that 13% of the carbon emissions produced from transporting food in the UK come from individuals driving to and from the shops. Pretty *et al*. (2005) calculate that while transporting food to retail outlets involves some 6 billion road vehicle kilometres per year, transporting food from retail outlets to the home involves around 10 billion car kilometres per year: so, car transport is certainly a significant part of the food logistics system. As noted above, this equates to 240,000 tonnes of CO_2; however, given that large trucks produce more pollutants per kilometre travelled than cars do (a full 40-tonne truck uses around 0.3litres of fuel to travel 1 km, emitting almost 1kg CO_2 in the process), then 6m tonnes of CO_2 can be attributed to lorries transporting groceries to the retailers. Emissions arising from different vehicles travelling 1km are shown in Figure 20 (p68).

Distance travelled in vehicle kilometres isn't the only factor that needs considering when assessing the environmental impact of food transport. A certain weight of food needs to be transported to feed the UK population, so the weight in each vehicle also needs to be taken into account to asses the relative efficiency of moving food in different vehicles. As an example, consider a single tonne of food. On its way to the supermarket, this might be one-twentieth of the load in a single articulated lorry. So the emissions associated with moving this tonne of mixed food one kilometre are calculated as 1/20 of the emissions associated with the truck travelling one km (50g CO_2). But no car travelling home from the shops ever carries as much as one tonne of food. Statistics tell us that on average, 15.6kg of food are purchased for each household in the UK each week. So a car taking food home from the shops probably has a 'payload' of less than 20kg. Thus it takes more than 50 cars to move that same tonne of food that was 1/20 of a truckload. In that case, moving a tonne of food in cars probably uses 5 litres of fuel, with emissions around 12kg of CO_2. Figure 21 (p68) shows emissions from the same vehicles as Figure 20 (p68) but now compared on this per tonne kilometre basis (assumed loads as per preceding text).

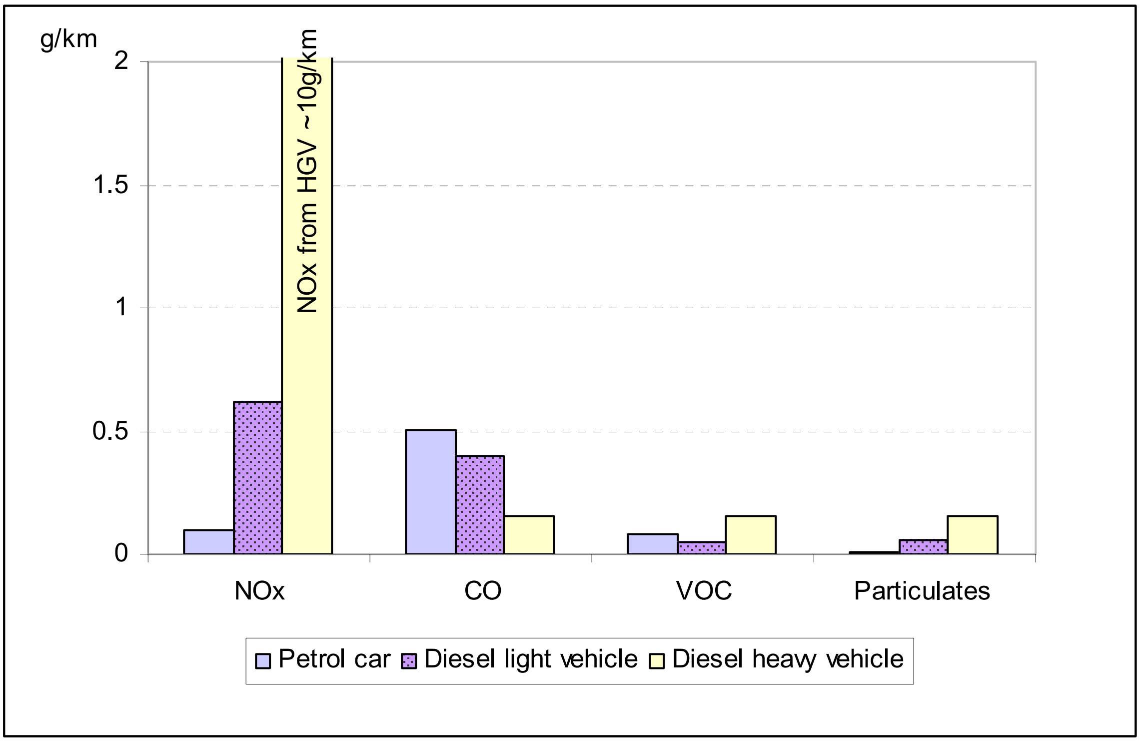

Figure 20: Per km emissions from vehicles in use

Original data from de Beaufort-Langeveld *et al*. 2003

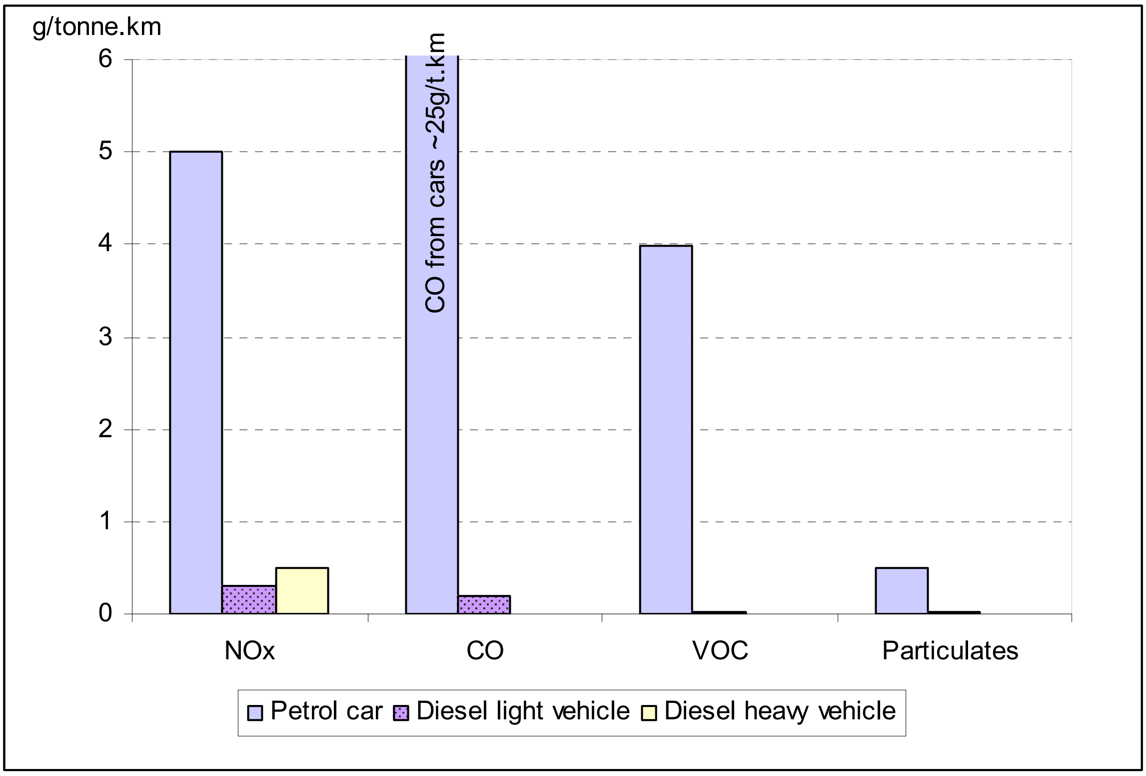

Figure 21: Per tonne.km emissions from vehicles in use

It is difficult to estimate the impacts associated with doorstep delivery of milk. Applying the reasoning above, that leads to the general conclusion that transporting goods in larger loads for as much of the journey to the consumer as possible reduces impacts, we can assert that having a litre of milk delivered is better than making a dedicated car journey to fetch one. However, whether the presence of a doorstep milk delivery service reduces the overall impacts associated with car-based food shopping is a different question, and one which cannot be answered with the evidence available.

How do impacts differ for the various types of liquid milk available to the consumer?

The principal difference is between fresh milk products, which require refrigeration at the retail stage, and UHT and sterilised milk products, which do not. So in principle, UHT milk products are free of the refrigeration-related impacts described in the previous section.

Whatever transport differences there are between supermarkets and convenience stores (and one could suggest that transport emissions associated with convenience stores to home are likely to be less than supermarket to home given the largely 'inconvenient' out-of-town locations preferred by the latter), the differences are greater for at least one growing sector of the liquid milk market. For flavoured milk, a growing impulse buy, convenience stores are selling nearly as much as (and experiencing faster growth rates than) supermarkets (41m litres compared to 46m litres in 2005) (Mintel, 2006). More generally, sales of drinking milk doubled in the convenience distribution channel between since 2002 and 2005 as a result of improved stock management (Mintel, 2006). Previously, a tendency to sell out of drinking milk, particularly from late afternoon, meant lost sales to consumers who would be typically seeking an emergency top-up purchase from such outlets (and presumably went on to a major retail outlet to make it).

The influence of sales volume

We have identified no published evidence that addresses this question (for milk or indeed for any other foodstuff), but it seems reasonable to speculate that lower sales volume would lead to less 'shelf space' for milk in the retailer – although whether that would lead to less refrigeration in the retail outlet is moot.

It is also difficult to argue that lower production would necessarily reduce overall transport emissions from the retailer to the consumer. A change in the mode of milk delivery would perhaps have stronger implications for overall environmental impact. The discussion of emissions per tonne kilometre (illustrated by Figure 21, p68) is important because changes in the way we buy food might involve more of it being moved further in medium-sized vehicles (home delivery of internet-purchased goods), more of it being moved further in cars (if consumers travel by car to farmers' markets or to a variety of specialist shops that are further away than the nearest supermarket), or even less of it being moved by car (if consumers increased their use of public transport, walking and cycling to reach food retailers). With the exception of effects associated with the rise or fall of the (largely) milk-dedicated doorstep distribution system, tying any of these to change in milk production or consumption levels is very difficult.

Potential for change

There is no consistent data on sales of UHT. TNS data, supplied to the research team by Nampak, presents declining sales, from 382m litres in year-ending September 2005 to 358m litres (7% of total milk sales) in year-ending September 2007. Mintel (2006) data presents a different picture. UHT milk sales rose 10% in the five years to 2005, with retail sales of 428m litres (8.9% of total milk sales). Mintel's market analysis indicated that increased UHT sales were skewed towards older adults and the retired, a growing sector of society (Mintel, 2006). Further growth (or a return to growth) of UHT sales would probably translate into refrigeration savings at the retail storage stage – assuming that UHT is bought instead of, rather than in addition to, fresh milk. Such growth may also contribute to less regular purchases of milk (since more can be bought at one time, the longer unopened shelf life allowing for longer storage in the home). Were this to lead to fewer shopping trips by car, vehicle emissions would fall and other environmental and social impacts such as congestion and local air pollution would reduce. However, while it's possible to speculate that a need for milk triggers a proportion of trips to the shops, there is no published evidence to support this proposition.

Sonnesson and Berlin (2003) provide scenario analysis for the environmental impacts of milk supply. Although the calculations are based on milk and cheese, the analysis shows that, as people drive further and more often to the shops, and e-shopping increases, the energy impacts at the retail-to-home stage increase by more than 50%. Contributions to the formation of photochemical oxidants are also increased as a result of more private car traffic. The impact of this stage doesn't increase in two future scenarios, the 'green-IT' future scenario (characterised by high fuel prices, lower use of private cars, e-shopping and a three-times per week home delivery system) and the 'harsh times' scenario (characterised by economic recession, lower access to cars, increased e-shopping and two times a week home delivery).

This raises the possibility of environmental benefits from encouraging again the doorstep delivery of milk. Doorstep delivery was hailed as the underlying reason for high volume sales and consumption, supporting stable "consumption levels" in the 1960s and 1970s whilst other countries saw their milk consumption drop (Blake, 1979). The regularity of delivery led households to continually over-estimate their intake by rounding up their requirements. The method of delivery was sustained by other institutional and social routines e.g. regular morning delivery to keep the milk fresh (useful before mass ownership of domestic refrigerators), efficiencies based on high trippage rates, weekly expenditure planning by households, size of 'milk round' constrained by the limitations imposed by weekly cash collection, size of depots constrained by dis-economies of scale above 30 'rounds'. These institutional and social routines are no longer embedded but doorstep delivery could benefit from the growth in 'e-tailing', the online purchase of milk (and other goods). Dairy Crest, the leading firm offering doorstep delivery in England and Wales, has a facility on its website enabling customers – particularly in urban areas where milk rounds have all but died out – to search for their nearest milkman and place orders online. Moreover, milkmen are offering more services – Dairy Crest milkmen for instance, offer fruit and vegetables, bread and cereals, household products (cling film, silver foil, bulbs, pet food) – operating like a small, mobile convenience store, or an alternative to the 'e-tail' offerings of major multiples.

Other factors may also encourage an expansion of doorstep delivery. First, doorstep delivery is more prominent among older and affluent consumers, two segments of the population that are set to increase (Mintel, 2006). Second, the traditional system of morning delivery may help avoid some of the problems - e.g. delivery failures, mode of delivery - foreseen for increased home delivery (Retail Logistics Taskforce, 2002) but there are still uncertainties surrounding the so-called ‘rebound effect’ – in other words, what customers will do instead of going to the supermarket.

4.10 Milk utilisation

Milk is consumed in the home and out of the home. From distribution channel data, we know that over 70% of the 6.726 bn litres of liquid milk goes direct to consumers: 3.6bn through supermarkets, 0.6 bn through convenience stores, 0.5 bn through doorstep delivery and 0.1 bn through vending machines (Mintel, 2006; Dairy UK 2007). This is approximately equal to 116 litres of milk per person per year or 3.8 pints per person per week. The remaining 1.9 bn litres are consumed in private establishments such as restaurants and pubs (1.3 bn litres); the remainder in public institutions such as schools, prisons and hospitals (0.6 bn litres).

Impacts

The way in which milk is stored, used and wasted affects the impacts at the utilisation stage. Storage in refrigerators and freezers is energy intensive and impacts on the environment primarily through electricity generation. The rate of consumption of electricity depends on the size and efficiency of the refrigerator.[39]

The electricity consumption attributable to fresh milk depends on the length of time it is kept for and how fully-stocked the fridge is. Carlsson-Kanyama and Faist (2000), provide a figure for the energy consumption of a domestic refrigeration of 0.034 MJ per litre per day. If we assume a range of milk storage times between 1 day and 4 days, then four days’ storage would require 0.136 MJ per litre (136MJ per 1,000 l milk). Using the same factors as those in Cranfield’s LCA model, we can calculate the other environmental impacts associated with this consumption to be:

Primary energy	**GWP $_{100}$**	**Eutrophication potential**	**Acidification potential**	**Abiotic resource depletion**	**POCP**
MJ	kg CO_2 eq.	kg PO_4^{3-} eq.	kg SO_2 eq.	kg Sb eq.	kg ethene eq.
120	6.1	0.001	0.02	0.08	1×10^{-4}
480	24	0.007	0.09	0.28	4×10^{-4}

Table 26: Impacts of milk use

According to Mintel (2006) and TNS (2007), the three most popular uses of milk are for tea/coffee, cereal and drinking it on its own as a cold drink. None of these uses

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[39] A quick and unscientific survey of manufacturers’ declared figures in product specifications shows that a small freezer (3-3.5 ft^3) can use from 485MJ per year to over 1,045MJ per year. Larger fridges and freezers obviously use more electricity than smaller ones made to the same standards of energy efficiency, but the difference can be relatively small: one A-rated 4.5 ft^3 fridge uses 540MJ per year, while one A-rated 10ft^3 fridge uses less than 20MJ per year more.

commonly involve cooking, which reflects a broader decline in home cooking (a trend associated with people becoming more spontaneous, less planning in making shopping lists and buying more meal solutions rather than ingredients). If milk is used in cooking, then energy consumption of milk utilisation increases; however the rate of increase depends on the form of cooking. For example, with a pint of milk, using a microwave to make custard will have less impact than using an oven to bake Yorkshire puddings. In terms of waste, a WRAP study found that we waste nearly one third (in weight) of all food we buy (5kg of an average 15.6kg per week). Interim data from Exodus market research (2006) into food waste for WRAP indicates that 6 in 10 people throw milk away, but that disposal is infrequent with one fifth of people throwing away milk at least once a week. This finding is consistent with that of Category Consulting (2007) market research data who report that of this one fifth, on average half a pint of milk or more is thrown away in a week. Preliminary conclusions from more detailed aspects of WRAP's study indicate that food wastage is significantly higher in some age groups and in some types of family. Food wastage appears to be higher among the under-25's than among the over-45's, higher in families with 1-2 children than in those with 3 or more, and higher in households which shop 2 or 3 times a week than in those that shop less frequently.[40] The frequency of milk purchases does not support reduced milk waste but Mintel's (2006) forecast reduction in the number of families and average household size may contribute to reduced waste. Research by Exodus Market Research (2006) for WRAP indicates that 59% and 52% of interviewees would probably throw away less food if they had more information on the environmental impacts and cost of waste respectively. We know of no specific recommendations for reducing milk waste but of the three fifths of people who could be encouraged to waste less, in addition to more information on the environmental impact and cost, information on how to dispose of waste in the least harmful way, clarification on sell by/use by dates and availability of smaller portions were mentioned as potential influences (Exodus Market Research, 2006). There is also no evidence on whether wastage rates in the home have changed as a result of the move to larger pack sizes and weekly supermarket purchasing of milk, instead of the daily doorstep pints.

In terms of social well being, milk contains vitamin B12 for red blood cells, calcium for strong bones and teeth, carbohydrate for energy, magnesium for muscle function, phosphorus for release of energy, potassium for nerve function, protein for growth and repair, riboflavin for healthy skin and zinc for the immune system (Dairy UK, 2007). One litre of milk contains 2.8 MJ metabolisable energy, 34 g of protein, 47 g of carbohydrate (lactose), 9 µg of vitamin B12 and 1.22 g of calcium (MDC, 2004).

Significance

Given that most milk is consumed within its sell by date, straight from the fridge, the energy-related impacts at the consumption stage are of a similar order of magnitude to those arising from transporting milk from farm to dairy. This significance hinges, clearly, on the storage related factors highlighted above. On the other hand, even with the very limited evidence available, it seems likely that the proportion of milk wasted at this stage is much higher than the proportion waste at any other point in the system. Milk wasted by the consumer is of course the most environmentally-

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[40] All information relating to WRAP work on food waste from Mark Barthel, personal communication

wasteful milk of all to be lost, since it takes with it impacts from production, processing and transport. A Swedish study (Sonesson *et al.* 2005) covering a small number of households found that dairy products were the biggest components of food wasted from homes, although the authors note some anomalies that make the levels of waste recorded in this exercise difficult to take as indicators of general behaviour.

How do impacts differ for the various types of liquid milk available to the consumer?

4.16 bn litres of milk sold in retailers is pasteurised milk, which needs refrigeration to remain fresh. Organic milk sales have increased 163% since 2004 but still represent a small proportion of the total market, accounting for 1.9% of the value of milk sales (Mintel, 2006). 418m litres is UHT and 38m litres is sterilised milk, both of which can be stored at ambient temperature. The remaining 182m litres includes other value-added products, including flavoured milk, filtered milk and other speciality milk (e.g. 2007 launch of Waitrose Wildcare milk, from 70 farmers who dedicate 10% of their farmland to wildlife habitats to improve biodiversity). Flavoured milk accounts for 88m of the 182m litres and is divided between long-life products like Yazoo (made by Campino) and fresh products like Frijj (made by Dairy Crest).

Most people (78%) buy their fresh milk in plastic containers; the 4-pint container is the most popular (39%) but sales of 1- and 2-pint containers are increasing the fastest. The relative merits (from an environmental perspective) of different packaging types have been discussed earlier.

Considering UHT and sterilised milk only, there is some evidence that consumer purchases of UHT are rising (up 10%, 2001-05) whilst those of sterilised milk are falling (down 40%, 2001-5) (Mintel, 2006), although more recent data (TNS 2007) indicates a fall in UHT sales. Users of ambient milk show a skew towards older adults and the retired (a growing sector of society) and also less affluent consumers in the D and E socio-economic groups (a fairly static sector). This shift from sterilised to UHT probably has environmental benefits in earlier stages of the life cycle: UHT is a lower-temperature process than sterilisation and can use lighter, lower-impact packaging. UHT has the additional attraction for processors of being faster than sterilisation and using equipment that occupies less space in the dairy.

While UHT and sterilised milk do not require refrigerated storage at the retail stage, all milk variants need refrigerating once opened. So a conventional LCA would likely find that the environmental impact associated with these products in the ‘use phase’ was very similar. So, whatever the potential gains at the retail stage, any shift from fresh to UHT milk is unlikely to lead to any reduction in the use of domestic refrigerators or indeed to any change in the electricity purchased to run them.

In terms of nutritional benefit, skimmed milk contains 3g fat per litre compared to 40g for whole milk (18g for semi-skimmed milk). Notwithstanding some variations in Vitamin A (310µg in 1 litre of whole milk compared to 10µg in 1 litre of skimmed) (Holland et al., 1999), the Food Standards Authority advises that semi-skimmed and skimmed milk products contain at least the same amount of protein, B vitamins, calcium, magnesium, phosphorus, potassium and zinc as full-fat versions.[41] There is very little nutritional variance across different milk types, including UHT milk (Holland

[41] Food Standards Agency: www.eatwell.gov.uk/healthydiet/nutritionessentials/milkanddairy/

et al., 1991). Some flavoured milk products and shakes contain added sugar, which has some undesirable health effects.

Some research has shown that organic milk contains more beneficial omega-3 essential fatty acids. Ellis *et al.* (2006) reported: "*Organic milk had a higher proportion of PUFA to monounsaturated fatty acids and of omega-3 fatty acids than conventional milk, and contained a consistently lower omega -6: omega -3 fatty acid ratio (which is considered beneficial) compared with conventional milk. There was no difference between organic and conventional milk with respect to the proportion of conjugated linoleic acid or vaccenic acid".* Previous such reports considered that red clover in forage was the main reason for this (e.g. Dewhusrt *et al*., 2003). The actual benefits for human health are not so clear.

The UK Food Standards Agency's (2006) response to Ellis *et al*.'s research was that it shows that "*organically produced milk can contain higher levels of types of fats called short-chain omega-3 fatty acids than conventionally produced milk".* The FSA's statement went on to say that *"the evidence suggests that these fatty acids appear to be of limited health benefit compared to the longer chain omega-3 fatty acids found in oily fish. Therefore, organic milk consumed in volumes consistent with a healthy diet, would not provide sufficient amounts of long-chain omega-3 fatty acids to provide significant health benefits, over and above those associated with conventional milk".*

How do impacts change if consumption increases/decreases?

More consumption of higher-value added milk products such as organic and speciality (e.g. local), and filtered and flavoured milk is likely to increase the revenues to the milk industry.

The implications of such shifts for earlier stages of the life cycle have largely been discussed in earlier sections of this report. It is generally held that, *ceteris paribus*, increasing product diversification leads to higher losses in processing and higher specific energy and water consumption, since cleaning becomes more frequent. While researchers and best practice programmes identify various ways of mitigating this effect, no evidence has emerged that it can be reversed.

Potential for change

On the one hand, forecasts for declining retail sales of cereal and tea/coffee for consumption in home, the two main drivers of milk consumption, do not support the proposition that milk consumption will increase (Mintel, 2006). On the other hand, the market for branded coffee shops is forecast to increase by over 50% between 2006 and 2011 (Mintel, 2006b), a trend reflecting the broader function of coffee bars as fashionable meeting places for young adults. This desire to drink coffee in shops rather than at home is re-balancing the market, with Mintel (2006b) estimating that the market size of branded coffee shops in value terms, which has more than doubled over the last five years, exceeded the value of retail sales of coffee in 2006. Also, trends show increased consumption of value-added products such as milkshakes.

The topic of packaging recycling, in which the consumer clearly has a key part to play, has already been discussed along with other aspects of milk packaging.

Reductions in the energy consumed by domestic refrigerators and the associated environmental impacts will also reduce the environmental impacts of milk utilisation – they are, however, outside the scope of this report.

Reducing domestic food wastage in general has, following WRAP's work, been identified as offering considerable potential to reduce environmental impacts throughout food chains, as production and processing activities carried out for no useful purpose are avoided. The absence of volume-based evidence about what people do with the milk they buy prevents any estimate of the potential for reducing the impacts of liquid milk production and consumption by following this path, but given the perishable nature of the product it would be surprising if there were no scope for change. Establishing how a domestic waste minimisation campaign might successfully be implemented is beyond the scope of this project, however.

4.11 Mechanisms for change (opportunities and barriers)

Government interventions

Command and control

Command and control measures can be effective for raising minimum performance of activities. The 'rules'[42] are set by the government, either in statutory instrument or in guidance, and regulatory bodies such as the Environment Agency enforce the rules.

Technical specifications may be categorised as **product** standards i.e. observable qualities of the product and **process** standards i.e. observable qualities of the production process, such as housing, or diet.

Product standards would relate to the actual impacts of dairy production. They are particularly effective in use when critical control points can be identified. For milk production product standards have been widely used by industry to increase milk quality, with milk being tested (e.g. for bacterial count) on collection from the farm. A major challenge in using product standards to control the externalities associated with milk production is that they are indeed external to the product. No 'marker property' of milk has (yet) been identified that distinguishes milk produced in an environmentally-better fashion. Current work on a standard carbon-labelling methodology does represent an effort to develop a new marker property, albeit not an inherent one, that will allow such distinctions to be made.

Process standards on the other hand are well established across the agricultural sector (e.g. the single farm payment is contingent upon compliance with a range of process standards, and provide an alternative route to reducing the impacts of dairy farming) and in control of the environmental impacts of industrial processes by the imposition of emissions standards. However, 'command and control' interventions generally require a lengthy process of introduction and are relatively costly to operate because of the need to fund the regulator. Costs, and the practical difficulties of implementation, rise as the number of entities covered by the rules

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[42] 'Rules' here include performance standards

rises. The revision of the Integrated Pollution Control regime that followed the adoption of the Integrated Pollution Prevention and Control Directive at European level brought environmental command and control regulation to the food and farming sector, although many smaller units are excluded. There is a general view that this regime, which includes emission limit values and a requirement to strive towards best practice benchmarks, has improved environmental performance at the site level in regulated sectors. The regulated part of the food and drink sector, however, still includes a higher-than-average proportion of poorly-rated sites (ENDS Report, 2007). The extension of command-and-control environmental regulation to the domestic sphere is the subject of some discussion, for example in relation to possible mechanisms to improve waste segregation by householders.

Self-regulation

Self-regulation has the attraction of lower set-up costs and lower operating costs than command-and-control. In this situation the government, usually with the agreement of the regulated parties, lays down general objectives and entrusts the task of devising and enforcing detailed rules to a body representative of the sector.

In some cases, such as the Voluntary Initiative (VI) used with the pesticide industries and pesticide users, the carrot of government assistance has been balanced with the stick of possible taxation. In other cases, assurance schemes have been used to develop and promote 'niche' products – such as Freedom Foods 'high animal welfare' products. Assurance schemes, where these meet or exceed the specifications set out by government, provide a valuable means of promoting government objectives, in particular where these concur with a public consensus and may thus provide a limited commercial benefit on first introduction. It is notable that most assurance schemes for animal health and welfare did not, on introduction, exceed the standards set out by Government. It is also of note that where assurance schemes operate in the absence of government standards, the resulting confusion of signals and statements can be counter-productive (the clarity of information which is passed to consumers through such assurance schemes is dealt with below, under 'disclosure'). Self regulation to address the impacts of dairy production on energy use and GWP may be in the form of new assurance schemes promoting 'low carbon' products, or may be tied into existing assurance schemes on the basis of additional requirements for the process.

Incentives and taxes

Compliance with non-mandatory product or process standards can be encouraged using financial incentives or the tax system.

Thus, cross-compliance being rewarded with the Single Farm Payment may be regarded as an incentive. It is notable that many incentives relating to improving agricultural practice are relevant to the arable sector more than the livestock (and in particular the dairy) sector. Hence, for example, the opportunity to enter grassland into set-aside is minimal. The Entry Level Scheme incentivises practices which would normally bring no direct financial benefit to farmers, but which provide environmental benefits which are deemed worth paying for from the public purse.

Whilst there are few penalty schemes operating which penalise poor environmental practice against agreed standards[43], the notion is not new to the dairy industry, which rewards or penalises farmers according to milk composition and quality. Regarding the two principal areas in which farmers might be encouraged to change practice, fertiliser use and calving patterns, incentives and taxes appear more useful for the latter. Controlling or reducing fertiliser use by, for example, the imposition of a graduated ‘fertiliser tax’ would be inconsistent with the high levels of variability in fertiliser requirements and use, and would be costly to monitor and police. An excise duty on manufactured (or perhaps inorganic) fertiliser would be simpler to apply, and might enable the economic and environmental optimum application rates to become more closely aligned. However, such a tax may also serve to drive production overseas, and so export rather than tackle the issue at hand. The use of an instrument so blunt as an excise duty may therefore be ineffective in achieving environmental goals, although it is beyond the scope of this work to explore in detail these wider implications.

At present, farmers are largely incentivised to produce milk according to the commercial requirements of the ‘downstream’ dairy industry, with the environmental consequences of these requirements being largely unconsidered beyond legal requirements, so that an all year round calving pattern is encouraged, leading to greater numbers of animals being reliant upon concentrates and grazed silage. Whilst the requirements of the dairy industry for liquid milk may follow a fairly even profile, the industry’s requirements for processing milk could be adjusted by placing a penalty on milk produced ‘out of season’.

Promoting private markets

Government can intervene to encourage competitive markets in areas in which these might otherwise not be established. For example, the possibility of a tradable permit system for on-farm GHG emissions has been examined recently by NERA Economic Consulting (NERA 2007). Such a system has intrinsic difficulties when applied to an industry such as dairy farming, including the resources required for inspection and verification, and difficulties in establishing appropriate proxies for emissions at farm-level.

Disclosure and measures to improve information flows

Disclosure is the term given to mandatory reporting, such as those in place for point source pollution incidents and notifiable animal diseases. Mandatory disclosure of fertiliser use could, for example, be used to monitor usage and to identify appropriate actions to reduce this; and such data might also be used by the industry to set reduction-targets.

Disclosure also relates to the provision of information, to farmers and to consumers for example, and in particular to the provision of information that might be seen to influence behaviour. Previous studies have demonstrated that behaviour change in farmers is subject to a number of variables, including peer pressure, personal preference and inherent trust in the information source; farmers also change their behaviour if it makes commercial sense to do so. Of particular note here is that

[43] Although it is understood that some retailers impose some environmental performance standards on farms contracted to supply milk for sale through their stores, particularly for value-added products.

farmers do tend to follow reasoned courses of action, including taking into account the perception of the industry by their neighbours, and that information in the right form can significantly affect behaviour.

Information flow to consumers on farming and food production would be intended, in the context of the environmental impacts of farming, to allow for consumers to adjust purchases in the light of relevant information.

For both groups the aspects of agreed terminology and trust in information are important, and there may be a role for government to develop agreed standards.

The impact of changes in the quota and subsidy regimes

Milk quotas were introduced in 1984 as a means to control supplies of raw milk and thereby limit subsidy spending, and as a means to licence owners to receive market price support. Colman *et al.* (2002) modelled the impact of the phasing out of quota as part of the Agenda 2000 policy package using INRA's Dairy Industry Model and the Manchester Dairy Model, together with a third model developed to simulate the entry of Accession Countries into the EU. This predicted, amongst other things, a decline in UK producer numbers and a growth in average herd sizes.

Subsequent to Colman (2002) the Mid-Term Review reforms of 2003 and 2004 have been implemented, decoupling subsidies from production. A re-analysis of the abolition of quota has been made by Moss *et al.* (2007), using the FAPRI-UK modelling system. Moss *et al*. predict significant reductions in UK dairy prices and production as a result of the abolition of quota, in contrast to a modest increase or no change in the EU as a whole. As long as the current conditions hold, under which quota in the UK trades at a negligible price and UK production is less than that allowed by quota, it can be assumed that quota in the UK is not restricting production. However, milk quota elsewhere in the EU has been binding, and restrictive quota systems are assumed to have led to a build up of latent supply. Therefore, the abolition of quota will lead to an increase in production of dairy commodities elsewhere in the EU, with consequential impacts on commodity prices in the UK. Relative to baseline, this is predicted to result in a 14% decrease in milk production (and dairy cows).

Since the drive downwards will be forced by commodity prices (*cf.* liquid milk), the subsequent impact on liquid milk, which is less tradable than processed commodities, will depend on the volumes moving from commodities to milk and the extent to which production is reduced in line with demand. Defra's report about EU Trade in Liquid Milk (Defra, 2007a) indicated that there are potential markets for UK-produced milk overseas (i.e. shelf-life is positive, distance is positive) but also highlighted that there is a potential market for French and German milk, for example, in the UK. However, dietary differences (e.g. a continental preference for UHT) may affect the value of exported fresh liquid milk and result in further downward pressure on milk prices.

In the absence of other changes in the inputs to liquid milk production, downward pressure on prices would be expected to lead to increased economic efficiency of production. However, the extent to which this translates into, for example, reduced N-fertiliser usage still depends, in part, on relationships perceived by farmers between input costs, output volume and output prices.

Technological interventions

Some possible technological interventions are noted below that do not relate specifically to factors and sub-systems discussed elsewhere in the text. Most of these relate to cows, feed and the digestion of feed, but we also include refrigeration here, since this pervades the liquid milk system from milking parlour to household. Several of these technological interventions are the subject of ongoing research, and where it is known, the location of that research is stated. Some of these interventions represent avenues for change in the longer term, while others, such as the use of 'Sweet Grass' varieties, have already been taken up by farmers.

Rumen function

The rumen is the main source of methane and ammonia in the dairy cow but it is the microbial population that controls it. Recent work suggests that the frequency and diversity of the microbial species in the rumen is not determined only by environmental factors, such as location and feed composition, but is affected to some extent by the genetics of the host cow. This is currently under study and, if the genetics can be unravelled, it may be possible to select cattle that have a more efficient, less polluting rumen.

Feed and ration composition

The amounts of methane and ammonia generated in the rumen are strongly influenced by the form and composition of the feed.

Carbohydrate to protein ratio

Rumen bacteria ferment carbohydrate for their growth but, if readily soluble carbohydrate, such as glucose and fructose, is not available then they will use protein as an energy source. This results in excess nitrogen being produced in the rumen where it combines with free hydrogen to produce ammonia that is absorbed into the blood, transported to the liver, converted into urea and excreted by the kidneys into the environment, where bacteria convert it back to ammonia.

Breakdown of feed protein for energy in the rumen can be reduced by supplying free carbohydrates. While this is relatively simple in housed cattle on concentrate rations, it is more difficult in grazed pasture. One solution, developed at IGER, is to increase the level of water soluble carbohydrates in grass, the 'Sweet Grass' varieties. Research has shown that dairy cows fed on Sweet Grass convert higher levels of their dietary protein to milk protein, with a consequent reduction in urinary N. These have been taken up by farmers as they confer production advantages, and newer varieties are being developed with higher sugar levels, better growth characteristics and improved nutritional qualities. As far as is known, the consequences for the impacts discussed earlier in this report have not been quantified.

Tannins and PPO

The presence of tannins (condensed polyphenols) in ruminant feedstuffs reduces the digestion of protein by rumen bacteria, thereby reducing ammonia emissions. The forage legume breeding programme at IGER is developing new varieties of clover that are higher in tannins, as well as developing varieties of birdsfoot trefoil, rich in condensed tannins, better suited to establishment and persistence in UK conditions. PPO (polyphenol oxidase) is a naturally occurring plant enzyme that generates condensed polyphenols. Further work by the clover breeding programme at IGER is delivering varieties of red clover that are high in PPO. The presence of high PPO red clovers in cattle forages will reduce protein degradation in the rumen and also in the silo, resulting in less pollution.

Additives to reduce methane

Work started at the Rowett Research Institute and now continuing at University of Wales, Aberystwyth, has shown that the addition of hydrogen receptors such as succinate or fumarate to ruminant feed diverts free hydrogen from N and C, thereby reducing the production of ammonia and methane. At present, the levels of additive and its cost make this approach prohibitive but the research aims to develop cost-effective options.

Waste treatment using anaerobic digestion

Anaerobic digestion (AD) of cattle manure is a fermentation process, producing biogas and digestate from slurry. Biogas consists mainly of methane and carbon dioxide, and can be burned as a fuel. Digestate is a liquid containing almost all of the plant nutrients in the original slurry, generally with reduced odours and enhanced plant-available N (through mineralisation of organic to ammoniacal-N). Ammoniacal-N is the sum of N in the forms of ammonia-N (NH3-N) and ammonium N (NH4+-N) and is also know as total ammoniacal N, or TAN. Digestion also raises the pH of slurry so that the proportion of TAN as ammonia-N increases. This means that subsequent losses of TAN as ammonia into the atmosphere during storage and land-spreading will be increased unless measures are taken to prevent the losses.

A variety of studies were conducted in the 1970s and 1980s into the technology, economics and underlying science of AD at several centres including ADAS, The Rowett, Aberdeen, The National Institute for Research in Dairying at Reading (NIRD), the Polytechnic of Wales, Imperial College London and Silsoe Research Institute (once the National Institute of Agricultural Engineering, NIAE). Those at NIAE concentrated on engineering and operational research studies.

The overall findings could be summarised as:

- basic operating parameters (e.g. temperature and residence time) were established
- biogas could be generated from cattle slurry (and other animal manures)
- use of biogas for direct heating is more effective than its use for electricity generation (mainly because the gas needs cleaning before use in conventional engines)
- a substantial portion of generated biogas is used to keep the digester at an above ambient operating temperature
- the economics were marginal and subsidies for ‘green’ energy had a large effect on what could make a plant economically viable
- other processes could have a marked effect on the economics, e.g. mechanical separation of solids followed by composting produces a saleable product. Digestion is not actually required for this of course: some monks in Ireland gained publicity from their farm digester and the revenue was gained from selling compost, not biogas.
- the scale of a farm-scale digester is ‘awkward’ in terms of its practical operation. It is not a trivial device to operate well, but most individual farms could not

support a trained operator. In consequence, those that were adopted tended to be run by enthusiasts. There is a huge difference in scale between these and backyard digesters used widely in China and India.
- matching farm-level supply and demand was not always easy and storage of biogas is expensive. Sub-optimal performance could result as a consequence of a mismatch.
- slurry supply on most dairy farms is seasonal, which can also lead to sub-optimal performance
- none of these studies applied LCA to AD

Much of the earlier drive towards AD was for odour control as well as generating electricity, but by the late 1990s the emphasis had shifted towards the potential to reduce greenhouse gas emissions. In 1997, MAFF funded Silsoe Research Institute (SRI) to investigate the potential benefits of anaerobic digestion by measuring the emissions from farm scale digesters to draw comparisons with conventional slurry handling procedures (Cumby *et al*., 2000). The study showed that AD could reduce unwanted (or fugitive) emissions of methane when compared with normal slurry management. It also showed how simple changes to operational procedures, e.g. timing of biogas-fed boiler use or pumping slurry into and out of the digester, could have a large effect on fugitive methane emissions. It was also clear that there were very few farm digesters out there.

This followed by a more comprehensive study of centralised AD (CAD) at Holsworthy in Devon (Cumby *et al*., 2005). This was the first (and probably only) CAD unit in Britain. It processes almost 300 m^3/day of input materials, to produce over 1.3 MW of electricity. These were dominated in volume by slurry from local dairy farms, but pig and poultry slurry were also processed. The more significant input streams were, however, abattoir and food wastes. These are generally 'richer' than manures and can thus produce more methane per unit volume than cattle slurry (which has already been through an anaerobic digestion process) and command a large gate fee for disposal by landfill or other biological treatment. During the study at Holsworthy, the intake was 57% slurry, 19% blood, 11% food, 8% chicken manure and 5% other wastes.

The scheme at Holsworthy received EU funding so that not all benefits that applied there would necessarily be repeated elsewhere. Some important features follow:

- the operating company provided low-cost storage tanks for the local, participating farmers, who received all the digestate from the plant
- all digestate was accompanied by analysis certificates for the main plant nutrients. Farm waste management plans were thus much easier to make and quantify
- farmers were sometimes paid to spread digestate at times that may have been inconvenient to them, but storage space was needed by the digester operators
- digestate was always more physically consistent than slurry and handing was much easier as a result
- there was a greater potential for umbilical systems utilising the strategically-located digestate store, thus enabling better utilisation, especially on arable land
- more N in digestate was as TAN and thus a ready source of fertility with potential for greater fertiliser saving (or environmental harm if not used effectively, e.g.

losses of ammonia are higher unless covered storage and / or low loss application techniques are used)

- the digestate had different properties to raw slurry, including more N. Only 23% of the N in the digestate came from the dairy slurry and, for example, the reduced net N_2O emissions were nearly all due to the losses avoided from broiler litter.
- this AD plant provided pasteurisation of all wastes, so increasing bio-security
- many of the environmental savings were attributable to reduced landfill of fee-paying organic wastes rather than from digesting slurry *per se* (Table 27 p82)
- the net environmental benefits for CAD depended on many factors, including the distances from which non-farm wastes were brought and the environmental costs of alternative methods of handling those wastes. The same applied to operating costs.
- the scale of the plant meant it was run by skilled operators with a chemical or process engineering background, which helps run a complex process like AD.

Estimated changes in emissions brought about by the Holsworthy CAD Plant, t/yr					
	Nitrous Oxide	**Ammonia**	**Nitrate**	**Methane**	**Carbon dioxide**
CAD Plant emissions					
Landfill saved			-0.2	-432.7	1556
Grid electricity saved				-1.8	-2803
Fugitive NH_3		2.5			
Fugitive CH_4				21.0	
Transport diesel				0.4	352
Transport oil					
Generator set oil					1
Agricultural emissions					
Digestate storage NH_3		101.0			
Digestate storage CH_4				3.2	
Digestate storage N_2O	-6.0				
Digestate mixing diesel					3
Digestate application diesel				0.1	104
Land spreading NH_3		71.1			
Post land spreading NO_3			-69.5		
Post land spreading N_2O	-2.2				
Fertiliser N saved					
Fertiliser P saved					
Fertiliser K saved					
Crop N saved	0.3	0.7	12.1	0.3	117
Total emissions					
Total, t	**-7.9**	**175**	**-57.6**	**-409**	**-670**

Table 27: Emission hot spots in AD system

Much of the benefit of CAD comes from the economy of scale that a large plant can offer. It was clear from the project experience itself and unsolicited feedback from at least one participating farmer that having digestate with a known composition and consistent properties made a large difference to how farmers valued digestate rather than slurry. The higher valuation meant that synthetic N use could be reduced radically or eliminated altogether.

Care is needed in extrapolating this to all farms in the country. Note that dairy farmers received more N than they supplied, and this balance will not be obtainable in all circumstances. The Holsworthy operators collected biological wastes from a large area, so that only a limited number of such operations can exist in the country.

It is difficult to know how successfully an intermediate CAD type could work in which farmers co-digested mixed manures only. Such an approach would help achieve benefits of scale, but without the gate fee that is charged at Holsworthy. It is likely that digestate would have a higher value than slurry and thus utilised more effectively. It should also reduce greenhouse gas emissions if the transport distances (and related burdens) are not too great.

Refrigeration technologies

While refrigeration may not be the dominant source of impacts at every stage of the liquid milk life cycle, for fresh milk it is present in most stages from the farm onwards. According to the Food Refrigeration and Process Engineering Research Centre at the University of Bristol, on-farm cooling of all the milk produced in the UK in a year involves the extraction of over 864GJ energy (FRPERC, 2006). Several refrigeration technologies that offer energy savings or avoid the use of halocarbon refrigerants (some of which contribute to GWP) are the subject of research or trials. Among these are air-cycle refrigeration, trigeneration (systems for the combined generation of heat, power and cooling) and CO_2-based refrigeration systems. FRPERC is leading a major research programme in this area, which seeks to establish more clearly the potential for energy savings from deployment of more efficient refrigeration in food systems. On the basis of early scoping work, it appears that this potential is likely to be in the region of 40-50% reduction in energy demand for food chains generally, although the milk system is believed to be more efficient than some others as a result of considerable capital equipment renewal on dairy farms since 2000. (J. Evans, FRPERC, personal communication).

Industry interventions

The available forms for interventions by industry and other stakeholders across an entire production-consumption system have been explored in the literature on so-called ‘Transition Theory’ (see, for example, Kemp *et.al*., 1998, Smith *et al*. 2005). In many respects, the Liquid Milk Roadmapping Project is an example of an attempt to put such theory into practice. We note, in Section 6 (p91), some specific actions that, on the basis of this review, different actors could take to reduce impacts directly or facilitate their reduction. It is also clear that some changes that might bring environmental benefit would require co-ordination along the liquid milk system (for example enabling the maximal adoption of spring-calving). The structures that best allow such changes to be brought about without infringement of competition laws may well merit further investigation.

5. Discussion

5.1 Data availability & quality

The table on the following pages summarises, in a graphical representation, three points in relation to each of the impacts considered in this project:

- the quality of the evidence on current impacts that is available, in terms of its relevance to the UK liquid milk system, its extent and its ‘robustness’
- the relative significance of the impact within the system on the basis of the available evidence
- the quality of the evidence available that allows the potential effects of change to be quantified.

The colour coding for data quality columns in this table is shown below:

No evidence	
Qualitative evidence, +/- limited quantitative material, e.g. from case studies	
Quantitative but considerable uncertainty, low relevance to UK system, etc.	
Quantitative, high relevance, low uncertainty	

Relative significance is indicated using the following scale:

No obvious link between impact and liquid milk system at this stage	NL
Unknown significance	?
Low	•
Medium	••
High	•••

Table 28: Data quality and significance summary

L-C stage	Detailed aspect	Impact	Relative significance in overall system	Quality of evidence linking impact to milk production & consumption system	
				Quality of evidence on current impact	Quality of evidence on potential for change
Raw milk production	**Overall**	*Primary energy*	•••		
		GWP	•••		
		Acidification	•••		
		Eutrophication	•••		
		POCP[44]	?		
		Water use	•		
		Biodiversity	•••		
		Land use (direct)	•••		
		Soil quality	•••		
		Landscape impact	•••		
		Employment	•		
		Vehicle movements	•		
	The cow/farm system	*Primary energy*	••		
		GWP	••		
		Acidification	••		
		Eutrophication	••		
		POCP	?		
		Water use	?		
		Biodiversity			
		Land use (direct)			
		Soil quality			
		Landscape impact			
		Employment	•		
		Vehicle movements	•		
	Forage	*Primary energy*	••		
		GWP	••		
		Acidification	•		
		Eutrophication	••		
		POCP	?		
		Water use			
		Biodiversity	•••		
		Land use (direct)	•••		
		Soil quality	•••		
		Landscape impact	•••		
		Employment	•		
		Vehicle movements	•		
	Concentrates	*Primary energy*	•••		
		GWP	••		
		Acidification	•		
		Eutrophication	•••		
		POCP	?		
		Water use			
		Biodiversity	••		
		Land use (direct)	•••		
		Soil quality	•••		
		Landscape impact	•••		
		Employment	•		
		Vehicle movements	••		

[44] Photochemical Ozone Creation Potential. A measure of the propensity of releases to contribute to low-level ozone creation

L-C stage (cont'd)	**Detailed aspect**	**Impact**	**Relative significance in overall system**	**Quality of evidence linking impact to milk production & consumption system**	
				Quality of evidence on current impact	**Quality of evidence on potential for change**
Distribution	**Raw milk to dairy**	*Primary energy*	•		
		GWP	•		
		Acidification	•		
		Eutrophication	•		
		POCP	••		
		Water use	•		
		Biodiversity	NL		
		Land use (direct)	NL		
		Soil quality	NL		
		Landscape impact	NL		
		Employment	NL		
		Vehicle movements	••		
	Dairy to retail outlet	*Primary energy*	•		
		GWP	•		
		Acidification	•		
		Eutrophication	•		
		POCP	••		
		Water use	•		
		Biodiversity	NL		
		Land use (direct)	NL		
		Soil quality	NL		
		Landscape impact	NL		
		Employment	NL		
		Vehicle movements	•••		
	Retailer to consumer	*Primary energy*	?		
		GWP	?		
		Acidification	?		
		Eutrophication	?		
		POCP	?		
		Water use	NL		
		Biodiversity	NL		
		Land use (direct)	NL		
		Soil quality	NL		
		Landscape impact	NL		
		Employment	NL		
		Vehicle movements	•••		
Processing overall		*Primary energy*	••		
		GWP	••		
		Acidification	•		
		Eutrophication	•		
		POCP	•••		
		Water use	••		
		Biodiversity	NL		
		Land use (direct)	NL		
		Soil quality	NL		
		Landscape impact	NL		
		Employment	NL		
		Vehicle movements	•		

L-C stage (cont'd)	Detailed aspect	Impact	Relative significance in overall system	Quality of evidence linking impact to milk production & consumption system	
				Quality of evidence on current impact	Quality of evidence on potential for change
Packaging		*Primary energy*	•••		
		GWP	••		
		Acidification	?		
		Eutrophication	?		
		POCP	?		
		Water use	?		
		Biodiversity	•		
		Land use (direct)	•		
		Soil quality	NL		
		Landscape impact	NL		
		Employment	NL		
		Vehicle movements	•		
Retailing		*Primary energy*	•		
		GWP	•		
		Acidification	•		
		Eutrophication	•		
		POCP	•		
		Water use	•		
		Biodiversity	NL		
		Land use (direct)	NL		
		Soil quality	NL		
		Landscape impact	NL		
		Employment	NL		
		Vehicle movements	•		
Utilisation		*Primary energy*	••		
		GWP	•		
		Acidification	•		
		Eutrophication	•		
		POCP	•		
		Water use	NL		
		Biodiversity	NL		
		Land use (direct)	NL		
		Soil quality	NL		
		Landscape impact	NL		
		Employment	NL		
		Vehicle movements	NL		

The GWP arising from raw milk production is heavily dominated by N_2O emissions. There is much uncertainty about these emissions, hence the relatively low quality ranking for evidence relating to this impact.

Land use and biodiversity impacts arising from packaging are related to the use of laminated board derived from wood pulp.

Retailing and processing have been assigned low-significance impacts on vehicle movements on the basis that the location and configuration of retail and processing sites influences the volume of vehicle movements.

The evidence about the potential for change may be improved by work that is known to be under way. Such work is mentioned in the main text of the report.

5.2 Normalisation to a unit of milk consumed

One of the intended outputs of this project was a catalogue of quantifiable impacts related to a single litre of milk consumed, if possible for each of the liquid milk product variants listed in Section 3.2. Such a catalogue would, in effect, constitute a semi-quantitative, extended life cycle assessment. It will be clear from the detail in Section 4 that the data does not exist to complete certain aspects of such an analysis. Importantly, no reliable data on liquid milk wastage rates in foodservice retail outlets or in the home have been identified, so it is not possible to apply an appropriate factor to reduce quantities of milk purchased to quantities of milk consumed for the different liquid milk products. WRAP's figure of 15% wastage of edible food in UK homes provides a first estimate that can be generally applied, but is understood to be based on survey work that focused largely on solid waste.

Notwithstanding those uncertainties and others mentioned in the text, Table 29 (p89) normalises the quantitative data that does exist to one litre of milk consumed. The volume of milk involved at each stage is shown and a brief explanation of the allocation and uplift factors applied is also provided. The fact that an impact measured at the level of the entire sector **can** be normalised by dividing the total amount produced, processed or consumed by the magnitude of the impact does not imply that changing production, processing or consumption by any particular amount will lead to any particular change in the impact. So the fact that 14,000 jobs normalised over 14 bn litres of milk worked out at 1×10^{-6} jobs per litre would in no way imply that increasing throughput to 28 bn litres would lead to the existence of 28,000 jobs.

Table 29: LCA stages – normalisation

L-C stage	Volume leaving the stage to provide 1 litre consumed	Impact	Units (all per litre milk consumed)	Value (blank if unknown, N/A if not likely to be accessible)	Comments
Raw milk production	1.30l 1.5% adjustment for on-farm milk use ex MDC data	*Primary energy*	MJ	3	Average impacts for UK milk from Cranfield LCA
		GWP	kg CO_2 eq	1	
		Acidification	kg SO_2 eq	2 x10^{-2}	12% of raw milk production impacts allocated
		Eutrophication	kg PO_4^{3-} eq	6x10^{-3}	
		Abiotic resource	kg Sb eq	3x10^{-3}	
		POCP[45]	kg C_2H_4 eq	1 x10^{-2}	
		Water use	litre	8	
		Biodiversity		N/A	
		Land use	ha	1x10^{-3}	
		Soil quality			
		Landscape impact		N/A	
		Employment	jobs	3x10^{-6}	
		Vehicle movements	vehicle km	N/A	
Transport to the dairy	1.28l Allowing for cream removal and processing loss	*Primary energy*	MJ	2 x10^{-1}	
		GWP	kg CO_2 eq	1 x10^{-2}	
		Acidification	kg SO_2 eq	6x10^{-5}	
		Eutrophication	kg PO_4^{3-} eq		
		Abiotic resource	kg Sb eq		
		POCP	kg C_2H_4 eq	5x10^{-6}	
		Water use	litre		
		Biodiversity		N/A	
		Land use (direct)		N/A	
		Soil quality		N/A	
		Landscape impact		N/A	
		Employment	jobs		
		Vehicle movements	vehicle km	1 x10^{-2}	

L-C stage **(cont'd)**	**Volume leaving the stage to provide 1 litre consumed**	**Impact**	**Units** **(all per litre milk consumed)**	**Value** **(blank if unknown, N/A if not likely to be accessible)**	**Comments**
Milk processing	1.2l Including material lost & becoming waste	*Primary energy*	MJ	1	Expected to be higher for UHT, u-filtered variants
		GWP	kg CO_2 eq	6 x10^{-2}	
		Acidification	kg SO_2 eq	1 x10^{-4}	
		Eutrophication	kg PO_4^{3-} eq	2x10^{-5}	
		Abiotic resource	kg Sb eq		
		POCP	kg C_2H_4 eq	1x10^{-4}	
		Water use	litre	1	
		Biodiversity		N/A	
		Land use (direct)		N/A	
		Soil quality		N/A	
		Landscape impact		N/A	
		Employment	jobs	2 x10^{-6}	
		Vehicle movements	vehicle km	N/A	
Packaging	packaging for 1.18l	*Primary energy*	MJ	2	4-pint HDPE bottles, production only. No allowance for recovery, reuse etc.
		GWP	kg CO_2 eq	6 x10^{-2}	
		Acidification	kg SO_2 eq		
		Eutrophication	kg PO_4^{3-} eq		
		Abiotic resource	kg Sb eq		
		POCP	kg C_2H_4 eq		
		Water use	litre		
		Biodiversity			
		Land use (direct)			
		Soil quality		N/A	
		Landscape impact		N/A	
		Employment	jobs		
		Vehicle movements	vehicle km		

6. Conclusions

This review reinforces the conclusions of other LCA studies of milk that, for most environmental themes, farm and pre-farm activities represent the points at which impacts are greatest. But it also provides strong support for the assertion that farmers alone do not have control over all of the factors that could lead to change in those impacts. Furthermore, it has highlighted the fact that opportunities for significant improvement do lie at other points in the system, such as processing, packaging and in the consumer's domain.

Evidence

This review has shown that the Cranfield University LCA model of agricultural products incorporates the significant variables associated with dairy farming, although it cannot (for obvious reasons) overcome uncertainties in underlying scientific knowledge, notably concerning the generation of nitrous oxide. The model has shown itself to be a robust tool for exploring those environmental impacts covered by LCA that are affected by changing farming practice.

The review has confirmed that evidence about impacts arising at the retail and consumer end of the system, and about factors that might influence those impacts, is weak. In particular, it has revealed a paucity of evidence about what happens to milk once it has been sold, whether to individual consumers or to foodservice users.

The weakness of evidence relating to the retail and consumer end of the system, combined with a lack of detail about processing and packaging, prevent the impacts associated with different liquid milk products being quantified.

The review has uncovered very limited material (and no sound basis) to allow the effects of milk production on biodiversity and the non-productive value of landscape to be linked to production levels or to changes in them. There may be a need for a different perspective on such impacts if they are to be part of 'product roadmapping' exercises. One possibility would be to treat biodiversity and landscape properties as valuable outputs ('co-products' in LCA terminology) of agricultural systems just as foodstuffs are, rather than regarding them as impacts.

While there is evidence that organic farming has some benefits associated with it, evidence about their scale is inconclusive, while LCA reveals some accompanying disbenefits.

The work has signalled the difficulty of making comparisons between the environmental impacts associated with different foods; comparison with meats and eggs (other sources of proteins) look very different if made on a mass basis or on a 'unit-of-protein' basis.

'Drivers' of environmental impact

This review has to some extent narrowed down the menu of options that offer the potential for significant change, through the 'significant effects' analysis in Section 5.1. Of the variables associated with farm practice, changing those listed below from their 'base' values in Cranfield University's model has the most significant influence on the environmental impact of milk production:

- the annual milk yield of individual cows
- whether farm practice is organic or non-organic
- the time of year at which calves are born
- the level of fertiliser application to grassland
- the proportion of forage maize in cows' diet
- the proportion of clover in cows' diet

It is important to stress that the influence of each of these variables on individual impacts is different, both in magnitude and – in some instances – in direction. It is clear that many of these significant effects are the subject of current research and development.

Beyond the farm gate, processing (particularly heat treatment) and packaging stand out as more significant stages of the life cycle, while despite the paucity of evidence it seems likely that wastage by consumers is greater than wastage at any other point in the system.

Refrigeration is a source of impacts at several points in the system, although its significance is greater at some stages than at others. Clearly, this has already been recognised elsewhere and 'environmentally-friendly' refrigeration is the subject of considerable research effort.

Potential for change

The following are suggested as opportunities for change at various points in the system that could reduce environmental impacts:

- promoting the necessity of matching feed to yield to maximise efficiency (as output per cow):
    - for low-yielding cattle, the best option may be to remove them from the system over time
    - for medium- and high-yielding cattle, making greater use of 'Milk Over Purchased Feed' as an indicator of performance
- continuing/developing initiatives to benchmark on-farm energy and water use / water management and adopting the means to reduce usage across the sector
- examining how fertiliser application and use might be made more effective at the farm-level, through the greater use of support tools designed for this process, and through the use of new technologies
- encouraging the application of 'best available techniques' in all milk processing
- encouraging the uptake of best practice in the operation of refrigeration systems, and of new refrigeration technologies, many of which use lower-impact refrigerants.

There are indications that pursuing some potentially beneficial changes in farm practice (e.g. moving towards a bias for calving to occur in the Spring) depends on changes by processors, retailers and perhaps consumers, notably:

- addressing the demand for milk (particularly fresh milk) in periods when production is 'least environmentally-efficient' and reviewing the price incentives for autumn calving
- addressing the market-pull for lower-impact milk, and (with processors and farmers) how this might be incentivised at farm-level

Similarly, the limited evidence about the environmental impacts of extensive, low-input farming systems utilising smaller animals suggests that such systems may well ameliorate some environmental impacts of livestock farming, such as soil compaction and erosion effects. For such systems to achieve large-scale uptake considerable reconfiguration of UK demand for dairy products in general would appear to be necessary. If this is considered to be a possible future for the UK dairy farming industry, a closer evaluation of the implications for system-wide resource efficiency and emissions would be merited, based around anticipated UK milk demand.

Greater market penetration of milk products with longer shelf life (including UHT) might facilitate such changes; however, it is recognised that a more seasonal pattern of production and processing might well present challenges to the optimal utilisation of capital equipment in the processing sector, and even require a reversal of the trend towards lowest-possible inventories that is almost ubiquitous in industry.

The shorter storage times applicable to fresh milk, which were quite possibly an impetus for the emergence of the daily doorstep delivery (Blake, 1979), may also act to bring the customer back to the shop sooner than he or she would otherwise return (retailers might well perceive this to be one of its advantages as a product, although consumers may also freeze fresh milk to extend its shelf life). Extended shelf life products (including of fresh milk variants) clearly reduce this effect, if it exists, and it is possible to speculate that their wider uptake might be one of many necessary elements in any strategy aimed at reducing car travel to food shops. No published evidence linking changes in shopping habits to individual food products has been encountered.

There is another group of changes that could take place and that would lead to significant changes in the impacts arising from milk production and consumption. These are changes that are beyond the direct control of the actors within the liquid milk system but whose implementation would probably require change on their part:

- low-environmental impact food distribution systems are more likely to cover many foods than one
- fundamental changes in the technology used to convert nitrogen to ammonia (see Appendix 1) would change the environmental profile of the production of many foods, not just that of milk.

While this report has considered impacts from a product-specific view, it is of course necessary to evaluate any potential from the standpoint of possible effects on compliance with what could be termed ‘area-based’ and time-dependent environmental controls (for instance, if a less uniform calving profile across the year arose, what would the consequences be for peak concentrations of nitrogen-containing contaminants in watercourses in west Britain?).

Further work

A number of areas for possible further work have been identified. These are listed below (in no particular order); some of this work would be relevant to more than just the milk system:

- work to understand soil carbon levels in different agricultural systems (there is ongoing research at Bangor University and elsewhere on this topic), and to incorporate soil carbon within modelling of agricultural systems for LCA
- work to clarify emission levels of N_2O from agricultural systems
- work to establish (and if possible quantify) the landscape benefits that can be attributed to dairy farming and to understand how these change in the absence of dairy farming
- possible work to incorporate biodiversity and/or landscape qualities as valuable outputs of agricultural systems alongside food products in LCA-type analyses. Although potentially very difficult methodologically, this might help to assess the balance of benefits and drawbacks associated with shifts to organic production, for example
- work to establish some measure of the value placed on landscapes, or landscape features, associated with dairy farming may well be necessary to inform analysis of the form noted in the previous point
- better understanding of the monthly changes in calving impacts (cf. spring or autumn), coupled with a greater understanding of the current demand for raw milk for liquid and other markets, would allow mechanisms to promote spring calving as the ‘preferred practice’ to be explored
- continued efforts to clarify the effects on biodiversity of organic farming
- work to investigate the consequences for the environment and for animal nutrition of using whole crop cereals as silage.
- work, including LC work compatible with that carried out on national average production by Cranfield University, to investigate further the environmental impacts of low-input dairy farming systems utilizing breeds of cow different from the Holstein-Friesian
- work, focused on volumetric accounting, to understand what happens to milk once it has been purchased
- assessment and improvement work on packaging that incorporates milk sold to foodservice users and institutions may well be worthwhile. Although not as large an area of consumption as that by individual consumers, this seems to be sufficiently large that its total neglect is difficult to understand
- the relationship between economic drivers (pence per litre, fertiliser costs, energy costs etc.) and production methods/production efficiency requires deeper analysis to understand why some dairy farming appears to operate sub-optimally (commercially and environmentally). Parallel to this, some investigation of the extent to which greater understanding by dairy farmers of the ‘unseen consequences of their industry’ would drive them to change practice could yield useful insights
- investigation of how market-driven solutions may be applied to changing the environmental impacts of liquid milk production. For example, is the potential market (and/or premium) for ‘low carbon’ or ‘green’ products to drive change throughout the sector?

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Appendix 1. Ammonium nitrate fertiliser

Ammonium nitrate (NH_4NO_3) is the most important nitrogen fertiliser used. It is most commonly made by neutralisation of nitric acid with ammonia, the nitric acid also being produced from ammonia. Ammonia production is energy intensive and utilises natural gas as a raw material. In this Appendix we discuss briefly the environmental impacts arsing in this section of the basic chemicals industry and the prospects for their reduction in future. This discussion draws heavily on European Commission (2007) and Jensen and Kongshaug (2003).

Ammonia

About 80% of world NH_3 production uses the steam reforming process, in which methane is first converted to hydrogen, which is subsequently reacted with nitrogen from the air to produce ammonia. Almost all of the methane used is in the form of natural gas. Almost 50% of global production NH_3 capacity is in Asia, less than 10% in Western Europe (Western Europe share has dropped by ~50% in 20 years).

0.5% of world ammonia production uses H_2 from water electrolysis as feedstock.

In the UK, Kemira Growhow has two plants, one at Ince, one in Hull. TERRA Nitrogen also has two, one on Severnside, one in Billingham. One could speculate about the effect of lower North Sea gas production on the future prospects of these plants.

The steam reforming process is energy intensive but highly developed to allow utilisation of heat generated by the reactions. Table App 1 (p101) is an illustrative breakdown of where the energy entering the process goes:

Energy flow	Share %
Product ammonia	71.9
Unrecovered process heat	10.5
Air compressor turbine	7.8
Syngas compressor turbine	5.7
Flue-gas heat	2.4
Refrigeration compressor turbine	1.8
Miscellaneous	0.6
Overall	**100**

Table 2.5: Example for energy flows in an ammonia production plant (1350 tonnes/day, fired primary reformer)
[13, Barton and Hunns, 2000]

Table App 1: Energy flows in ammonia production

Source: European Commission (2007)

The BREF gives a range of reported values for primary energy consumption, summarising them as 22-25GJ feedstock energy and 4-9GJ fuel energy, both as lower heating value per tonne NH_3. BAT is described as net energy consumption in the range 27.6 – 31.8 GJ(LHV)/tonne NH3. It is noted that the physical state and purity level of the product of the product affect energy consumption reported.

Jensen & Kongshaug (2003) illustrated the seven-fold decline of energy needed for N-fixation during the 20th century:

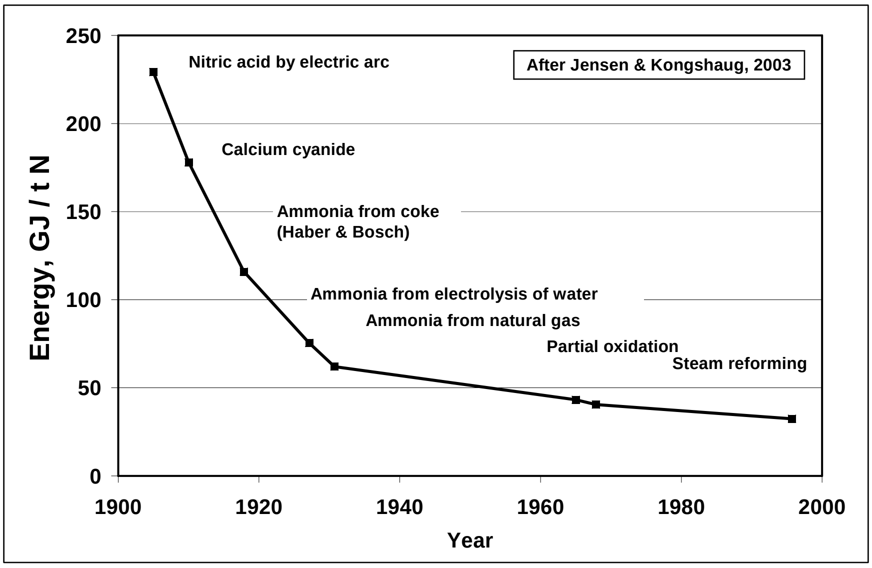

Table App 2: Energy decline in N-fixation

Source: Jensen & Kongshaug (2003)

The following emission levels are quoted in European Commission (2007):

- NOx: 0.6 – 1.3kg/t NH3
- NH_3 to water: 0.03-0.08kg/t NH3
- NH_3 to air: 0.01-0.03kg/t NH3

The carbon in the natural gas raw material is converted first to CO and then to CO_2. The fate of this CO_2 is a little uncertain. If there were stoichiometric conversion then 1.29t CO_2 would be produced for every 1t NH_3. But this is a source of CO2 for industrial use and for the Solvay soda process, which also uses ammonia (and so is normally co-located with an ammonia plant). An emission rate of 8% in flue gas, i.e. 500kg CO_2 /t NH_3 is quoted (the original source is given as EFMA 200). Whether this is combustion product + vented reaction product, just the former or just the latter is unclear from European Commission (2007).

Nitric acid

Nitric acid is prepared from ammonia by catalytic oxidation with air. The conversion is exothermic and theoretically releases 6.3GJ/tonne 100% HNO_3. (European Commission, 2007) indicates actual levels of net energy export achieved:

	GJ/tonne 100 % HNO_3	Remark
Modern M/H plant	2.4	As HP steam
Average net export of European plants	1.6	
Best plants 30 years ago	1.1	

Table 3.4: Overview of energy export from HNO_3 production
[94, Austrian UBA, 2001, 107, Kongshaug, 1998]

Table App 3: HNO_3 energy export
Source: European Commission (2007)

Jensen & Kongshaug (2003) reported that energy recovery from nitric acid plants increased nearly three-fold from the 1950s to the 1990s (Figure App 1 below).

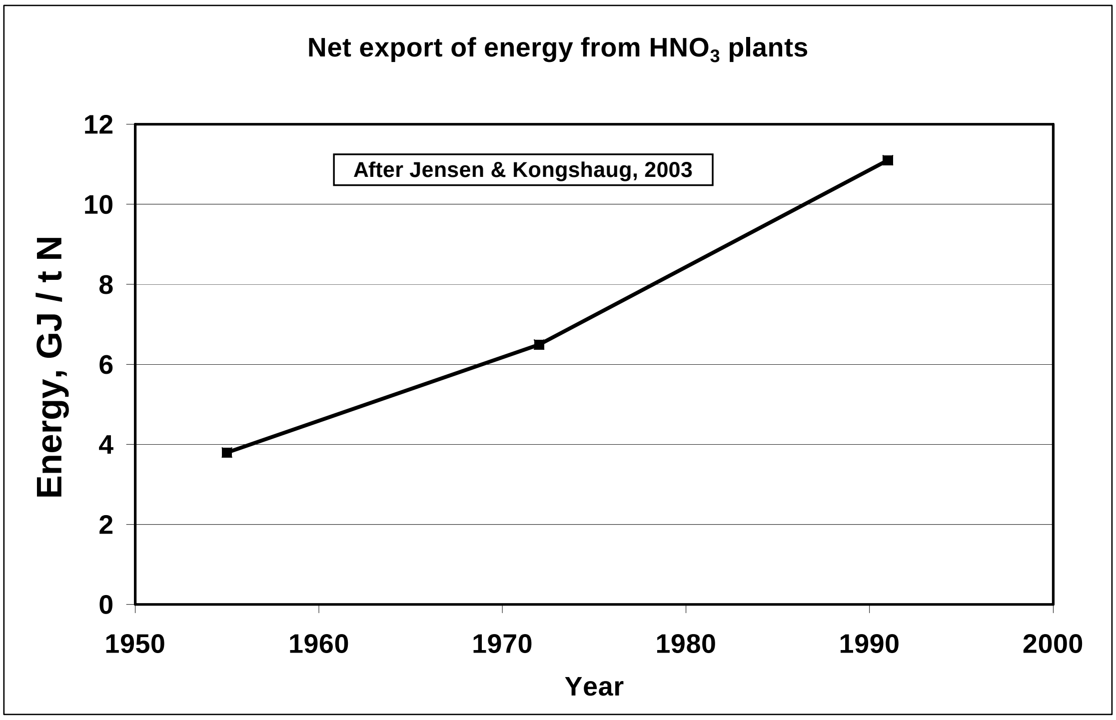

Figure App 1: HNO_3 energy export
Jensen & Kongshaug (2003)

Nitrous oxide emissions make an important contribution to the environmental impact of HNO_3 production (and hence to that of NH_4NO_3 fertiliser). According to [Kongshaug, 1998], the average European plant emits 6 kg of N_2O per tonne of HNO_3. BAT levels (Table App 4 p104) are considerably lower than this, so there is clearly scope for improvement:

		N_2O emission level *	
		kg/tonne 100 % HNO_3	ppmv
M/M, M/H and H/H	New plants	0.12 – 0.6	20 – 100
	Existing plants	0.12 – 1.85	20 – 300
L/M plants		No conclusion drawn	
* the levels relate to the average emission levels achieved in a campaign of the oxidation catalyst			

Table 3.14: N_2O emission levels associated with the application of BAT for the production of HNO_3

Table App 4: N_2O BAT emission in HNO_2 production

Source: European Commission (2007, p140)

Jensen & Kongshaug (2003) noted that Agri-Hydro had developed an abatement process with about 60-80% reduction in N_2O emissions and this was put on a plant in 1991. Assuming a 70% reduction, this amounts to 0.18 kg of N_2O per tonne of HNO_3, i.e. well within BAT. A number of techniques that can be used to contribute to this reduction are specified, although there appears to be some industry resistance to the benchmark for existing plants.

Ammonium nitrate (AN)

There are three plants producing ammonium nitrate or calcium ammonium nitrate fertiliser in the UK Kemira GrowHow at Ince, TERRA at Severnside & Billigham. Total capacity is around 1,400 tonnes per day. It is believed (Dyer, personal communication) that most nitrogen fertiliser used in the UK is now imported, as producers in major oil-producing countries have access to lower-cost natural gas inputs to ammonia production.

The ammonia-nitric acid reaction is highly exothermic and again the heat is normally used to produce steam, which is then used to preheat the incoming nitric acid, or dry downstream products.

Table App 5 (p105) gives an idea of current energy consumption and emissions. Again, there appears to be some scope for impact reduction in terms of energy demand through a shift from “European average” performance to ‘modern AN plant’ performance.

Other impacts of AN production arise from dust and NH_3 emissions. Quoted values for the latter vary from 0 to 50g/tonne product, depending on production technology used, existence of scrubbing or otherwise, and the target finished product (solution or solid, for example).

So it seems that ammonia production accounts for much of the primary energy in ammonium nitrate fertiliser production, although the above does not include natural gas extraction. Williams *et al*. (2006) use 41MJ/kg N as primary energy input to AN production, and N accounts for 34.5% of the weight of dry AN). This value is higher than those based simply on process energy (including credits for exothermic reactions). This was based on the approach taken by Audsley *et al.* (1997) in an EU Harmonisation project. They took that view that while most of the methane used was as a feedstock in ammonia synthesis, the effect was to use methane as a fuel and it was thus accounted.

The improvements in process performance reported by Jensen & Kongshaug (2003) in the 20th century show how ingenuity and necessity have reduced the environmental burdens of fertiliser production considerably. It is reasonable to ask what potential exists for further improvement.

Product	Steam	Electricity	Cooling water	Total	
	kg/tonne product	kWh/tonne product	m^3/day	GJ/tonne product	
CAN	13	13.2	24500 *		AMI, Linz
	150 – 200	10 – 50			[148, EFMA, 2000] / [52, infoMil, 2001]
Solid AN		25 – 60			New AN facility [148, EFMA, 2000]
	0 – 50				[148, EFMA, 2000]
				0.7	European average [52, infoMil, 2001]
				0.09 – 0.22	Modern AN plants [52, infoMil, 2001]
ANS	- 170 **	5			[148, EFMA, 2000]

* with a ΔT of 10 °C, production of 663000 tonnes CAN in 2000

** steam export

Table 9.3: Energy and cooling water consumption for the production of CAN/AN

Table App 5: Energy and water use in CAN/AN production

Source: European Commission (2007, p370)

It seems likely that the best plants are close to the thermodynamic limits for the individual processes used, but there is clearly potential for poorer performing plants to catch up. Other opportunities are for more natural gas to be utilised in areas of oil production where is has been considered a waste product and simply flared off (still better than merely being vented). This would possibly increase the transport burdens for users in the UK, but these tend to be relatively small. The overall benefit would be in turning a waste or by-product into something useful.

There may be completely novel processes for the conversion of atmospheric nitrogen to ammonia, yet to be invented, but a possible existing route is for the H_2 used in the Haber process to come from solar or hydro-driven water electrolysis. The clear potential benefit here is for a radical reduction in the non-renewable energy required for part of the process. It is beyond the scope of this report to develop the LCA of this process. Clearly the environmental benefits associated with this could only be realised if the process were economically viable, and since this route is now used for 0.5% of world ammonia production, it would appear that this situation has not yet been reached.

Given the achievements in improving process performance in the 20th century, it is reasonable to speculate that fossil fuel requirements and N_2O emissions will come down globally in future years. Part of the motivation for this could be in the widespread, rapid adoption of environmental assessments (e.g. 'carbon foot-printing') of commodities and products. If purchasers or regulators (e.g. UK Government or the EU) specifies upper limits on fossil energy use or specific N_2O emissions, it could accelerate the process of improvement.

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