Material change for
a better environment

Final Report

Life cycle assessment of example packaging systems for milk

Retail Distribution System

A Life Cycle Assessment covering the potential environmental impact of different example milk containers for pasteurised milk available on the UK market, distributed via a retail system. The purpose is to inform and educate WRAP and our stakeholders about the nature of the environmental impacts of each milk container system and the benefits that can be achieved through alternative end-of-life options. The information should not be used to make comparative assertions between formats.

Project code: EVA044
Research date: August 2007 – June 2009

Date: January 2010

WRAP helps individuals, businesses and local authorities to reduce waste and recycle more, making better use of resources and helping to tackle climate change.

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Front cover photography: milk bottles displayed in chilled section.

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Executive summary

Waste & Resources Action Programme (WRAP) engages with a range of stakeholders in the milk industry to help increase the recycled content of packaging and promote lightweighting. WRAP is often asked by retailers and brand owners to comment on which materials represent the best environmental option, and to quantify the benefits of making changes to systems, such as increasing recycled content.

In 2007, WRAP commissioned Environmental Resources Management Limited (ERM) to carry out this study to review the environmental performance of various milk containers and the environmental benefits that can be achieved through recycling initiatives and lightweighting. Milk containers have been specifically selected due to a need to understand the effects and potential effects of recent innovations in milk packaging, as well as existing packaging options for milk.

To ensure that the study met quality requirements, it was necessary for the assessment and reporting to be consistent with the requirements of the ISO standards on life cycle assessment (ISO 14040:2006 and ISO 14044:2006). As a result, the study has undergone critical review by an external panel of experts.

Goal of the study

The goal of this study was to assess the potential environmental impact of different milk container examples for pasteurised milk available on the UK market with the purpose of informing and educating WRAP and our stakeholders about the nature of the environmental impacts of each milk container system and the benefits that can be achieved through alternative end-of-life options.

The packaging systems reviewed are:

- HDPE[1] bottles;
- PET[2] bottles;
- pillow pouches, including serving jug;
- stand-up pouches;
- cartons with screwcap; and
- gable-top cartons.

Both distribution to retail and doorstep distribution were considered, with this report covering the retail distribution systems. A separate report has been published covering doorstep distribution, and also includes glass bottles.

For both distribution systems, the formats were, where feasible, assessed for: 100% virgin content; for up to two variations on the technically feasible recycled content; and for a lightweighting scenario. For some packaging formats, this was not feasible. For example, cartons are currently only available with 100% virgin content, although research is on-going with regard to introducing recycled content. The scenarios assessed are listed in the table below.

Table 0.1 Scenarios assessed for each milk container systems

Scenario	HDPE bottle 2 pints	PET bottle 1 litre	PE pillow pouch 2 pints	Stand-up pouch 1 litre	Carton with screwcap 1 litre	Gable-top carton with closure 1 litre
0% recycled content	x	x	x	x	X	x
30% recycled content	x	x				
50% recycled content	x					
10% lightweighting	x	x	x	x	X	x

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[1] *High Density Polyethylene, the conventional plastic used in milk bottles.*

[2] *Polyethylene Terephthalate, used to make transparent bottles. Some milk is supplied in this format.*

Life cycle stages considered

The study assesses the potential environmental impacts for the full life cycle of each milk packaging system, also often called a 'cradle to grave' approach. This means that the milk container systems were assessed from raw material extraction through to final waste processing. The waste management processes assessed were landfill, incineration and recycling.

Excluded from the system boundaries were: ink used and the printing process itself; impacts of use in the home; and milk wastage through the supply chain. This was due to a lack of data on these processes.

Allocation

In this study the avoided burdens (or 'end-of-life') approach has been taken. This approach considers the end of life fate of the material by expanding the system to include the avoided alternative production of these outputs. In the case of energy from waste, the generation of electricity from fossil fuel sources is avoided and the environmental impacts from this process are subtracted. This is also the case for captured landfill gas used to generate electricity. By recycling a material after its use, another material cycle is replaced. Using the avoided burdens approach, the environmental impacts of producing the avoided material are credited to the product sent to recycling.

This means that, since all the benefit of recycling is allocated to the material being recycled, the material input to the product being studied is modelled as bearing the environmental impacts of primary production, irrespective of whether or not it has a recycled content. To do otherwise would risk double-counting the impact of recycling. As a sensitivity analysis an alternative approach (the cut-off or 'recycled content' approach) is investigated.

Impact categories

The *potential* contribution made by each milk container system to a set of environmental impact categories was assessed. The impact categories were selected to address a breadth of environmental issues for which methods have been developed for calculating the contribution that environmental flows may have to these impacts.

Results

A number of conclusions that can be drawn from the study apply across the milk packaging systems. The extraction or growing of raw material and the processing of these into packaging formats, whether this be the primary or secondary or transit packaging, is found to contribute the most to the environmental profile of the milk container systems. This means that the largest relative environmental savings are to be achieved through the improvement of these elements of the packaging life cycle.

Overall, the findings are found to support the waste hierarchy. This means that the results indicate that significant relative environmental savings can be achieved through minimisation, i.e. lightweighting. This, of course, is dependent on lightweighting being achievable without compromising the functionality of the milk container. Recycling, i.e. the recycling of materials after use, is also shown to provide considerable environmental savings. This is followed by energy recovery and then disposal in landfill.

Results for each packaging format are summarised in box 1.

Conclusions

The study has demonstrated the potential for reducing the environmental impacts of milk packaging through lightweighting, increasing recycled content and diversion to recycling at end of life.

Lightweighting each format by 10% shows lowest potential environmental impacts for all the impact categories assessed.

As modelled, recycled HDPE and PET have been shown to have lower environmental impacts than the corresponding virgin materials.

Although recycled content and lightweighting have been considered separately, it does not mean that these are mutually exclusive. Through process optimisation and technology developments, lightweighting and increasing recycled content may be combined for a number of containers.

The authors consider that the benefits displayed for the example milk container systems investigated in this study would be replicated for the wider milk container market.

Limitations of the study

This study is an assessment of example milk packaging systems for chilled pasteurised milk. It was the intention that the study should cover average milk packaging systems as available on the UK market. However, despite considerable efforts by the project team and the steering committee, it has not been possible to collect sufficient data to allow this. Therefore, the results of this study cannot be said in full to reflect average market performance or be used in drawing specific conclusions relating to the relative performance of all milk packaging. Instead, the results give an insight into:

- the type of impacts that the different milk packaging systems studied have on the environment;
- the magnitude of the selected environmental impacts for the different milk packaging systems studied;
- areas where knowledge of the different milk packaging systems is lacking;
- an indication of any environmental benefits of:
  - incorporating recycled content in the containers;
  - lightweighting containers; or
  - increased recycling of used milk containers.

The results of the study are limited by the data collected, the assumptions made where data gaps occurred, and the systems assessed. Data gaps were evident for all packaging systems assessed, especially with regard to the filling and packing, distribution and retail stages of the life cycle, with varying degrees of completeness depending on milk container type. For certain aspects, data gaps were so evident that estimations would amount to guesses and these were therefore excluded from the system boundaries. This includes milk wastage through the supply chain.

As a consequence of the example case study approach and the variation in data quality and accuracy for certain processes, it was decided not to make any direct comparison between the different milk containers studied. In order to make comparative assertions, data gaps need to be filled and more complete data are required, for example, for the filling process for several of the containers studied.

The results of this study have been interpreted in the context of these limitations.

Box 1 Summary Results for each packaging format assessed

HDPE bottle system

Production of the HDPE bottle itself and associated raw material extraction makes the predominant contribution to the impact categories assessed, except for freshwater aquatic eco-toxicity.

Comparing the different waste management options, the results indicate that recycling is the best option for HDPE bottles. Recycling bottles back into bottles provides the lowest impacts for the categories of abiotic resource depletion, climate change, and photo-oxidant formation. General recycling provides the lowest impacts for the categories of eutrophication and acidification.

Recycling one tonne of HDPE bottles back into bottles has the potential environmental saving of approximately 1066 kg of CO_2 equivalents compared to landfill, and approximately 2075 kg of CO_2 equivalents compared to energy from waste.

Using the cut-off approach, increasing the recycled content leads to significant improvements in potential environmental impacts.

PET bottle system

Production of the PET bottle itself and associated raw material extraction makes the predominant contribution to all of the impact categories assessed.

Comparing the different waste management options, the results indicate that recycling is the best option for PET bottles. Recycling bottles back into bottles provides the lowest impacts for the categories of abiotic resource depletion, climate change, and eutrophication. General recycling provides the lowest impacts for the categories of photo-oxidant formation and acidification.

Using the cut-off approach, increasing the recycled content leads to significant improvements in potential environmental impacts.

Pillow pouch system and stand-up pouch system

Production of the pouch and distribution packaging, and associated raw material extraction, make the predominant contributions to all of the impact categories assessed.

The jug required for use with a pillow pouch was investigated with different reuse rates and found to make a minimal contribution to the overall results.

Comparing the different waste management options, the results indicate that recycling is the best option for the impact categories of climate change, eutrophication, and acidification. For the impact categories of abiotic resource depletion and photo-oxidant formation, energy from waste has the lowest potential environmental impacts.

Carton with screwcap system and gable-top carton system

Production of the laminate, followed by cap (for the screwcap system) and distribution packaging, make the predominant contributions to the impact categories assessed.

Comparing the different waste management options, the results indicate that recycling is the best option for the impact categories of photo-oxidant formation, eutrophication, and acidification. For the impact categories of abiotic resource depletion and climate change, energy from waste has the lowest potential environmental impacts.

Contents

Glossary

HDPE	High density polyethylene
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
PET	Polyethylene terephthalate
rHDPE	recycled high density polyethylene
rPET	recycled polyethylene terephthalate
WRAP	Waste & Resources Action Programme
WRATE	Waste and Resources Assessment Tool for the Environment

1.0 Introduction

1.1 Background to the study

WRAP works in partnership with industry to encourage and to enable businesses and consumers to be more efficient in their use of materials, and to increase recycling rates. WRAP's work is undertaken through seven key programmes: construction; manufacturing; organics; retail; behavioural change; business growth; and local authority support.

Established as a not-for-profit company in 2000, WRAP is backed by Government funding from Defra and the devolved administrations in Scotland, Wales and Northern Ireland.

Working in seven key areas mentioned above, WRAP's work focuses on market development and support to drive forward recycling and materials resource efficiency within these sectors, as well as wider communications and awareness activities including the multi-media national Recycle Now campaign for England.

More information on all of WRAP's programmes can be found on www.wrap.org.uk.

WRAP actively works with a range of stakeholders in the milk industry to help lightweight and to increase the recycled content of packaging. Retailers and brand owners often ask WRAP to comment on which materials represent the best environmental option. As a result, WRAP has commissioned this study better to inform stakeholders as to the environmental performance and tradeoffs of the various milk containers. An important step for WRAP in appraising and engaging on initiatives in the milk packaging arena is to understand the scale and source of potential impacts associated with both milk packaging currently on the market and the potential benefits of recent innovations in milk packaging. This study focuses on the potential environmental impacts associated with different milk packaging options and the impact of the waste management routes available.

1.2 Project implementation

This project was carried out for WRAP by Environmental Resources Management Limited (ERM). The project has been performed with full funding from WRAP.

The project was carried out over the period August 2007 to November 2008. During this time, the study was informed by a steering committee, which also contributed with information to the study. The steering committee comprised representatives for the dairy industry and material and packaging specialists employed by WRAP:

- Will Clark, Sustainable and Environmental Manager, Dairy UK;
- Keith James, Environmental Policy Manager, WRAP;
- Nicola Jenkins, Project Manager, Retail Innovation, WRAP;
- Richard Pryor, Innovations Controller, Dairy Crest; and
- Richard Taplin, Packaging Manager – Technical, Arla Foods.

In addition, a number of organisations and WRAP staff supported the study through the provision of data and comments. Their contributions to the project have been invaluable in compiling the life cycles of the different milk containers studied. The companies are:

- Arla Foods UK plc;
- CCL Label GmbH;
- Dairy Crest Ltd;
- Daylesford Organics;
- HOOD Packaging Corporation;
- LINPAC Allibert Limited;
- Nampak Plastics Europe;
- NEXTEK Ltd;
- Musgrave Retail Partners GB;
- Portola Packaging Ltd;
- Printpack Ltd;
- Robert Wiseman & Sons Ltd;
- RPC Containers;
- Systems Labelling Ltd;
- Tesco Stores Ltd; and
- Tetra Pak UK.

Some companies contributing to this study have requested not to be mentioned in this report.

1.3 Life cycle assessment

Life cycle assessment (LCA) is a standardised method for measuring and comparing the environmental consequences of providing, using and disposing of a product[1].

The international standard for life cycle assessment, ISO 14040 (ISO 2006), states that "*LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)".*

When conducting an LCA, all life cycle stages of the product being studied are mapped. Also commonly called cradle-to-grave assessment, and as described in the quote above, these life cycle stages encompass all steps and processes in the product's life, from production and supply of raw materials, through production and assembly, packing and distribution, product installation and use, to final disposal or recycling at the end of its life.

At each of these stages, natural resources are consumed and emissions (to air, water and soil) are released to the environment. When carrying out an LCA for any given product, these consumptions and emissions (inputs and outputs) are quantified for each life cycle stage, using a systematic and internationally-standardised process. The result is a life cycle inventory (LCI).

The inputs and outputs compiled in the life cycle inventory are then related to environmental impacts, such as climate change and resource depletion, using scientifically-derived methods. The result is a quantified environmental impact profile of the product under study.

Such an approach provides valuable information about key stages of the product life cycle and relates them to specific and accountable issues. By identifying the steps within the life cycle which have the most significant impact on the environment, environmental management efforts can be directed effectively.

1.4 Milk production and distribution in the UK

UK dairy farms produce between 13 and 14 billion litres of raw milk each year (SCPT 2008). Of this, around six billion litres is processed into liquid milk – mainly for drinking. Almost all milk consumed in the UK is produced in the UK. Imports accounting for a very small proportion of the liquid milk sold in the UK, although imports of organic milk are reported to be rising.

There are more than 100 dairy processors in the UK, varying widely in size. Of these, three major milk companies[2] dominate the liquid processing industry, accounting between them for around 90% of the UK's liquid milk supply (SCPT 2008, Foster et al 2007). They sell bottled milk to the main grocery retailers, food service companies and for doorstep delivery by the milkman.

Most UK milk is packaged for direct consumption by the consumer. The majority of these products are distributed through a chilled distribution chain. With chilled milk's limited shelf life, distribution and chill chain management is a significant part of the processing sector.

About 78% of chilled and ambient liquid milk sold through shops and doorstep delivery is in plastic containers (HDPE and PET), with HDPE accounting for the vast majority. Glass bottles account for 11% and, mainly, cartons for the rest (Foster et al 2007).

In line with general shopping habits, there is a long term increase in the proportion of milk bought from supermarkets, which currently account for 65% of all milk purchasing (SCPT 2008). By contrast, doorstep delivery has declined from 30% in 1984 to its current 7%. Milk purchased in convenience stores accounts for 23%, and the remaining 5% is accounted for by internet, farm, and other forms of purchasing.

As part of the Milk Roadmap project[3], the parties along the milk supply chain have committed to a number of environmental targets. With regard to packaging, the milk processing industry has committed to ensuring that:

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[1] *ISO 14040 defines a product as any good or service.*

[2] *Arla Foods, Dairy Crest and Robert Wiseman.*

[3] *The Milk Roadmap project, lead by the Dairy Supply Chain Forum, sought to identify practical and achievable ways of reducing the environmental impacts associated with liquid milk using current patterns of production and consumption. The Milk*

- by 2010, HDPE milk bottles contain a minimum of 10% UK recycled content;
- by 2015, packaging materials contain a minimum of 30% recycled content; and
- by 2020, packaging materials contain 50% recycled content.

Roadmap report was produced by the Forum's Sustainable Consumption and Production Taskforce and was published in May 2008.

2.0 Goal of the Study

The goal of this study was to identify the relative life cycle environmental impacts of different examples of packaging for pasteurised milk available on the UK market. Two separate distribution systems were assessed: a retail system (supermarkets); and a doorstep system (the milkman). The two systems are not directly comparable[1] and during the latter part of the project, it was decided to report the findings in two separate reports, of which this is one.

The two supply routes were chosen by WRAP to achieve two main objectives: one was to cover the majority of milk sold in the UK (some 65% of milk is currently sold via supermarkets (Foster et al 2007)); the other was to include a returnable glass bottle system in the study.

This report covers the retail delivery system only.

The study investigated the following milk packaging systems identified as being of interest to the client:

- rigid plastic containers:
  - HDPE bottles;
  - PET bottles;
- flexible plastic pouches:
  - pillow pouches, including serving jug;
- stand-up plastic pouches (SUP):
  - chalk-based pouches;
- paper-based cartons:
  - cartons with screwcap; and
  - gable top cartons with closure.

For both distribution systems, the formats were, where feasible, assessed with: 100% virgin material content, up to two variations on technically possible recycled content; and a lightweighting scenario. For some packaging formats, this was not feasible. For example, cartons are currently only available with 100% virgin content, and, although research is on-going with regard to introducing recycled content, implementation is considered to be at some point in the future.

WRAP desired that the study should be consistent with the requirements of the ISO standards on LCA for studies intended to be disclosed to the public (ISO 14040:2006 and ISO 14044:2006). To this end, the authors have followed the guidance and requirements of the standards and the study has undergone critical review by an external review panel.

The results of this research will both inform decisions on the development of future policy in this area and provide a more robust evidence base for WRAP activities. The results will also feed into the continued work of the Milk Roadmap project.

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[1] *The main reason why the two distribution methods are considered not to be comparable are the very different reasons consumers may have for choosing one system over the other – e.g. tradition, mobility, convenience, and time for the doorstep system compared to 'all shopping in one', cost and 'on the way home' for the retail system.*

3.0 Scope of the Study

3.1 Functions of the product system

When assessing different products, it is important that the functions of different product systems are equivalent in order to allow clear interpretation and fair comparison of the results. The function of beverage packaging is manifold and normally separated into primary and secondary functions.

Primary functions include:

- containment of a certain quantity of product;
- preservation and protection;
- storage; and
- enabling loading and transport.

Secondary functions include:

- information (e.g. nutritional information, sell by date, use by date);
- image / promotion;
- guarantee (provides visible evidence that product has not been tampered with); and
- consumer satisfaction / acceptance.

Some also define additional secondary, or tertiary, functions such as environmental issues (e.g. low carbon footprint, recyclability).

The functional unit defined in the following section captures the main primary functions of the milk container systems by referring to a specific type of product, packaging size, and supply route. Additional functions are not included, as it is presumed, for the purposes of this study, that these elements of the packaging are designed so that they do not affect the quality of the milk within the constraints of the current milk supply systems. This includes shelf life, as well as migratory and barrier properties of the packaging.

3.2 Functional unit

The functional unit for this study is *example/typical packaging systems for containing, protecting, storing and transporting 1,000 pints*[1] *of pasteurised cow's milk to the consumer in the UK*. For the retail system, the milk is assessed as sold via a supermarket, or similar large outlet.

Data for the inventory and impact assessment in this report are expressed on the basis of the functional unit.

Although the most popular milk container size on the market at present is four pints, several of the containers assessed in this study are only available as one litre formats. Therefore, two pints or one litre packaging sizes were the main focus of the study.

The reference flow for the different container sizes, i.e. the number of containers that it takes to fulfil the functional unit, is shown in *Table 3.1* below.

Table 3.1 Reference flows for the milk container sizes evaluated

Container size	Reference flows	HDPE bottle	PET bottle	Pillow pouch	Stand-up pouch	Carton with screwcap	Gable-top carton with closure
2 pint	500	x		x			
1 litre	568		x		x	x	x

3.3 Milk packaging systems studied

The study sought to establish the potential environmental impacts of various milk container systems. *Table 3.2* below lists the material composition of the primary packaging for each of the milk packaging systems investigated. Secondary and transit packaging is also included. The data are shown per single container, not per functional unit, and is based on data provided by the different suppliers.

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[1] *One Imperial pint is 0.568 litre.*

Table 3.2 Material composition of the milk packaging systems studied

Material	Unit	HDPE bottle 2 pints	PET bottle 1 litre	PE pillow pouch 2 pints	Stand-up pouch 1 litre	Carton with screwcap 1 litre	Gable-top carton with closure 1 litre
PRIMARY PACKAGING							
Container body							
HDPE*	g	26.00					
LDPE	g			1.66	3.81	3.83	3.57
LLDPE	g			3.55			
PET*	g		40.00				
PP	g				5.82		
Liquid paper board	g					21.30	23.77
Other				0.15	6.10		
Closure							
Aluminium	g	<0.04	<0.04				
HDPE	g	1.70	1.70			2.10	1.30
LDPE	g					5.00	1.89
PET	g	<0.07	<0.07				
PP	g	0.05	0.05				
Label							
LDPE		1.00	1.00				
Total	g	28.85	42.85	5.37	15.73	32.23	30.53
ADDITIONAL PRIMARY PACKAGING							
Jug							
PP	g			154			
SECONDARY PACKAGING							
Box for pouches							
Corrugated cardboard	g			200	220		
Box for jugs							
Corrugated cardboard	g			200			
Shrink wrap							
LDPE	g		18			18	18
TRANSIT PACKAGING							
Roll cage container							
Steel	g	37,400	37,400			37,400	37,400
HDPE*	g	600	600			600	600
PACKAGING CONFIGURATION							
Containers per box				8	12		
Jugs per box				20			
Containers per shrink wrap			6			6	6
Containers per roll cage		140	160			160	160
No of reuses of roll cages		500	500			500	500

* Virgin or recycled.

** In order to pour the milk a jug is required. In UK supermarkets, purpose-built jugs are provided next to the filled pillow pouches in the milk chiller cabinet. Each jug weights 154 g. For assumptions on jug use for the purpose of this study, see section 4.3.3.

It should be pointed out that a range of carton packages exists, of which the two evaluated as part of this study are from the heavier end of the specification range. They were selected as they are the most popular versions for milk used in the UK. An instant option to lightweight cartons would therefore be to substitute with a carton from the lighter end of the specification range.

Table 3.3 below shows the different scenarios evaluated for each milk container. The recycling content scenarios are based on input from the different suppliers as to what is technically feasible at present or likely to be so in the near future. For milk containers, where the incorporation of recycled content is feasible, the recycled content of the containers is generally envisaged to increase in the future.

Table 3.3 Scenarios assessed for each milk container systems

Scenario	HDPE bottle 2 pints	PET bottle 1 litre	PE pillow pouch 2 pints	Stand-up pouch 1 litre	Carton with screwcap 1 litre	Gable-top carton with closure 1 litre
0% recycled content	x	x	x	x	x	x
30% recycled content of container body	x	x				
50% recycled content of container body	x					
10% lightweighting of container body	x	x	x	x	x	x

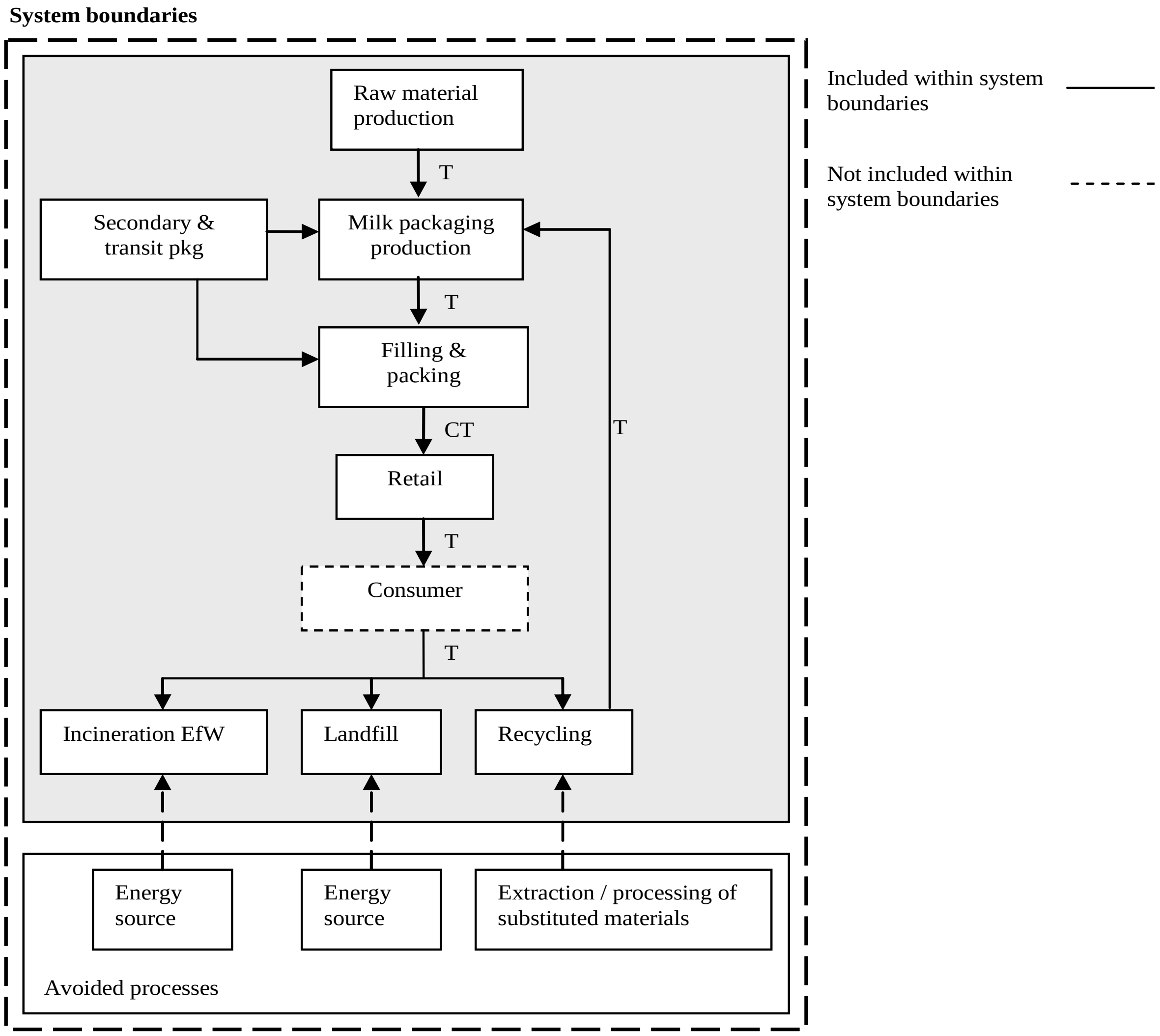
Each milk packaging system is further described in the inventory analysis.

3.4 System boundaries

The systems studied in this LCA focus on the full life cycle of the milk container systems from raw material production to end-of-life management. Energy and material inputs are traced back to the extraction of resources, and emissions and wastes from each life cycle stage are quantified. The waste management options investigated are landfill, incineration and recycling.

Figure 3.1 is a simplified flow diagram illustrating the system boundaries for the avoided burden approach taken in this study. The shadowed areas of the figure illustrate processes directly related to the life cycle of the milk containers, and the bottom part of the figure represents substituted processes.

Figure 3.1 Summary diagram of the system boundaries applied.



As can be seen from the figure, the following life cycle steps were included within the system boundaries:

- raw material extraction and production (i.e. polymers, liquid paper board, aluminium);
- transportation of raw materials to converter;
- conversion of materials into milk packaging;
- secondary and transit packaging used for delivery to dairy;
- transportation of the milk packaging to the dairy;
- filling and packing of the milk containers;
- secondary and transit packaging used for delivery to retail;
- transportation of the filled milk containers to retail;
- refrigeration in retail;
- transport to the home;
- waste collection;
- end-of-life management (landfill, incineration, and recycling);
- avoided processes from energy recovered from captured landfill gas, energy recovered by waste incineration, and secondary materials recovered through recycling (see also Section 3.5);
- production of fuels and electricity consumed by processes; and
- production and disposal of materials and chemicals consumed at each stage.

Excluded from the system boundaries were: the ink used and the printing process itself; use in the home; and product wastage. This was due to a lack of information about the types of inks used for the different containers, and the percentage of milk wastage through the supply chain.

The life cycle stages included within the system boundaries are described in more detail below.

3.4.1 Raw material production

Production of raw materials such as polymers, liquid paper board and aluminium was included in the study. Extraction of non-renewable resources, cultivation of renewable resources and their processing was included, covering material and energy resources, as well as emissions of substances to air, water and soil, and waste. For liquid paper board, for example, this means that materials and energy, as well as emissions and waste from the forestry processes of nursery, tree growth, forest maintenance and felling, were included, along with transport to the pulp mill and further processing into liquid paper board.

3.4.2 Transport of raw materials to converter

Transport from the raw material producer to the converter was included. Where it was not possible to define specific distances or sector average distances, an average distance of 250 km delivered by a lorry larger than 32 tonnes was assumed.

3.4.3 Converting (primary packaging production)

Conversion of raw materials into packaging was included in the study. This included the production of the bottle, pouch and carton, as well as any closures and labels. Where no specific data were available, generic electricity consumption data for extrusion and injection moulding were used (as contained in the Ecoinvent (1) life cycle inventory database).

3.4.4 Production of secondary and transit packaging for distribution to dairy

Production of the materials used for secondary and transit packaging was included in the study. In some cases, this included only the extraction of raw materials and their processing, but not conversion into the specific packaging product. This was, for example, the case for milk roll containers, where only the specifications of the roll container were known, not its production.

The exclusion of the conversion process for some of the secondary and transit packaging used is considered to have a minimal impact on the overall results. This is partly because the weight of the secondary and transit packaging required for milk packaging is relatively low when considering the significant trip rates for some of the transit packaging (e.g. milk roll containers).

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(1) Ecoinvent is a peer-reviewed database, containing life cycle inventory data for over 3 500 processes in the energy, transport, building materials, chemicals, paper/board, agriculture and waste management sectors. It aims to provide a set of unified and generic LCI data of high quality. The data generally cover Swiss and/or Western European conditions.

Where no information was available on the secondary and transit packaging used, assumptions were made or the packaging was excluded. Exclusion of the packaging was only the case for pallets.

3.4.5 Transport of packaging material to dairy

Transport from the converting plant to the dairy was included. Where it was not possible to define specific distances, an average distance of 200 km by a 32 tonne lorry was assumed. This was considered by the steering committee to be a reasonable estimate.

3.4.6 Dairy (filler/packer)

Energy consumption, and any substance or material use, during filling and packing was included. Although the project did not consider the production and treatment of milk, but only packaging for milk, milk was included in those processes where the milk and the packaging are interlocked, and where separating the process with a degree of scientific accuracy is not possible. The filling process is one such process, as the filling machines use energy for the transport of the milk, transport of the packaging, filling, as well as transport and packing of the filled container.

For some of the milk containers, filling data were not made available. For these, filling is estimated based on the data provided for other containers.

No milk container loss is assumed during filling and packing due to lack of specific information about loss rates for all the different packaging formats assessed.

After packing, the milk is kept in refrigerated storage for the short time before its dispatch to the retailer. This has not been included in this study due to a lack of information about the average time the packaged milk is held in storage. In addition, the quantity of milk wasted due to the quality of the packaging and the amount of primary packaging wasted during the filling and packing processes was not included. This was also due to a lack of data.

3.4.7 Production of secondary and transit packaging for distribution to retail

Secondary and transit packaging for distribution to retail was included.

Milk roll containers are generally used as transit packaging for milk containers. The roll container modelled in the study weighs 38 kg, and is based on information provided by K. Hartwall. The roll containers are produced from mild steel with recycled HDPE wheels. The life span is estimated to be 8-10 years, equivalent to approximately 500 trips (Richard Taplin 2008). This includes routine repairs. It is assumed that when the roll containers are no longer usable, the metal is recycled.

3.4.8 Distribution of packed product to retail

Transport from the dairy to the supermarket was included. Milk sold via supermarkets is generally delivered direct from the dairies to the retailer without going first to a dairy depot or Retail Distribution Centre (RDC)[1]. Where it was not possible to define specific distances or sector average distances, an average distance of 185 km delivered by a lorry larger than 16 tonnes was assumed.

Each refrigerated lorry holds 100 filled milk roll containers. Any storage or space efficiencies during distribution have not been taken into account. Instead, it is assumed that weight is the limiting factor when transporting.

Based on data from a dairy, refrigeration during distribution was estimated to add another 15% to fuel consumption. The data were based on milk delivered in glass bottles. No data have been identified for the other milk containers studied. As a consequence, the same additional consumption (15%) has been applied to refrigerated distribution for all the milk container systems.

Transport of the milk was not included.

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[1] *Milk sold via convenience shops, e.g. 'corner shops' and petrol stations, is generally delivered to the dairy depot where it is stored for approximately a day before being delivered to the shop in smaller lorries. Only supermarkets are considered in this study.*

3.4.9 Retail

Energy consumption during storage in the supermarket was included. This is another example where the milk and the packaging are interlocked. The energy consumption required to keep a constant temperature in the chilled store room and the in-shop chiller cabinets is very much dependant on the volume taken up in the cabinet.

It was not possible to obtain data on refrigeration in store from UK retailers. Instead, the retail stage of the study is based on literature data, which provides energy consumption for cool rooms of 0.0025 MJ per litre per day and of 0.12 MJ per litre volume per day for refrigerated displays (Foster et al 2006). The data does not take into account different storage or space efficiencies in refrigeration.

The throughput of milk in the supermarket is high. No general data have been made available, but an example is provided in a report from the Food Chain Centre, which looked specifically at milk delivery to the supermarket chain ASDA (FCC 2007). According to this report, milk is on average delivered three times a week. Based on this, the average throughput of milk is assumed to be 24 hours in this study with an average of 18 hrs assumed to be spent in the cool rooms and six hours in the in-shop chiller cabinets.

3.4.10 Transport to the home by the consumer

For transport to the home by the consumer, it is not possible to make an accurate assessment of the proportion of the transport that should be allocated to the milk purchased. This is partly because consumers use different ways of getting to the supermarket (foot, cycle, bus, car) and have different distances to the shop. However, an example scenario can be calculated based on a number of assumptions.

Pretty (Pretty et al 2005) calculated that, based on UK government statistics, food shopping for a UK household involved about 8 km of car travel per household per week (as well as some travel by bus, bicycle and on foot). The food expenditure survey suggests that food consumption is about 12 kg per person per week. With an average UK household size of 2.32 persons, this equates to 28 kg per household per week. Of course, non-food items are also purchased in supermarkets. However, these are excluded for the purposes of this exercise due to a lack of data.

These statistics are used for the assumptions made for this study:

- only car travel is considered;
- an ‘average’ car is assumed;
- the only purpose of the car trip is food shopping;
- the journey from the home to the supermarket is 4 km (i.e. 8 km roundtrip);
- each household purchases 28 kg per food shopping trip; and
- the type of milk container has no significant influence on the fuel consumption of the car (i.e. the car does not consume more fuel whether the milk is purchased in a HDPE bottle or a carton).

Based on this, the milk container’s contribution to the environmental impacts for transport to the home can be calculated.

3.4.11 Milk wastage due to packaging failure

It was intended that the production of milk that is wasted throughout the supply chain due to packaging failure would be included in the study. However, only limited data were made available to the project team, and it was therefore not possible to calculate or to estimate the milk wastage rate throughout the supply chain for the different packaging formats with sufficient accuracy. As a consequence, this was excluded from the system boundaries.

3.4.12 Waste collection

Collection and transport of used milk packaging to waste management facilities was included for the packaging landfilled or incinerated. For landfill and incineration, it was estimated that the distance is 20 km in refuse collection vehicles. For recycling, a distance of 20 km by refuse collection vehicle was assumed, with additional transport to the recycling facility.

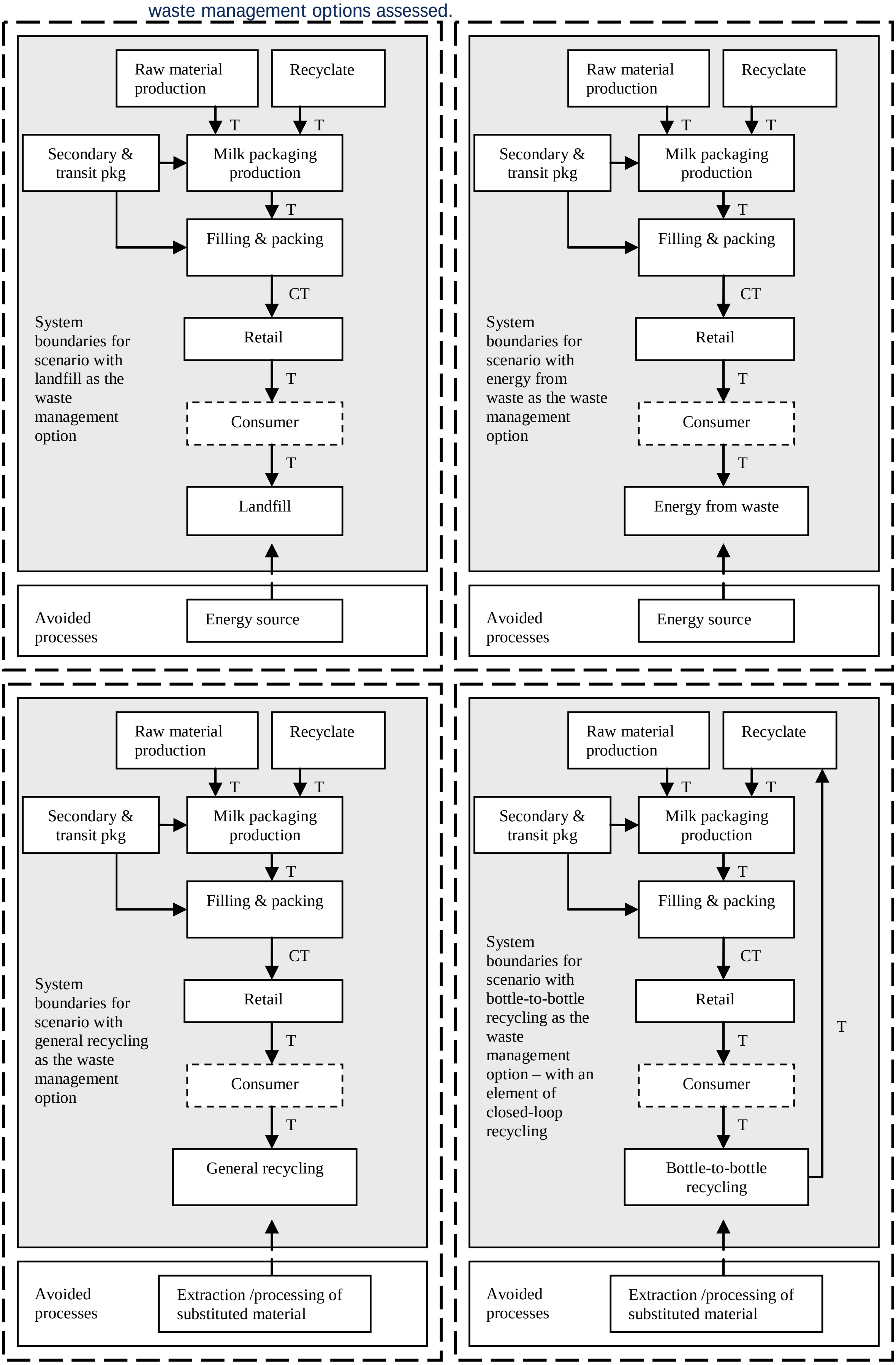
3.4.13 End-of-life management

The management of wastes from the packaging systems was included in the study. Due to uncertainty concerning the proportion of some of the container types diverted down the different waste management routes currently prevalent in the UK, WRAP requested that the individual routes of landfill, energy from waste (EfW), and recycling should be assessed and reported separately. In effect, this means that the system boundaries as depicted in Figure 3.1 should be presented as four separate systems with different waste management options as shown in Figure 3.2 below.

It must be highlighted that none of the scenarios presenting the end-of-life results landfill, energy from waste, and recycling separately represent the current UK situation for any of the packaging systems assessed. Although 100% landfill or 100% energy from waste may be conceivable, 100% recycling would never be achieved – not in the UK or any other country.

The waste management methods assessed reflect the current UK market situation in terms of disposal routes, or where this is not known, the general market situation.

Figure 3.2 Summary diagram of the system boundaries applied- depicted separately for the different waste management options assessed.



3.4.14 Additional system boundary issues

Infrastructure

Infrastructure (construction and demolition of plant, buildings, roads, vehicles etc) was not included within the system boundaries. The reason for excluding infrastructure, besides from practical aspects, was that, based on experience from previous LCA studies, the contribution from these is negligible compared to the flows (e.g. the mass of materials, consumption of fuels and energy) included within the system boundaries in the time frame of the functional unit.

Raw material production and the treatment of biogenic carbon dioxide (CO_2)

The carbon contained within paper products, food and green waste is often termed biogenic, or short-cycle carbon. When renewable materials (e.g. trees) grow, they absorb CO_2 from the atmosphere and convert this into carbohydrates and oxygen during photosynthesis. At the end of these materials' life, the carbon stored in the material is released again, either through degradation or combustion, as CO_2 or CO_2 precursors (eg CH_4), to the atmosphere. This series of flows is known as the carbon cycle. This carbon has in a relatively short timescale been taken up from the atmosphere and released again.

One approach for dealing with biogenic carbon in LCA is to exclude the absorption and release of this cycled CO_2 from the climate change impact calculations. One reason for doing this is that to ensure that all biogenic CO_2 flows are accounted for correctly across all life cycle stages and data sources is a significant task. Unless long-term storage occurs in the life cycle, ultimately such a task has no influence on the impact profile of the product. This is the approach taken in this study. Biogenic carbon degradation products other than CO_2 are accounted for within the study as they may contribute to climate change impacts. A common degradation product is CH_4, which is a powerful greenhouse gas.

3.5 Allocation

Allocation is a term used in LCA to describe the designation of environmental loads between different parts of a system. For example, when a refinery produces both petrol and diesel fuel in a distillation column, the net CO_2 emissions from the column must be distributed (or allocated) between the two products.

The ISO standards on LCA provide a stepwise procedure for the allocation of material and energy flows and environmental emissions when this occurs. Preferably, allocation should be avoided, either through increasing the level of detail, or through a method called system expansion. System expansion means adding a number of processes, which one of the systems possesses and others do not, thereby avoiding distributing the environmental loads. Where system expansion is not practicable, the ISO standard recommends that allocation on the basis of mass is used. This is a practical approach often used in LCA. For some processes, allocation based on mass is not considered appropriate. For these, other relationships (generally economic value) can be used for allocation.

An example of allocation used in this study is the distribution of the packaged milk and transport to the home. Here mass has been used to allocate the environmental burdens between the milk and the packaging, and for transport to the home between the packaging and other groceries (including milk). For the filling and packing process, it has not been possible to obtain enough information to divide the process into sub-processes. In this case, it was deemed more appropriate to include the full process rather than using mass for allocation.

In the generic aggregated data used, mass or economic allocations may have been made that cannot be changed (for example, co-production allocation of refinery products or chemicals).

The packaging systems investigated in this study present a function (containment, protection, storage and transportation of 1,000 pints[1] of pasteurised cow's milk to the consumer), but have several outputs, for instance energy recovered through waste combustion (energy from waste). In order to ensure system equivalence, it is necessary to account for these outputs. The approach applied in this report is sometimes called the avoided burdens (or end-of-life) approach. This approach considers the end of life fate of the material. This is done by expanding the system to include the avoided alternative production of these outputs. In the case of energy from waste, the generation of electricity from fossil fuel sources is avoided and the environmental impacts from this process are subtracted. This is also the case for captured landfill gas used to generate electricity. By recycling a

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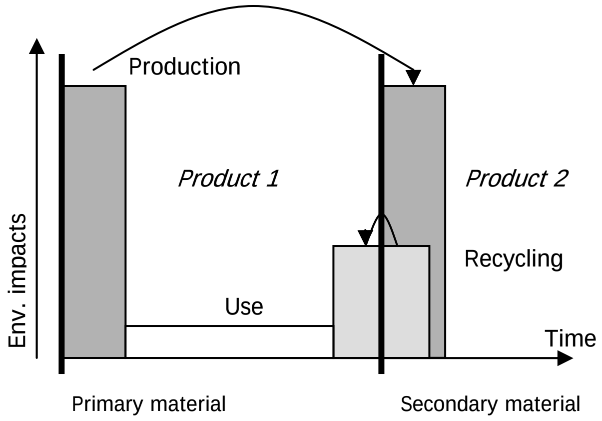
[1] *One Imperial pint is 0.568 litre.*

material after use, another material cycle is replaced. Using the avoided burdens approach, the environmental impacts of producing the avoided material are credited to the product sent to recycling (see *Figure 3.2*).

The ISO standards for LCA allow for different approaches to this allocation problem. However, they do state that the approach used for outflows of recycled material should be consistent with the approach used for inflows of recycled materials. This means that since the avoided burden approach allocates all the benefit of recycling to the material being recycled, the material input to the product being studied always bears the environmental impacts of primary production, irrespective of whether or not it has a recycled content.

Figure 3.2 Schematic representation of the avoided burden approach (Frischknecht 2007).



The ISO standards on LCA include no reference to recycled content. However, they do provide guidance on the recycling at end of life in quite some detail. In the standards, this is addressed for closed-loop and open-loop recycling separately.

Closed-loop recycling can be applied where the material is recycled in the same product system, or where the inherent properties of the material are maintained during recycling. This is the case for, for example, bottle-to-bottle plastic recycling. In this project, for HDPE and PET bottle systems where bottle-to-bottle recycling is considered as the waste management option, closed-loop recycling has been modelled. Where the amount of recovered material is higher than the recycled input to the product system, the net output enters open-loop recycling.

The ISO standards do not give a specific allocation method for dealing with recycling. Instead, the method to be applied depends on the product and the purpose of the study. Several methods are commonly used, including: the avoided burdens approach; the cut-off approach, which considers the share of recycled material in the product but only the collection stage of recycling; the 50:50 approach, which divides equally the impacts of recycling between the product being recycled and the product using recyclate; and consequential LCAs, which consider the likely consequences of a change (eg increasing recycled content) and may expand the system boundaries beyond what is generally considered the product life cycle.

It may be argued that the avoided burden approach is inequitable, in that it gives no credit for recycled content in the product. However, when considering recycling in the context of the ISO standards, one may argue that the most important issue is to maintain the properties of the material and thereby to enable the material to be recycled and replace the maximum quantity of virgin material. In simple terms, the argument is not that, when drinking milk, you should be concerned about the recycled content of the milk container, but rather that the materials in the container can be recycled, and preferably recycled a number of times.

As part of the sensitivity analysis, a different approach, the ‘cut-off’ approach, has been applied (see *Section 6.3.1).*

3.5.1 Material substitution through recycling

For some materials, it is not practical or feasible to recycle them in the same product system. For example, the fibres used in cartons are paramount for the structure of the carton and therefore long fibres are required. If using recycled fibres, the carton weight would increase in order to provide the same structural performance. Therefore, cartons currently being recycled in the UK are recycled into the paperboard component of plasterboard. The plasterboard also requires high structural performance, but the secondary fibres from cartons are of high enough quality to be used. If such fibres were not available, virgin fibres would be used (Williamson 2007). The use of secondary fibres from carton recycling will therefore alleviate the production of virgin fibres. In addition, it is assumed that the paperboard component of the plasterboard is not recycled further.

For other products, such as HDPE and PET bottles, although their subsequent use is known, no specific information about the actual fate of the used bottles has been identified. This is especially the case for bottles being sent to the Far East for recycling. For recycling in the UK, there is some information available. For example, it is known that HDPE bottles are generally recycled into lower grade products such as pipes and benches. However, there is little information available about the proportion being recycled into each of these product types. Assumptions have therefore been applied that seek to illustrate realistic, but still optimistic, scenarios.

The assumption used for the general recycling of HDPE and PET bottles in this study is that the material is being recycled into a lower grade product that is disposed of after use. To account for the lower grade, it is assumed that a certain quantity of extra secondary material is required to achieve the same functionality as virgin material. For HDPE recycling the WRATE process credits one tonne of waste HDPE with the avoidance of the extraction and production of 825 kg virgin HDPE. For PET recycling, the WRATE process credits one tonne of waste PET with the avoidance of 770 kg virgin PET.

For recycling HDPE and PET bottles back into new bottles (closed-loop recycling), it is known that the secondary plastic provides the same functionality as virgin material. Therefore, the bottle to bottle recycling scenarios assume a substitution of virgin material of 1:1, i.e. one tonne of secondary material is credited with one tonne of virgin material.

The pouches are assumed to be recycled as part of the plastic film waste stream. Recycled plastic film is generally used to produce refuse sacks or agricultural film. For plastic film recycling the WRATE process credits one tonne of waste plastic film with the avoidance of 400 kg virgin PE.

3.6 Assumptions

As with any LCA, assumptions had to be made to define and to model the life cycle of the different milk containers. Due to a lack of available data, a relatively large number of assumptions had to be made for this study. This has resulted in the scope of the study being reduced with regard to ambition and application. One significant change in scope is that no comparison is now carried out between the different milk container types. It was determined that the data are simply not robust enough to support such comparisons.

However, not all the assumptions are considered to have the potential to affect the outcomes of the life cycle inventories and impact assessment results significantly. Where the significance of an assumption, or the uncertainty as to the correctness of the assumption, is high, this was highlighted or assessed further in the sensitivity analysis.

3.7 Limitations

This study is an assessment of *example packaging systems* for chilled pasteurised milk. It was intended that the study should cover *average milk packaging systems* as available on the UK market. However, despite considerable efforts by the project team and the steering committee, it was not possible to collect such data. Therefore, the results of this study cannot be said to reflect average market performance, or be used in drawing specific conclusions relating to the relative performance of all milk packaging. Instead, the results give an insight into:

- the type of impacts that the different milk container systems studied have on the environment;
- the magnitude of the selected environmental impacts for the different milk container systems studied;
- areas where knowledge of the different milk container systems is lacking;
- an indication of any environmental benefits of:
  - lightweighting containers;
  - increasing recycling of the used milk containers; or
  - incorporating recycled content in the containers (as part of the sensitivity analysis only).

The aim of the study was to inform and to educate WRAP about the nature of the environmental impacts of each example packaging system and the life cycle environmental benefits that can be achieved through lightweighting, recycling at end-of-life, or incorporating recycled content. It is still possible to draw conclusions to this effect from the study.

The results of the study are limited by the data collected, the assumptions made where data gaps occurred, and the systems assessed. Data gaps were evident for all the packaging systems assessed; especially with regard to the distribution and retail stages of the life cycle, but also for secondary and transit packaging, and the filling and packing stage for some of the packaging systems.

As a result of the limited data obtained for the distribution and retail stages of the life cycle, the study cannot be used as the basis for assessing the efficiency of packaging formats for logistics systems or in the retail environment. The study does include an estimate of the distances travelled and energy consumed in distribution and retail. The use of these estimates is limited to judging the significance of these life cycle stages in the context of the full life cycle.

It was intended that the environmental impacts of milk wasted through the supply chain due to packaging failure should be included in the scope of the study. However, only limited data for certain life cycle stages were made available to the project team, and, as a consequence, product wastage was excluded from the study. Therefore, it was not possible to incorporate in the study the different packaging systems' degree of mechanical integrity and product protection.

3.7.1 Reasons for non-comparability

On project initiation, it was intended that the study should be a comparative assessment of different average milk packaging systems available on the UK market. However, as described previously it was not possible to get cooperation throughout the whole supply chain of each packaging system for the systems modelled to represent average UK packaging systems. Based on this, combined with the different levels of certainty regarding the data used for the various packaging systems and the data gaps of the systems, it was decided that the study should not include comparison of the packaging systems. The reason for this is that including comparison could be deemed to give an indication of the data being robust enough to support comparison. Examples of non-comparability due to the data sources and modelling methods used include the following:

- The HDPE bottle production data is representative of one of the data supplier's sites. It therefore does not represent the average HDPE bottle produced by that converter, but rather a best case scenario.
- The PET bottle production is modelled as a one-stage blown bottle. This was done as the PET bottle currently has a very small share of the milk packaging market and this is the production method used. However, if the use of PET bottles for milk packaging increased significantly, the two-stage blowing process is more likely to be used. The energy use and transport impacts of the two-stage process are different to those of the one-stage process, and the system assessed in this study would therefore not be representative.
- For certain processes, the level of certainty with regard to the data used varies for the different packaging systems assessed. For example, this is the case for the following.
    - The primary packaging: No data were made available for the converting of the closure, seal and label for the PET bottle. Instead it was assumed that these were the same as for the HDPE bottle. Similarly, no data were made available for the converting of the carton closures and instead generic industry data for injection moulding were used.
    - The secondary and transit packaging used for delivery of the primary packaging to the dairy: for the HDPE and PET bottles and stand-up pouch it is based on actual data supplied by the converters; for the cartons it is based on industry average data (not specific to this type of carton); for the pillow pouch, no data were made available and instead the data for the stand-up pouch have been used. The secondary and transit packaging: for the closure and seal for the HDPE bottle, this is based on actual data supplied by the converter; for the label, it is based on actual data supplied by the dairy. No data were made available for the secondary and transit packaging for the closure for the PET bottle and cartons, or the seal and label, and instead data for the HDPE bottle system were used.
    - The filling process: for the HDPE bottle, this is based on allocation of a proportion of site data to the filling process; for the cartons and the stand-up pouch, it is based on filling machine specifications; and for the pillow pouch it is based on measured filling data. No data were made available for the filling of the PET bottle and instead it was assumed that the data was the same as for the HDPE bottle.
    - The distribution packaging: for the HDPE and PET bottles, this was based on data provided by the dairy; for the pillow pouch, this was estimated based on distribution packaging for supply to a UK supermarket; for the stand-up pouch, this was provided by the converter and was based on data for distribution packaging used in Denmark; and for the cartons, this was based on data provided by the converter for UK distribution.
- The data representing the bottle-to-bottle recycling processes for the HDPE and PET bottles include inconsistencies that it has not been possible to clarify with the data supplier. In addition, the data were provided prior to the opening of the UK recycling plant, although the data provider stated that the data

represents a model for the UK plant and is based on prior build experience in Switzerland and especially the plant in Rostock, Germany. No additional data, based on actual processes at the UK recycling plant, have been made available subsequent to the plant's opening. As such, the representativeness of the data may be questioned.

- The modelling of the end-of-life stage of the packaging systems has been done as scenarios considering the waste treatment options of landfill, incineration and recycling separately, as per WRAP's request. As such, none of the scenarios do on their own represent currently situation in the UK.

3.8 Data and data quality requirements

The data and data quality requirements considered in order to perform this LCA are listed below.

Specific, or primary, data are most critical for the main processes directly involved in: the production of the milk containers; converting; filling; production waste; and bottle to bottle recycling. For the production of secondary and transit packaging, for example, generic data have been used since the mass flow for this packaging in relation to the functional unit is limited.

In summary, specific data were researched for:

- types and weights of the primary, secondary and transport packaging;
- production of primary packaging (i.e. bottles, pouches, cartons, closures, and labels);
- forming and filling;
- packing;
- distribution / supply systems (transport distances, types of transport, storage requirements);
- retail;
- milk wastage through the supply chain by milk container type;
- type of waste management for the primary, secondary and transit packaging;
- bottle to bottle and carton recycling processes; and
- electricity mix used, i.e. the split between different electricity generation methods such as coal, wind power, etc.

Generic, or secondary, data were used for:

- production of raw materials (when generic data are of sufficient quality, or specific data not available);
- production of closures and labels (when generic data are of sufficient quality or where specific data are not available);
- secondary and transit packaging production;
- packaging waste management;
- waste management operations (when generic data are of sufficient quality or where specific data are not available);
- electricity generation;
- productions of fuels; and
- emission data from transport.

The inclusion of data in this LCA has been carried out iteratively. Initially, information about the systems and data for all main processes were requested from converters, dairies and supermarket chains. While evaluating these data, new sub-processes and details were discovered which required additional data. For some processes, the datasets were improved, whilst for others generic data had to be used. The impact assessment was then run and preliminary results were generated. This resulted in the identification of the main impact contributions, followed by a final refinement of data and sensitivity analysis.

No cut-off criteria have been used by default for input or output data. All known inputs to and emissions from all processes included within the system boundaries, regardless of their importance, have been included in the modelling. If their contribution to the environmental indicators was found to be insignificant, no further refinement was undertaken. Refinement and sensitivity analyses were carried out for the variables of highest environmental significance.

The data quality requirements as set out at the initiation of this project are defined in *Table 3.4* below, based on the ISO standard (ISO 14044:2006).

Table 3.4 Data quality requirements

Parameter	Description	Requirement
Time-related coverage	Desired age of the data and the minimum length of time over which data should be collected.	Data should represent the situation in 2006/07. General data and data from databases should represent the situation in 2007, and not be more than five years old.
Geographical coverage	Area from which data for unit process should be collected.	Data should be representative of the situation in the UK.
Technology coverage	Technology mix.	Data should be representative of the situation in the UK in the context of average technology mix installed.
Precision	Measure of the variability of the data values for each data category expressed.	No defined requirement in study scope.
Completeness	Assessment of whether all relevant input and output data are included for a certain dataset.	Specific datasets should be assessed and where concerns arise be compared with literature data and databases.
Representativeness	Degree to which the data represents the identified time-related, geographical and technological scope.	The data should fulfil the defined time-related, geographical and technological scope.
Consistency	How consistent the study method has been applied to different components of the analysis.	The study method should be applied to all the components of the analysis.
Reproducibility	Assessment of the method and data, and whether an independent practitioner will be able to reproduce the results.	The information about the method and the data values should allow an independent practitioner to reproduce the results reported in the study.
Sources of data	Assessment of data sources used.	Data should be derived from credible sources and databases.

3.8.1 Time-related and geographic scope

The systems investigated represent examples of milk packaging available on the UK market. Therefore, UK facilities for milk packaging production, dairies etc were contacted for specific data.

Where specific data were not available, generic, often non-UK, data were used and, where appropriate, these were manipulated to take into account the particular characteristics of the UK situation.

3.8.2 Time scope

Since one of the goals of this study was to provide sufficient input to inform the decision of future policy on milk packaging, it was necessary that the temporal scope enables this. The temporal scope for this study was determined as short term (2007-2010), for which current technology and energy sources are considered to be appropriate. A longer timescale may be considered more appropriate for policy making. However, this would require the projection of technologies, energy sources, treatment volumes and effects of scale, which was outside the scope of this study.

The milk container conversion and filling data used represent the situation in 2006/07. However, the datasets used from the literature cover a wider period.

3.8.3 Technological scope

The specific data obtained for this study reflect technologies employed in current business operations with regard to process configurations, performance and operation.

3.9 Inventory analysis

Inventory analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. For each of the milk packaging systems assessed, inventories of significant environmental flows to and from the environment, and internal material and energy flows, were produced.

The inventories generated provide data on hundreds of internal and elemental flows for each milk packaging system. As such, only summary inventory flows for the milk container systems have been included in this final report, namely:

- raw material use for the packaging systems;
- water use;
- non-renewable CO2 emissions;
- CH4 emissions; and
- energy use (as 'cumulative energy demand').

Water use has been included due to environmental and political concerns relating to water use in the UK and globally. Inventory data for raw material use, energy use, CO_2 and CH_4 emissions have been included upon request from WRAP's project team. Energy use is presented as the 'cumulative energy demand', using factors as presented in the SimaPro software. These factors distinguish between both renewable and non-renewable 'cumulative energy demand'.

The WRATE (1) software does not assess cumulative energy demand, and does not allow the export and reporting of individual inventory flows in the same way as SimaPro, although it does allow the inventory to be viewed. As a result, summary inventory data have only been generated for the life cycle stages up to waste collection.

3.10 Impact assessment

The impact assessment phase of an LCA assigns the results of the inventory to different impact categories.

The potential contributions that each milk container system makes to the impact categories listed below have been assessed. The impact categories, selected in agreement with WRAP, address a breadth of environmental concerns where thorough methods have been developed for calculating the potential contribution made to the impact of concern.

In this study, the following impact categories were considered:

- abiotic resource depletion;
- climate change;
- photo-oxidant formation;
- eutrophication;
- acidification;
- human toxicity; and
- aquatic freshwater ecotoxicity.

For some impact categories, particularly human toxicity and eco-toxicity, a number of simplifying assumptions are made in the modelling used to derive characterisation factors. The substances that contribute to human toxicity are numerous and cover a number of different effects: acute toxicity; irritation effects; allergenic effects; irreversible damage; genotoxicity; carcinogenic effects; toxicity to the reproductive system; and neurotoxicity. The same is the case for eco-toxicity. Knowledge is still developing about cause and effect for a number of these substances and, as a result, their adequacy in representing impacts is still the subject of scientific discussion. However, they are widely used, and they were therefore included in the assessment as issues of interest.

It must be stressed that the impact categories used in LCA relate to **potential impacts**. That is, they express what would happen if the cause-effect relationship is enacted. In practice, it is not known if, for example, each and every cancer-triggering molecule enters a human body and does in fact cause cancer. Nevertheless, it has the potential so to do.

The impact assessment method employed in this study is the problem-oriented approach developed by CML (Centre for Environmental Science, Leiden University) and which is incorporated into the SimaPro LCA software tool. The impact categories assessed are further described in *Appendix 1*.

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(1) The Waste and Resources Assessment Tool for the Environment (WRATE), a waste management life cycle assessment tool developed for the Environment Agency, has been used to model the waste management scenarios, from collection to final disposal, to identify more environmentally preferable routes for the management of the wastes.

3.11 Reporting

According to the ISO standards, when the results of an LCA are to be communicated to any third party, a third-party report shall be prepared. The report shall be made available to any third party to whom the communication is made. For LCA studies supporting comparative assertions intended to be disclosed to the public, additional reporting requirements apply.

At WRAP’s request, the report has been prepared to fulfil the requirements of the ISO standard for a third party report and it has been critically reviewed on that basis.

3.12 Critical review

In accordance with the ISO standard on LCA, the study has been reviewed by an external review panel. The panel’s report and the authors’ responses are presented in the Appendix 3.

The review panel addressed the following issues:

- for the goal and scope:
    - reviewed the scope of the study for consistency with the goal of the study, and that both are consistent with the ISO standards; and
    - prepared a review statement.
- for the inventory:
    - reviewed the inventory for transparency and consistency with the goal and scope and with the ISO standard;
    - checked data validation and that the data used are consistent with the system boundaries. It is unreasonable to expect the reviewer to check data and calculations beyond a small sample; and
    - prepared a review statement.
- for the impact assessment:
    - reviewed the impact assessment for appropriateness and conformity with ISO standard; and
    - prepared a review statement.
- for the interpretation:
    - reviewed the conclusions of the study for appropriateness and conformity with the goal and scope of the study; and
    - prepared a review statement.
- for the draft final report:
    - reviewed the draft final report for consistency with reporting guidelines in the ISO standard and checked that recommendations made in previous review statements have been addressed adequately; and
    - prepared a review statement including consistency of the study and international standards, scientific and technical validity, transparency and relation between interpretation, limitation and goal.

3.12.1 Critical review panel

The critical review was performed by a panel comprising:

- Walter Klöpffer, editor-in-chief of the International Journal of LCA (chair);
- Andreas Detzel, Institut für Energie und Umweltforschung (IFEU), and
- Chris Foster, EuGeos Limited.

All three have extensive experience in the area of LCA of packaging and of peer review. Walter Klöpffer has provided review services throughout the study, whereas the full panel has reviewed the draft final report.

4.0 Inventory analysis

This chapter describes in more detail the milk container systems assessed, together with the data used to generate the life cycle inventory for these systems. Due to confidentiality issues, the level of detail is restricted.

The inventory analysis procedure involves data collection and calculations to quantify relevant inputs and outputs related to the functional unit for each milk container system. Data sources include both specific and generic data.

Sections 4.1 to *4.6* describe the data and assumptions used to generate the life cycle inventories for each milk container system. The sections are composed so that each section can be read separately.

4.1 HDPE bottles

4.1.1 The HDPE bottle systems studied

The HDPE bottle assessed in this study is designed for the distribution of pasteurised milk (chilled) and is produced from HDPE, with a cap, seal and label. The seal is composed of polyolefin foam, aluminium and PET, and the cap from HDPE. The label is produced from LDPE. This composition of the HDPE bottle is considered by the project steering committee to be representative of the majority of the HDPE milk bottles currently available on the UK market.

The vast majority of HDPE bottles for milk currently on the UK market are produced from virgin HDPE (vHDPE). Marks & Spencer, a UK market leader in using recycled content packaging, currently provides organic milk in HDPE bottles with a 10% recycled content (rHDPE). WRAP research has shown that it is possible to produce HDPE bottles with a recycled content of 30% and 50% without technical difficulties. Trials have been conducted in certain supermarkets with the 30% rHDPE bottle. Due to the recycled HDPE flakes containing some colouration, the bottles with 50% recycled content have a visible green tint to them. This is considered unacceptable for milk packaging. However, the producer has provided assurances that this can be eliminated with some technical input and a 50% recycled content is seen as a viable bottle composition for the future.

Table 4.1 below shows the material composition of the HDPE bottle systems studied in this report. The bottle systems with 50% recycled content and the 10% lightweighting are hypothetical future systems.

Table 4.1 Material composition of the HDPE bottle systems studied (per functional unit)

Material	Unit	HDPE bottle, 2 pint, 100% vHDPE	HDPE bottle, 2 pint, 30% rHDPE	HDPE bottle, 2 pint, 50% rHDPE	HDPE bottle, 2 pint, 30% rHDPE & 10% lightweight
Primary packaging					
Container body					
HDPE	g	13,000.0	9,100.0	6,500.0	8,190.0
rHDPE	g		3,900.0	6,500.0	3,510.0
Closure					
HDPE	g	850.0	850.0	850.0	850.0
PET	g	32.6	32.6	32.6	32.6
PP	g	24.9	24.9	24.9	24.9
Aluminium	g	19.1	19.1	19.1	19.1
Label					
LDPE	g	500.0	500.0	500.0	500.0
Packaging for delivery to dairy					
For container body					
LDPE[1]	g	140.4	140.4	140.4	140.4
For closure					
LDPE[2]	g	2.5	2.5	2.5	2.5
Corrugated board[2]	g	133.3	133.3	133.3	133.3
For label					
LDPE[3]	g	12.5	12.5	12.5	12.5
Corrugated board[3]	g	533.3	533.3	533.3	533.3
Packaging for delivery to retail					

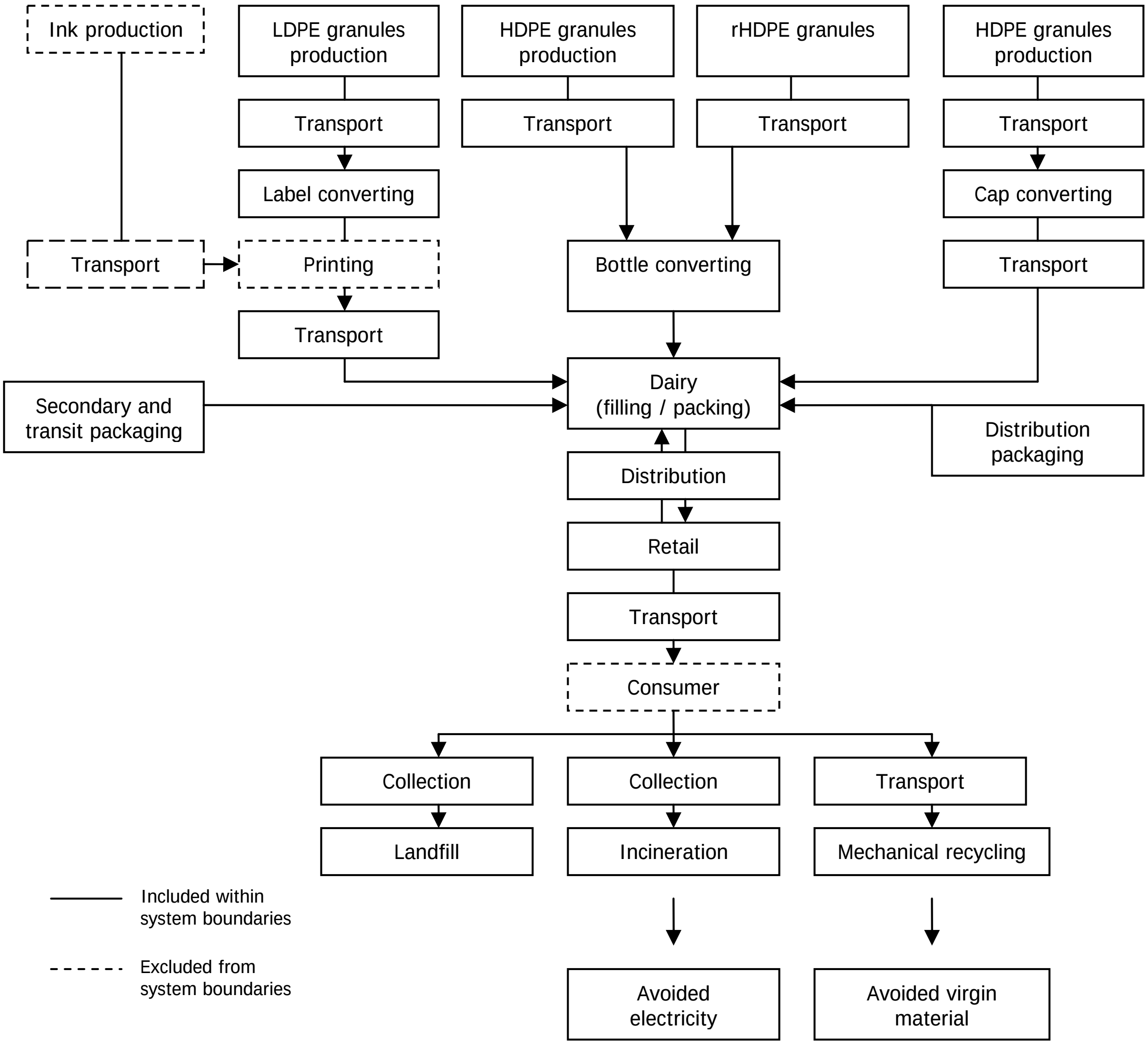
Material	**Unit**	**HDPE bottle, 2 pint, 100% vHDPE**	**HDPE bottle, 2 pint, 30% rHDPE**	**HDPE bottle, 2 pint, 50% rHDPE**	**HDPE bottle, 2 pint, 30% rHDPE & 10% lightweight**
Roll cage container					
Mild steel[4]	g	264.3	264.3	264.3	264.3
rHDPE[4]	g	4.3	4.3	4.3	4.3
Total, retail	**g**	**15,517**	**15,517**	**15,517**	**14,217**

Notes:

1. A proportion (36%) of bottles is bagged prior to passing through the wall. The bag weighs approximately 3% of its content.
2. Each plastic bag and corrugated box holds 3,000 caps. Each bag weighs 15 g, and each box weighs 800 g.
3. Each corrugated box holds reels of 12,000 labels. Each plastic film weighs 0.3 kg and each box weighs 12.8 kg.
4. The roll cage container weighs 38 kg, of which 37.4 kg is steel and 600 g is polyethylene wheels. Each roll cage container holds 140 2-pint HDPE bottles. The roll cage container is reused a number of times, the dairies estimate they on average are reused 500 times (including repairs) before being disposed of.

The system boundaries for the HDPE bottle system are illustrated in *Figure 4.1* below.

Figure 4.1 System boundaries for the HDPE bottle system



4.1.2 Raw materials

Data describing the extraction and processing of crude oil and natural gas to produce HDPE were sourced from PlasticsEurope (as contained within the Ecoinvent life cycle inventory database). Transport distances for the raw materials from the supplier to the bottle converting plant were provided by Nampak.

The rHDPE is, for this study, modelled as originating from the Closed Loop Recycling plant in Dagenham. This plant has only recently started operating and the data for the hot washing and decontamination with an Erema Vacurema system is therefore based on the specifications of the plant and knowledge and experience from already built facilities in Switzerland and Rostock, Germany. Prior to the opening of the plant, rHDPE has generally been purchased from Europe. For the example HDPE bottle assessed as part of this study, the producer has reported that rHDPE from the Dagenham plant will be used following the plants opening. The transport distance for the rHDPE has been determined based on this.

4.1.3 Converting

In the UK, HDPE bottle converting plants and larger dairies are in general located adjacent to one another, allowing for the HDPE bottles to be supplied via a conveyor belt through a ‘hole in the wall’. Generally, this is only the case for larger dairies that have a significant throughput of HDPE bottles. For smaller dairies, the blown HDPE bottles are transported to the dairy. It has not been possible to obtain information on the proportion of HDPE bottles delivered through the ‘hole in the wall’ system in the UK. The example HDPE bottle studied in this project is blown at a converting plant adjacent to the dairy.

During the conversion process, virgin HDPE pellets are blended with re-grind from internal processes, along with any externally supplied recycled HDPE pellets. The blended HDPE is then injection blow moulded into bottles and any excess material is trimmed and re-grinded. The conversion process is not altered through the inclusion of recycled HDPE.

The HDPE cap is produced from the injection moulding of HDPE pellets with additives in the form of pigment, anti-oxidants and slip agents. In modelling the cap, the additives have not been included. The seal is produced from polyolefin foam with thin aluminium and PET film layers applied.

The label is produced from the film extrusion of a blend of LDPE granules and additive (slip agent). In modelling the label, the additive has not been included.

The data for the conversion of raw materials into bottles were provided by Nampak for its Chadwell Heath plant. Data for the production of the cap and seal were provided by Portola Packaging for its plant in Doncaster, and data for the production of the label were provided by CCL Label for its plant in Völkermarkt in Austria. The data provided are confidential. CCL Label does not generally provide the label for the example bottle studied. However, it was not possible to obtain data from the actual label provider.

4.1.4 Secondary and transit packaging for delivery to dairy

Since, for this example HDPE bottle, the converting plant is situated adjacent to the dairy, limited secondary packaging, and no transit packaging, is required. However, since the dairy is not continuously accepting bottles, approximately 36% of bottles are bagged in LDPE film and stored. When the dairy is again accepting bottles, the bottles are de-bagged and passed onto the dairy. After use, the film is recycled.

The secondary and transit packaging used for cap delivery to dairy may vary based on the size of the consignment. It is understood that for smaller consignments, the caps are generally transported to the dairy in corrugated boxes with a plastic liner. For larger consignments, one data provider has reported that the caps are generally transported in bulk containers (pallecons) lined with a plastic bag. For the purposes of this study, the data provided by the cap producer has been used.

The label producer has provided no information on the packaging used for transporting the labels to the dairy. Instead, data provided by the dairy has been used.

Data for the secondary packaging for the bottles were provided by Nampak, for the caps by Portola Packaging, and for the labels by a dairy. The data provided are confidential.

4.1.5 Transport to the diary

Portola Packaging has reported that 50% of the seals and caps are transported by road and 50% by sea.

For the label, the distance between the plant and the UK has been applied.

4.1.6 Filling and packing

From the converter, the HDPE bottles are taken via conveyor belts through the ‘hole in the wall’ to the diary, where the bottles are filled and seals, caps and labels are applied. The filled bottles are then packed onto milk roll containers.

The electricity consumed in the filling of the HDPE bottles was estimated by a dairy, based on the production at one of its sites. The electricity use is based on total site usage with a proportion allocated to the filling process. Washing of the bottles is not required and washing of the filling machine was not included due to a lack of data. The data provided is confidential.

4.1.7 Secondary and transit packaging for delivery to retail

Milk in HDPE bottles is supplied to retail in milk roll containers. An average roll container holds 140 two pint HDPE bottles. No secondary packaging is required for HDPE bottles.

4.1.8 Distribution

Distribution to retail is generally achieved as part of a roundtrip with several deliveries to retailers underway. A dairy has reported an average distance between drop-offs of 35 miles, with five to eight drops underway for one of its larger dairies. However, this varies from dairy to dairy and by region (i.e. urban area, rural area). For the purposes of this study, an average distance of 185 km was assumed.

As described in the scope section, refrigeration during the transport was estimated by a dairy to add another 15% to fuel consumption.

4.1.9 Retail

When arriving at the supermarket, the milk roll containers are stored at 5°C in chilled store rooms. The length of storage varies, depending on the frequency of deliveries to store and consumer shopping habits (e.g. day of the week, seasonal festivities, etc). When stock in the shop is close to being replenished, the roll containers are taken onto the shop floor and swapped for an empty roll container in the chiller cabinets. In the UK, chiller cabinets are generally open fronted and kept at 3°C. For the purposes of this study, it was assumed that the milk containers are stored in the chilled store room for 18 hours and in the in-shop chiller cabinets for six hours.

No data were obtained for the refrigeration of the milk in the supermarket. Instead, literature data were used as described in the scope section of the report.

4.1.10 End-of-life

As explained in the goal and scope, due to a lack of information for all the packaging systems studied, each waste management method is considered separately.

Data for bottle-to-bottle recycling were provided by Nextek. The recycling process involves hot washing and decontamination using the Erema Vacurema system enabling food grade recyclates to be produced. The data were provided prior to the opening of the Dagenham recycling plant, but represents the plant based on the specifications of the plant and experience from already built facilities in Switzerland and especially the plant in Rostock, Germany. The data provided are confidential.

Data for landfill, incineration and general recycling is based on WRATE data.

According to WRAP’s 2008 Annual Bottle Survey, approximately 35% of plastic bottles in the UK household waste stream were recycled in 2007 (WRAP 2008). The majority of these bottles were either PET or HDPE bottles, with the ratio between the two bottle types being estimated at 52% PET and 48% HDPE.

Of the plastic bottles collected for recycling, approximately 30% are recycled in the UK into lower grade products such as pipes, benches etc (Paul Davidson 2008). However, interest is growing for higher grade recyclates, including bottle-to-bottle recycling. The remaining 70% are sold to export markets, generally China. It is not known what products these waste bottles are recycled into. The global demand is expected to continue to increase over the long term.

4.1.11 Summary inventory results for the HDPE packaging systems studied

A summary of selected inventory data for the HDPE bottle system is shown in *Table 4.2* below. The data represent the life cycle inventory results from cradle to retail. Waste collection and waste management has not been included, as the WRATE software tool does not allow results to be generated in this aggregated format.

Table 4.2 Summary life cycle inventory results for the HDPE bottle system from cradle to retail* (per functional unit)

Inventory	Unit	HDPE bottle, 2 pint, 100% vHDPE	HDPE bottle, 2 pint, 30 % rHDPE	HDPE bottle, 2 pint, 30 % rHDPE (closed-loop)	HDPE bottle, 2 pint, 50 % rHDPE	HDPE bottle, 2 pint, 50 % rHDPE (closed-loop)	HDPE bottle, 2 pint, 30% rHDPE & 10 % lightweight	HDPE bottle, 2 pint, 30% rHDPE & 10 % lightweight (closed-loop)
Raw material use: coal	kg coal	5.93	5.93	5.53	5.93	5.26	5.79	5.43
Raw material use: oil	kg oil	15.1	15.1	11.5	15.1	9.2	13.9	10.7
Raw material use: natural gas	m^3 gas	12.9	12.9	10.0	12.9	8.12	11.91	9.35
Carbon dioxide (fossil)	kg CO_2	41.5	41.4	35.3	41.3	31.2	39.2	33.7
Methane	kg CH_4	0.251	0.251	0.196	0.251	0.159	0.233	0.183
Water	m^3	56.1	56.1	55.9	56.1	55.8	56.0	55.9
Energy use, non-renewable	MJ eq	1434	1433	1135	1432	936	1332	1064
Energy use, renewable	MJ eq	36.4	36.4	32.9	36.4	30.5	35.2	32.1

* Please note, waste collection and waste management has not been included, as the WRATE software tool does not allow results to be generated in this aggregated format.

4.2 PET bottles

4.2.1 *The PET bottle systems studied*

The PET bottle assessed in this study is produced from PET, with a cap, seal and label. The seal produced from polyolefin foam, aluminium and PET, and the cap from HDPE. The label is produced from LDPE.

PET bottles have a very small market share of the UK milk packaging market. They are used for speciality milk (e.g. Jersey cow's milk) and flavoured milk products. The composition of the PET bottle assessed in this study is considered by the steering committee to be representative of the majority of PET bottles on the UK market used for milk products.

It is technically possible to produce PET bottles with recycled content from 0-100%. It is believed that approximately 50% of the PET bottles currently used for milk are produced from 30% recycled PET (rPET).

Table 4.3 below shows the material composition of the PET bottle systems studied. The bottle systems include 100% vPET, 30% rPET, and a 10% lightweight system as a hypothetical future system.

Lightweighting is already feasible for PET bottles. However, a consequence of a lighter bottle is that the dairies would be required to invest in new filling lines. This is a considerable investment on the part of the dairies who, with the small market share of PET, are reluctant to make such changes.

Table 4.3 Material composition of the PET bottle systems studied (per functional unit)

Material		**Unit**	**PET bottle, 1 ltr, 100% vHDPE**	**PET bottle, 1 ltr, 30% rHDPE**	**PET bottle, 1 ltr, 30% rHDPE & 10% lightweight**
Primary packaging					
Container body					
	vPET	g	22,720.0	15,904.0	14,313.6
	rPET	g		6,816.0	6,134.4
Closure					
	HDPE	g	965.6	965.6	965.6
	PET	g	37.1	37.1	37.1
	PP	g	28.2	28.2	28.2
	aluminium	g	21.7	21.7	21.7
Label					
	LDPE	g	568.0	568.0	568.0
Packaging for delivery to dairy					
For container body					
	LDPE[1]	g	1,136.0	1,136.0	1,136.0
For closure					
	LDPE[2]	g	2.8	2.8	2.8
	Corrugated board[2]	g	151.5	151.5	151.5
For label					
	LDPE[3]	g	14.2	14.2	14.2
	Corrugated board[3]	g	605.9	605.9	605.9
Packaging for delivery to retail					
Roll cage container					
	Mild steel[4]	g	265.5	265.5	265.5
	rHDPE[4]	g	4.3	4.3	4.3
Shrink wrap					
	LDPE[5]	g	1,704.0	1,704.0	1,704.0
Total, retail		**g**	**28,225**	**28,225**	**25,953**

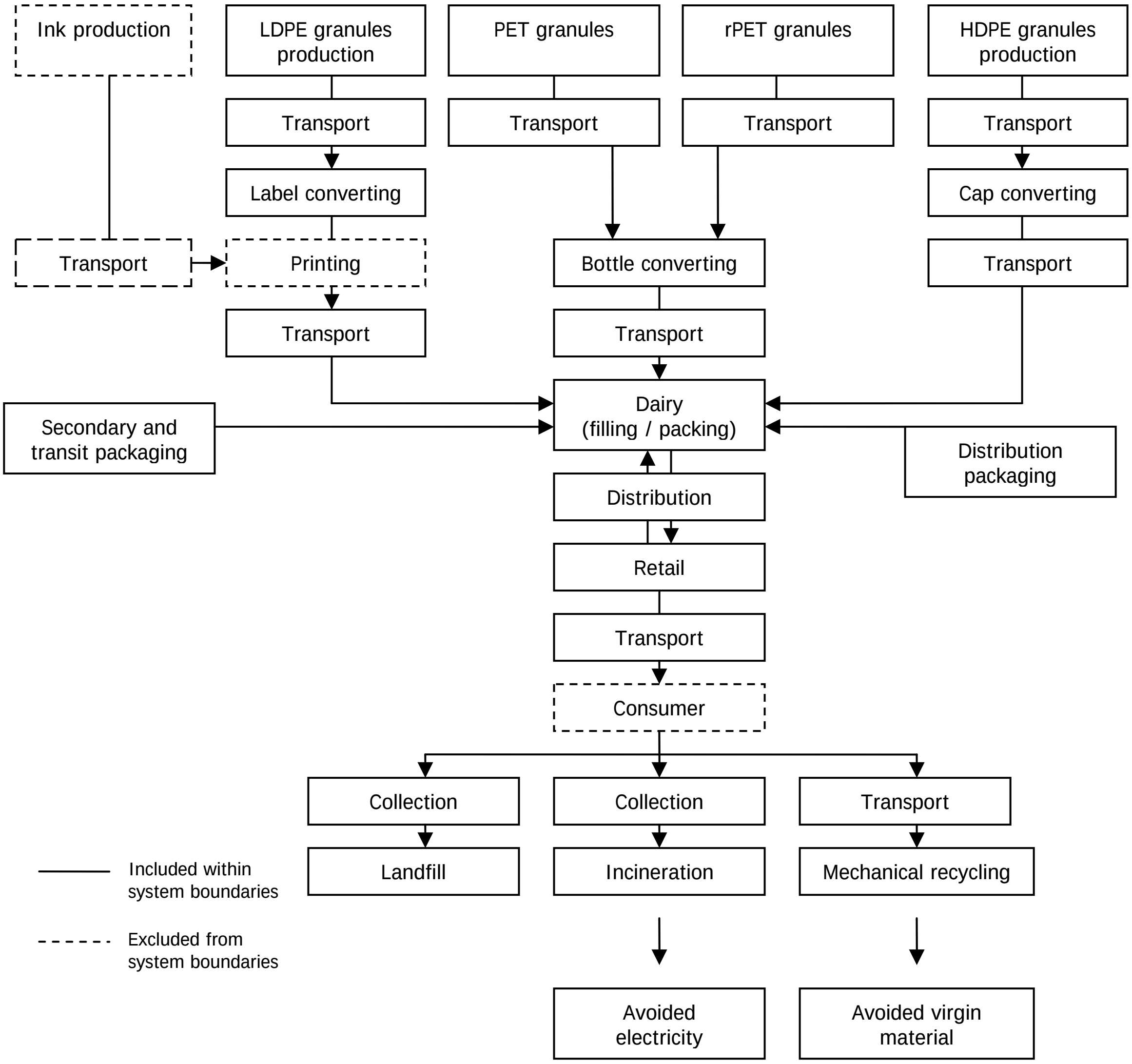
Notes:

1. The bottles are assumed bagged for transport. The estimated weight of the bag is equivalent to 2 g per bottle.
2. Each plastic bag and corrugated box holds 3,000 caps. Each bag weighs 15 g, and each box weighs 800 g.
3. Each corrugated box holds reels of 12,000 labels. Each plastic film weighs 0.3 kg and each box weighs 12.8 kg.

4. The roll cage container weighs 38 kg, of which 37.4 kg is steel and 600 g is polyethylene wheels. Each roll cage container holds 160 one-litre PET bottles. The roll cage container is reused a number of times, the dairies estimate they on average are reused 500 times (including repairs) before being disposed of.
5. It is assumed that the filled bottles are shrink wrapped prior to packing onto roll cage container. It is estimated that 3 g of LDPE film is required per bottle.

The system boundaries for the PET bottle system are illustrated in *Figure 4.2* below.

Figure 4.2 System boundaries for the PET bottle system



4.2.2 Raw materials

Data describing the extraction and processing of crude oil and natural gas to produce PET, HDPE and LDPE were sourced from PlasticsEurope (as contained within the Ecoinvent database). Transport distances for the raw materials from the supplier to the bottle converting plant were provided by RPC Containers.

The rPET is, for this study, modelled as originating from the Closed-Loop Recycling plant in Dagenham. This plant has only recently started operating, and the data for the URRC recycling process is therefore based on the specifications of the plant and knowledge and experience from already built facilities in Switzerland and Rostock, Germany. Prior to the opening of the plant, rPET has generally been purchased from Germany. For the example PET bottle assessed as part of this study, the producer has reported that rPET from the Dagenham plant will be used following the plants opening. The transport distance for the rPET has been determined based on this.

4.2.3 Converting

The example PET bottle studied in this project was assumed to be blown in a single stage. This is believed to be representative of the current situation for PET milk bottles in the UK. Were the PET bottle to gain a larger share of the pasteurised milk market, the bottles would most likely be produced in the two stage process; first as preforms, and then blown to full bottles.

During the converting process, virgin PET granules are blended with re-grind from internal processes, along with any externally supplied recycled PET pellets. The blended PET is dried and then injection stretch blow moulded into bottles. Any excess material is trimmed and re-grinded. The conversion process is not altered through the inclusion of rPET pellets.

It was not possible to obtain information about the cap and label used for the example PET bottle. Therefore, the same data as for the HDPE bottle was used. The data are considered to be representative for caps applied to PET bottles.

The HDPE cap is produced from the injection moulding of a blend of HDPE granules and additives in the form of pigment, anti-oxidants and slip agents. In modelling the cap, the additives have not been included. The seal is produced from polyolefin foam with thin aluminium and PET film layers applied.

The label is produced from the extrusion of a blend of LDPE granules and additive (slip agent). In modelling the label, the additive has not been included.

The data for the conversion of raw materials into bottles were provided by RPC Containers for its Llantrisant plant. Data for the production of the cap and seal were provided by Portola Packaging for its Doncaster plant, and data for the production of the label were provided by CCL Label for its plant in Völkermarkt in Austria. The data provided are confidential.

4.2.4 Secondary and transit packaging for delivery to diary

The blown PET bottles are bagged in LDPE bags and packed on pallets using ‘corner boards’ (‘vee-board') and cardboard sheet to provide stability. The corner board is reused on average five times. After use, the board and the film are recycled. Due to a lack of information on the weight of these items, estimates have been used.

According to the cap producer for the HDPE bottles, the caps are transported to the dairy in corrugated boxes with a plastic liner.

No information was given on the packaging used for transporting the label to the dairy. Instead, data provided by the dairy for HDPE bottles has been used.

Data for the secondary packaging for the bottles were provided by RPC Containers, for the caps by Portola Packaging, and for the labels by Dairy Crest. The data provided are confidential.

4.2.5 Transport to the diary

No specific data were available for the transport of the bottles to the dairy. Therefore, an average distance of 200 km by a medium sized lorry (16 to 32 tonnes) was assumed.

Portola Packaging has reported that 50% of the seals and caps are transported by road and 50% by sea.

For the label, the distance between the plant and a plant in the UK has been applied.

4.2.6 Filling

At the dairy, the bottles are loaded onto the filling line, filled and seals, caps and labels are applied.

No data were available on the filling for PET bottles. Instead, data from filling of HDPE bottles were used.

4.2.7 Secondary and transit packaging for delivery to retail

Milk in PET bottles is supplied to retail in milk roll containers. An average roll container holds 160 one litre PET bottles. Often PET bottles are shrink wrapped in quantities of 6, 9 or 12 bottles (R. Pryor 2007). No information about the shrink wrap has been obtained. Therefore, 3 g of film is assumed per bottle.

4.2.8 Distribution

As discussed in the scope definition, based on discussions with the dairies, an average distance of 370 km between the dairy and the retailer has been applied for all packaging systems. Refrigeration during the transport was estimated by one of the data providers to add another 15% to fuel consumption. Each refrigerated lorry holds 100 filled milk roll containers.

4.2.9 Retail

When arriving at the supermarket, the filled milk roll containers are stored at 5°C in chilled store rooms. The length of storage varies, depending on shopping habits (e.g. day of the week, seasonal festivities, etc). When the stock in the shop is close to being replenished, the roll containers are taken onto the shop floor and swapped for an empty roll container in the chiller cabinets. In the UK, chiller cabinets are generally open fronted and kept at 3°C. For the purposes of this study, it was assumed that the milk containers are stored in the chilled store room for 18 hours and in the in-shop chiller cabinets for six hours.

No data were obtained for the refrigeration of the milk in the supermarket. Instead, literature data were used as described in the scope section.

4.2.10 End-of-life

As explained in the goal and scope, due to a lack of information for all the packaging systems studied, each waste management method is considered separately.

Data for the bottle-to-bottle recycling was provided by Nextek. It involves the 'URRC' process, which includes a superclean process enabling food grade recyclates to be produced. The data were provided prior to the opening of the Dagenham recycling plant, but represents the plant based on the specifications of the plant and experience from already built facilities in Switzerland and especially the plant in Rostock, Germany. The data provided is confidential.

Data for landfill, incineration and general recycling are based on WRATE data.

According to WRAP's 2008 Annual Bottle Survey (WRAP 2008), approximately 35% of the plastic bottles in the UK household waste stream were recycled in 2007 (WRAP 2008). The majority of these bottles were either PET or HDPE bottles, which the ratio between the two bottle types being estimated at 52% PET and 48% HDPE.

Of the plastic bottles collected for recycling, approximately 30% are recycled in the UK into lower grade products such as polyester fibres, sheeting, strapping etc (Paul Davidson 2008). However, interest is growing for higher grade recyclates, including bottle-to-bottle recycling. The remaining 70% are sold to export markets, generally China. It is not known what products these waste bottles are recycled into. The global demand is expected to continue to increase.

4.2.11 Inventory summary for the PET packaging systems studied

A summary of selected inventory data for the PET bottle system is shown in *Table 4.4* below. The data represents the life cycle inventory results from cradle to retail. Waste collection and waste management has not been included, as the WRATE software tool does not allow results to be generated in this aggregated format.

Table 4.4 Summary life cycle inventory results for the PET bottle system from cradle to retail* (per functional unit)

Inventory	Unit	PET bottle, 1 litre, 100% vPET	PET bottle, 1 litre, 30 % rPET	PET bottle, 1 litre, 30 % rPET (closed-loop)	PET bottle, 1 litre, 30% rPET & 10 % lightweight	PET bottle, 1 litre, 30% rPET & 10% lightweight (closed-loop)
Raw material use: coal	kg coal	8.53	8.54	7.04	8.04	6.69
Raw material use: oil	kg oil	24.9	24.9	19.6	23.0	18.2
Raw material use: natural gas	m^3 gas	22.6	22.6	17.4	20.9	16.2
Carbon dioxide (fossil)	kg CO_2	82.2	82.4	66.1	76.4	61.8
Methane	kg CH_4	0.392	0.392	0.307	0.363	0.287
Water	m^3	178	179	144	167	136
Energy use, non-renewable	MJ eq	2465	2468	1936	2282	1804
Energy use, renewable	MJ eq	60.8	60.9	53.7	58.5	52.0

* Please note, waste collection and waste management has not been included, as the WRATE software tool does not allow results to be generated in this aggregated format.

4.3 Pillow pouches

4.3.1 *The pillow pouch systems studied*

The pillow pouch assessed in this study is designed for the distribution of pasteurised milk (chilled) and is produced from LDPE, LLDPE and titanium dioxide.

Milk in pillow pouches has not been available on the UK market for a number of years. At present, pillow pouches are used by the organic dairy Calon Wen and are currently being trialled in selected Waitrose, Tesco and Sainsbury stores. Overall, this system has a very small market share. The composition of the pillow pouch assessed in this study is considered by the steering committee to be representative of the pillow pouch currently being trialled in the UK.

Table 4.5 below shows the material composition of the pillow pouch systems studied in this report. At present, the pillow pouch is only available produced from 100% virgin materials. Due to UK food contact regulations, the manufacturer has stated that they are not likely to introduce recycled content until specific targets are set. Therefore only two scenarios are considered for the flexible pouch systems in this report: a pouch produced from virgin material; and a hypothetical 10% lightweighted pouch.

Table 4.5 Material composition of the pillow pouch systems studied (per functional unit)

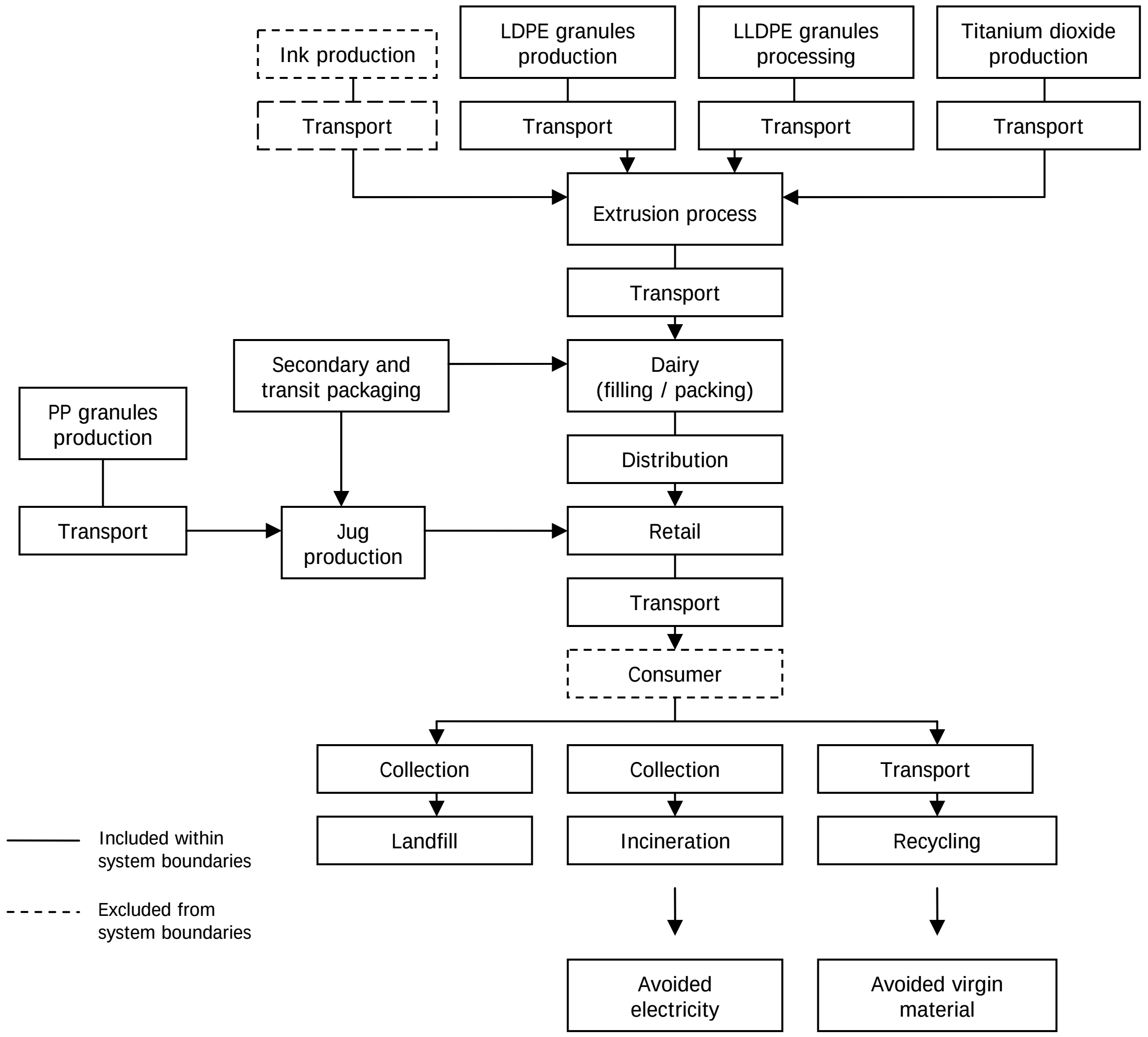
Material	**Unit**	**Pillow pouch, 2 pints, 100% vHDPE**	**Pillow pouch, 2 pints, 100% vHDPE & 10% lightweight**
Primary packaging			
Pouch			
LDPE	g	830.0	747.0
LLDPE	g	1,775.0	1597.5
Titanium dioxide	g	75.0	67.5
Jug			
PP[1]	g	194.4	194.4
Packaging for delivery to dairy			
Core board[2]	g	60.0	60.0
LDPE[3]	g	12.2	12.2
Corrugated board[3]	g	48.8	48.8
Packaging for delivery to retail			
For filled pouch			
Corrugated board[4]	g	12,500	12,500
For jug			
Corrugated board[5]	g	14.3	14.3
Total, retail	**g**	**15,510**	**15,242**

Notes:

1. In UK supermarkets, purpose-built jugs are provided next to the filled pillow pouches in the milk chiller cabinet. Each jug weighs 154 g. The jug is assumed to be reused 396 times.
2. The pouches are wrapped on reels of 8,200 pouches per reel. The reel is estimated to weigh 1 kg.
3. The reels are assumed wrapped with a plastic film and then packaged in corrugated boxes. The plastic film is assumed to weigh 200 g per 8,200 pouches and the box 800 g per 8,200 pouches.
4. For one supermarket in the UK, the filled pouches are packed 8 in a box of 200 g.
5. It is assumed that the jugs are delivered in corrugated boxes weighing 200 g and holding 20 jugs.

The system boundaries for the flexible pouch system are illustrated in *Figure 4.3* below.

Figure 4.3 System boundaries for the flexible pouch system



4.3.2 Raw materials

Data describing the extraction and processing of crude oil and natural gas to produce LDPE and LLDPE were sourced from PlasticsEurope (as contained within the Ecoinvent database). Data for the production of titanium dioxide are from a confidential source contained within the Ecoinvent database. Hood Packaging has provided transport distances from their suppliers to the pouch film converting plant.

4.3.3 Converting

The example pillow pouch studied in this project is produced from a three-layer film. During the conversion process, virgin LDPE and LLDPE granules, titanium dioxide and additives such as slip agents are blended and extruded to film. In modelling the film, the additives have not been included. The film is then folded and heat sealed to form a long tube.

The jug, which is used for providing stability when pouring the milk, is produced from injection moulded PP. No data were available on the production of the jug. Instead, generic data for injection moulding was used (as contained within the Ecoinvent database).

No data were available on the average use and life span of the jug. Therefore, for the purposes of this study, the jug was assumed to be used for two years by an average household size and then replaced. The average consumption of liquid milk by a UK consumer was 1.627 litres per week in 2005/06 (Defra 2008a), and the average UK household size in 2006 was 2.34 persons (ONS 2006), resulting in the average UK household consuming 396 litres of milk in a two year period. This means that, in order to fulfil the functional unit of 1,000 pints of milk, 1.43 jugs are required. The jug is assumed to be disposed as general household waste.

The data for the production of the flexible pouch were provided by Hood Packaging. The data provided are confidential. At present, the pouch material is produced in Canada. However, production is envisaged to move to Europe in the future. As this may be some time ahead, production in Canada was modelled for the purposes of this study.

4.3.4 Secondary and transit packaging for delivery to dairy

The pouch film is wrapped onto a core reel, with each reel holding 8200 pouches. No weight for the core reel was been provided. Therefore, the weight reported for the stand-up pouch was used.

Additional packaging used is not known. Therefore, packaging as reported for the stand-up pouch was used.

4.3.5 Transport to the dairy

Transport of the pouch film from the Canadian film converter to a UK dairy is applied.

4.3.6 Filling and packing

At the dairy, the film reel is transferred to a vertical form, fill and seal machine. Continuous milk flow technology is used to minimize surface contact with the milk. After filling, the pouch is closed through heat sealing.

Data were estimated based on measurements during the filling process and were provided by Hood Packaging. The data provided are confidential.

4.3.7 Secondary and transit packaging to retail

For this study, the secondary and transit packaging is estimated based on that used for milk supplied in pillow pouches to Waitrose. The current system is cardboard boxes of eight pouches to a box. The cardboard boxes weigh approximately 200 g. The boxes are assumed to be recycled after use.

Similarly, the jugs are also provided to Waitrose in cardboard boxes. It was not possible to obtain information about the boxes used for the jugs. For this study, it was assumed that the corrugated box weighs 200 g and holds a total of 20 jugs. The boxes are assumed to be recycled after use.

4.3.8 Distribution

As discussed in the scope definition, based on discussions with the dairies, an average distance of 370 km between the dairy and the retailer has been applied for all milk container systems. A similar distance is assumed for the jug.

4.3.9 Retail

When arriving at the supermarket, the filled pillow pouches are generally stored at 5°C in chilled store rooms. The length of storage varies depending on consumer shopping habits (eg day of the week, seasonal festivities, etc). When additional stock is required in the shop, the pouches are taken onto the shop floor and put on the chiller cabinet shelves. In the UK, chiller cabinets are generally open fronted and kept at 3°C. For the purposes of this study, it was assumed that the milk containers are stored in the chilled store room for 18 hours and in the in-shop chiller cabinets for six hours.

No data were obtained for the refrigeration of the milk in the supermarket. Instead, literature data were used which is described in the scope section.

4.3.10 Use of jug

It is assumed that the use of the jug has no impacts, i.e. any impacts associated with washing the jug after every use, or after a number of uses, have not been included.

4.3.11 End-of-life

As explained in the goal and scope, due to a lack of information for all the packaging systems studied, each waste management method is considered separately.

Data for landfill, incineration and recycling are based on WRATE data.

4.3.12 Inventory summary for the flexible pouch systems studied

A summary of selected inventory data for the flexible pouch system is shown in *Table 4.6* below. The data represents the life cycle inventory results from cradle to retail. Waste collection and waste management has not been included, as the WRATE software tool does not allow results to be generated in this aggregated format.

Table 4.6 Summary life cycle inventory results for the flexible pouch system from cradle to retail* (per functional unit)

Inventory	Unit	Flexible pouch, 2 pints, 100% virgin	Flexible pouch, 2 pints, 100% virgin & 10 % lightweight
Raw material use: coal	kg coal	3.44	3.41
Raw material use: oil	kg oil	4.33	4.06
Raw material use: natural gas	m^3 gas	4.15	3.93
Carbon dioxide (fossil)	kg CO_2	22.8	22.3
Methane	kg CH_4	0.0857	0.0816
Water	m^3	148	147
Energy use, non-renewable	MJ eq	530	507
Energy use, renewable	MJ eq	430	430

* Please note, waste collection and waste management has not been included, as the WRATE software tool does not allow results to be generated in this aggregated format.

4.4 Stand-up pouches

4.4.1 The stand-up pouch systems studied

The stand-up pouch assessed in this study is designed for the distribution of pasteurised milk (chilled) and is produced from PP, LDPE, dolomite, and titanium dioxide.

Milk in stand-up pouches has a very small market share in the UK. It is available from the organic produce supplier, Daylesford Organic. The composition of the stand-up pouch assessed in this study is a slightly different version to that used by Daylesford Organic. It is therefore not representative of stand-up pouches for milk in the UK, but is used for milk in other countries.

Table 4.7 below shows the material composition of the stand-up pouch systems studied in this report. The stand-up pouch is produced from 100% virgin materials. Including recycled content would increase the thickness of the pouch due to performance requirements, and is therefore not considered feasible (Magnus Carlberg 2008). Therefore, only two scenarios are considered for the stand-up pouch systems in this report: a pouch produced from 100% virgin materials; and a 10% lightweighted pouch, as a hypothetical future system.

Table 4.7 Material composition of the stand-up pouch systems studied (per functional unit)

Material	Unit	Stand-up pouch, 1 ltr, 100% vHDPE	Stand-up pouch, 1 ltr, 100% vHDPE & 10% lightweight
Primary packaging			
Pouch			
LDPE	g	2,164.1	1,947.7
PP	g	3,305.8	2,975.2
Dolomite	g	3,271.7	2,944.5
Titanium dioxide	g	193.1	173.8
Packaging for delivery to dairy			
Core board[1]		65.3	65.3
LDPE[2]	g	17.7	17.7
Corrugated board[2]		40.0	40.0
Packaging for delivery to retail			
Corrugated board[3]	g	10,413.3	10,413.3
Total, retail	**g**	**19,471**	**18,578**

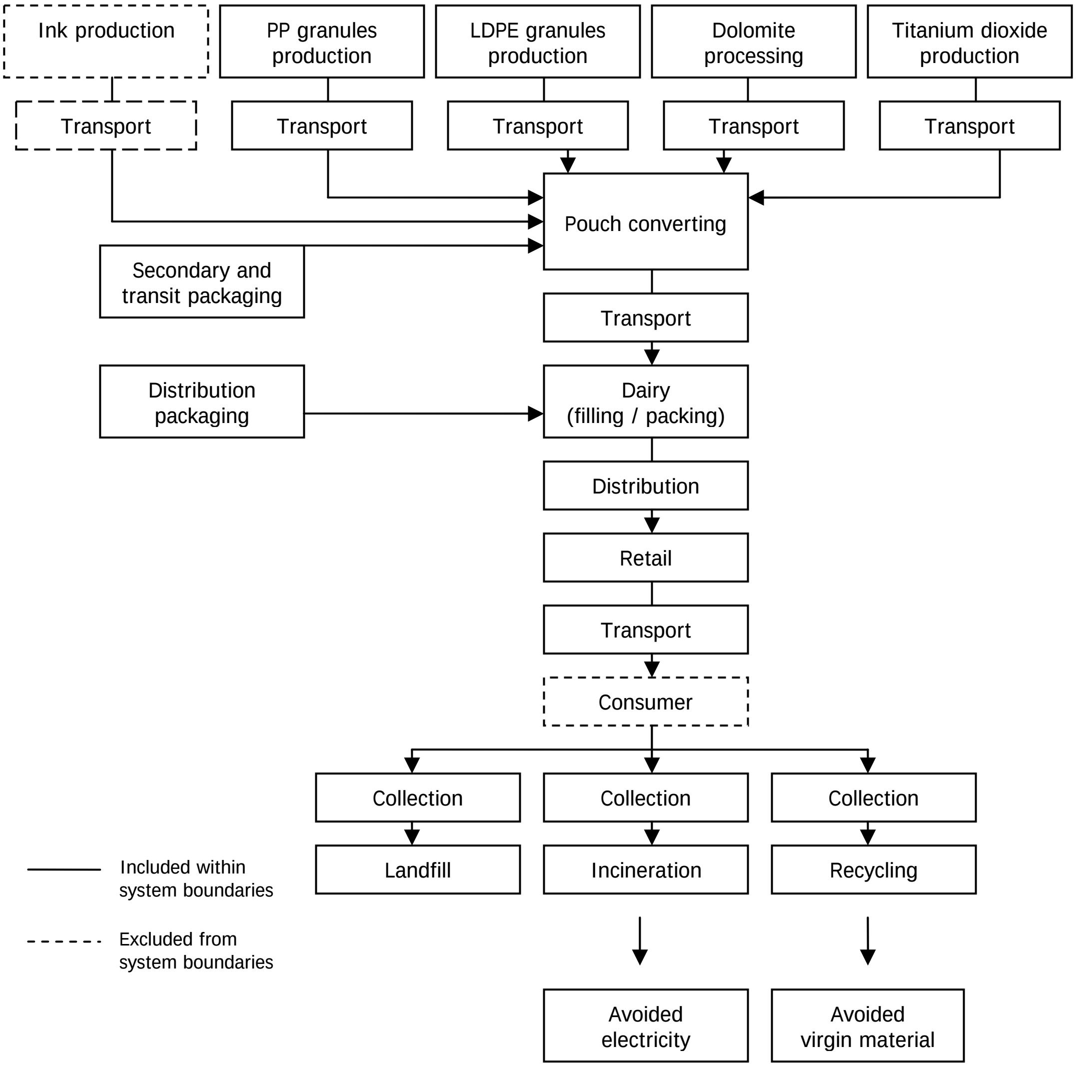
Notes:

1. The pouches are wrapped on reels of 4,500 pouches per reel. The reel weighs 520 g.

2. The reels are wrapped with a plastic film. The reels are then packed onto pallets with corrugated sheeting in between, and stretch wrapped. The plastic weighs 140 g and the corrugated board 270g.
3. The pouches are packed 12 to a box, which the box weighing 220 g.

The system boundaries for the stand-up pouch system are illustrated in *Figure 4.4* below.

Figure 4.4 System boundaries for the stand-up pouch system



4.4.2 Raw materials

Data describing the extraction and processing of crude oil and natural gas to produce LDPE and PP were sourced from PlasticsEurope (as contained within the Ecoinvent database). Data for the production of titanium dioxide are from a confidential source contained within the Ecoinvent database. Similarly, data for the extraction and processing of dolomite is from the Ecoinvent database.

Ecolean has provided average transport distances from their suppliers to the pouch converting plant.

4.4.3 Converting

The example stand-up pouch studied in this project is produced from a three-layer film. During the conversion process, virgin LDPE, PP, dolomite and titanium dioxide are blended with re-grind from internal processes. The blend is extruded to a three-layer film that is folded, heat sealed and cut into pouches.

Data for the conversion of the stand-up pouch were provided by Ecolean. The data provided are confidential.

4.4.4 Secondary and transit packaging for delivery to dairy

The pouches are wrapped onto a core reel, with each reel holding 4500 pouches. Five reels are packed on a pallet with corrugated sheets in between, and a protective plastic film sleeve is applied over the pallet.

Data for the secondary and transit packaging were provided by Ecolean. The data provided are confidential.

4.4.5 Transport to dairy

Transport distances from the pouch converting plant in Sweden to the UK were provided by the pouch manufacturer.

4.4.6 Filling

Data for the filling of the pouches are estimated based on the information in the operator manual for the filling machine.

The data for the filling of the pouches is based on filling machine specifications and were provided by Daylesford Organics. The data provided are confidential.

4.4.7 Secondary and transit packaging

Milk in stand-up pouches is supplied to retail in cardboard boxes of 12 pouches to a box (Richard Taplin 2008). The cardboard boxes are assumed to weigh 220 g, based on data supplied by Ecolean for Danish distribution. The boxes are assumed recycled after use.

4.4.8 Distribution

As discussed in the scope definition, based on discussions with the dairies, an average distance of 370 km between the dairy and the retailer has been applied for all milk container systems. Refrigeration during the transport was estimated to add another 15% to fuel consumption.

4.4.9 Retail

When arriving at the supermarket, the filled stand-up pouches are generally stored at 5°C in chilled store rooms. The length of storage varies depending on consumer shopping habits (e.g. day of the week, seasonal festivities, etc). When additional stock is required in the shop, the pouches are taken onto the shop floor and put on the shelves of the chiller cabinet. In the UK, chiller cabinets are generally open fronted and kept at 3°C. For the purposes of this study, it was assumed that the milk containers are stored in the chilled store room for 18 hours and in the in-shop chiller cabinets for six hours.

No data were obtained for the refrigeration of the milk in the supermarket. Instead, literature data were used, which are described in the scope section.

4.4.10 End-of-life

As explained in the goal and scope, due to a lack of information for all the packaging systems studied, each waste management method is considered separately. Data for landfill, incineration and recycling are based on WRATE data.

According to the producer' website the stand-up pouch can be recycled as mixed plastic and is compatible with HDPE in concentrations of up to 20%. Mixed plastics are generally recycled into lower grade products such as pallets, trays, artificial wood, etc.

4.4.11 Inventory summary for the stand-up pouch systems studied

A summary of selected inventory data for the stand-up pouch system is shown in *Table 4.8* below. The data represent the life cycle inventory results from cradle to retail. Waste collection and waste management were not included, as the WRATE software tool does not allow results to be generated in this aggregated format.

Table 4.8 Summary life cycle inventory results for the stand-up pouch system from cradle to retail* (per functional unit)

Inventory	Unit	Stand-up pouch, 1 ltr, 100% virgin	Stand-up pouch, 1 ltr, 100% virgin & 10 % lightweight
Raw material use: coal	kg coal	4.77	4.70
Raw material use: oil	kg oil	7.39	6.67

Inventory	Unit	Stand-up pouch, 1 ltr, 100% virgin	Stand-up pouch, 1 ltr, 100% virgin & 10 % lightweight
Raw material use: natural gas	m^3 gas	6.11	5.72
Carbon dioxide (fossil)	kg CO_2	31.3	29.7
Methane	kg CH_4	0.128	0.119
Water	m^3	76.2	75.8
Energy use, non-renewable	MJ eq	795	743
Energy use, renewable	MJ eq	360	360

* Please note, waste collection and waste management has not been included, as the WRATE software tool does not allow results to be generated in this aggregated format.

4.5 Carton with screwcap

4.5.1 The carton with screwcap systems studied

Two carton systems were considered in this study, one being a carton with a screwcap. The carton is produced by Tetra Pak, who is the supplier to the three main dairies in the UK.

The carton is designed to distribute pasteurised milk (chilled) and is constructed from liquid paper board and LDPE, with a LDPE neck and a HDPE cap. The carton itself consists of paper board to ensure structural integrity with an outer LDPE layer to protect against moisture and bacteria and an inner adhesion layer of LDPE and another LDPE layer to seal in the milk.

The carton is produced from 100% virgin materials. Including recycled content would increase the thickness of the carton due to its performance requirements and is therefore not considered feasible (Ian Williamson 2008). Therefore, only two scenarios were considered for the carton with screwcap systems in this report: a carton produced from 100% virgin materials; and a hypothetical 10% lightweighted carton.

Table 4.9 below shows the shows the material composition of the carton with screwcap systems studied in this report.

Table 4.9 Material composition of the carton with screwcap systems studied (per functional unit)

Material	Unit	Carton with screwcap, 1 ltr, 100% virgin	Carton with screwcap, 1 ltr, 100% virgin & 10% lightweight
Primary packaging			
Carton			
Liquid paper board	g	12,098.4	10,888.6
LDPE	g	2,175.4	1,957.9
Closure			
LDPE	g	2,840.0	2,840.0
HDPE	g	1,192.8	1,192.8
Packaging for delivery to dairy			
For carton laminate			
Core board[1]	g	368.6	368.6
LDPE[1]	g	22.1	22.1
For closure			
LDPE[2]	g	2.8	2.8
Corrugated board[2]	g	151.5	151.5
Packaging for delivery to retail			
Shrink wrap			
LDPE[3]	g	1,704.0	1,704.0
Roll cage container			
Mild steel[4]	g	265.5	265.5
rHDPE[4]	g	4.3	4.3
Total, retail	**g**	**20,825**	**19,398**

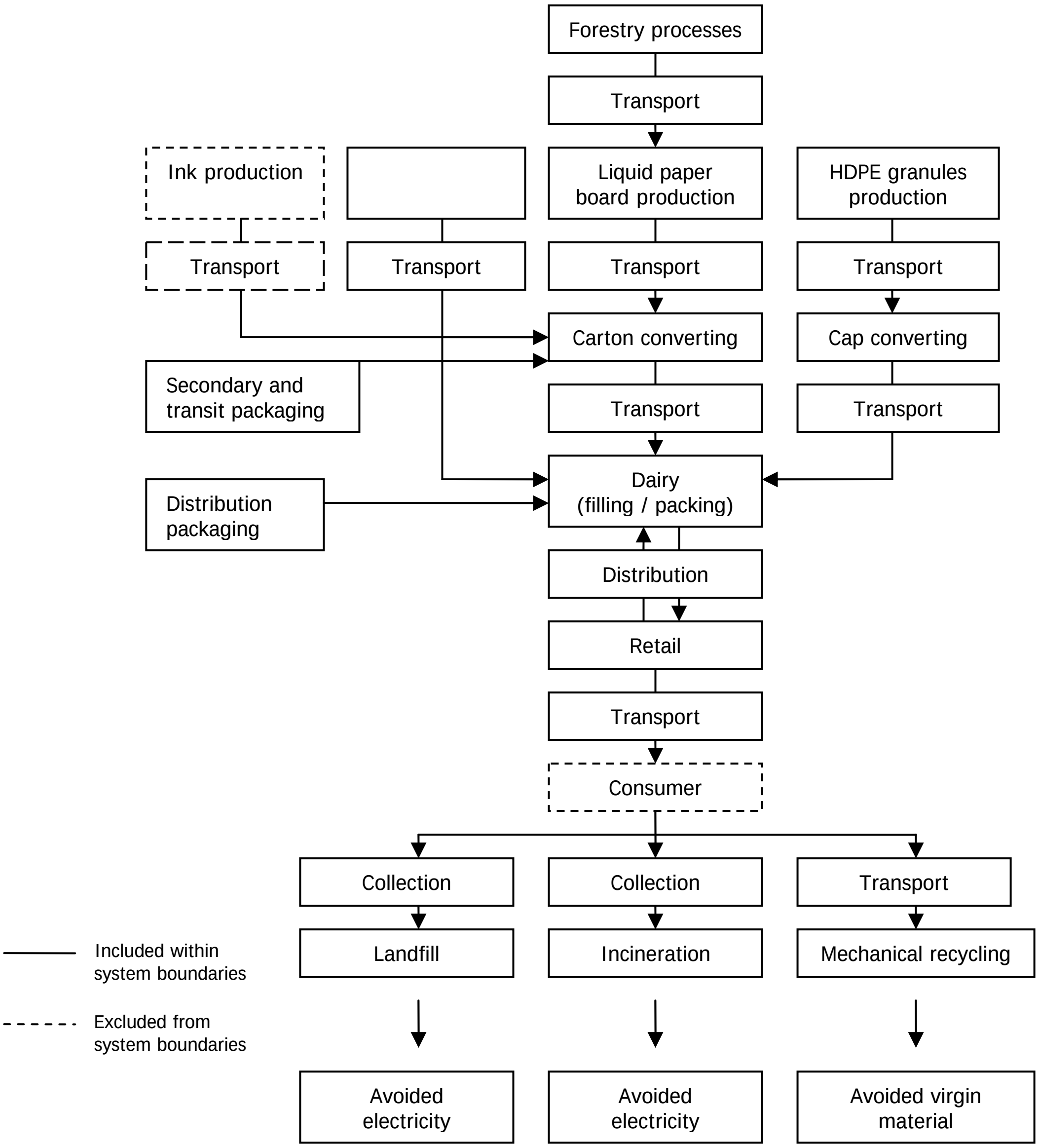
Notes:

1. The carton laminate is wrapped on reels of 1,000 m^2 laminate per reel. Each reel weighs 10 kg. The reels are then wrapped in plastic film. On average 600 g of film is used per reel.

2. The caps are assumed to be packaged in a plastic bag inside a corrugated box with each box holding 3,000 caps. Each bag is assumed to weigh 15 g and the box 800 g.
3. The cartons are assumed shrink wrapped before loading onto the roll cage container. The plastic is assumed to weigh 3 g per carton.
4. The roll cage container weighs 38 kg, of which 37.4 kg is steel and 600 g is polyethylene wheels. Each roll cage container holds 160 cartons. The roll cage container is reused a number of times, the dairies estimate they on average are reused 500 times (including repairs) before being disposed of.

The system boundaries for the carton with screwcap system are illustrated in *Figure 4.5* below.

Figure 4.5 System boundaries for the carton with screwcap system



4.5.2 Raw materials

Data describing the growing of trees, felling and pulping to produce liquid paper board is sourced from the Ecoinvent database. This literature data was used on the advice of Tetra Pak.

Data describing the extraction and processing of crude oil and natural gas to produce LDPE were sourced from PlasticsEurope (as contained within the Ecoinvent dataset). Transport distances from the pulp mill to the converter have been determined based on information provided by Tetra Pak.

4.5.3 Converting

The laminate for the example carton is produced in Sweden, after which it is transported to the dairy in the UK. During the conversion process, virgin LDPE is extruded onto a large area of liquid paper board.

The cap is produced from injection moulding of a blend of HDPE and additives in the form of pigment, slip agents etc. In modelling the cap, the additives have not been included. It has not been possible to obtain information about the production of the cap from the cap producer. Instead, generic injection moulding data have been used (as contained in the Ecoinvent dataset).

The data for the conversion of raw materials into cartons and the filling data were provided by Tetra Pak.

4.5.4 Secondary and transit packaging for delivery to dairy

The laminate is wrapped onto core reel, and shrink film is applied for protection. No weights for the core reel or shrink film were provided by the producer. Industry average data were applied. The data are confidential.

For the caps, similar secondary and transit packaging as used for the caps for the HDPE bottles was assumed.

4.5.5 Transport to dairy

Transport distances from the converting plant in Sweden to the UK were calculated based on information provided by Tetra Pak.

4.5.6 Filling

At the dairy, the cartons are reel fed to the filling machine where they are cut into size, formed into a tube and the bottom is sealed prior to filling. The neck, or otherwise called lid, is moulded and applied in the filling machine.

The data for the filling and packing of the cartons is based on filling machine specifications and were provided by Tetra Pak UK. The data provided are confidential.

4.5.7 Secondary and transit packaging for delivery to retail

The filled cartons are then shrink wrapped into quantities of six, nine or 12 and packed onto milk roll containers. An average roll container holds 160 one litre cartons.

4.5.8 Distribution

As discussed in the scope definition, an average distance of 370 km between the dairy and the retailer has been applied for all packaging systems. Refrigeration during transport was estimated to add another 15% to the fuel consumption.

4.5.9 Retail

When arriving at the supermarket, the milk roll containers are generally stored at 5°C in store rooms. The length of storage varies depending on shopping habits (eg day of the week, seasonal festivities, etc). When stock in the shop is close to being replenished, the cartons are taken onto the shop floor and put on chiller cabinet shelves. In the UK, chiller cabinets are generally open fronted and kept at 3°C. For the purposes of this study, it was assumed that the milk containers are stored in the chilled store room for 18 hours and in the in-shop chiller cabinets for six hours.

No data were obtained for the refrigeration of the milk in the supermarket. Instead, literature data were used which is described in the scope section.

4.5.10 End-of-life

As explained in the goal and scope, due to a lack of information for all the packaging systems studied, each waste management method was considered separately.

At present, any cartons sent for recycling within the UK are transported to Sweden for recycling into the paper component of plasterboard. In Sweden, the cartons are repulped and the plastic film is separated using flotation techniques. The plastic is incinerated and the energy recovered. The fibres are recycled into the paperboard component of plasterboard as mentioned above. According to Tetra Pak, the requirements to the fibre quality for use in this type of plasterboard are quite high, and generally virgin fibres are used. However, fibres from cartons do qualify as virgin fibre as they are still relatively long.

By recycling the fibres and using them for the production of the paperboard component of plasterboard, the production of virgin fibres for the paperboard is avoided. It is assumed that the avoided virgin fibres are in the form of sulphate pulp, and that one tonne of secondary fibres replaces 900 kg of sulphate pulp.

Data for the recycling process has been provided by Tetra Pak. The data are confidential.

Data for landfill and incineration are based on WRATE data.

Used beverage cartons are disposed off in the UK through the Municipal Solid Waste (MSW) stream or recovered through recycling schemes set up between Tetra Pak UK Ltd and individual local authorities. The carton recycling schemes in the UK are relatively new and, at present, consumer participation is low. However, the number of local authorities joining has increased significantly in the last year. At present, any cartons sent for recycling within the UK are transported to Sweden for recycling into the paperboard component of plasterboard. However, alternative options are being considered, including recycling in Norway into paper. Efforts are also being put into establishing recycling facilities in the UK.

Cartons currently being recycled in the UK are mainly collected through bring schemes (with a small proportion collection via kerbside collection). Before being sent to Sweden for recycling, the cartons undergo sorting in the UK. The separated beverage cartons are then compacted and baled and shipped to the paper mill in Sweden.

4.5.11 Inventory summary for the carton with screwcap packaging systems studied

A summary of selected inventory data for the carton with screwcap system is shown in *Table 4.10* below. The data represents the life cycle inventory results from cradle to retail. Waste collection and waste management has not been included, as the WRATE software tool does not allow results to be generated in this aggregated format.

Table 4.10 Summary life cycle inventory results for the carton with screwcap system from cradle to retail* (per functional unit)

Inventory	Unit	Carton with screwcap, 1 litre, 100% virgin	Carton with screwcap, 1 litre, 100% virgin & 10 % lightweight
Raw material use: coal	kg coal	4.85	4.77
Raw material use: oil	kg oil	8.9	9.9
Raw material use: natural gas	m^3 gas	8.65	8.65
Carbon dioxide (fossil)	kg CO_2	32.9	35.8
Methane	kg CH_4	0.170	0.173
Water	m^3	200	190
Energy use, non-renewable	MJ eq	1015	1054
Energy use, renewable	MJ eq	431	391

* Please note, waste collection and waste management has not been included, as the WRATE software tool does not allow results to be generated in this aggregated format.

4.6 Gable top carton with closure

4.6.1 The gable-top carton systems studied

Two carton systems were considered in this study, one being a gable-top carton with closure.

The carton is designed to distribute pasteurised milk (chilled) and is constructed from liquid paper board and LDPE, with a LDPE neck and a HDPE cap. The carton itself consists of the paper board to ensure structural integrity with an outer LDPE layer to protect against moisture and bacteria and an inner adhesion layer of LDPE and another LDPE layer to seal in the milk.

The carton is produced from 100% virgin materials. Including recycled content would increase the thickness of the carton due to its performance requirements and is therefore not considered feasible (Ian Williamson 2008). Therefore, two scenarios are considered for the gable-top carton systems in this report: a carton produced from

100% virgin materials; and a 10% lightweighted pouch, as a hypothetical future system. *Table 4.11* below shows the shows the material composition of the gable-top carton systems studied in this report.

Table 4.11 Material composition of the gable-top carton systems studied (per functional unit)

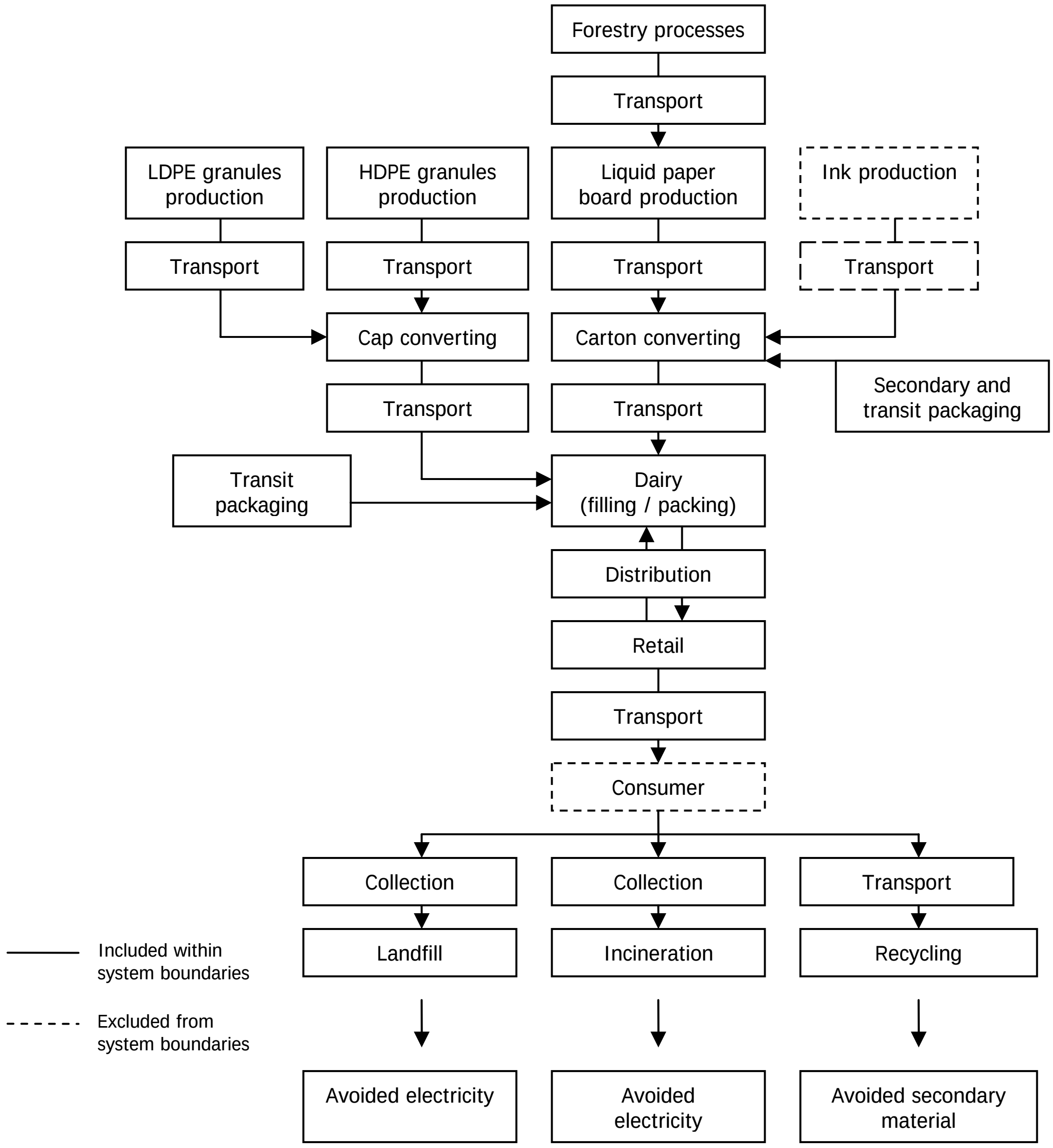
Material	**Unit**	**Gable-top carton with reclosure, 1 ltr, 100% virgin**	**Gable-top carton with reclosure, 1 ltr, 100% virgin & 10% lightweight**
Primary packaging			
Carton			
Liquid paper board	g	13,501.4	12,151.2
LDPE	g	2,027.8	1,825.0
Closure			
LDPE	g	1,073.5	1,073.5
HDPE	g	738.4	738.4
Packaging for delivery to dairy			
For carton laminate			
Core board[1]	g	494.5	494.5
LDPE[1]	g	29.7	29.7
For closure			
LDPE[2]	g	2.8	2.8
Corrugated board[2]	g	151.5	151.5
Packaging for delivery to retail			
Shrink film			
LDPE[3]	g	1,704.0	1,704.0
Roll cage container			
Mild steel[4]	g	265.5	265.5
rHDPE[4]	g	4.3	4.3
Total, retail	**g**	**19,993**	**18,440**

Notes:

1. The carton laminate is wrapped on reels of 1,000 m^2 laminate per reel. Each reel weighs 10 kg. The reels are then wrapped in plastic film. On average 600 g of film is used per reel.
2. The caps are assumed to be packaged in a plastic bag inside a corrugated box with each box holding 3,000 caps. Each bag is assumed to weigh 15 g and the box 800 g.
3. The cartons are assumed shrink wrapped before loading onto the roll cage container. The plastic is assumed to weigh 3 g per carton.
4. The roll cage container weighs 38 kg, of which 37.4 kg is steel and 600 g is polyethylene wheels. Each roll cage container holds 160 cartons. The roll cage container is reused a number of times, the dairies estimate they on average are reused 500 times (including repairs) before being disposed of.

The system boundaries for the gable-top carton system are illustrated in *Figure 4.6* below.

Figure 4.6 System boundaries for the gable-top carton with closure system



4.6.2 Raw materials

Data describing the growing of trees, felling and pulping to produce liquid paper board is sourced from the Ecoinvent database. This literature data was used on the advice of Tetra Pak.

Data describing the extraction and processing of crude oil and natural gas to produce LDPE were sourced from PlasticsEurope (as contained within the Ecoinvent dataset). Transport distances from the pulp mill to the converter have been determined based on information provided by Tetra Pak.

4.6.3 Converting

Carton blanks for the example carton is produced in Sweden, after which they are transported to the dairy in the UK. During the conversion process, virgin LDPE is extruded onto a large area of liquid paper board and the laminate is cut to shape and heat sealed along the long side.

The cap is produced from injection moulding of a blend of HDPE and additives in the form of pigment, slip agents etc. In modelling the cap, the additives have not been included. It has not been possible to obtain information about the production of the cap from the cap producer. Instead, generic injection moulding data have been used (as contained in the Ecoinvent dataset).

The data for the conversion of raw materials into cartons and the filling data were provided by Tetra Pak.

4.6.4 Secondary and transit packaging for delivery to dairy

Packaging paper is wrapped around the carton blanks, and the cartons are stacked on pallets and the pallets are shrink-wrapped. After use, the paper and film are recycled. No weights have been obtained concerning the packaging from the producer. Instead, industry average data for reel fed cartons were applied. The data are confidential.

For the caps, similar secondary and transit packaging as used for the caps for the HDPE bottles was assumed.

4.6.5 Transport to dairy

Transport distances from the converting plant in Sweden to the UK were calculated based on information provided by Tetra Pak.

4.6.6 Filling

At the dairy, the carton blanks are opened up and the cap and neck are applied. The top is then sealed prior to filling and bottom after filling.

The data for the filling and packing of the cartons is based on filling machine specifications and were provided by Tetra Pak UK. The data provided are confidential.

4.6.7 Secondary and transit packaging for delivery to retail

The filled cartons are then shrink wrapped into quantities of six, nine or 12 and packed onto milk roll containers. An average roll container holds 160 one litre cartons.

4.6.8 Distribution

As discussed in the scope definition, an average distance of 370 km between the dairy and the retailer has been applied for all packaging systems. Refrigeration during transport was estimated to add another 15% to fuel consumption.

4.6.9 Retail

When arriving at the supermarket, the milk roll containers are generally stored at 5°C in store rooms. The length of storage varies depending on shopping habits (e.g. day of the week, seasonal festivities, etc). When stock in the shop is close to being replenished, the cartons are taken onto the shop floor and put on chiller cabinet shelves. In the UK, chiller cabinets are generally open fronted and kept at 3°C. For the purposes of this study, it was assumed that the milk containers are stored in the chilled store room for 18 hours and in the in-shop chiller cabinets for six hours.

No data were obtained for the refrigeration of the milk in the supermarket. Instead, literature data were used which is described in the scope section.

4.6.10 End-of-life

As explained in the goal and scope, due to a lack of information for all the packaging systems studied, each waste management method was considered separately.

At present, any cartons sent for recycling within the UK is transported to Sweden for recycling into the paperboard component of plasterboard. In Sweden, the cartons are repulped and the plastic film is separated using flotation techniques. The plastic is incinerated and the energy recovered. The fibres are recycled into the paperboard component of plasterboard as mentioned above. According to Tetra Pak, the requirements to the fibre quality for use in this type of plasterboard are quite high and generally virgin fibres are used. However, fibres from cartons do qualify as virgin fibres, and are therefore still relatively long.

By recycling the fibres and using them for the production of the paperboard component of plasterboard, the production of virgin fibres for the paperboard is avoided. It is assumed that the avoided virgin fibres are in the form of sulphate pulp, and that one tonne of secondary fibres replaces 900 kg of sulphate pulp.

Data for the recycling process has been provided by Tetra Pak. The data are confidential.

Data for landfill and incineration are based on WRATE data.

Used beverage cartons are disposed in the UK through the municipal solid waste (MSW) stream or recovered through recycling schemes set up between Tetra Pak UK Ltd and individual local authorities. The carton recycling schemes in the UK are relatively new and, at present, consumer participation is low. However, the number of local authorities joining has increased significantly in the last year. At present, any cartons sent for recycling within the UK are transported to Sweden for recycling into the paperboard component of plasterboard. However, alternative options are being considered, including recycling in Norway into paper. Efforts are also being put into establishing recycling facilities in the UK.

Cartons currently being recycled in the UK are mainly collected through bring schemes (with a small proportion collection via kerbside collection). Before being sent to Sweden for recycling, the cartons undergo sorting in the UK. The separated beverage cartons are then compacted and baled and shipped to the paper mill in Sweden.

4.6.11 Inventory summary for the gable-top carton packaging systems studied

A summary of selected inventory data for the gable-top carton system is shown in *Table 4.12* below. The data represent the life cycle inventory results from cradle to retail. Waste collection and waste management was not included, as the WRATE software tool does not allow results to be generated in this aggregated format.

Table 4.12 Summary life cycle inventory results for the gable-top carton system from cradle to retail* (per functional unit)

Inventory	Unit	Gable-top carton with reclosure, 1 litre, 100% virgin	Gable-top carton with reclosure, 1 litre, 100% virgin & 10 % lightweight
Raw material use: coal	kg coal	3.90	3.80
Raw material use: oil	kg oil	7.07	8.01
Raw material use: natural gas	m^3 gas	6.38	6.38
Carbon dioxide (fossil)	kg CO_2	27.3	29.9
Methane	kg CH_4	0.128	0.130
Water	m^3	282	271
Energy use, non-renewable	MJ eq	815	851
Energy use, renewable	MJ eq	483	439

* Please note, waste collection and waste management has not been included, as the WRATE software tool does not allow results to be generated in this aggregated format.

4.7 Generic data

Generic data have been used for common processes, materials, transport steps and electricity generation in the assessment. The key life cycle inventory (LCI) databases used to describe these processes were as follows.

- Ecoinvent (version 2.0) - Ecoinvent is a peer-reviewed database, containing life cycle inventory data for over 3 500 processes in the energy, transport, building materials, chemicals, paper/board, agriculture and waste management sectors. It aims to provide a set of unified and generic LCI data of high quality. The data are mainly investigated for Swiss and Western European conditions; and

- WRATE (version 1.0.1) – WRATE (Waste and Resources Assessment Tool for the Environment) is a peer-reviewed database, containing life cycle inventory data for waste management processes for municipal solid waste including waste collection, transport, treatment and disposal activities, taking account of the associated infrastructure, together with the avoided burdens associated with materials recycling and energy recovery. The data cover UK conditions.

The generic data from the Ecoinvent dataset relate predominantly to Western European process technologies and, as such, will confer some differences from equivalent UK systems. Assuming that technologies do not differ considerably, the most significant difference is likely to be with respect to electricity mix. It was not possible within the scope of this project to manipulate all the datasets used to represent the UK electricity mix. However, care was taken that direct inputs of electricity, for example to container conversion, cap and label production, refrigeration, and end-of-life processes reflect appropriate geographies.

Details of secondary datasets used in the assessment are summarised in *Table 4.13* and *Table 4.14* below.

Table 4.13 Datasets used to model fuel / energy production processes

Fuel / energy source	Geography	Year	Technology	Reference
Grid electricity, UK	UK	2000	Average technology	Ecoinvent data used of energy production (Ecoinvent Report No. 6). Electricity mix for 2006 taken from the Environment Agency WRATE tool, and originally sourced from Dti (BERR) statistics.
Grid electricity, Sweden	Sweden		Average technology	Ecoinvent Report No. 6
Grid electricity, Canada	Canada		Average technology	Ecoinvent data used of energy production (Ecoinvent Report No. 6). Electricity mix for 2005 taken from the website of the International Energy Agency.
Grid electricity, China	China	2005	Average technology	Ecoinvent Report No. 6
Natural gas, high pressure, at consumer	Sweden	2000	Average technology	Ecoinvent Report No. 6
Propane / butane production				Ecoinvent Report No. 6
Light fuel oil	Europe		Average technology	Ecoinvent Report No. 6
Steam	Europe	1995	Average technology	Ecoinvent Report No. 12

Table 4.14 Datasets used to model fuel / energy production processes

Fuel / energy source	Geography	Year	Technology	Main sources	Reference
High density polyethylene, HDPE	Europe	1999	Average technology	PlasticsEurope, adapted to ecoinvent methodology.	Ecoinvent Report No. 11
Low density polyethylene, LDPE	Europe	1999	Average technology	PlasticsEurope, adapted to ecoinvent methodology.	Ecoinvent Report No. 11
Linear low density polyethylene, LLDPE	Europe	1999	Average technology	PlasticsEurope, adapted to ecoinvent methodology.	Ecoinvent Report No. 11
Polypropylene, PP	Europe	1999	Average technology	PlasticsEurope, adapted to ecoinvent methodology.	Ecoinvent Report No. 11
PET (bottle grade)	Europe	1999	Average technology	PlasticsEurope, adapted to ecoinvent methodology.	Ecoinvent Report No. 11
LDPE film	Europe	1995	Current technology	PlasticsEurope, adapted to ecoinvent methodology.	Ecoinvent Report No. 11
Titanium dioxide	Europe	1990s	Chloride process	UBA BAT Notes 2001, adapted to ecoinvent methodology.	Ecoinvent Report No. 8
Dolomite	Europe		Average technology	Various, adapted to ecoinvent methodology.	Ecoinvent Report No. 7
Liquid paper board	Europe	1995 - 2000	Average technology, integrated mill	Habersatter et al (1998) and env. reports from several Scandinavian producers, adapted to ecoinvent methodology.	Ecoinvent Report No. 11, Part III
Sulphate pulp	Europe	2000	Modern average technology	Ecodata from KCL (2002), and Corporate Environmental Reports (CERs) from Södra Cell (2002) and Metsä-Botnia (2001), adapted to ecoinvent methodology.	Ecoinvent Report No. 11, Part III
Packaging, corrugated board	Europe	2005	Average technology	FEFCO (2006), adapted to ecoinvent methodology.	Ecoinvent Report No. 11, Part III
Aluminium	Europe	1995 - 2005	Average technology	EAA (2000), personal communication, and Mori & Adelhardt (1998), adapted to ecoinvent methodology.	Ecoinvent Report No. 10
Steel, low alloy	Europe	2001	EU technology mix	IPPC (2000) and Roth et al (1999), adapted to ecoinvent methodology.	Ecoinvent Report No. 10
Hydrogen peroxide	Average of 8 European producers	1995 - 2000	Anthraquinone process	Boustead & Fawer (1998), Dall'Acqua et all (1999) and Vogel (2000), adapted to ecoinvent methodology.	Ecoinvent Report No. 8
Sodium hydroxide	Europe	1995 - 2000	Average of different technologies	EC IPPC BAT documentation, adapted to ecoinvent methodology.	Ecoinvent Report No. 8
Sulphuric acid	Europe		Average / state-of-the-art technology	ESA-EFMA (2000), Müller (1994), and Patyk (1997), adapted to ecoinvent methodology.	Ecoinvent Report No. 8
Soap	Europe	Mid-1990s	Fatty acid alcohol sulfonate production	Dall'Acqua et al (1999), adapted to ecoinvent methodology.	Ecoinvent Report No. 12
Compressed air			Average technology	BFE (2005), adapted to ecoinvent methodology.	Ecoinvent Report No. 23
Injection moulding	Europe	1997	Present technologies	Habersatter et al (1998) and conversion report from PlasticsEurope (Boustead 1997), adapted to ecoinvent methodology.	Ecoinvent Report No. 11, Part II

Fuel / energy source	Geography	Year	Technology	Main sources	Reference
HDPE landfill, EfW, recycling	UK	2006	Average technology		Environment Agency (2007) WRATE
PET landfill, EfW, recycling	UK	2006	Average technology		Environment Agency (2007) WRATE
LDPE film landfill, EfW, recycling	UK	2006	Average technology		Environment Agency (2007) WRATE
Paper landfill, EfW, recycling	UK	2006	Average technology		Environment Agency (2007) WRATE
Transport by rail, freight, diesel	US	2005	Average technology	Von Rozycki (2003), adapted to ecoinvent methodology.	Ecoinvent Report No. 14
Transport by transoceanic freight ship	Global	2000	HFE based steam turbine and diesel engines	DLR (2001), adapted to ecoinvent methodology.	Ecoinvent Report No. 14
Transport by 40 yd Ro-ro	UK	2006	Average vehicle operation		Environment Agency (2007) WRATE.
Transport by lorry (>32 tonnes, 16 – 32 tonnes, 3.5 – 16 tonnes), MWC	Switzerland / Europe	2005	Average vehicle operation	TREMOVE (2007) and EMEP/CORINAIR (2006), adapted to ecoinvent methodology.	Ecoinvent Report No. 14

4.8 Data quality assessment

The following outlines the assessment of the quality of the specific and generic data used in this study, using the data quality requirements defined in *Table 3.4* in *Section 3.8*.

4.8.1 Specific data

Table 4.15 outlines the processes for which primary data have been collected for the different milk containers studied as part of this project. The data obtained are representative of milk containers available on the UK market and are generally considered to be of good quality.

However, for some processes the data are considered to be incomplete or of questionable quality. This is especially the case for the filling and packing data. For example, no specific data were available for the filling and packing data for the stand-up pouch and, instead, literature data from the operator manual for the filling machine were used as best alternative.

Data obtained from a dairy for HDPE bottle filling are based on full plant operations with estimates applied as to the allocation of inputs and outputs to the container size in question. Comparison with older literature sources showed a considerable improvement in energy use in the data provided by the dairy. This improvement in energy use is due to the fast development of dairy processes over the past decade. In recent years, significant resources have been invested to modernise and to optimise UK dairy filling processes, with significant energy savings achieved.

Table 4.15 Processes for which specific data have been used

Life cycle stage	HDPE bottle	PET bottle	Pillow pouch	Stand-up pouch	Carton with screwcap	Gable-top carton
Raw material production						
Transport of raw materials	x	x	x		x	x
Converting of container	x	x	x	x	x	x
Converting of cap	x		-	-		
Converting of seal	x		-	-	-	-
Converting of label			-	-	-	-
Converting of jug	-	-		-	-	-
Transport to dairy	-					
Filling and packing	x		x	x	x	x
Transport to retail						
Retail						
Transport to home						
Use	-	-	-	-	-	-
Waste collection						
Transport to recycling					x	x
Landfill						
Incineration						
Recycling, bottle-to-bottle UK	x	x	-	-	-	-
Carton recycling, Sweden	-	-	-	-	x	x
General recycling, UK					-	-
General recycling, China					-	-

4.8.2 Generic data

The majority of secondary datasets used fulfil data quality requirements for geographical and technology coverage. Since representativeness is a combination of these (plus time-related coverage), this criterion is, for the most part, also fulfilled. It has been difficult to assess generic LCI datasets with regard to completeness and precision, as the datasets used generally do not contain enough specific information to allow evaluation at this level. However, all generic data used in the assessment were sourced from the Ecoinvent dataset (version 2.0) or WRATE (version 1.0.1). Both are peer-reviewed databases and so are considered to be of acceptable completeness and precision.

The age of the secondary databases is a concern, as a number of the datasets relate to technologies in 2000 or earlier. Most notably, this is the case for the generic datasets used for the polymers. This is a common problem in conducting LCAs, but, since data collection and verification is resource-intensive, this is an issue that is likely to persist. The age of the data may also be reflected in technological coverage, in that an older technology is used or the efficiency of the process has been improved in the meantime, making the data not fully representative. However, it has not been possible to assess the extent to which this is the case.

The following materials did not fulfil all data quality requirements and have been found to have an influence on resulting impact profiles (see *Section 3.8):*

- polymer production;
- titanium dioxide; and
- liquid paper board.

The use of these generic datasets is a limitation of the study and the results should be viewed with this in mind.

5.0 Impact assessment

Each of the milk container systems have been assessed for their potential environmental impact for the following impact categories.

- Abiotic resource depletion – an indication of resource depletion by considering the proportion of the available resource (in years) for each abiotic raw material consumed by the activities in question, and summing their contribution to depletion of known stocks, giving a measure of total depletion in years. Raw materials extracted that contribute to resource depletion are aggregated according to their impact on resource depletion compared with antimony reserves as a reference. Therefore, impacts are expressed in kg Sb (antimony) equivalents.

- Climate change – gases contributing to the greenhouse effect are aggregated according to their impact on radiative warming compared to carbon dioxide as the reference. Therefore, impacts are expressed in kg CO2 equivalents.

- Photo-oxidant formation – gases contributing to smog formation are aggregated according to their relative photo-oxidant potential compared to ethylene as the reference. Therefore, impacts are expressed in kg C2H4 equivalents.

- Eutrophication – phosphorus is the key nutrient for eutrophication in freshwater and nitrate is the key substance for saltwater. Those substances that have the potential for causing nitrification are aggregated using nitrification potentials, which are a measure of the capacity to form biomass compared to phosphate (PO43-). Therefore, impacts are expressed in kg PO43- equivalents.

- Acidification – gases contributing to air acidification are aggregated according to their acidification potential. These potentials have been developed for potentially acidifying gases such as SO2, NOX, HCl, HF and NH3 on the basis of the number of hydrogen ions that can be produced per mole of a substance, using SO2 as the reference. Therefore, impacts are expressed in kg SO2 equivalents.

- Human toxicity – the impact assessment method used in this assessment is based on calculated human toxicity potentials and is not related to actual impact. These Human Toxicity Potentials (HTP) are a calculated index that reflects the potential harm of a unit of chemical released into the environment. Characterisation factors, expressed as HTPs, are calculated using USES-LCA, describing fate, exposure and effects of toxic substances compared with 1,4-dichlorobenzene as a reference. Therefore, impacts are expressed in kg 1,4-dichlorobenzene equivalents.

- Aquatic eco-toxicity – eco-toxicity potentials for the aquatic environment are calculated using USES-LCA, describing fate, exposure and effects of toxic substances compared with 1,4-dichlorobenzene as a reference. Therefore, impacts are expressed in kg 1,4-dichlorobenzene equivalents.

For human toxicity and eco-toxicity, a number of simplifying assumptions are made in the modelling used to derive characterisation factors, as the fate of emissions in the environment and their interaction in ecosystems is are determined by many variables. As a result, their adequacy in representing impacts is still the subject of scientific research. The toxicity results presented in the following should be viewed with this in mind.

Summary impact assessment results for each milk packaging system assessed are shown in the following sections. For each milk container, the results are presented in three sub-sections: results for different recycled content and lightweight scenarios; results for different waste management options; and results for the different life cycle stages.

Commentary under tables and figures highlight key points in the impact assessment results.

Complete tables of impact assessment results is provided in *Appendix 2*.

5.1 The HDPE bottle systems

5.1.1 *Impact assessment results for the recycled content and lightweighting scenarios*

The impact assessment results for different two pint HDPE bottle recycled content and lightweighting scenarios are presented for the different waste management options in *Table 5.1* to *Table 5.7* below. The results are shown per functional unit, i.e. per 1000 pints.

Table 5.1 Impact assessment results for the HDPE bottle scenarios with landfill as the waste management option (per functional unit)

Impact category	Unit	HDPE bottle, 100% virgin, landfill	HDPE bottle, 30% recycled, landfill	HDPE bottle, 50% recycled, landfill	HDPE bottle, 30% recycled, 10% lightweight, landfill
Abiotic resource depletion	kg Sb eq	0.623	0.623	0.622	0.578
Climate change	kg CO_2 eq	48.0	47.9	47.9	45.3
Photo-oxidant formation	kg C_2H_4 eq	0.0431	0.0430	0.0430	0.0396
Acidification	kg SO_2 eq	0.0162	0.0161	0.0161	0.0153
Eutrophication	kg PO_4^{3-} eq	0.141	0.140	0.140	0.131
Human toxicity	kg 1,4-DB eq	7.59	7.58	7.57	7.15
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.843	0.842	0.842	0.801

Points of note

- With the system boundary settings used for this study, only minor differences are seen between the results of the HDPE bottle systems with varying recycled content. This is due to the approach used of awarding all the potential environmental benefits to the end-of-life stage (as described in section 3.5). The difference seen in the results is due to the different transport distances applied for the delivery of the vHDPE and rHDPE to the converter.
- Reducing the weight of the HDPE bottle by 10% is shown to cause lower overall potential environmental impacts across all impact categories. The impacts are 8.1% lower or less as shown in Table 5.2 below.

Table 5.2 Differences in potential environmental impacts achieved for the HDPE bottle scenarios with landfill as the waste management option (per functional unit)

Impact category	Differences in potential environmental impacts, 100% vHDPE vs 30% rHDPE	Differences in potential environmental impacts, 100% vHDPE vs 50% rHDPE	Differences in potential environmental impacts, 100% vHDPE vs 30% rHDPE, 10% lightweight
Abiotic resource depletion	0.086%	0.14%	7.2%
Climate change	0.18%	0.30%	5.7%
Photo-oxidant formation	0.14%	0.23%	8.1%
Acidification	0.61%	1.0%	5.5%
Eutrophication	0.38%	0.64%	6.8%
Human toxicity	0.15%	0.26%	5.8%
Freshwater aquatic eco-toxicity	0.078%	0.13%	5.0%

Impact assessment results for HDPE bottles with the waste management options of incineration with energy recovery are shown in *Table 5.3* and *5.4* below, and for closed loop recycling in *Table 5.5*.

Table 5.3 Impact assessment results for the HDPE bottle scenarios with energy from waste as the waste management option (per functional unit)

Impact category	Unit	HDPE bottle, 100 % virgin, EfW	HDPE bottle, 30 % recycled, EfW	HDPE bottle, 50 % recycled, EfW	HDPE bottle, 30 % recycled, 10 % lightweight, EfW
Abiotic resource depletion	kg Sb eq	0.353	0.353	0.352	0.333
Climate change	kg CO_2 eq	61.1	61.1	61.0	57.2
Photo-oxidant formation	kg C_2H_4 eq	0.0417	0.0417	0.0417	0.0384
Acidification	kg SO_2 eq	0.0146	0.0145	0.0144	0.0138
Eutrophication	kg PO_4^{3-} eq	0.113	0.113	0.112	0.106
Human toxicity	kg 1,4-DB eq	6.27	6.26	6.25	5.95
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.120	0.119	0.119	0.143

Points of note

- Again, due to the system boundary settings used for this study, only minor differences are seen between the results of the HDPE bottle systems with varying recycled content.
- Reducing the weight of the bottle by 10% is shown to lead to potential environmental impacts of 8.1% lower or less across all impact categories compared to the other scenarios, except for freshwater aquatic eco-toxicity. This category shows an increased impact for 10% lightweighting scenario. This is incurred through the lower environmental benefit achieved from crediting the energy from waste with fossil fuel based energy due to less material being incinerated.

Table 5.4 Differences in potential environmental impacts for the HDPE bottle scenarios with energy from waste as the waste management option (per functional unit)

Impact category	Differences in potential environmental impacts, 100 % vHDPE vs 30 % rHDPE	Differences in potential environmental impacts, 100 % vHDPE vs 50 % rHDPE	Differences in potential environmental impacts, 100 % vHDPE vs 30 % rHDPE, 10 % lightweight
Abiotic resource depletion	0.15%	0.26%	5.8%
Climate change	0.14%	0.23%	6.4%
Photo-oxidant formation	0.14%	0.24%	8.1%
Acidification	0.68%	1.1%	5.1%
Eutrophication	0.48%	0.80%	6.3%
Human toxicity	0.19%	0.31%	5.1%
Freshwater aquatic eco-toxicity	0.55%	0.92%	-19%

Table 5.5 Impact assessment results for the HDPE bottle scenarios with bottle-to-bottle recycling in the UK as the waste management option (per functional unit)

Impact category	**Unit**	**HDPE bottle, 100% virgin, BtB* recycling UK**	**HDPE bottle, 30% recycled, BtB* recycling UK**	**HDPE bottle, 50% recycled, BtB* recycling UK**	**HDPE bottle, 30% recycled, 10% lightweight, BtB* recycling UK**
Abiotic resource depletion	kg Sb eq	0.261	0.259	0.257	0.253
Climate change	kg CO_2 eq	34.2	33.8	33.5	33.3
Photo-oxidant formation	kg C_2H_4 eq	0.0111	0.0131	0.0144	0.0107
Acidification	kg SO_2 eq	0.0117	0.0223	0.0293	0.0114
Eutrophication	kg PO_4^{3-} eq	0.0700	0.110	0.137	0.0699
Human toxicity	kg 1,4-DB eq	4.28	4.35	4.39	4.20
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.544	0.546	0.548	0.547

*Bottle-to-Bottle.

Points of note

- Increasing the recycled content of the bottle is shown to reduce the potential environmental impacts of the HDPE bottle system for the impact categories of abiotic resource depletion, climate change and photo-oxidant formation.
- Reducing the weight of the bottle by 10% is shown to lead to lower potential environmental impacts across all impact categories compared to the other scenarios.

Impact assessment results for HDPE bottles with the waste management options of general recycling in the UK and China are shown in *Table 5.6* to *5.7* below. The differences in potential environmental impacts are not shown in tabular format here. However, similar trends as above are seen for both recycling options.

Table 5.6 Impact assessment results for the HDPE bottle scenarios with recycling in the UK as the waste management option (per functional unit)

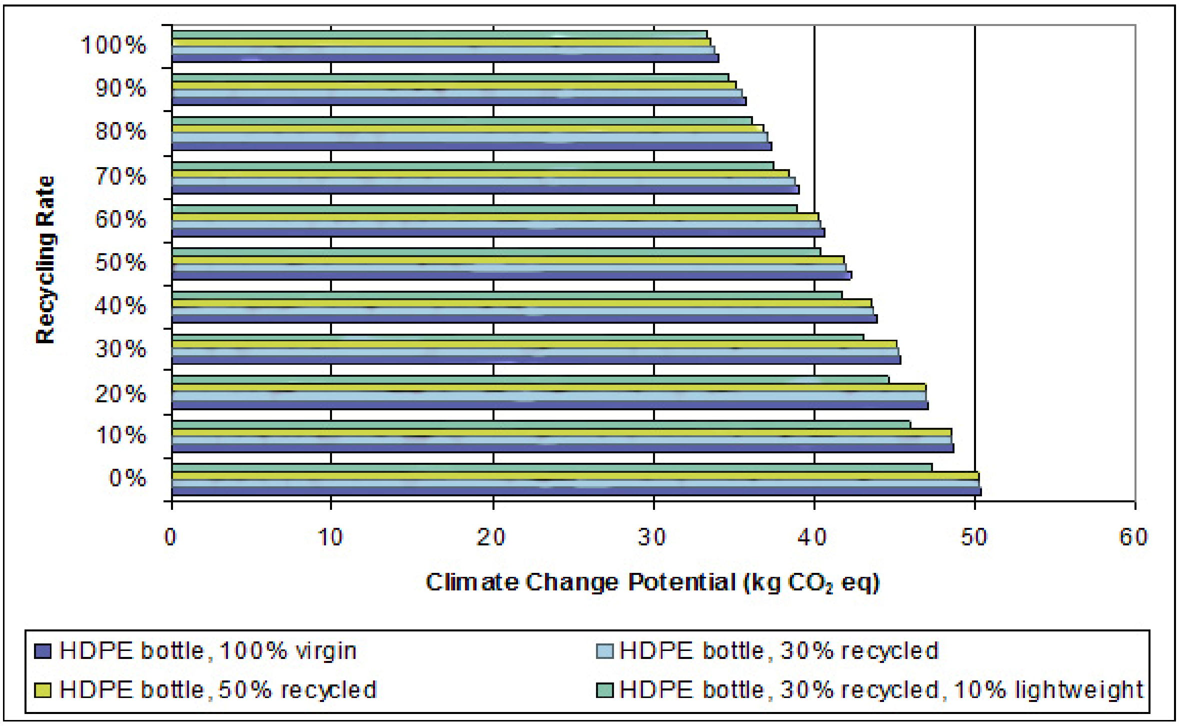
Impact category	**Unit**	**HDPE bottle, 100% virgin, recycling UK**	**HDPE bottle, 30% recycled, recycling UK**	**HDPE bottle, 50% recycled, recycling UK**	**HDPE bottle, 30% recycled, 10% lightweight, recycling UK**
Abiotic resource depletion	kg Sb eq	0.345	0.344	0.344	0.326
Climate change	kg CO_2 eq	35.6	35.5	35.4	34.0
Photo-oxidant formation	kg C_2H_4 eq	0.0363	0.0363	0.0362	0.0335
Acidification	kg SO_2 eq	0.00527	0.00517	0.00510	0.00540
Eutrophication	kg PO_4^{3-} eq	-0.0484	-0.0489	-0.0493	-0.0404
Human toxicity	kg 1,4-DB eq	4.13	4.12	4.11	4.01
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.753	0.752	0.752	0.719

Table 5.7 Impact assessment results for the HDPE bottle scenarios with recycling in China as the waste management option (per functional unit)

Impact category	Unit	HDPE bottle, 100% virgin, recycling China	HDPE bottle, 30% recycled, recycling China	HDPE bottle, 50% recycled, recycling China	HDPE bottle, 30% recycled, 10% lightweight, recycling China
Abiotic resource depletion	kg Sb eq	0.365	0.364	0.364	0.345
Climate change	kg CO_2 eq	38.6	38.6	38.5	37.1
Photo-oxidant formation	kg C_2H_4 eq	0.0406	0.0406	0.0405	0.0378
Acidification	kg SO_2 eq	0.0111	0.0110	0.0109	0.0112
Eutrophication	kg PO_4^{3-} eq	0.0138	0.013	0.013	0.0218
Human toxicity	kg 1,4-DB eq	5.86	5.85	5.84	5.74
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.784	0.783	0.783	0.750

Figure 5.1 below shows the overall results for the HDPE bottle system with increased recycling. As can be seen, increasing the recycling rate shows a decrease in the overall impact of the HDPE bottle system. For the quantities not being recycled, it is assumed that 82.4% is landfilled and 17.6% is incinerated with energy recovery. These percentages are based on 2007/08 Defra municipal waste management statistics (Defra 2008b).

Figure 5.1 Environmental impact results associated with increased recycling for the HDPE bottle system



5.1.2 Impact assessment results for different end-of-life scenarios

The impact assessment results for different waste management options are presented in *Table 5.8* to *Table 5.11* below. The results are shown per functional unit, i.e. per 1000 pints.

Table 5.8 Impact assessment results for the 100% vHDPE bottle system with different waste management options (per functional unit)

Impact category	Unit	HDPE bottle, 100% virgin, landfill	HDPE bottle, 100% virgin, energy from waste	HDPE bottle, 100% virgin, BtB* recyc UK	HDPE bottle, 100% virgin, recyc UK	HDPE bottle, 100% virgin, recyc China	Difference in potential env. impacts, energy from waste vs landfill	Difference in potential env. impacts, BtB* recyc vs landfill	Difference in potential env. impacts, general recyc UK vs landfill	Difference in potential env. impacts, general recyc China vs landfill
Abiotic resource depletion	kg Sb eq	0.623	0.353	0.261	0.345	0.365	0.270	0.362	0.278	0.258
Climate change	kg CO$_2$ eq	48.0	61.1	34.2	35.6	38.6	-13.1	13.9	12.5	9.38
Photo-oxidant formation	kg C$_2$H$_4$ eq	0.0431	0.0417	0.0111	0.0363	0.0406	0.00131	0.0319	0.00672	0.00241
Acidification	kg SO$_2$ eq	0.0162	0.0146	0.0117	0.00527	0.0111	0.00165	0.00451	0.0110	0.00513
Eutrophication	kg PO$_4^{3-}$ eq	0.141	0.113	0.0700	-0.0484	0.0138	0.0273	0.0706	0.189	0.127
Human toxicity	kg 1,4-DB eq	7.59	6.27	4.28	4.13	5.86	1.32	3.31	3.46	1.73
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.843	0.120	0.544	0.753	0.784	0.723	0.299	0.0898	0.0591

* Bottle-to-Bottle

Table 5.9 Impact assessment results for the 30% rHDPE bottle system with different waste management options (per functional unit)

Impact category	Unit	HDPE bottle, 30% recycled, landfill	HDPE bottle, 30% recycled, energy from waste	HDPE bottle, 30% recycled, BtB* recyc UK	HDPE bottle, 30% recycled, recyc UK	HDPE bottle, 30% recycled, recyc China	Difference in potential env. impacts, energy from waste vs landfill	Difference in potential env. impacts, BtB* recyc vs landfill	Difference in potential env. impacts, general recyc UK vs landfill	Difference in potential env. impacts, general recyc China vs landfill
Abiotic resource depletion	kg Sb eq	0.623	0.353	0.259	0.344	0.364	0.270	0.364	0.278	0.258
Climate change	kg CO$_2$ eq	47.9	61.1	33.8	35.5	38.6	-13.1	14.2	12.5	9.38
Photo-oxidant formation	kg C$_2$H$_4$ eq	0.0430	0.0417	0.0131	0.0363	0.0406	0.00131	0.0299	0.00672	0.00241
Acidification	kg SO$_2$ eq	0.0161	0.0145	0.0223	0.00517	0.0110	0.00165	-0.00617	0.0110	0.00513
Eutrophication	kg PO$_4^{3-}$ eq	0.140	0.113	0.110	-0.0489	0.013	0.0273	0.0299	0.189	0.127
Human toxicity	kg 1,4-DB eq	7.58	6.26	4.35	4.12	5.85	1.32	3.23	3.46	1.73
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.842	0.119	0.546	0.752	0.783	0.723	0.296	0.0898	0.0591

* Bottle-to-Bottle

Table 5.10 Impact assessment results for the 50% rHDPE bottle system with different waste management options (per functional unit)

Impact category	Unit	HDPE bottle, 50% recycled, landfill	HDPE bottle, 50% recycled, energy from waste	HDPE bottle, 50% recycled, BtB* recyc UK	HDPE bottle, 50% recycled, recyc UK	HDPE bottle, 50% recycled, recyc China	Difference in potential env. impacts, energy from waste vs landfill	Difference in potential env. impacts, BtB* recyc vs landfill	Difference in potential env. impacts, general recyc UK vs landfill	Difference in potential env. impacts, general recyc China vs landfill
Abiotic resource depletion	kg Sb eq	0.622	0.352	0.257	0.344	0.364	0.270	0.365	0.278	0.258
Climate change	kg CO_2 eq	47.9	61.0	33.5	35.4	38.5	-13.1	14.4	12.5	9.38
Photo-oxidant formation	kg C_2H_4 eq	0.0430	0.0417	0.0144	0.0362	0.0405	0.00131	0.0285	0.00672	0.00241
Acidification	kg SO_2 eq	0.0161	0.0144	0.0293	0.00510	0.0109	0.00165	-0.0133	0.0110	0.00513
Eutrophication	kg PO_4^{3-} eq	0.140	0.112	0.137	-0.0493	0.0129	0.0273	0.00278	0.189	0.127
Human toxicity	kg 1,4-DB eq	7.57	6.25	4.39	4.11	5.84	1.32	3.18	3.46	1.73
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.842	0.119	0.548	0.752	0.783	0.723	0.294	0.0898	0.0591

* Bottle-to-Bottle

Table 5.11 Impact assessment results for the 10% lightweighted 30% rHDPE bottle system with different waste management options (per functional unit)

Impact category	Unit	HDPE bottle, 30% recycled, 10% lightweight landfill	HDPE bottle, 30% recycled, 10% lightweight, energy from waste	HDPE bottle, 30% recycled, 10% lightweight, BtB* recyc UK	HDPE bottle, 30% recycled, 10% lightweight, recyc UK	HDPE bottle, 30% recycled, 10% lightweight, recyc China	Difference in potential env. impacts, energy from waste vs landfill	Difference in potential env. impacts, BtB* recyc vs landfill	Difference in potential env. impacts, general recyc UK vs landfill	Difference in potential env. impacts, general recyc China vs landfill
Abiotic resource depletion	kg Sb eq	0.578	0.333	0.253	0.326	0.345	0.246	0.325	0.253	0.233
Climate change	kg CO_2 eq	45.3	57.2	33.3	34.0	37.1	-11.9	12.0	11.3	8.23
Photo-oxidant formation	kg C_2H_4 eq	0.0396	0.0384	0.0107	0.0335	0.0378	0.00119	0.0289	0.00609	0.00178
Acidification	kg SO_2 eq	0.0153	0.0138	0.0114	0.00540	0.0112	0.00150	0.00391	0.00994	0.00411
Eutrophication	kg PO_4^{3-} eq	0.131	0.106	0.0699	-0.0404	0.0218	0.0249	0.0612	0.171	0.109
Human toxicity	kg 1,4-DB eq	7.15	5.95	4.20	4.01	5.74	1.20	2.95	3.14	1.41
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.801	0.143	0.547	0.719	0.750	0.658	0.254	0.0817	0.0510

* Bottle-to-Bottle

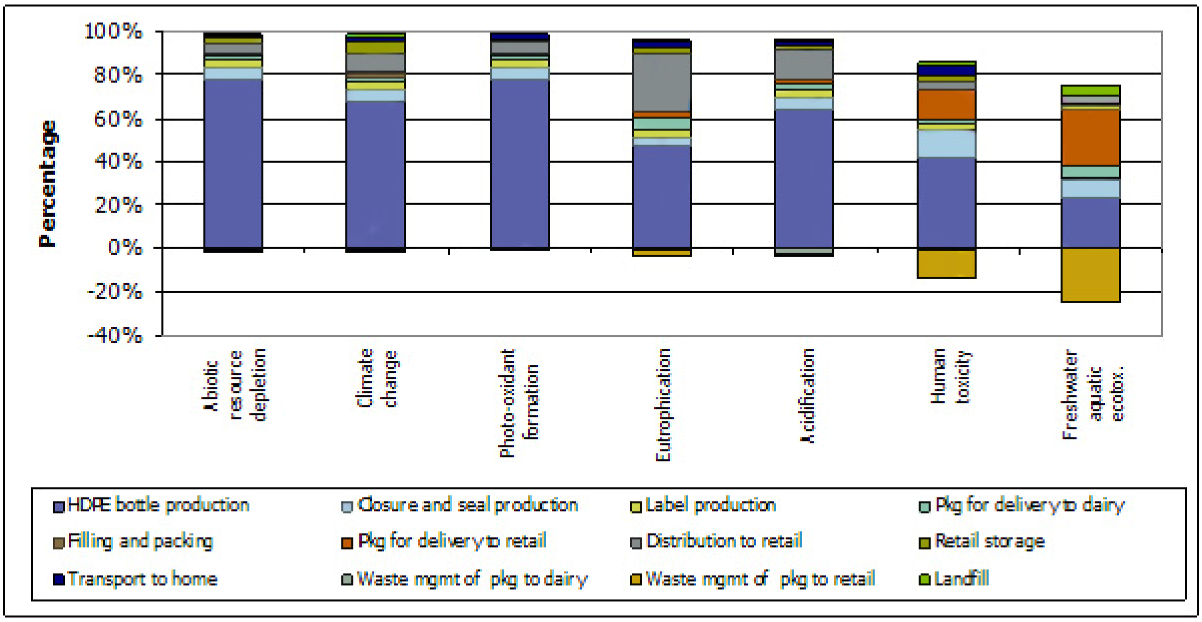
Points of note

- Recycling the HDPE bottle back into bottles in the UK provides the lowest potential environmental impacts for the impact categories of abiotic resource depletion, climate change, and photo-oxidant formation. For the impact categories of eutrophication, acidification and human toxicity, the HDPE bottle system with general recycling in the UK as the waste management option has the lowest potential environmental impacts. For freshwater ecotoxicity, energy from waste has the lowest environmental impact.
- Landfilling the HDPE bottles provides the highest potential environmental impacts for all the impact categories assessed except for climate change. Incinerating the bottle with energy recovery contributes the most to climate change.
- Compared to landfill, which is still the most likely end-of-life route for HDPE bottles, recycling the bottles is shown to lead to lower potential environmental impacts across all impact categories. This is the case whether the bottle undergoes bottle-to-bottle recycling or general recycling both in the UK and China.
- Compared to landfill, lower potential environmental impacts are shown when the bottle is being incinerated with energy recovery. This is true for all impact categories, except for the impact category of climate change.
- Due to the distances involved, UK recycling of the HDPE bottles is more beneficial in environmental terms than recycling in China. It should be emphasised that, due to a lack of data, the general recycling process is assumed to be similar for the UK and China.

5.1.3 Impact assessment results for the different life cycle stages

The environmental impacts associated with the different life cycle stages for the HDPE bottle system, with landfill as the waste management option for the primary packaging, are shown in *Figure 5.2* below. The results are presented per impact category as 100% stacked columns.

Figure 5.2 Environmental impact results associated with the different life cycle stages for the virgin HDPE bottle with landfill as the waste mgmt option for the primary packaging



Points of note

- HDPE bottle production, distribution packaging and its waste management, and distribution are the predominant contributors to the impact categories assessed as part of this study.
- The reason for bottle production making a significant contribution is the bottle's weight compared to the weight of the cap, seal, label and secondary and transit packaging used in the system.
- The distribution packaging is seen to contribute mainly to human toxicity and freshwater aquatic eco-toxicity, but little to the other impact categories. The contribution of the packaging is somewhat outweighed by the benefits of the assumption that the majority of the packaging is recycled after use.
- Distribution contributes mainly to the impact categories of climate change, eutrophication and acidification.
- The closure and seal contributes some to the impact categories of human toxicity and freshwater aquatic ecotoxicity.
- The contribution of the filling and packing of the bottles is insignificant when considering the total impacts.
- Landfill of the primary packaging contributes little to the overall results of all impact categories assessed.

Figures 5.3 to *5.6* show a breakdown of the results for the impact categories of climate change and freshwater aquatic eco-toxicity, as examples.

Figure 5.3 Impact profile for the HDPE bottle scenarios with the waste management options of landfill, energy from waste, recycling in the UK and recycling in China – climate change

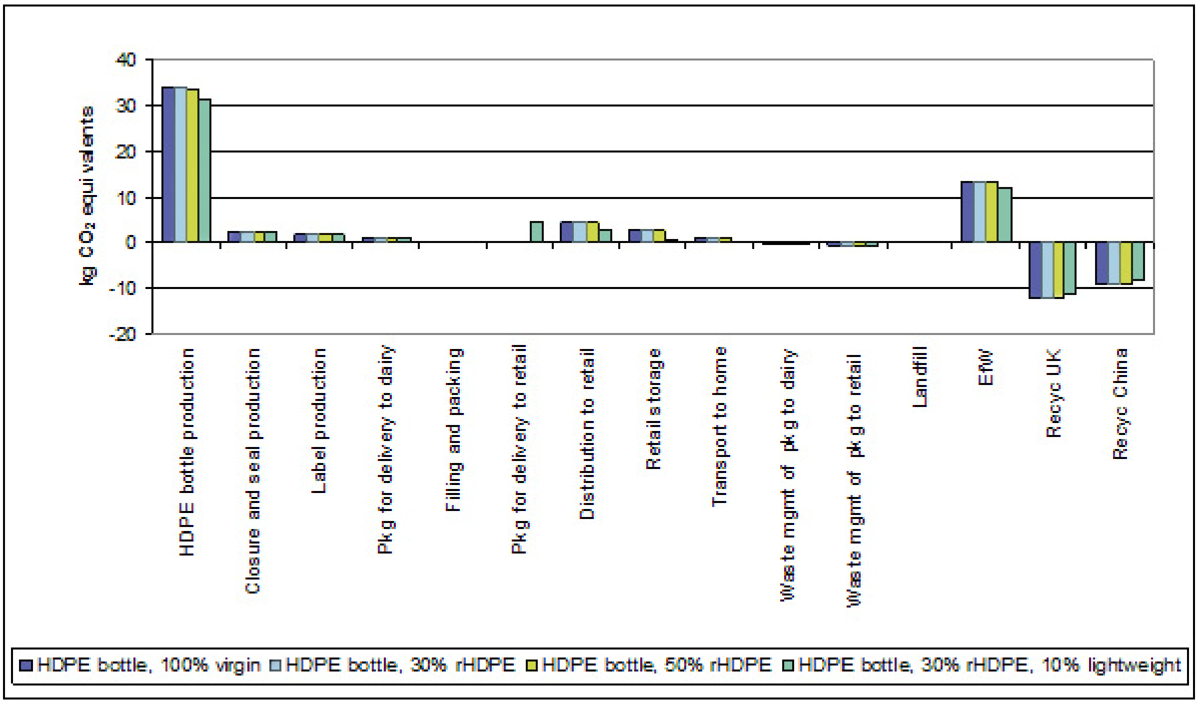
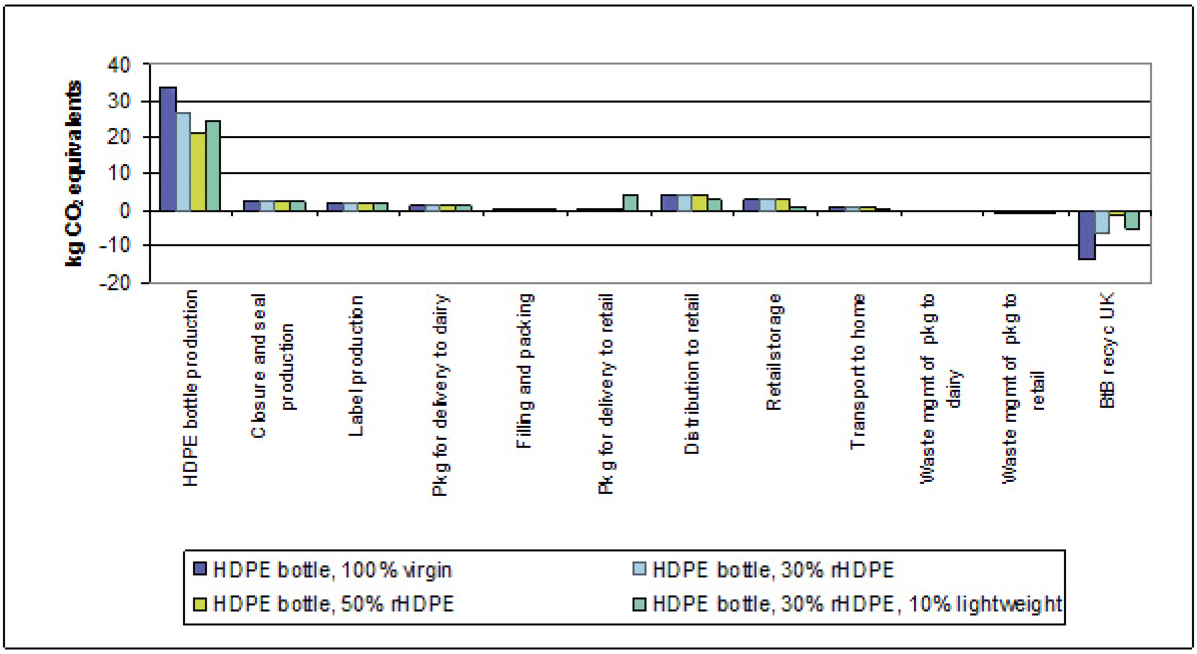


Figure 5.4 Impact profile for the HDPE bottle scenarios with the waste management option of bottle to bottle recycling in the UK (closed-loop recycling) – climate change



Points of note

- Bottle production, distribution to diary, and incineration with energy recovery are the predominant contributors to climate change impacts.
- Impacts in HDPE bottle production are primarily incurred in the raw material stage.
- Impacts in the distribution stage are incurred as a result of diesel combustion in transportation and subsequent emissions.
- Impacts in the energy from waste stage are incurred as a result of the combustion of the materials and subsequent carbon dioxide emissions.
- Benefits in the recycling scenarios assessed are achieved through the assumption that the recycled HDPE results in the avoided production of virgin HDPE.
- The 10% lightweight system shows lower potential environmental impacts as a result of reduced HDPE production (as described in Section 5.1.1).
- The life cycle stages associated with cap and label production, secondary and transit packaging production and its subsequent waste management, filling and packing, retail, transport to the home and landfill contribute relatively little to the impact profile for this category.

Figure 5.5 Impact profile for the HDPE bottle scenarios with the waste management options of landfill, energy from waste, recycling in the UK and recycling in China – freshwater aquatic eco-toxicity

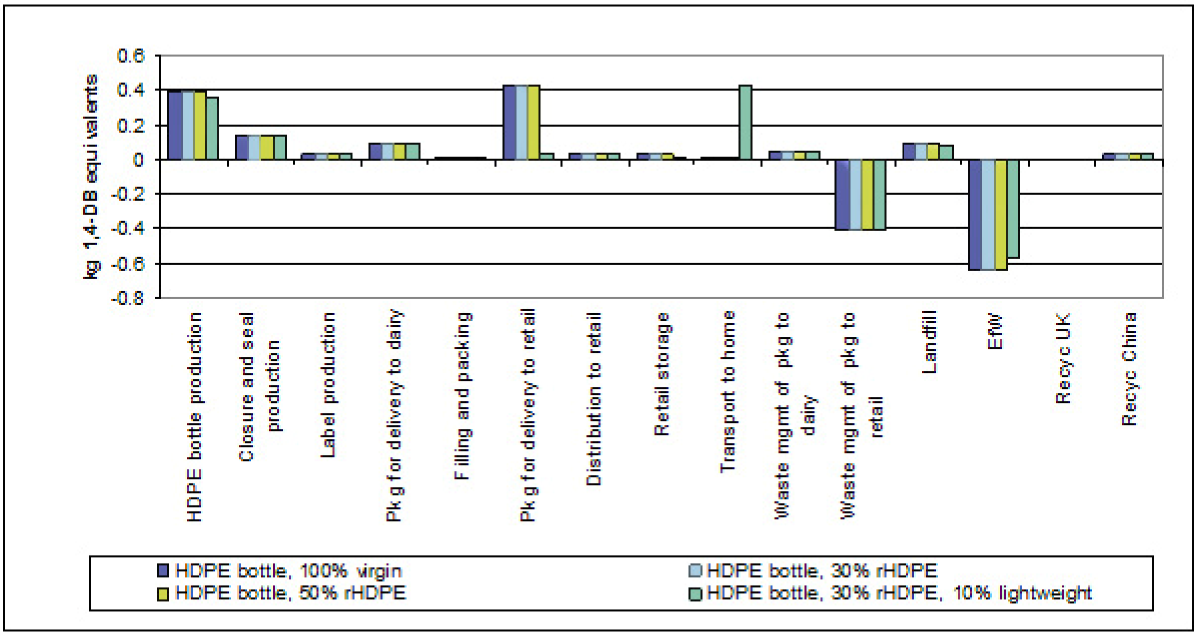
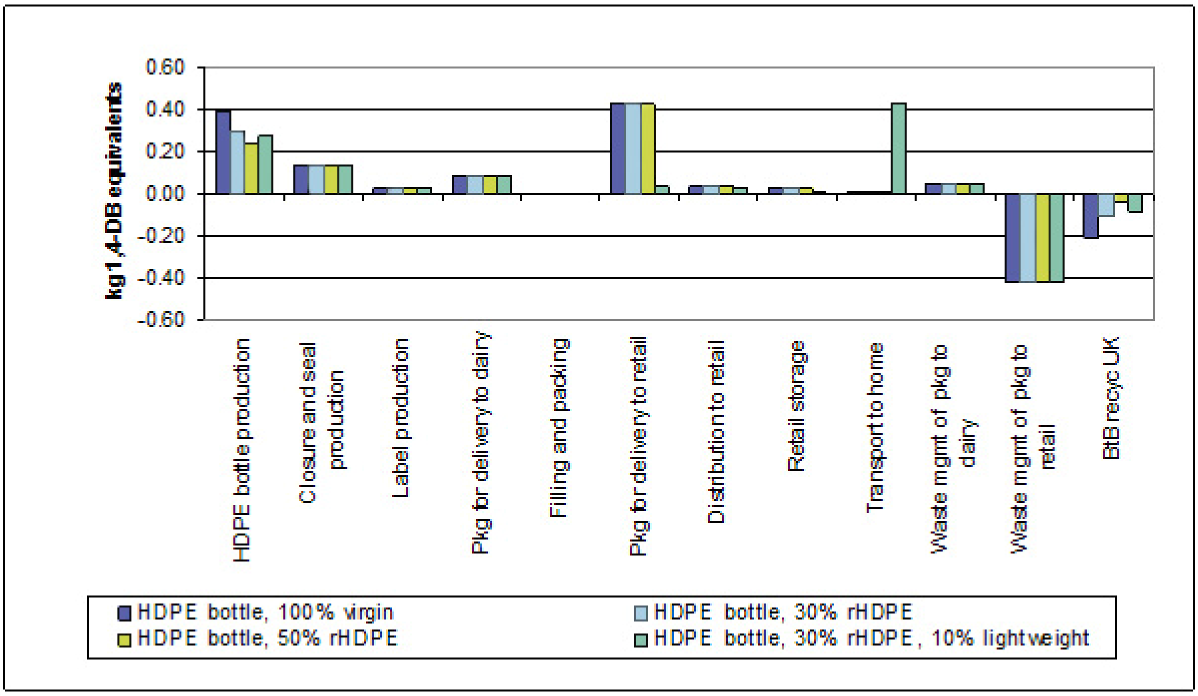


Figure 5.6 Impact profile for the HDPE bottle scenarios with the waste management option of bottle to bottle recycling in the UK (closed-loop recycling) – freshwater aquatic eco-toxicity



Points of note

- Bottle production and distribution packaging make the predominant contributions to freshwater aquatic eco-toxicity impacts, although the waste management assumptions for the distribution packaging somewhat outweigh the impacts.
- Impacts in HDPE bottle production are primarily incurred as a result of the extraction, refining and processing of the oil and gas into HDPE granules and the energy consumption associated with this.
- Impacts in the distribution packaging production are incurred almost fully as a consequence of the steel used for milk roll containers.
- Benefits in the waste management of distribution packaging stage are achieved through the assumption that the steel is recycled at the end of the milk roll container's life.
- Benefits in the incineration of the HDPE bottle are achieved through the assumption that the energy recovered is used for electricity generation (thereby reducing the need for fossil fuel generated electricity).
- The life cycle stages associated with filling and packing, distribution to retail, retail, transport to the home, waste management of the packaging for delivery to dairy, and general recycling contribute relatively little to the impact profile for this category.

5.2 The PET bottle systems

5.2.1 Impact assessment results for the recycled content and lightweighting scenarios

The impact assessment results for different one litre PET bottle recycled content and lightweighting scenarios are presented for the different waste management options in *Table 5.12* to *Table 5.18* below. The results are shown per functional unit, i.e. per 1000 pints.

Table 5.12 Impact assessment results for the PET bottle scenarios with landfill as the waste management option (per functional unit)

Impact category	Unit	PET bottle, 100% virgin, landfill	PET bottle, 30% recycled, landfill	PET bottle, 100% virgin, 10% lightweight, landfill
Abiotic resource depletion	kg Sb eq	1.04	1.04	0.958
Climate change	kg CO_2 eq	90.6	90.8	84.1
Photo-oxidant formation	kg C_2H_4 eq	0.0565	0.0566	0.0525
Acidification	kg SO_2 eq	0.0836	0.0837	0.0764
Eutrophication	kg PO_4^{3-} eq	0.301	0.301	0.277
Human toxicity	kg 1,4-DB eq	23.2	23.2	21.3
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	3.00	3.01	2.79

Points of note

- With the system boundary settings used for this study, only minor differences are seen between the results for the PET bottle from virgin material and the PET bottle with 30% recycled content. This is due to the approach used of awarding all the potential environmental benefits to the end-of-life stage (as described in Section 3.5). The difference in the results is due to the different transport distances applied for the delivery of the virgin and secondary PET to the converter.
- Under this method, environmental impacts increase for the PET bottle with 30% recycled content, as shown in the negative percentages in Table 5.13. The reason for this is that the virgin PET is transported by sea, according to the converter, whereas the secondary PET is modelled as being transported by road. Freight ships have a significant load capacity compared to lorries, and the impact per kg of goods transported is therefore nominal.
- Reducing the weight of the bottle by 10% is shown to cause to lower potential environmental impacts across all impact categories. The impacts are 8.6% lower or less as shown in Table 5.13 below.

Table 5.13 Differences in potential environmental impacts for the PET bottle scenarios with landfill as the waste management option (per functional unit)

Impact category	Differences in potential environmental impacts, 100% vPET vs 30% rPET	Differences in potential environmental impacts, 100% vPET vs 30% rPET 10% lightweight
Abiotic resource depletion	-0.13%	7.8%
Climate change	-0.20%	7.2%
Photo-oxidant formation	-0.24%	6.9%
Acidification	-0.18%	8.6%
Eutrophication	-0.12%	7.9%
Human toxicity	-0.14%	8.1%
Freshwater aquatic eco-toxicity	-0.28%	7.3%

Impact assessment results for PET bottles with the waste management options of energy from waste, bottle-to-bottle recycling in the UK, general recycling in the UK, and general recycling in China are shown in *Table 5.14* to *5.18* below. The percentage differences in potential environmental impacts are not shown in tabular format for energy from waste, and general recycling in the UK and China, since similar trends as above are seen for these waste management options.

Table 5.14 Impact assessment results for the PET bottle scenarios with EfW as the waste management option (per functional unit)

Impact category	Unit	PET bottle, 100% virgin, energy from waste	PET bottle, 30% recycled, energy from waste	PET bottle, 100% virgin, 10% lightweight, energy from waste
Abiotic resource depletion	kg Sb eq	0.813	0.814	0.752
Climate change	kg CO_2 eq	122	122	112
Photo-oxidant formation	kg C_2H_4 eq	0.0555	0.0556	0.0516
Acidification	kg SO_2 eq	0.0846	0.0847	0.0772
Eutrophication	kg PO_4^{3-} eq	0.291	0.291	0.268
Human toxicity	kg 1,4-DB eq	23.1	23.1	21.2
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.39	2.40	2.22

Table 5.15 Impact assessment results for the PET bottle scenarios with bottle-to-bottle recycling in the UK as the waste management option (per functional unit)

Impact category	Unit	PET bottle, 100% virgin, BtB* recycling UK	PET bottle, 30% recycled, BtB* recycling UK	PET bottle, 100% virgin, 10% lightweight, BtB* recycling UK
Abiotic resource depletion	kg Sb eq	0.445	0.440	0.416
Climate change	kg CO_2 eq	54.1	54.0	50.8
Photo-oxidant formation	kg C_2H_4 eq	0.0260	0.0259	0.0249
Acidification	kg SO_2 eq	0.0222	0.0219	0.0206
Eutrophication	kg PO_4^{3-} eq	0.131	0.130	0.122
Human toxicity	kg 1,4-DB eq	7.15	7.06	6.73
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	1.16	1.15	1.11

* Bottle-to-Bottle.

Points of note

- Increasing the recycled content of the bottle is shown to reduce the potential environmental impacts of the PET bottle system. With the system boundary settings used for this study, the impacts are 1.4% lower or less as shown in Table 5.16 below.
- As for the other waste management options, reducing the weight of the PET bottle by 10% is shown to cause lower overall potential environmental impacts across all impact categories. Where bottle-to-bottle recycling is considered, the impacts are 6.5% lower or less as shown in Table 5.16 below.
- Note, the bottle-to-bottle recycling scenario has been modelled as a partially closed-loop and open-loop scenario.

Table 5.16 Differences in potential environmental impacts for the PET bottle scenarios with bottle-to-bottle recycling as the waste management option (per functional unit)

Impact category	Differences in potential environmental impacts, 100% vPET vs 30% rPET	Differences in potential environmental impacts, 100% vPET vs 30% rPET 10% lightweight
Abiotic resource depletion	0.98%	5.6%
Climate change	0.14%	5.9%
Photo-oxidant formation	0.28%	4.0%
Acidification	1.4%	5.8%
Eutrophication	0.87%	6.5%
Human toxicity	1.3%	4.6%
Freshwater aquatic eco-toxicity	0.53%	3.7%

Table 5.17 Impact assessment results for the PET bottle scenarios with recycling in the UK as the waste management option (per functional unit)

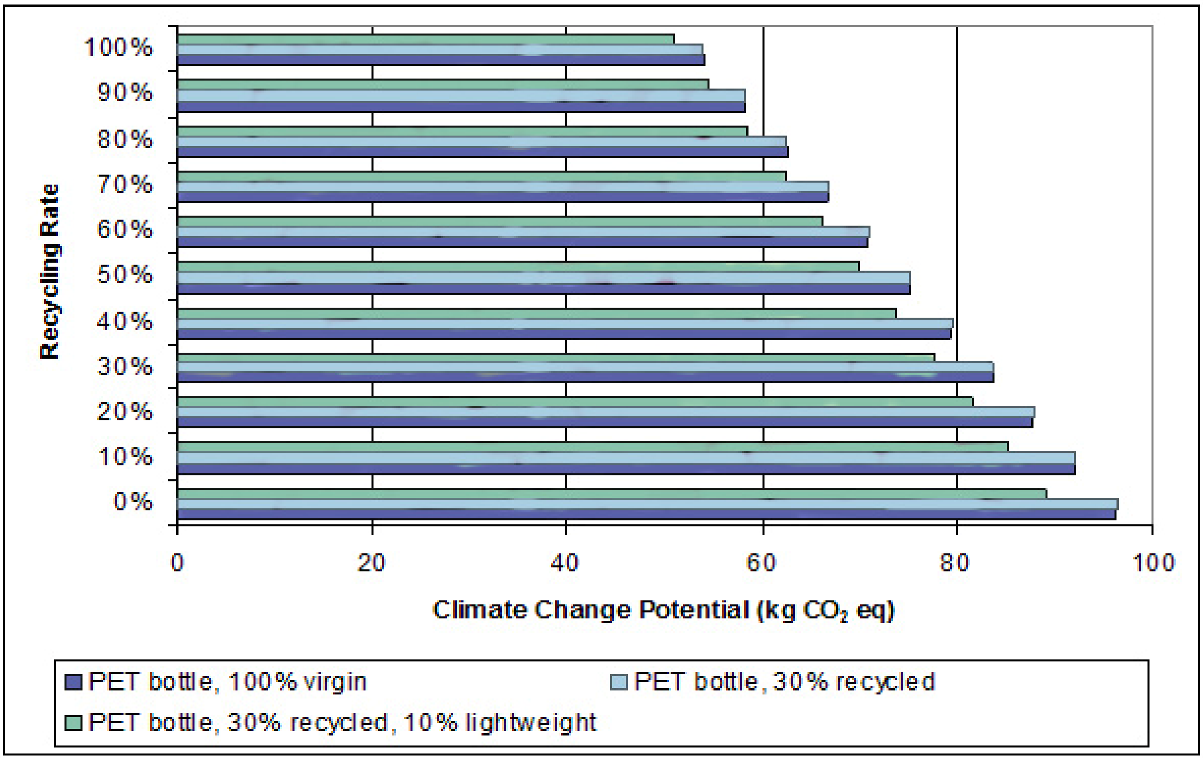
Impact category	Unit	PET bottle, 100% virgin, recycling UK	PET bottle, 30% recycled, recycling UK	PET bottle, 100% virgin, 10% lightweight, recycling UK
Abiotic resource depletion	kg Sb eq	0.573	0.574	0.536
Climate change	kg CO_2 eq	68.3	68.5	63.9
Photo-oxidant formation	kg C_2H_4 eq	0.0455	0.0456	0.0426
Acidification	kg SO_2 eq	0.0655	0.0656	0.0600
Eutrophication	kg PO_4^{3-} eq	-0.00779	-0.00744	-0.00213
Human toxicity	kg 1,4-DB eq	17.4	17.5	16.1
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.73	2.74	2.54

Table 5.18 Impact assessment results for the PET bottle scenarios with recycling in China as the waste management option (per functional unit)

Impact category	Unit	PET bottle, 100% virgin, recycling China	PET bottle, 30% recycled, recycling China	PET bottle, 100% virgin, 10% lightweight, recycling China
Abiotic resource depletion	kg Sb eq	0.606	0.608	0.567
Climate change	kg CO_2 eq	73.5	73.7	68.6
Photo-oxidant formation	kg C_2H_4 eq	0.0528	0.0529	0.0493
Acidification	kg SO_2 eq	0.0754	0.0755	0.0690
Eutrophication	kg PO_4^{3-} eq	0.0973	0.0977	0.0935
Human toxicity	kg 1,4-DB eq	20.4	20.4	18.8
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.78	2.79	2.59

Figure 5.7 below shows the overall result for the PET bottle system with increasing recycling. As can be seen, increasing the recycling rate shows a decrease in the overall impact of the PET bottle system. For the quantities not recycled, it is assumed that 82.4% is landfilled and 17.6% is incinerated with energy recovery. These percentages are based on 2007/08 Defra municipal waste management statistics (Defra 2008b).

Figure 5.7 Environmental impact results associated with increased recycling for the PET bottle system



5.2.2 Impact assessment results for different end-of-life scenarios

The impact assessment results for different waste management options are presented in *Table 5.19* to *Table 5.21* below. The results are shown per functional unit, i.e. per 1000 pints.

Table 5.19 Impact assessment results for the 100% vPET bottle system with different waste management options (per functional unit)

Impact category	Unit	PET bottle, 100% virgin, landfill	PET bottle, 100% virgin, energy from waste	PET bottle, 100% virgin, BtB* recyc UK	PET bottle, 100% virgin, recyc UK	PET bottle, 100% virgin, recyc China	Differences in potential env. impacts, energy from waste vs landfill	Differences in potential env. impacts, BtB recyc vs landfill	Differences in potential env. impacts, general recyc UK vs landfill	Differences in potential env. impacts, general recyc China vs landfill
Abiotic resource depletion	kg Sb eq	1.04	0.813	0.445	0.573	0.606	0.227	0.594	0.466	0.433
Climate change	kg CO$_2$ eq	90.6	122	54.1	68.3	73.5	-31.2	36.6	22.3	17.1
Photo-oxidant formation	kg C$_2$H$_4$ eq	0.0565	0.0555	0.0260	0.0455	0.0528	0.00100	0.0305	0.0110	0.00368
Acidification	kg SO$_2$ eq	0.0836	0.0846	0.0222	0.0655	0.0754	-0.00100	0.0613	0.0181	0.00821
Eutrophication	kg PO$_4^{3-}$ eq	0.301	0.291	0.131	-0.00779	0.0973	0.0100	0.170	0.309	0.204
Human toxicity	kg 1,4-DB eq	23.2	23.1	7.15	17.4	20.4	0.0700	16.0	5.75	2.82
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	3.00	2.39	1.16	2.73	2.78	0.616	1.85	0.272	0.220

* Bottle-to-Bottle.

Table 5.20 Impact assessment results for the 30% rPET bottle system with different waste management options (per functional unit)

Impact category	Unit	PET bottle, 30% recycled, landfill	PET bottle, 30% recycled, energy from waste	PET bottle, 30% recycled, BtB* recyc UK	PET bottle, 30% recycled, recyc UK	PET bottle, 30% recycled, recyc China	Differences in potential env. impacts, energy from waste vs landfill	Differences in potential env. impacts, BtB recyc vs landfill	Differences in potential env. impacts, general recyc UK vs landfill	Differences in potential env. impacts, general recyc China vs landfill
Abiotic resource depletion	kg Sb eq	1.04	0.814	0.440	0.574	0.608	0.227	0.600	0.466	0.433
Climate change	kg CO$_2$ eq	90.8	122	54.0	68.5	73.7	-31.2	36.8	22.3	17.1
Photo-oxidant formation	kg C$_2$H$_4$ eq	0.0566	0.0556	0.0259	0.0456	0.0529	0.00100	0.0307	0.0110	0.00368
Acidification	kg SO$_2$ eq	0.0837	0.0847	0.0219	0.0656	0.0755	-0.00100	0.0618	0.0181	0.00821
Eutrophication	kg PO$_4^{3-}$ eq	0.301	0.291	0.130	-0.00744	0.0977	0.0100	0.171	0.309	0.204
Human toxicity	kg 1,4-DB eq	23.2	23.1	7.06	17.5	20.4	0.0700	16.1	5.75	2.82
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	3.01	2.40	1.15	2.74	2.79	0.616	1.86	0.272	0.220

* Bottle-to-Bottle.

Table 5.21 Impact assessment results for the 10% lightweighted 30% rPET bottle system with different waste management options (per functional unit)

Impact category	Unit	PET bottle, 30% recycled, 10% lightweight landfill	PET bottle, 30% recycled, 10% lightweight, energy from waste	PET bottle, 30% recycled, 10% lightweight, BtB* recyc UK	PET bottle, 30% recycled, 10% lightweight, recyc UK	PET bottle, 30% recycled, 10% lightweight, recyc China	Differences in potential env. impacts, energy from waste vs landfill	Differences in potential env. impacts, BtB recyc vs landfill	Differences in potential env. impacts, general recyc UK vs landfill	Differences in potential env. impacts, general recyc China vs landfill
Abiotic resource depletion	kg Sb eq	0.958	0.752	0.416	0.536	0.567	0.207	0.543	0.422	0.392
Climate change	kg CO_2 eq	84.1	112	50.8	63.9	68.6	-28.2	33.3	20.2	15.5
Photo-oxidant formation	kg C_2H_4 eq	0.0525	0.0516	0.0249	0.0426	0.0493	0.000914	0.0277	0.00991	0.00328
Acidification	kg SO_2 eq	0.0764	0.0772	0.0206	0.0600	0.0690	-0.000884	0.0557	0.0163	0.00737
Eutrophication	kg PO_4^{3-} eq	0.277	0.268	0.122	-0.00213	0.0935	0.00931	0.156	0.279	0.184
Human toxicity	kg 1,4-DB eq	21.3	21.2	6.73	16.1	18.8	0.0774	14.6	5.21	2.54
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.79	2.22	1.11	2.54	2.59	0.562	1.68	0.246	0.198

* Bottle-to-Bottle.

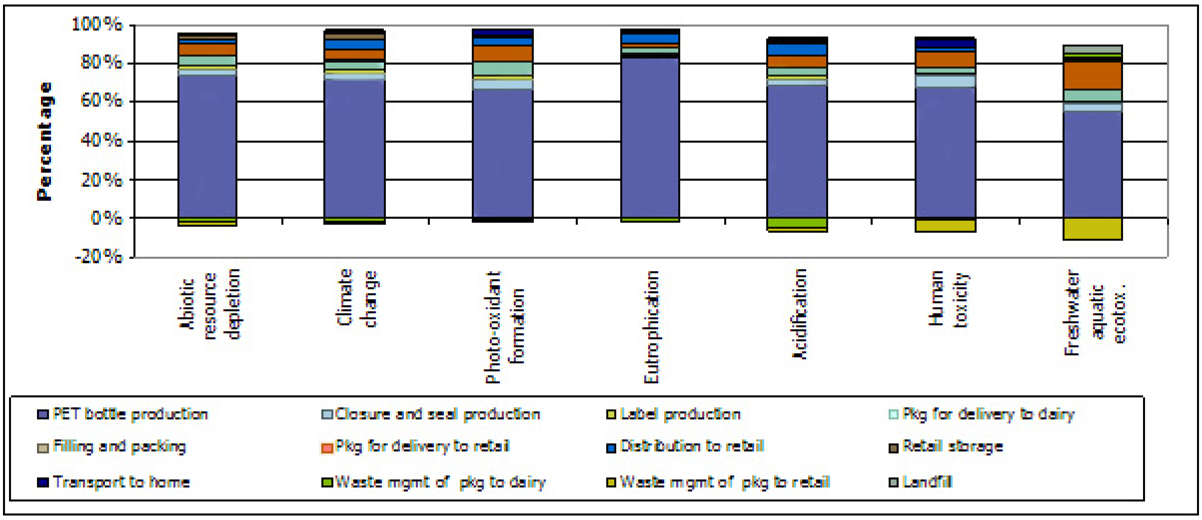
Points of note

- Recycling the PET bottle back into bottles in the UK provides the lowest potential environmental impacts for the impact categories of abiotic resource depletion, climate change, eutrophication, human toxicity and freshwater aquatic eco-toxicity. For the impact categories of photo-oxidant formation and acidification, the PET bottle system with general recycling in the UK as the waste management option has the lowest potential environmental impacts.
- Landfilling the PET bottles provides the highest potential environmental impacts for the impact categories of abiotic resource depletion, photo-oxidant formation, acidification, human toxicity and freshwater aquatic ecotoxicity. Incinerating the bottle with energy recovery contributes the most to the impact categories of climate change, eutrophication and human toxicity.
- Compared to landfill, which is still the most likely end-of-life route for PET bottles, recycling the bottles is shown to lead to lower potential environmental impacts across all impact categories. This is the case whether it is bottle-to-bottle recycling or general recycling both in the UK and China.
- Compared to landfill, incinerating the PET bottles with energy recovery is shown to lead to lower potential environmental impacts across all impact categories, except for climate change and acidification.

5.2.3 Impact assessment results for the different life cycle stages

The environmental impacts associated with the different life cycle stages for the virgin PET bottle system, with landfill as the waste management option for the primary packaging, are shown in *Figure 5.8* below. The results are presented per impact category as 100% stacked columns.

Figure 5.8 Potential environmental impact results associated with the different life cycle stages for the virgin PET bottle with landfill as the waste mgmt option for the primary packaging



Points of note

- PET bottle production is the predominant contributor to all the impact categories assessed. The reason for the significant contribution from bottle production is its weight compared to the weights of the cap, seal, label and secondary and transit packaging used in the system.
- The closure and seal contributes little to the overall results, although slightly more to the impact categories of human toxicity and freshwater aquatic eco-toxicity.
- The packaging used for delivery to the dairy and retail contributes little to the overall result except for the impact category of freshwater aquatic eco-toxicity.
- The contribution of the packaging is somewhat outweighed by the benefits of the assumption that the majority of the secondary and transit packaging is recycled after use.
- The contribution of the filling and packing of the bottles is insignificant when considering the total impacts.
- Distributing the bottles to retail makes some contribution to the overall results, reaching more than 6% for the impacts for the impact categories of eutrophication and acidification.
- Landfill of the primary packaging contributes little to the overall results of all impact categories assessed.

Figures 5.9 to *5.12* show a breakdown of the results for the impact categories of climate change and acidification, as examples.

Figure 5.9 Impact profile for the PET bottle scenarios with the waste management options of landfill, energy from waste, general recycling in the UK and recycling in China – climate change

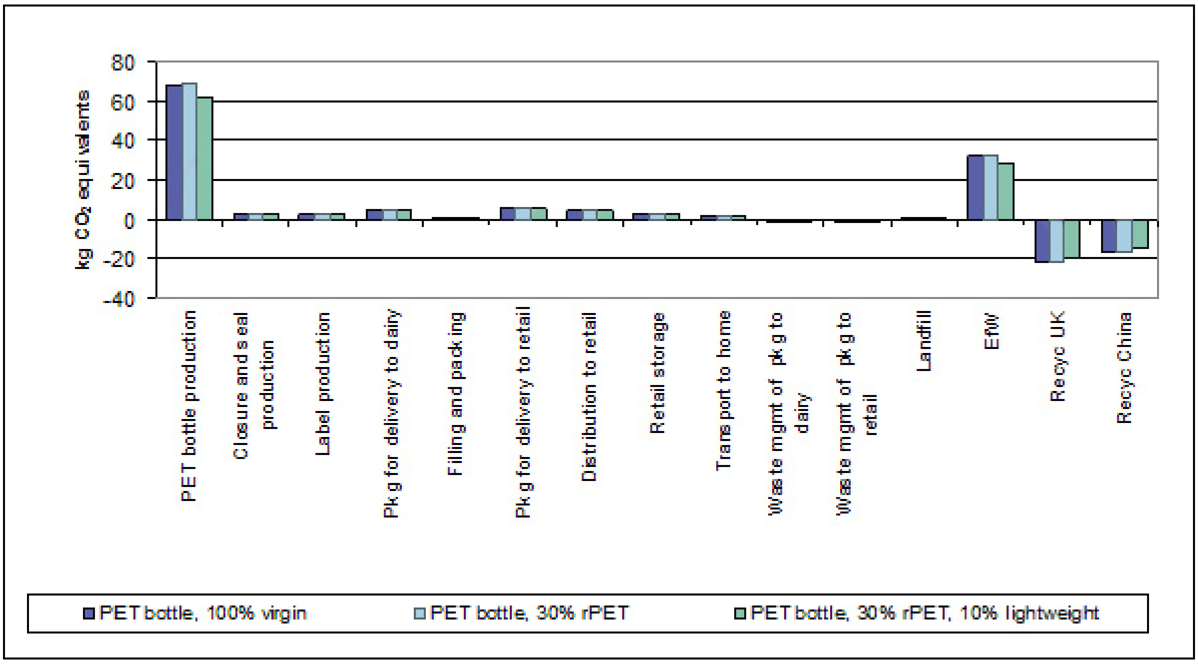
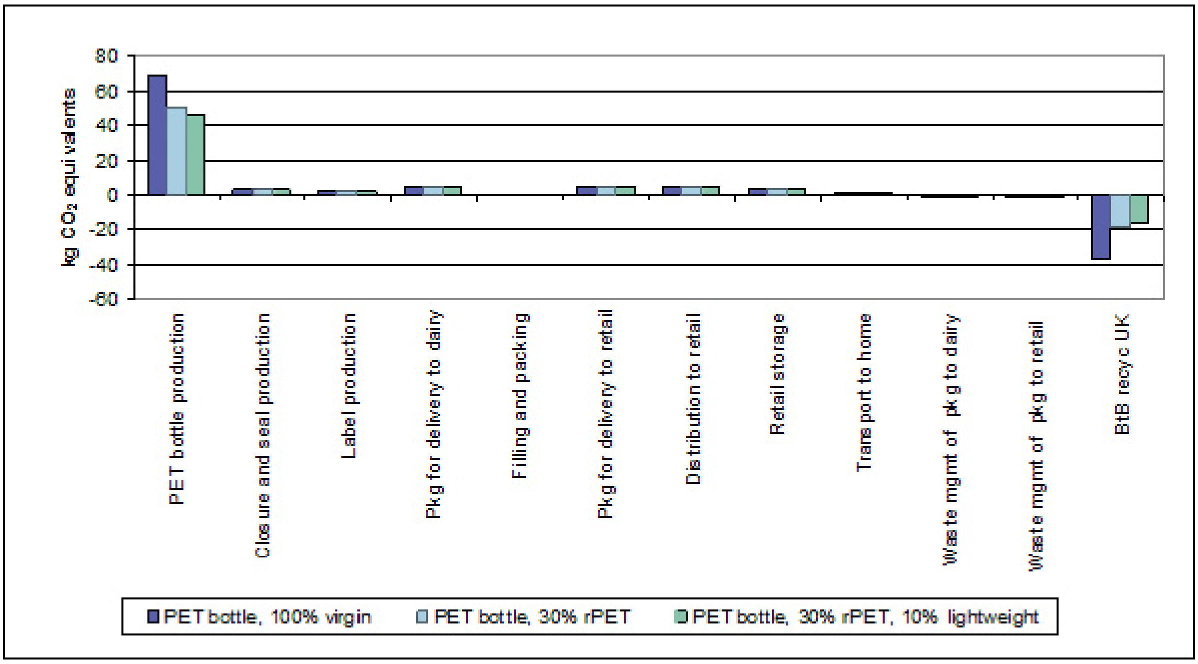


Figure 5.10 Impact profile for the PET bottle scenarios with the waste management options of bottle-to-bottle recycling (closed-loop recycling) – climate change



Points of note

- Bottle production and incineration with energy recovery make the two predominant contributions to this impact category.
- Impacts in PET bottle production are primarily incurred in the raw material stage.
- Impacts in the energy from waste stage are incurred as a result of the combustion of the materials and subsequent carbon dioxide emissions.
- Benefits in the recycling scenarios assessed are achieved through the assumption that the recycled PET results in the avoided production of virgin PET.

- The 10% lightweight system shows lower potential environmental impacts as a result of reduced PET production.
- The life cycle stages associated with cap and seal production, label production, secondary and transit packaging and its waste management, distribution, retail, transport to the home and landfill contribute relatively little to the impact profile for this category.

Figure 5.11 Impact profile for the PET bottle scenarios with the waste management options of landfill, energy from waste, general recycling in the UK and China – acidification

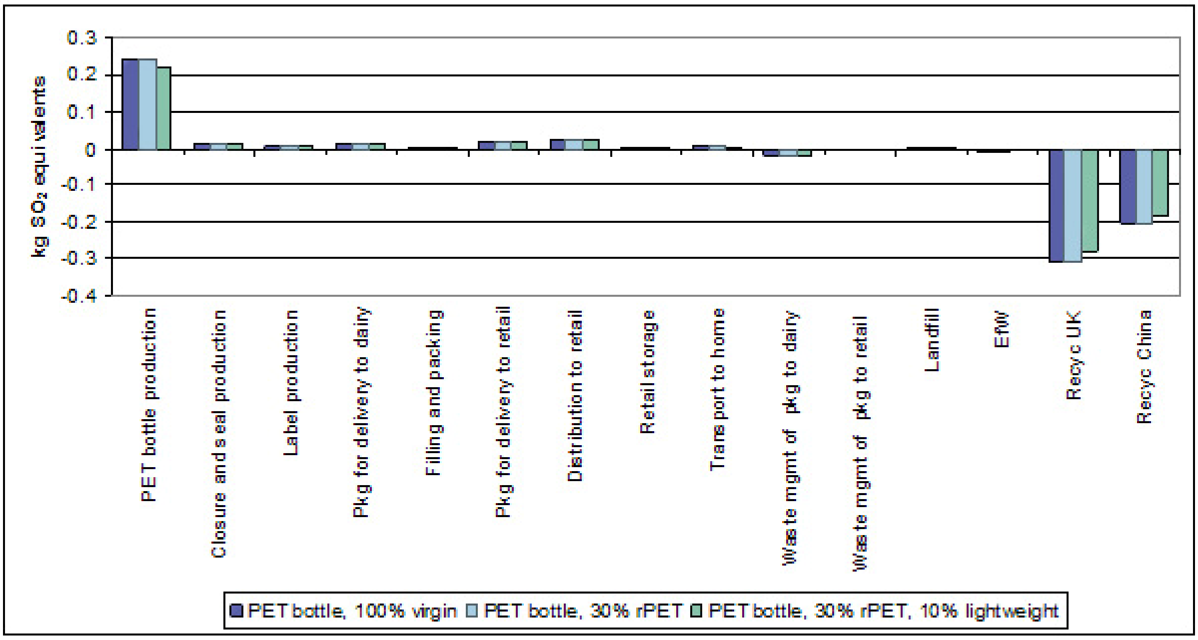
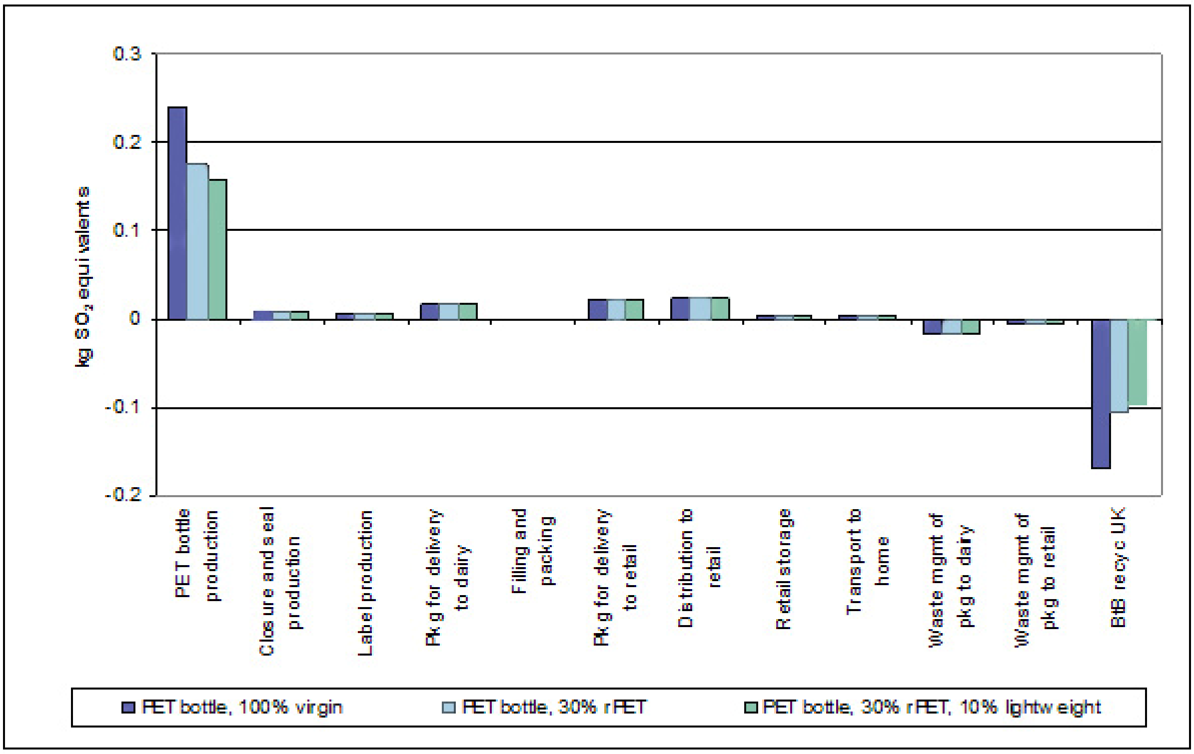


Figure 5.12 Impact profile for the PET bottle scenarios with the waste management option of bottle-to-bottle recycling in the UK (closed-loop recycling) – acidification



Points of note

- PET bottle production makes the predominant contribution to the impact category of acidification.
- Distribution to retail and its packaging also makes some contribution to this impact category. Impacts in the distribution stage are incurred as a result of the emission of acidifying gases during lorry transport.

5.3 The pillow pouch systems

5.3.1 Impact assessment results for the current and lightweight scenarios

Comparisons of the impact assessment results for the current and future lightweight pillow pouch scenarios are presented for the different waste management options in *Table 5.22* to *Table 5.25* below. The results are shown per functional unit, i.e. per 1000 pints.

Table 5.22 Potential environmental impact results for the current and future lightweight pillow pouch scenarios with landfill as the waste management option (per functional unit)

Impact category	Unit	Pillow pouch, 100% virgin, landfill	Pillow pouch, 100% virgin, 10% lightweight, landfill	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.208	0.198	4.7%
Climate change	kg CO_2 eq	23.1	22.5	2.8%
Photo-oxidant formation	kg C_2H_4 eq	0.0159	0.0152	4.3%
Eutrophication	kg PO_4^{3-} eq	0.0247	0.0244	1.5%
Acidification	kg SO_2 eq	0.0904	0.0874	3.3%
Human toxicity	kg 1,4-DB eq	5.76	5.65	2.0%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.17	2.15	0.94%

Points of note

- Reducing the weight of the pouch by 10% is shown to lead to lower potential environmental impacts across all impact categories.
- Based on the assumptions made for the pillow pouch system, the potential environmental impacts of lightweighting are shown to be lower by a relatively small margin. The main reason for this is that the environmental impact of the pouch itself contributes less to the overall result of the pillow pouch system compared to other inputs. A 10% reduction in the weight of the pouch results in potential environmental impacts lower by 4.7% or less for the impact categories assessed.
- Similarly, lower potential environmental impacts are achieved using different waste management options as shown in Tables 5.23 to 5.25 below. As when landfill is considered as the waste management option, the potential environmental impacts of lightweighting are shown to be lower by a relatively small margin.

Table 5.23 Potential environmental impact results for the current and future lightweight pillow pouch scenarios with energy from waste as the waste management option (per functional unit)

Impact category	Unit	Pillow pouch, 100% virgin, energy from waste	Pillow pouch, 100% virgin, 10% lightweight, energy from waste	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.153	0.149	3.1%
Climate change	kg CO_2 eq	25.8	24.9	3.5%
Photo-oxidant formation	kg C_2H_4 eq	0.0156	0.0150	4.2%

Impact category	Unit	Pillow pouch, 100% virgin, energy from waste	Pillow pouch, 100% virgin, 10% lightweight, energy from waste	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Eutrophication	kg PO_4^{3-} eq	0.0244	0.0241	1.4%
Acidification	kg SO_2 eq	0.0849	0.0824	2.9%
Human toxicity	kg 1,4-DB eq	5.49	5.40	1.6%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.02	2.02	0.35%

Table 5.24 Potential impact assessment results for the current and future lightweight pillow pouch scenarios with UK recycling as the waste management option (per functional unit)

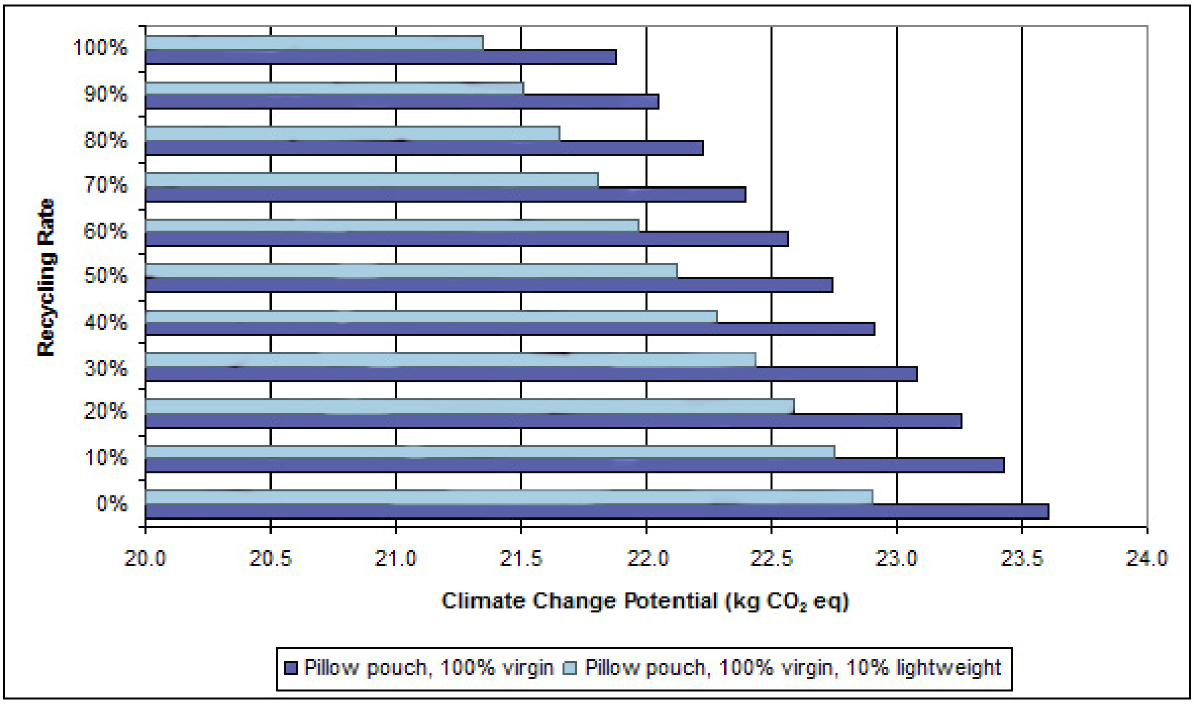
Impact category	Unit	Pillow pouch, 100% virgin, recycling UK	Pillow pouch, 100% virgin, 10% lightweight, recycling UK	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.175	0.168	3.9%
Climate change	kg CO_2 eq	21.9	21.3	2.5%
Photo-oxidant formation	kg C_2H_4 eq	0.0157	0.0150	4.2%
Eutrophication	kg PO_4^{3-} eq	0.0242	0.0239	1.4%
Acidification	kg SO_2 eq	0.0827	0.0803	3.0%
Human toxicity	kg 1,4-DB eq	5.45	5.36	1.6%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.15	2.13	0.87%

Table 5.25 Potential impact assessment results for the current and future lightweight pillow pouch scenarios with recycling in China as the waste management option (per functional unit)

Impact category	Unit	Pillow pouch, 100% virgin, recycling China	Pillow pouch, 100% virgin, 10% lightweight, recycling China	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.179	0.172	4.0%
Climate change	kg CO_2 eq	22.5	21.9	2.6%
Photo-oxidant formation	kg C_2H_4 eq	0.0166	0.0158	4.5%
Eutrophication	kg PO_4^{3-} eq	0.0254	0.0250	1.7%
Acidification	kg SO_2 eq	0.0953	0.0917	3.8%
Human toxicity	kg 1,4-DB eq	5.80	5.68	2.1%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.15	2.14	0.89%

Figure 5.13 below shows the overall results for the pillow pouch system with increasing recycling. As can be seen, increasing the recycling rate shows a decrease in the overall impact of the pillow pouch system. For the quantities not being recycled, it is assumed that 82.4% is landfilled and 17.6% is incinerated with energy recovery. These percentages are based on 2007/08 Defra municipal waste management statistics (Defra 2008b).

Figure 5.13 Environmental impact results associated with increased recycling for the pillow pouch system



5.3.2 Impact assessment results for different end-of-life scenarios

The impact assessment results for different waste management options for the current and future lightweight pillow pouch scenarios are presented in *Table 5.26* and *Table 5.27* below. The results are shown per functional unit, i.e. per 1000 pints.

As landfill is the most likely end-of-life route for the pillow pouch currently in the UK, the energy from waste and recycling options are compared to this.

Table 5.26 Potential impact assessment results for the pillow pouch system with different waste management options (per functional unit)

Impact category	Unit	Pillow pouch, landfill	Pillow pouch, energy from waste	Pillow pouch, recyc UK	Pillow pouch, recyc China	Differences in potential environmental impacts, energy from waste vs landfill	Differences in potential environmental impacts, UK recycling vs landfill	Potential environmental saving, Chinese recycling vs landfill
Abiotic resource depletion	kg Sb eq	0.208	0.153	0.175	0.179	0.0544	0.0325	0.0285
Climate change	kg CO_2 eq	23.1	25.8	21.9	22.5	-2.64	1.26	0.635
Photo-oxidant formation	kg C_2H_4 eq	0.0159	0.0156	0.0157	0.0166	0.000264	0.000163	-0.000708
Eutrophication	kg PO_4^{3-} eq	0.0247	0.0244	0.0242	0.0254	0.000334	0.000504	-0.000675
Acidification	kg SO_2 eq	0.0904	0.0849	0.0827	0.0953	0.00552	0.00767	-0.00492
Human toxicity	kg 1,4-DB eq	5.76	5.49	5.45	5.80	0.267	0.308	-0.0429
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.17	2.02	2.15	2.15	0.146	0.0194	0.0132

Table 5.27 Potential impact assessment results for the 10% lightweighted pillow pouch system with different waste management options (per functional unit)

Impact category	Unit	Pillow pouch, 10% lightweight landfill	Pillow pouch, 10% lightweight, energy from waste	Pillow pouch, 10% lightweight, recyc UK	Pillow pouch, 10% lightweight, recyc China	Differences in potential environmental impacts, energy from waste vs landfill	Differences in potential environmental impacts, UK recycling vs landfill	Potential environmental saving, Chinese recycling vs landfill
Abiotic resource depletion	kg Sb eq	0.198	0.149	0.168	0.172	0.0494	0.0296	0.0259
Climate change	kg CO_2 eq	22.5	24.9	21.3	21.9	-2.39	1.14	0.576
Photo-oxidant formation	kg C_2H_4 eq	0.0152	0.0150	0.0150	0.0158	0.000240	0.000154	-0.000638
Eutrophication	kg PO_4^{3-} eq	0.0244	0.0241	0.0239	0.0250	0.000303	0.000465	-0.000607
Acidification	kg SO_2 eq	0.0874	0.0824	0.0803	0.0917	0.00501	0.00712	-0.00432
Human toxicity	kg 1,4-DB eq	5.65	5.40	5.36	5.68	0.242	0.281	-0.0378
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.15	2.02	2.13	2.14	0.132	0.0175	0.0119

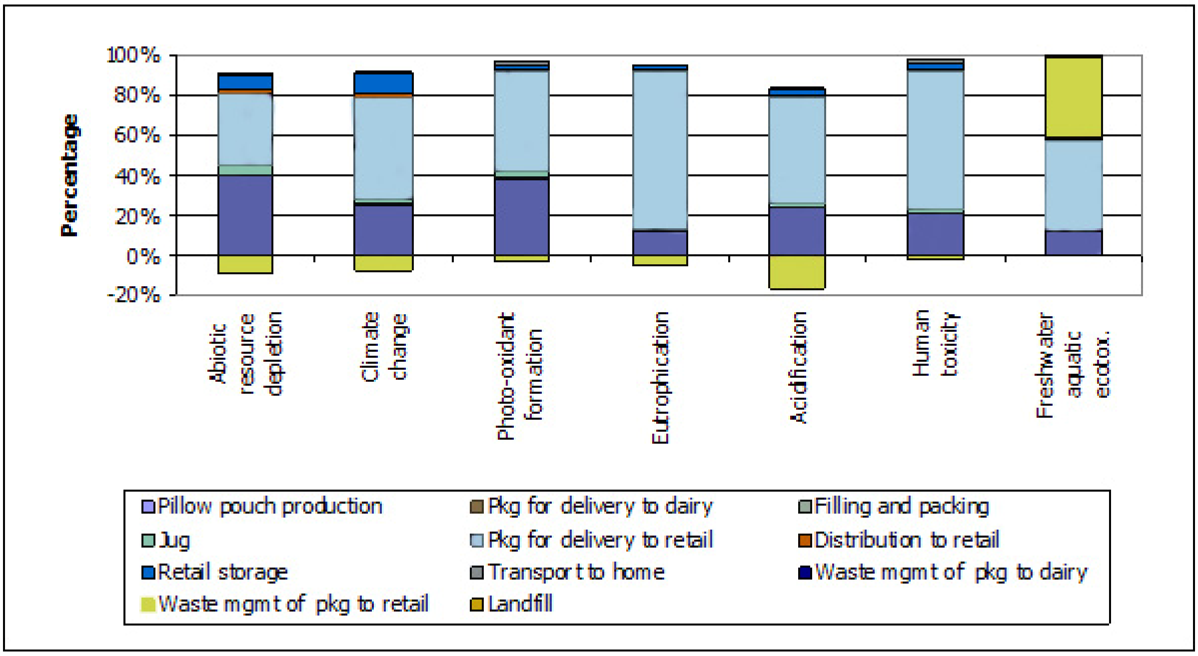
Points of note

- Recycling the pillow pouch in the UK provides the lowest potential environmental impacts for the impact categories of climate change, eutrophication, acidification and human toxicity. For the impact categories of abiotic resources, photo-oxidant formation and freshwater aquatic ecotoxicity, the pillow pouch system with energy from waste as the waste management option has the lowest potential environmental impacts.
- Landfilling contributes the most to the impact categories of abiotic depletion, human toxicity and freshwater aquatic ecotoxicity. Recycling in China contributes to most to the impact categories of photo-oxidant formation, eutrophication and acidification.
- The highest potential climate change impact is caused by incinerating the pillow pouch.
- Compared to landfill, which is currently the most likely end-of-life route for pillow pouches, recycling the pouch in the UK is shown to lead to lower potential environmental impacts across all impact categories. It must be noted that this is based on the assumption that the pouch is recycled as part of the plastic film waste stream.
- Lower potential environmental impacts are also shown when the pouch is incinerated with energy recovery rather than landfilled, except for climate change, which shows an 12% increase.
- Lower potential environmental impacts are achieved if the pouch is sent for recycling in China compared to landfilling it for the impact categories of abiotic resource depletion, global warming, and freshwater aquatic eco-toxicity. For the impact categories of photo-oxidant formation, eutrophication, acidification and human toxicity recycling in China gives rise to higher environmental impacts.

5.3.3 Impact assessment results for the different life cycle stages

The environmental impacts associated with the different life cycle stages for the pillow pouch system, with landfill as the waste management option for the primary packaging, are shown in *Figure 5.14* below.

Figure 5.14 Environmental impact results associated with the different life cycle stages for the pillow pouch with landfill as the waste mgmt option for the primary packaging

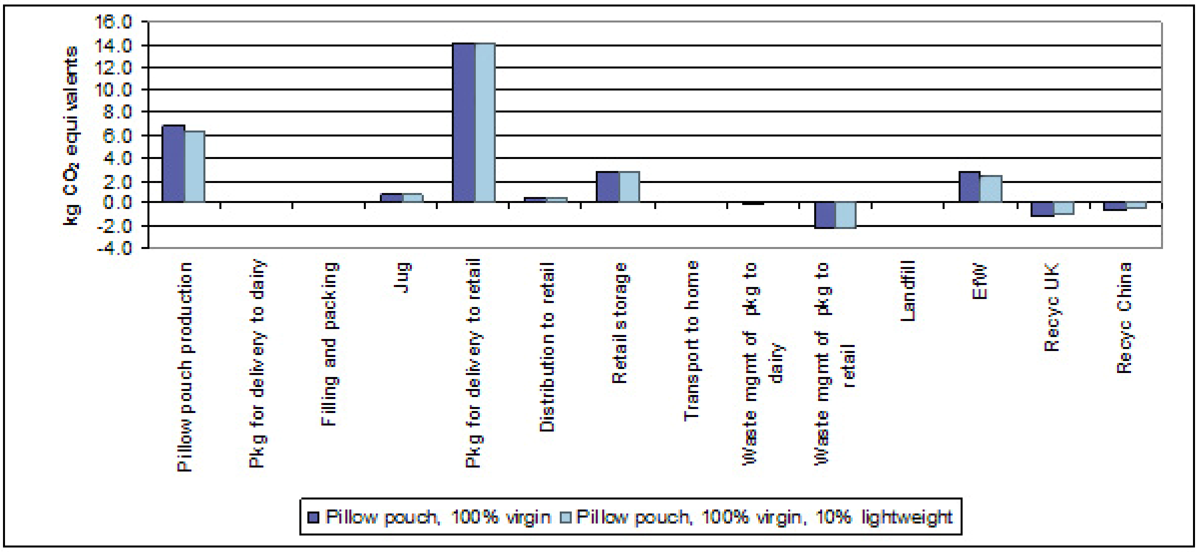


Points of note

- Pouch production and distribution packaging are the two predominant contributors to the impact categories assessed.
- The impact of the distribution packaging is somewhat outweighed by the benefit of its assumed recycling after use, except for freshwater aquatic ecotoxicity where recycling after use leads to an impact.
- The reason for the distribution packaging having such a high impact is a result of the weight of the corrugated board in comparison to that of the pouch. The main contributors to the impact are high consumption of fossil fuels and fossil fuel derived electricity in the corrugated board production.
- The jug, with its assumed high reuse rate, contributes little to the impact categories.
- Landfill of the pouch and jug after use contribute little to the overall results.

Figures 5.15 and *5.16* show a breakdown of the results for the impact categories of climate change and freshwater aquatic ecotoxicity, as examples.

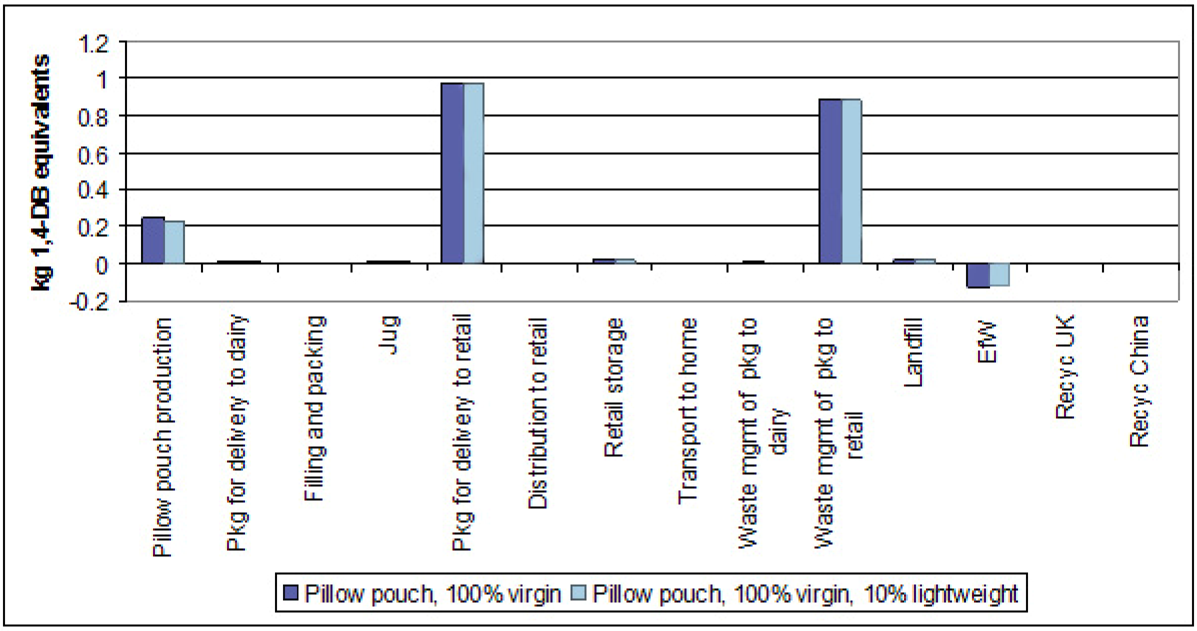
Figure 5.15 Impact profile for the pillow pouch scenarios – climate change



Points of note

- Pouch production and distribution packaging are the two predominant contributors to climate change impacts.
- Impacts in pouch production are incurred both in the pouch converting and raw material stage.
- Impacts in distribution packaging are incurred as a result of the consumption of fossil fuels and fossil fuel derived electricity in the corrugated board production.
- Impacts in retail are incurred as a result of fossil fuel derived electricity consumed for refrigeration.
- Impacts in the energy from waste stage are incurred as a result of the combustion of materials and subsequent carbon dioxide emissions. It must be noted that the process is assumed to include only electricity generation, direct use of heat recovered from waste combustion plant is rare in the UK.
- Recycling is seen to provide benefits through the avoidance of virgin material production. The benefit of sending the pouches and jugs to China for recycling is less compared to recycling these in the UK due to the impact of transporting the waste around the globe. It must be noted that the recycling processes are assumed to be similar for both countries due to a lack of information about Chinese recycling processes.
- Landfill is shown to contribute minimally to this impact category.

Figure 5.16 Impact profile for the pillow pouch scenarios – freshwater aquatic ecotoxicity



Points of note

- Distribution packaging and its waste management are the two predominant contributors to freshwater aquatic eco-toxicity.
- Combustion processes are key factors influencing acidification impacts, due to the emission of acidifying gases.
- The reason for the distribution packaging having such a high impact is a result of acidifying gas emissions from fossil fuel derived electricity generation used in the board production.

5.4 The stand-up pouch systems

5.4.1 Impact assessment results for the current and lightweight scenarios

Comparisons of the impact assessment results for the current and future lightweight stand-up pouch scenarios are presented for the different waste management options in *Table 5.28* to *Table 5.31* below. The results are shown per functional unit, i.e. per 1000 pints.

Table 5.28 Potential impact assessment results for the current and future lightweight stand-up pouch scenarios with landfill as the waste management option (per functional unit)

Impact category	Unit	Stand-up pouch, 100% virgin, landfill	Stand-up pouch, 100% virgin, 10% lightweight, landfill	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.327	0.303	7.4%
Climate change	kg CO_2 eq	33.2	31.4	5.4%
Photo-oxidant formation	kg C_2H_4 eq	0.0247	0.0232	6.4%
Eutrophication	kg PO_4^{3-} eq	0.0257	0.0246	4.6%
Acidification	kg SO_2 eq	0.107	0.100	7.0%
Human toxicity	kg 1,4-DB eq	6.82	6.58	3.5%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.15	2.10	2.4%

Points of note

- Reducing the weight of the pouch by 10% is shown to lead to lower potential environmental impacts across all impact categories.
- Based on the assumptions made for the stand-up pouch system, the differences in potential environmental impacts are shown to be 7.4% or less for the different impact categories.
- Similarly, lower potential environmental impacts are achieved using different waste management options as shown in Tables 5.29 to 5.31 below.

Table 5.29 Potential impact assessment results for the current and future lightweight stand-up pouch scenarios with energy from waste as the waste management option (per functional unit)

Impact category	Unit	Stand-up pouch, 100% virgin, energy from waste	Stand-up pouch, 100% virgin, 10% lightweight, energy from waste	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.160	0.152	4.7%
Climate change	kg CO_2 eq	41.3	38.7	6.3%
Photo-oxidant formation	kg C_2H_4 eq	0.0239	0.0224	6.3%
Eutrophication	kg PO_4^{3-} eq	0.0247	0.0236	4.3%
Acidification	kg SO_2 eq	0.0901	0.0843	6.5%
Human toxicity	kg 1,4-DB eq	6.00	5.84	2.6%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	1.71	1.70	0.35%

Table 5.30 Potential impact assessment results for the current and future lightweight stand-up pouch scenarios with UK recycling as the waste management option (per functional unit)

Impact category	Unit	Stand-up pouch, 100% virgin, recycling UK	Stand-up pouch, 100% virgin, 10% lightweight, recycling UK	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.229	0.214	6.3%
Climate change	kg CO_2 eq	29.4	28.0	4.9%
Photo-oxidant formation	kg C_2H_4 eq	0.0244	0.0229	6.3%
Eutrophication	kg PO_4^{3-} eq	0.0244	0.0234	4.3%
Acidification	kg SO_2 eq	0.0887	0.0830	6.4%
Human toxicity	kg 1,4-DB eq	5.92	5.77	2.5%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.09	2.05	2.1%

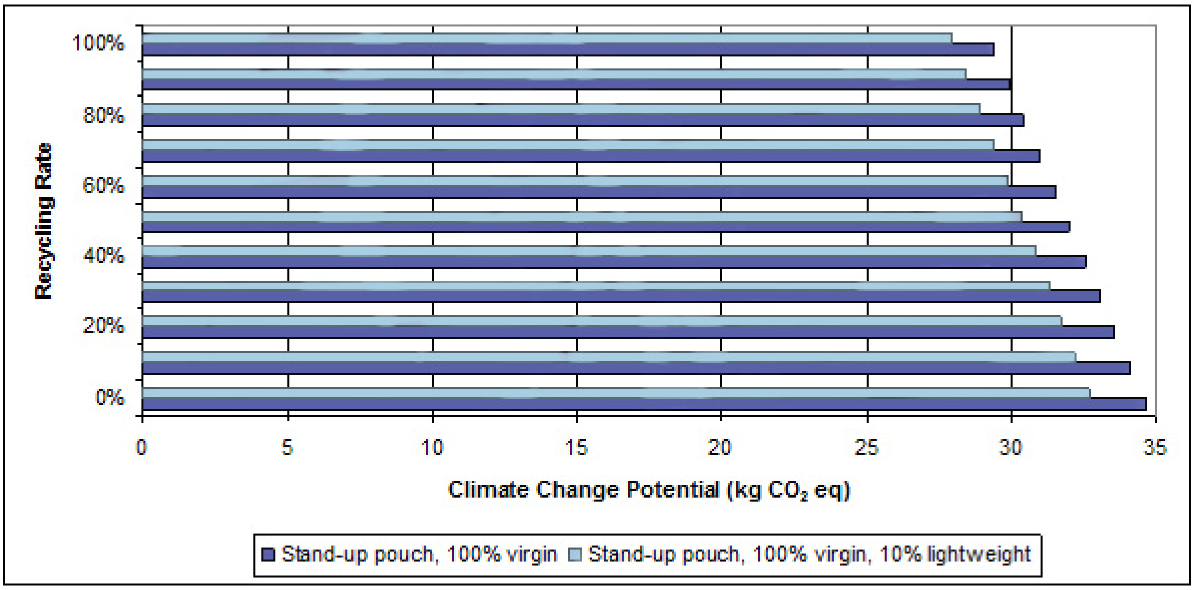
Table 5.31 Potential impact assessment results for the current and future lightweight stand-up pouch scenarios with recycling in China as the waste management option (per functional unit)

Impact category	Unit	Stand-up pouch, 100% virgin, recycling China	Stand-up pouch, 100% virgin, 10% lightweight, recycling China	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.241	0.225	6.5%
Climate change	kg CO_2 eq	31.3	29.7	5.2%

Impact category	Unit	Stand-up pouch, 100% virgin, recycling China	Stand-up pouch, 100% virgin, 10% lightweight, recycling China	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Photo-oxidant formation	kg C_2H_4 eq	0.0271	0.0253	6.7%
Eutrophication	kg PO_4^{3-} eq	0.0280	0.0266	5.0%
Acidification	kg SO_2 eq	0.127	0.118	7.5%
Human toxicity	kg 1,4-DB eq	7.00	6.74	3.7%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.11	2.06	2.2%

Figure 5.17 below shows the overall result for the stand-up pouch system with increased recycling. As can be seen, increasing the recycling rate shows a decrease in the overall impact of the stand-up pouch system. For the quantities not being recycled, it is assumed that 82.4% is landfilled and 17.6% is incinerated with energy recovery. These percentages are based on 2007/08 Defra municipal waste management statistics (Defra 2008b).

Figure 5.17 Environmental impact results associated with increased recycling for the stand-up pouch system



5.4.2 Impact assessment results for different end-of-life scenarios

The impact assessment results for different waste management options for the current and future lightweight stand-up scenarios are presented in *Table 5.32* and *Table 5.33* below.

As landfill is the most likely end-of-life route for the stand-up pouch currently in the UK, the energy from waste and recycling options are compared to this, and the differences in potential environmental impacts are listed in the table.

Table 5.32 Impact assessment results for the stand-up pouch system with different waste management options (per functional unit)

Impact category	Unit	Stand-up pouch, landfill	Stand-up pouch, energy from waste	Stand-up pouch, recyc UK	Stand-up pouch, recyc China	Differences in potential env. impacts, energy from waste vs landfill	Differences in potential env. impacts, UK recycling vs landfill	Differences in potential env. impacts, Chinese recycling vs landfill
Abiotic resource depletion	kg Sb eq	0.327	0.160	0.229	0.241	0.167	0.0983	0.0860
Climate change	kg CO_2 eq	33.2	41.3	29.4	31.3	-8.12	3.83	1.91
Photo-oxidant formation	kg C_2H_4 eq	0.0247	0.0239	0.0244	0.0271	0.000813	0.000308	-0.00237
Eutrophication	kg PO_4^{3-} eq	0.0257	0.0247	0.0244	0.0280	0.00103	0.00132	-0.00231
Acidification	kg SO_2 eq	0.107	0.0901	0.0887	0.127	0.0170	0.0183	-0.0204
Human toxicity	kg 1,4-DB eq	6.82	6.00	5.92	7.00	0.821	0.903	-0.177
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.15	1.71	2.09	2.11	0.448	0.0620	0.0429

Table 5.33 Impact assessment results for the 10% lightweighted stand-up pouch system with different waste management options (per functional unit)

Impact category	Unit	Stand-up pouch, 10% lightweight landfill	Stand-up pouch, 10% lightweight, energy from waste	Stand-up pouch, 10% lightweight, recyc UK	Stand-up pouch, 10% lightweight, recyc China	Differences in potential env. impacts, energy from waste vs landfill	Differences in potential env. impacts, UK recycling vs landfill	Differences in potential env. impacts, Chinese recycling vs landfill
Abiotic resource depletion	kg Sb eq	0.303	0.152	0.214	0.225	0.151	0.0885	0.0774
Climate change	kg CO_2 eq	31.4	38.7	28.0	29.7	-7.30	3.44	1.72
Photo-oxidant formation	kg C_2H_4 eq	0.0232	0.0224	0.0229	0.0253	0.000732	0.000277	-0.00214
Eutrophication	kg PO_4^{3-} eq	0.0246	0.0236	0.0234	0.0266	0.000925	0.00119	-0.00208
Acidification	kg SO_2 eq	0.100	0.0843	0.0830	0.118	0.0153	0.0165	-0.0184
Human toxicity	kg 1,4-DB eq	6.58	5.84	5.77	6.74	0.739	0.813	-0.159
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.10	1.70	2.05	2.06	0.403	0.0558	0.0386

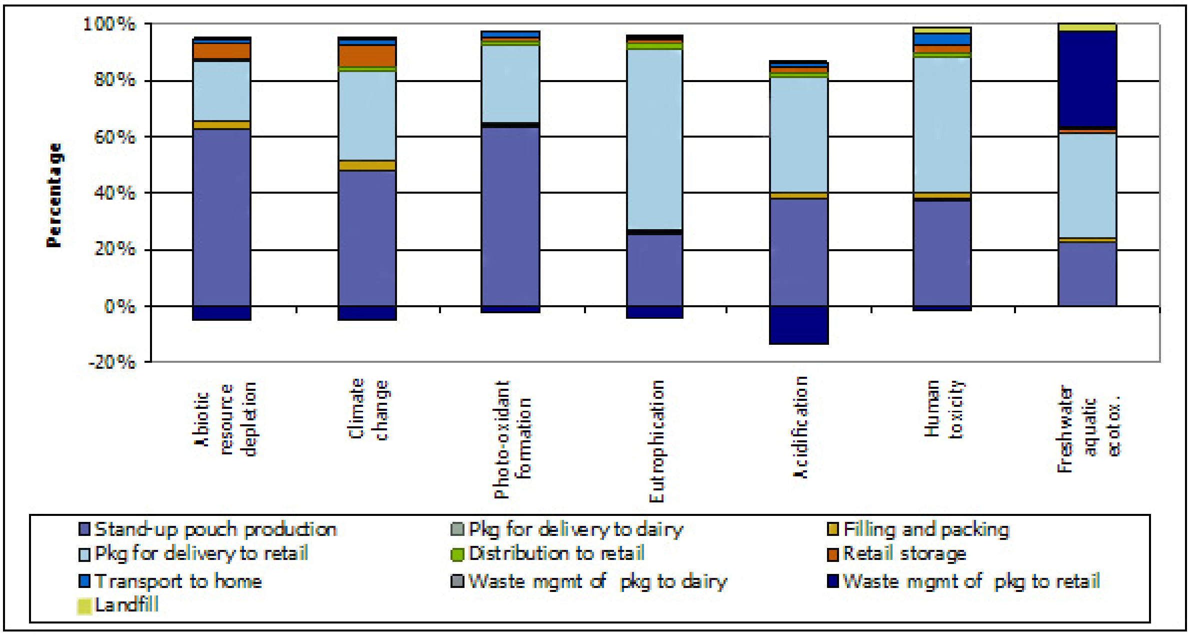
Points of note

- Recycling the stand-up pouch in the UK provides the lowest potential environmental impacts for the impact categories of climate change, eutrophication, acidification and human toxicity. For the impact categories of abiotic resources, photo-oxidant formation and freshwater aquatic ecotoxicity, the stand-up pouch system with energy from waste as the waste management option has the lowest potential environmental impacts.
- Landfilling contributes the most to the impact categories of abiotic depletion, human toxicity and freshwater aquatic ecotoxicity. Recycling in China contributes to most to the impact categories of photo-oxidant formation, eutrophication and acidification.
- The highest potential climate change impact is caused by incinerating the stand-up pouch.
- Compared to landfill, which is currently the most likely end-of-life route for pillow pouches, recycling the pouch in the UK is shown to lead to lower potential environmental impacts across all impact categories. It must be noted that this is based on the assumption that the pouch is recycled as part of the plastic film waste stream.
- Lower potential environmental impacts are also shown when incinerating the pouch with energy recovery rather than landfilling it, except for climate change. Climate change is higher for incineration due to the greenhouse gas emissions associated with the combustion of the pouch.
- Lower potential impacts are achieved are achieved for abiotic resource depletion, climate change and freshwater aquatic ecotoxicity if sending the pouch for recycling in China rather than landfilling it.

5.4.3 Impact assessment results for the different life cycle stages

The environmental impacts associated with the different life cycle stages for the stand-up pouch system, with landfill as the waste management option for the primary packaging, are shown in *Figure 5.18* below.

Figure 5.18 Potential environmental impact results associated with the different life cycle stages for the stand-up pouch with landfill as the waste mgmt option for the primary packaging

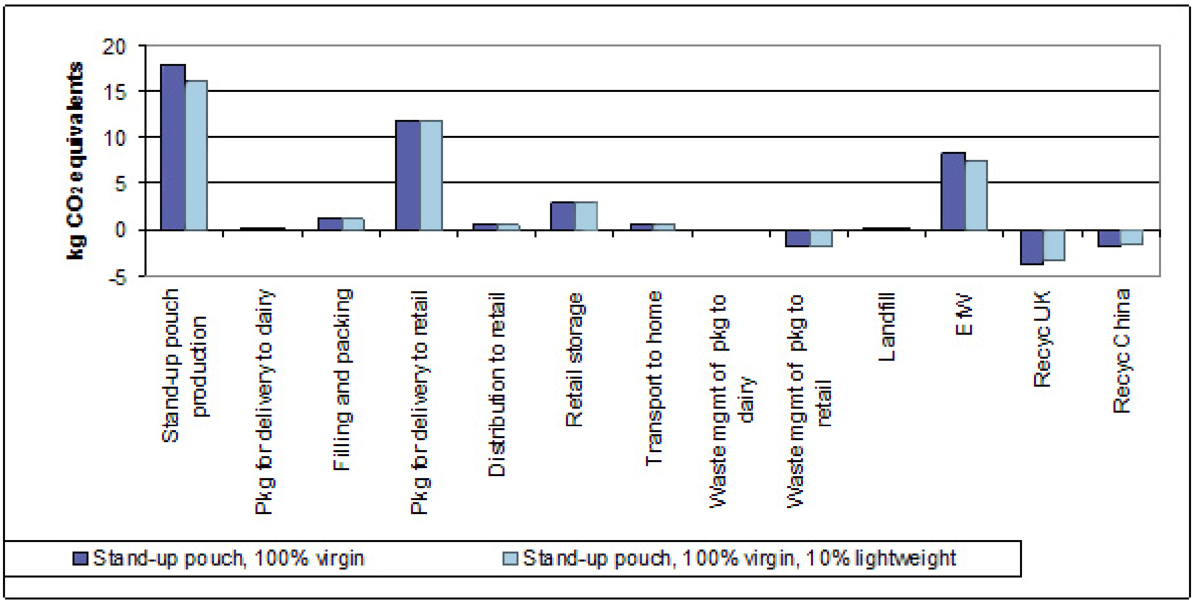


Points of note

- Pouch production and distribution packaging are the two predominant contributors to the impact categories assessed.
- The impact of the distribution packaging is somewhat outweighed by the benefit of its assumed recycling after use, except for freshwater aquatic ecotoxicity, where the recycling after use leads to an impact.
- The energy use for refrigeration in retail is shown to contribute some for the impact categories of abiotic resource depletion and climate change.
- The other life cycle stages contribute little to the overall results.

Figures 5.19 and *5.20* show a breakdown of the results for the impact categories of climate change and freshwater aquatic ecotoxicity, as examples.

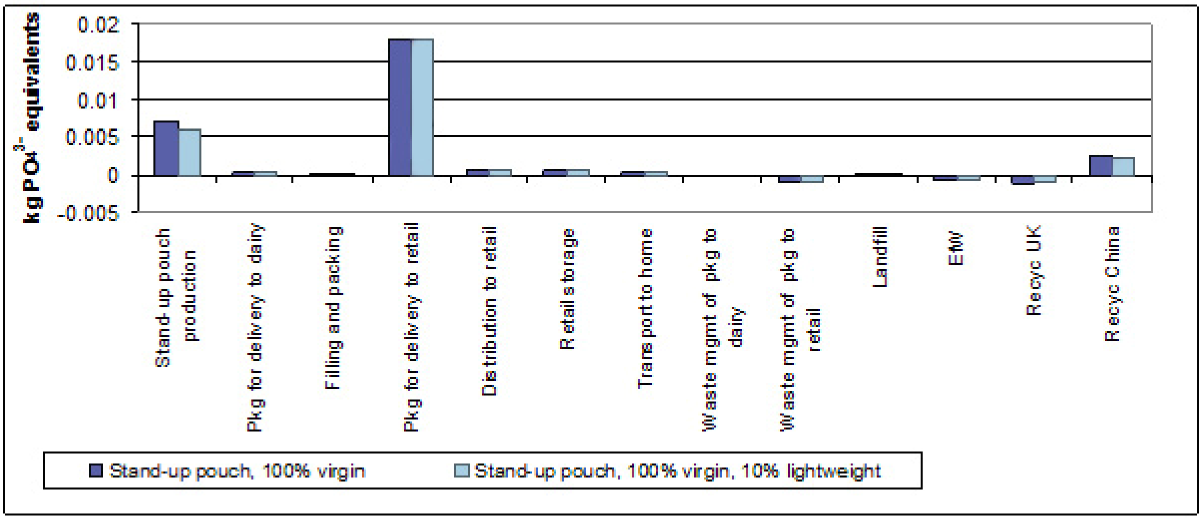
Figure 5.19 Impact profile for the stand-up pouch scenarios – climate change



Points of note

- Pouch production, distribution packaging, and incineration at end-of-life are the three predominant contributors to climate change impacts.
- Impacts in pouch production are primarily incurred in the raw material stage.
- Impacts in distribution packaging are incurred as a result of the consumption of fossil fuels and fossil fuel derived electricity in the corrugated board production.
- Impacts in the retail stage are incurred as a result of the consumption of fossil fuel derived electricity for refrigeration.
- Impacts in the energy from waste stage are incurred as a result of the combustion of the materials and subsequent carbon dioxide emissions. It must be noted that the process used to represent incineration of pouches in the UK includes only electricity generation, direct use of heat recovered from waste combustion plant is rare in the UK.
- Benefits in the recycling scenarios assessed are achieved through the assumption that the recycled pouch results in the avoided production of virgin polymers. The benefit of sending the pouches to China for recycling is less compared to recycling these in the UK due to the impact of transporting the waste to China. It must be noted, that the recycling processes are assumed to be similar for both countries due to a lack of information about Chinese recycling processes.

Figure 5.20 Impact profile for the stand-up pouch scenarios – eutrophication



Points of note

- Distribution packaging and stand-up pouch production are the two predominant contributors to eutrophication.
- Life cycle stages that contribute to the emission of effluent with high biological oxygen demand to watercourse contribute to the results of this impact category.
- Impacts in distribution packaging production are incurred in the board base paper production processes. Interrogating the results closer shows that eutrophication impacts are predominantly incurred from natural gas consumption in the board base paper production processes.
- Impacts in pouch production are primarily incurred in the raw material stage. Interrogating the results closer shows that the eutrophication impacts are predominantly incurred from natural gas consumption polymer production.

5.5 The carton with screwcap systems

5.5.1 Impact assessment results for the current and lightweight scenarios

The potential environmental impact assessment results for the current and future lightweight carton with screwcap scenarios are presented for the different waste management options in *Table 5.34* to *Table 5.36* below. The results are shown per functional unit, i.e. per 1000 pints.

Table 5.34 Potential environmental impact assessment results for the current and future lightweight carton with screwcap scenarios with landfill as the waste management option (per functional unit)

Impact category	Unit	Carton with screwcap, 100% virgin, landfill	Carton with screwcap, 100% virgin, 10% lightweight, landfill	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.379	0.374	1.3%
Climate change	kg CO_2 eq	40.5	39.1	3.5%
Photo-oxidant formation	kg C_2H_4 eq	0.0304	0.0297	2.1%
Eutrophication	kg PO_4^{3-} eq	0.0207	0.0193	6.8%
Acidification	kg SO_2 eq	0.135	0.130	4.0%
Human toxicity	kg 1,4-DB eq	8.11	7.77	4.2%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	1.24	1.17	5.3%

Points of note

- Reducing the weight of the carton by 10% is shown to lead to lower potential environmental impacts across all impact categories.
- Based on the assumptions made for the carton system, the potential environmental impacts of lightweighting are shown to be lower by a relatively small margin. The main reason for this is that the 10% assumption is just for the board and the environmental impact of the board itself contributes less to the overall result of the carton system compared to other inputs. A 10% reduction in the weight of the board results in potential impacts 6.8% lower or less for the different impact categories.
- Similarly, lower potential environmental impacts are achieved using different waste management options as shown in Tables 5.35 and 5.36 below.
- As seen in Table 5.35 below, for cartons where the waste management option is incineration with energy recovery, there is a potential environmental burden associated with the lightweighting of the carton for abiotic resource depletion. This is an indication that the quantity of abiotic resources avoided through energy recovery is higher than the quantity of abiotic resources used during the other life cycle stages of the carton. As more fossil fuel derived electricity is avoided for the current carton with screwcap, due to the heavier weight, the impact is higher for the lightweight scenario.

Table 5.35 Potential environmental impact assessment results for the current and future lightweight carton with screwcap scenarios with energy from waste as the waste management option (per functional unit)

Impact category	Unit	Carton with screwcap, 100% virgin, energy from waste	Carton with screwcap, 100% virgin, 10% lightweight, energy from waste	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.208	0.208	-0.18%
Climate change	kg CO_2 eq	35.0	34.7	0.83%
Photo-oxidant formation	kg C_2H_4 eq	0.0316	0.0307	2.6%
Eutrophication	kg PO_4^{3-} eq	0.0209	0.0194	7.1%
Acidification	kg SO_2 eq	0.127	0.121	4.5%
Human toxicity	kg 1,4-DB eq	7.43	7.10	4.5%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.868	0.808	6.9%

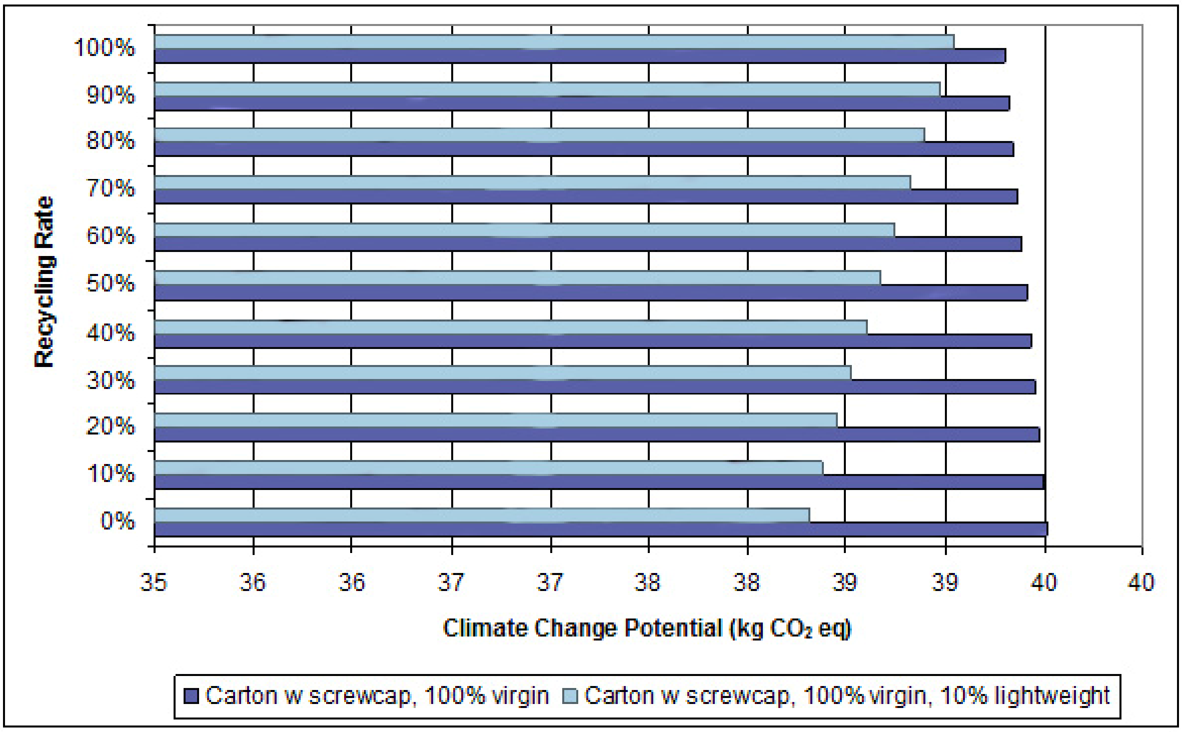
Table 5.36 Potential environmental impact assessment results for the current and future lightweight carton with screwcap scenarios with UK recycling as the waste management option (per functional unit)

Impact category	Unit	Carton with screwcap, 100% virgin, recycling in Sweden	Carton with screwcap, 100% virgin, 10% lightweight, recycling in Sweden	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.254	0.250	1.5%
Climate change	kg CO_2 eq	39.8	39.0	1.8%
Photo-oxidant formation	kg C_2H_4 eq	0.0284	0.0279	1.6%
Eutrophication	kg PO_4^{3-} eq	0.0125	0.0119	4.8%
Acidification	kg SO_2 eq	0.100	0.0975	2.7%
Human toxicity	kg 1,4-DB eq	6.59	6.36	3.6%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.663	0.624	5.8%

Figure 5.21 below shows the overall results for the carton with screwcap system with increased recycling. For the quantities not being recycled, it is assumed hat 82.4% is landfilled and 17.6% is incinerated with energy recovery. These percentages are based on 2007/08 Defra municipal waste management statistics (Defra 2008b).

As can be seen, increasing the recycling rate shows an increase in the overall impact of the carton system due to the overall climate change result for recycling being higher than for energy from waste.

Figure 5.21 Environmental impact results associated with increased recycling for the carton with screwcap system



5.5.2 Impact assessment results for different end-of-life scenarios

The impact assessment results for different waste management options for the current and future lightweight carton with screwcap scenarios are presented in *Table 5.37* and *Table 5.38* below.

As landfill is the most likely end-of-life route for cartons currently in the UK, the energy from waste and recycling options are compared to this, and the differences in potential environmental impacts are listed in the table.

Table 5.37 Potential impact assessment results for the carton with screwcap system with different waste management options (per functional unit)

Impact category	Unit	Carton with screwcap, landfill	Carton with screwcap, energy from waste	Carton with screwcap, recyc Sweden	Differences in potential environmental impacts, energy from waste vs landfill	Differences in potential environmental impacts, Swedish recycling vs landfill
Abiotic resource depletion	kg Sb eq	0.379	0.208	0.254	0.171	0.125
Climate change	kg CO_2 eq	40.5	35.0	39.8	5.48	0.712
Photo-oxidant formation	kg C_2H_4 eq	0.0304	0.0316	0.0284	-0.00120	0.00199
Eutrophication	kg PO_4^{3-} eq	0.0207	0.0209	0.0125	-0.000204	0.00827
Acidification	kg SO_2 eq	0.135	0.127	0.100	0.00872	0.0353
Human toxicity	kg 1,4-DB eq	8.11	7.43	6.59	0.679	1.52
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	1.24	0.868	0.663	0.373	0.578

Table 5.38 Potential impact assessment results for the 10% lightweighted carton with screwcap system with different waste management options (per functional unit)

Impact category	Unit	Carton with screwcap, 10% lightweight landfill	Carton with screwcap, 10% lightweight, energy from waste	Carton with screwcap, 10% lightweight, recyc Sweden	Differences in potential environmental impacts, energy from waste vs landfill	Differences in potential environmental impacts, Swedish recycling vs landfill
Abiotic resource depletion	kg Sb eq	0.374	0.208	0.250	0.165	0.124
Climate change	kg CO_2 eq	39.1	34.7	39.0	4.36	0.0310
Photo-oxidant formation	kg C_2H_4 eq	0.0297	0.0307	0.0279	-0.00102	0.00180
Eutrophication	kg PO_4^{3-} eq	0.0193	0.0194	0.0119	-0.000112	0.00746
Acidification	kg SO_2 eq	0.130	0.121	0.0975	0.00902	0.0326
Human toxicity	kg 1,4-DB eq	7.77	7.10	6.36	0.668	1.41
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	1.17	0.808	0.624	0.367	0.551

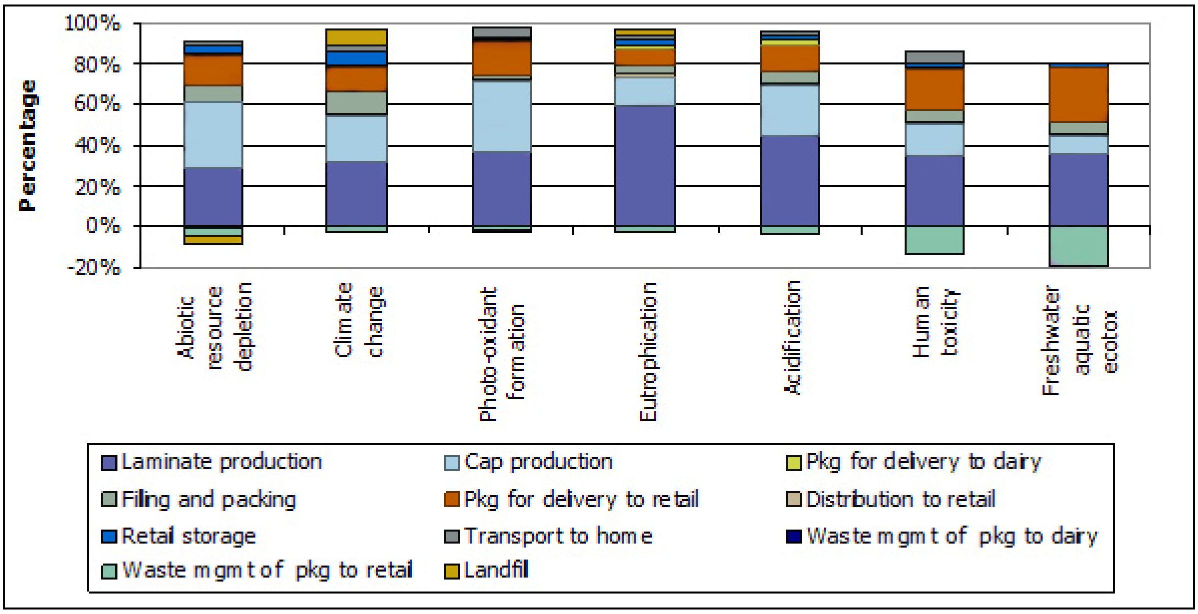
Points of note

- The carton with screwcap system with recycling in Sweden as the waste management option provides the lowest potential environmental impacts for the impact categories of photo-oxidant formation, eutrophication, acidification, human toxicity and freshwater aquatic ecotoxicity. For the impact categories of abiotic resources and climate change, the system with incineration with energy recovery has the lowest potential environmental impacts.
- The carton with screwcap system with landfilling as the waste management option contributes the most to the impact categories of abiotic depletion, acidification, human toxicity and freshwater aquatic ecotoxicity. For the impact categories of photo-oxidant formation and eutrophication, the system with incineration with energy recovery has the highest potential environmental impacts.
- Landfilling and recycling of the carton in Sweden contribute the most to climate change.
- Compared to landfill, which is currently the most likely end-of-life route for cartons, recycling the cartons in Sweden is shown to lead to lower potential environmental impacts across all impact categories, although for photo-oxidant formation, eutrophication and acidification the differences are small. It must be noted that this is based on the assumption that the waste fibres substitute virgin fibres in its next life.
- Lower potential environmental impacts are also shown when incinerating the cartons with energy recovery rather than landfilling them, except for the impact categories of photo-oxidant formation and eutrophication although the difference is very small.

5.5.3 Impact assessment results for the different life cycle stages

The environmental impacts associated with the different life cycle stages for the carton with screwcap system, with landfill as the waste management option for the primary packaging, are shown in *Figure 5.22* below.

Figure 5.22 Potential environmental impact results associated with the different life cycle stages for the carton with screwcap with landfill as the waste mgmt option for the primary packaging

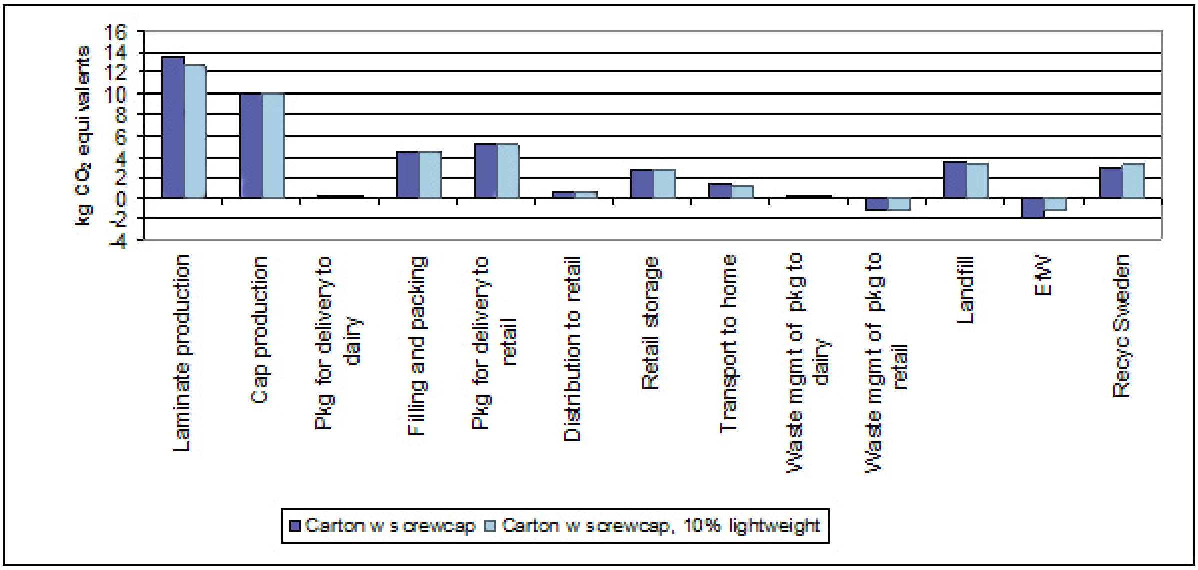


Points of note

- Laminate and cap production, distribution packaging and distribution to retail are the predominant contributors to the impact categories assessed.
- The impact of the distribution packaging is somewhat outweighed by the benefit derived from it being assumed to be recycled after use.
- The filling and packing of the cartons contributes little to the overall results, although some impact is seen for the impact categories of abiotic resource depletion, climate change and human toxicity.
- Landfill of the carton contributes to a minor extent to climate change, and shows some benefit for abiotic resource depletion and photo-oxidant formation.

Figures 5.23 and *5.24* show a breakdown of the results for the impact categories of climate change and human toxicity, as examples.

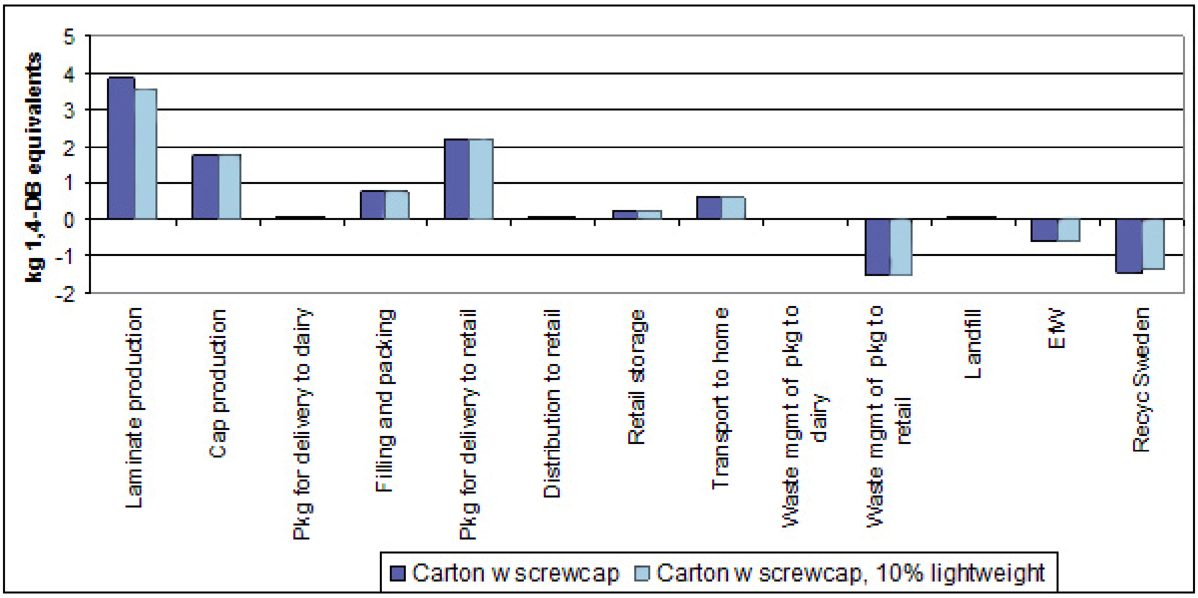
Figure 5.23 Impact profile for the carton with screwcap scenarios – climate change



Points of note

- Laminate and cap production are the predominant contributors to climate change impacts.
- Impacts in laminate production are primarily incurred through fossil fuel derived electricity consumption in both the liquid paper board and polymer production.
- Impacts in cap production are incurred through fossil fuel derived electricity consumption in both the polymer production and the injection moulding process.
- Impacts in the distribution packaging production are incurred almost fully as a consequence of the steel used for milk roll containers.
- Impacts in the distribution stage are incurred as a result of diesel combustion in transportation and the subsequent emissions.
- The 10% lightweight scenario shows lower potential environmental impacts as a result of reduced liquid paper board use, and the impact this has on transportation, and the avoidance of fibre disposal. It shows less benefits for energy from waste due to lesser material entering the process. Finally, it shows higher contribution to the recycling process due to less virgin fibre production being avoided. It must be noted that it is assumed that the recycling process is not altered in any way by lightweighting the carton, except for the quantity of material entering the process.
- The life cycle stages associated with the secondary and transit packaging used for delivery to the dairy and its waste management, transport to the home, waste management of the secondary and transit packaging used for delivery to retail, and incineration contribute relatively little to the impact profile for this category.

Figure 5.24 Impact profile for the carton with screwcap scenarios – human toxicity



Points of note

- Laminate production is the predominant contributor to human toxicity.
- Impacts in laminate production incurred through fossil fuel and electricity consumption in the liquid paper board and polymer production.
- Impacts in the distribution packaging production are incurred almost fully as a consequence of the steel used for milk roll containers.
- The 10% lightweight scenario shows lower potential environmental impacts as a result of reduced liquid paper board production, and the impact this has on transportation, and the avoidance of fibre disposal. It shows less benefits for energy from waste and recycling due to lesser material entering the process.
- The life cycle stages associated with secondary and transit packaging for delivery to the dairy and its waste management, retail and landfill contribute relatively little to the impact profile for this category.

5.6 The gable-top cartons with closure systems

5.6.1 Impact assessment results for the current and lightweight scenarios

Potential impact assessment results for the current and future lightweight one litre gable-top carton scenarios are presented for the different waste management options in *Table 5.39* to *Table 5.41* below. The results are shown per functional unit, i.e. per 1000 pints.

Table 5.39 Potential impact assessment results for the current and future lightweight gable-top carton scenarios with landfill as the waste management option (per functional unit)

Impact category	Unit	Gable-top carton, 100% virgin, landfill	Gable-top carton, 100% virgin, 10% lightweight, landfill	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.282	0.276	2.1%
Climate change	kg CO_2 eq	34.1	32.5	4.6%
Photo-oxidant formation	kg C_2H_4 eq	0.0304	0.0296	2.4%
Eutrophication	kg PO_4^{3-} eq	0.0200	0.0184	7.8%
Acidification	kg SO_2 eq	0.115	0.109	5.3%
Human toxicity	kg 1,4-DB eq	7.70	7.31	5.0%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	1.16	1.08	6.4%

Points of note

- Reducing the weight of the pouch by 10% is shown to lead to lower potential environmental impacts across all impact categories.
- Based on the assumptions made for the lightweight gable-top carton system, the potential environmental impacts of lightweighting are shown to be lower by a relatively small margin. The main reason for this is that the 10% assumption is just for the board and the environmental impact of the board itself contributes less to the overall result of the carton system compared to other inputs. A 10% reduction in the weight of the board results in potential impacts that are shown to be lower by 7.8% or less for the different impact categories.
- Similarly, lower potential environmental impacts are achieved using different waste management options as shown in Tables 5.40 and 5.41 below.

Table 5.40 Potential impact assessment results for the current and future lightweight gable-top carton scenarios with EfW as the waste management option (per functional unit)

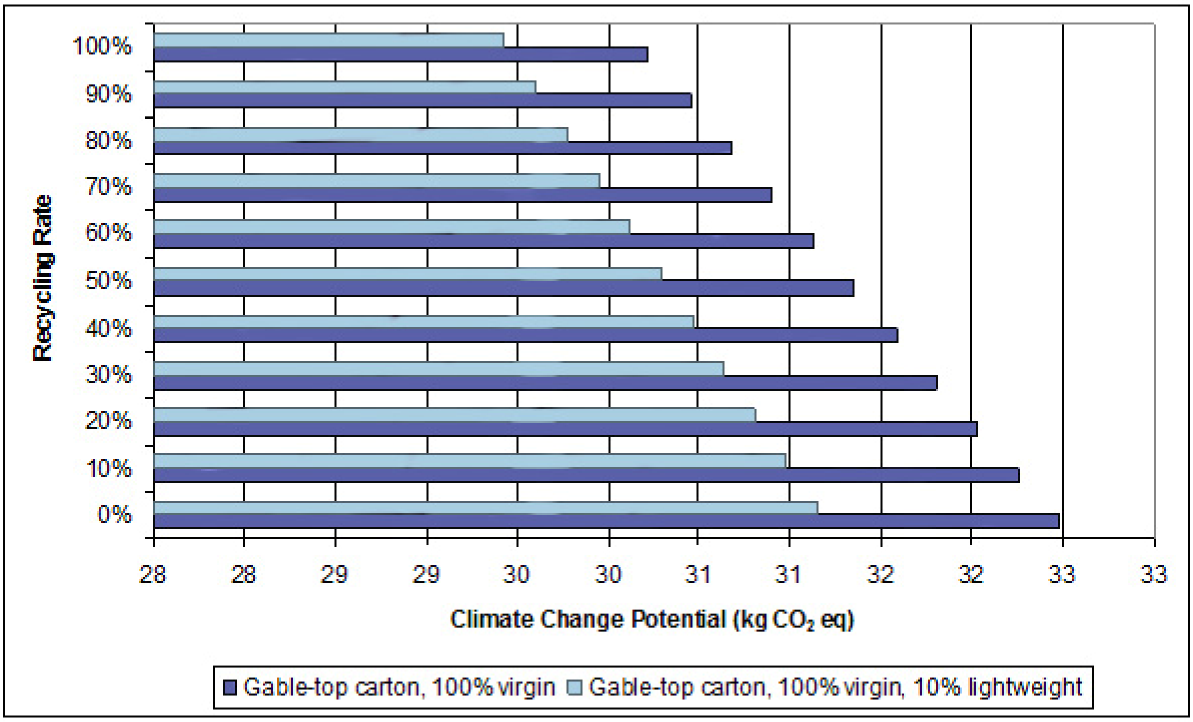
Impact category	Unit	Gable-top carton, 100% virgin, energy from waste	Gable-top carton, 100% virgin, 10% lightweight, energy from waste	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.149	0.149	-0.12%
Climate change	kg CO_2 eq	25.1	24.8	1.2%
Photo-oxidant formation	kg C_2H_4 eq	0.0320	0.0311	2.9%
Eutrophication	kg PO_4^{3-} eq	0.0205	0.0189	8.1%
Acidification	kg SO_2 eq	0.111	0.105	5.8%
Human toxicity	kg 1,4-DB eq	7.23	6.85	5.2%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.897	0.830	7.5%

Table 5.41 Potential impact assessment results for the current and future lightweight gable-top carton scenarios with recycling in Sweden as the waste management option (per functional unit)

Impact category	Unit	Gable-top carton, 100% virgin, recycling in Sweden	Gable-top carton, 100% virgin, 10% lightweight, recycling in Sweden	Differences in potential environmental impacts, 100% virgin vs 100% virgin 10% lightweight
Abiotic resource depletion	kg Sb eq	0.198	0.194	2.3%
Climate change	kg CO_2 eq	30.2	29.4	2.6%
Photo-oxidant formation	kg C_2H_4 eq	0.0282	0.0277	1.8%
Eutrophication	kg PO_4^{3-} eq	0.0108	0.0101	6.1%
Acidification	kg SO_2 eq	0.0797	0.0766	3.9%
Human toxicity	kg 1,4-DB eq	6.22	5.95	4.3%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.665	0.622	6.5%

Figure 5.25 below shows the overall results for the gable-top carton system with increasing recycling. As can be seen, increasing the recycling rate shows a decrease in the overall impact of the gable-top carton system. For the quantities not being recycled, it is assumed that 82.4% is landfilled and 17.6% is incinerated with energy recovery. These percentages are based on 2007/08 Defra municipal waste management statistics (Defra 2008b).

Figure 5.25 Environmental impact results associated with increased recycling for the gable-top carton system



5.6.2 Impact assessment results for different end-of-life scenarios

The impact assessment results for different waste management options for the current and future lightweight gable-top carton scenarios are presented in *Table 5.42* and *Table 5.43* below.

As landfill is the most likely end-of-life route for cartons currently in the UK, the energy from waste and recycling options are compared to this, and the differences in potential environmental impacts are listed in the table.

Table 5.42 Potential environmental impact assessment results for the gable-top carton system with different waste management options (per functional unit)

Impact category	Unit	Gable-top carton, landfill	Gable-top carton, energy from waste	Gable-top carton, recyc Sweden	Differences in potential environmental impacts, energy from waste vs landfill	Differences in potential environmental impacts, Swedish recycling vs landfill
Abiotic resource depletion	kg Sb eq	0.282	0.149	0.198	0.133	0.0834
Climate change	kg CO_2 eq	34.1	25.1	30.2	8.92	3.83
Photo-oxidant formation	kg C_2H_4 eq	0.0304	0.0320	0.0282	-0.00162	0.00221
Eutrophication	kg PO_4^{3-} eq	0.0200	0.0205	0.0108	-0.000583	0.00914
Acidification	kg SO_2 eq	0.115	0.111	0.0797	0.00386	0.0354
Human toxicity	kg 1,4-DB eq	7.70	7.23	6.22	0.473	1.48
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	1.16	0.897	0.665	0.261	0.492

Table 5.43 Potential environmental impact assessment results for the 10% lightweighted gable-top carton system with different waste management options (per functional unit)

Impact category	Unit	Gable-top carton, 10% lightweight landfill	Gable-top carton, 10% lightweight, energy from waste	Gable-top carton, 10% lightweight, recyc Sweden	Differences in potential environmental impacts, energy from waste vs landfill	Differences in potential environmental impacts, Swedish recycling vs landfill
Abiotic resource depletion	kg Sb eq	0.276	0.149	0.194	0.127	0.0820
Climate change	kg CO_2 eq	32.5	24.8	29.4	7.68	3.07
Photo-oxidant formation	kg C_2H_4 eq	0.0296	0.0311	0.0277	-0.00142	0.00199
Eutrophication	kg PO_4^{3-} eq	0.0184	0.0189	0.0101	-0.000481	0.00824
Acidification	kg SO_2 eq	0.109	0.105	0.0766	0.00420	0.0324
Human toxicity	kg 1,4-DB eq	7.31	6.85	5.95	0.461	1.36
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	1.08	0.830	0.622	0.254	0.462

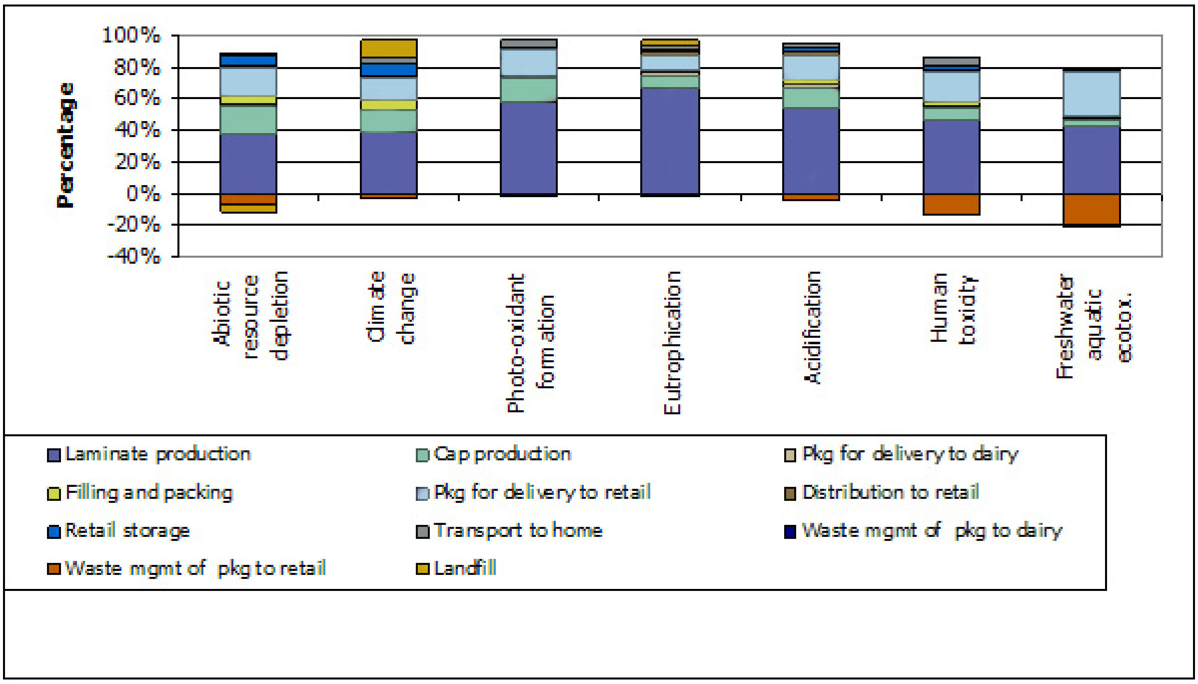
Points of note

- The gable-top carton scenario with recycling in Sweden as the waste management option provides the lowest potential environmental impacts for the impact categories of photo-oxidant formation, eutrophication, acidification, human toxicity and freshwater aquatic ecotoxicity. For the impact categories of abiotic resources and climate change, the scenario with incineration with energy recovery has the lowest potential environmental impacts.
- The gable-top carton system with landfilling as the waste management option contributes the most to the impact categories of abiotic depletion, climate change, acidification, human toxicity and freshwater aquatic ecotoxicity. For the impact categories of photo-oxidant formation and eutrophication, the system with incineration with energy recovery has the highest potential environmental impacts.
- Compared to landfill, which is currently the most likely end-of-life route for cartons, recycling the cartons in Sweden is shown to lead to lower potential environmental impacts across all impact categories. It must be noted that this is based on the assumption that the waste fibres substitute virgin fibres in its next life.
- Lower potential environmental impacts are also shown when incinerating the cartons with energy recovery rather than landfilling them, except for the impact categories of photo-oxidant formation and eutrophication, although the difference is very small.

5.6.3 Impact assessment results for the different life cycle stages

The environmental impacts associated with the different life cycle stages for the gable-top carton system, with landfill as the waste management option for the primary packaging, are shown in *Figure 5.26* below.

Figure 5.26 Potential environmental impact results associated with the different life cycle stages for the gable-top carton with landfill as the waste mgmt option for the primary packaging

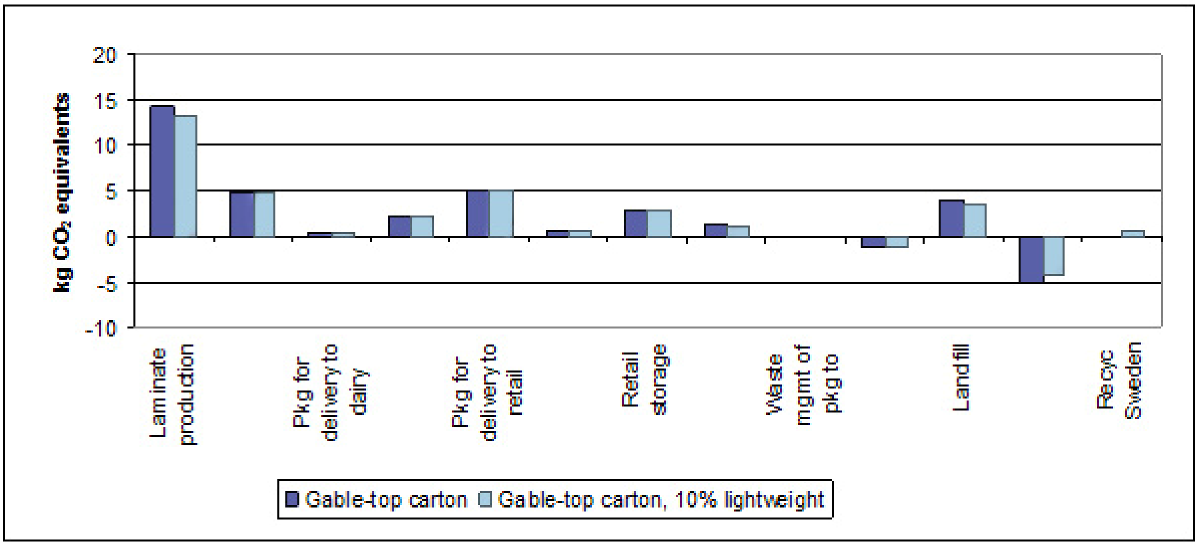


Points of note

- Laminate and cap production, distribution packaging and distribution to retail are the predominant contributors to the impact categories assessed.
- However, the impact of the distribution packaging is somewhat outweighed by the benefit of its assumed recycling after use.
- The contribution of the secondary and transit packaging for delivery to the dairy is insignificant.
- Filling and packing of the cartons contributes little to the overall results, although some impact is seen for the impact categories of abiotic resource depletion and climate change.
- Transport from retail to the home contributes little to the overall results, although some impact is seen for the impact categories of photo-oxidant formation and human toxicity.
- Landfill of the carton contributes to climate change, and shows some benefit for abiotic resource depletion and photo-oxidant formation.

Figures 5.27 and *5.28* show a breakdown of the results for the impact categories of climate change and photo-oxidant formation, as examples.

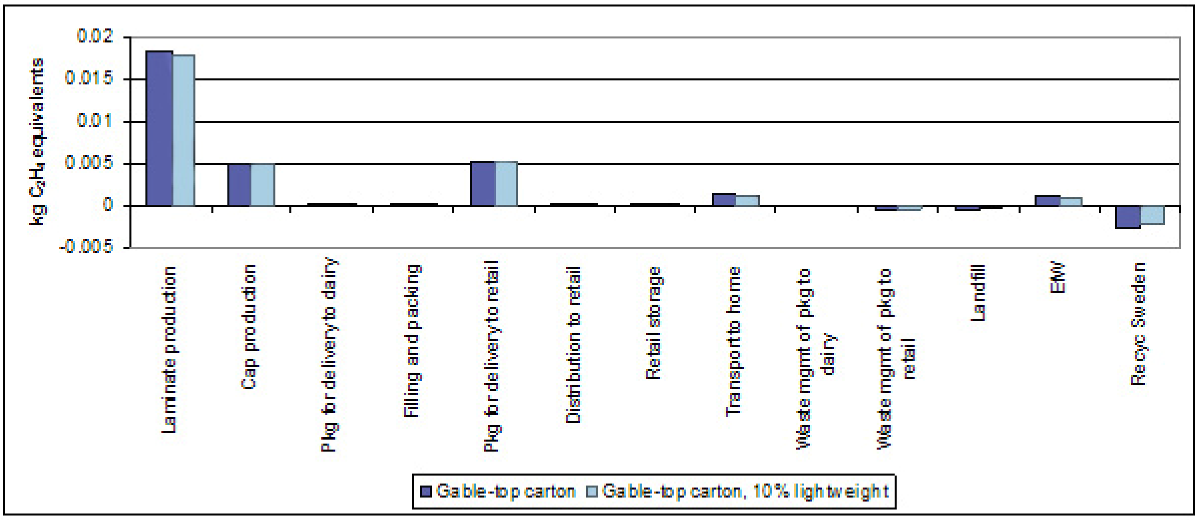
Figure 5.27 Impact profile for the gable-top carton scenarios – climate change



Points of note

- Laminate and cap production, transit packaging for delivery to retail as well as distribution to retail are the predominant contributors to climate change impacts.
- Impacts in laminate production are primarily incurred through fossil fuel derived electricity consumption in both the liquid paper board and polymer production.
- Impacts in cap production are incurred through fossil fuel derived electricity consumption in both the polymer production and the injection moulding process.
- Impacts in the distribution packaging production are incurred almost fully as a consequence of the steel used for milk roll containers.
- Impacts in the distribution stage are incurred as a result of diesel combustion in transportation and the subsequent emissions.
- The 10% lightweight scenario shows lower potential environmental impacts as a result of reduced liquid paper board use, and the impact this has on transportation, and the avoidance of fibre disposal. It shows less benefit for energy from waste due to lesser material entering the process. Finally, it shows higher contribution to the recycling process due to less virgin fibre production being avoided. It must be noted that it is assumed that the recycling process is not altered in any way by lightweighting the carton, except for the quantity of material entering the process.
- The life cycle stages associated with the secondary and transit packaging used for delivery to the dairy and its waste management, transport to the home, waste management of the secondary and transit packaging used for delivery to retail, and recycling contribute relatively little to the impact profile for this category.

Figure 5.28 Impact profile for the gable-top carton scenarios – photo-oxidant formation



Points of note

- Laminate production makes the predominant contribution to photo-oxidant formation impacts.
- Impacts in laminate production are primarily incurred as a result of combustion of coal in power stations generating electricity for consumption in the liquid paper board and polymer production.
- The 10% lightweight scenario shows lower potential environmental impacts as a result of reduced liquid paper board production, and the impact this has on transportation, and the avoidance of fibre incineration. It shows less benefits for landfill and recycling due to lesser material entering the process.
- The life cycle stages associated with secondary and transit packaging for delivery to the dairy and its waste management, filling and packing, retail and landfill and energy from waste contribute relatively little to the impact profile for this category.

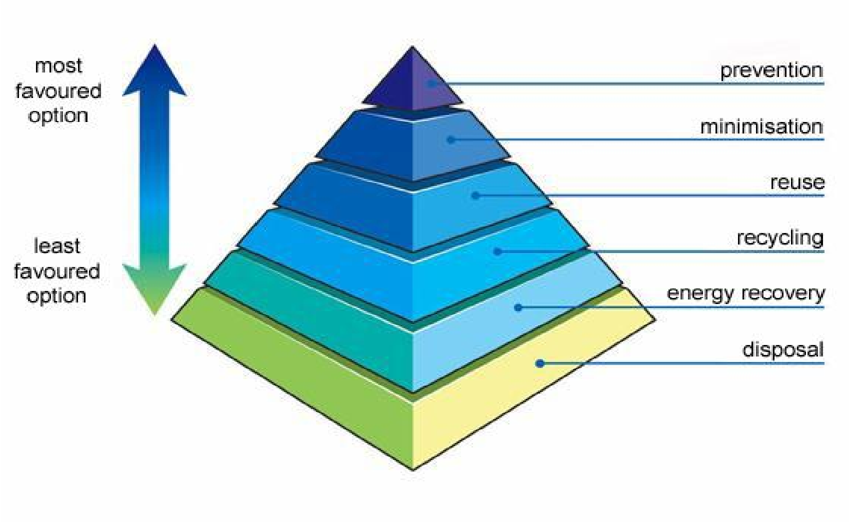
6.0 Interpretation of results

6.1 Significant findings

The conclusions to be drawn from this study must be seen in the context of the limitations of the study as described in *Section 3.7*. With this in mind, the main findings can be summarised as follows:

- The findings overall support the waste hierarchy, as shown in Figure 6.1. The results show that minimisation, i.e. lightweighting, can provide significant environmental savings. This, of course, is assuming that lightweighting is still achievable without compromising the functionality of the milk container. Recycling, i.e. the recycling of materials after use, is also shown to provide considerable environmental savings. This is followed by energy recovery and then disposal in landfill.
- The results indicate that recycling the plastic bottles back into bottles in the UK provides the lowest potential environmental impacts for certain impact categories. However, general recycling in the UK seems to provide the lowest potential environmental impacts for other impact categories. This is based on the assumption that the secondary plastic material substitutes virgin material. This will not always be the case and this should therefore be seen as a best case scenario.
- For the plastic bottles, the life cycle stage contributing the most to the environmental performance of these packaging systems is the bottle production stage. For example, for the impact category of climate change the bottle production stage (including raw materials) account for 71% for the HDPE and 76% for the PET bottle respectively. If functionality requirements allow, this does suggest that improvements at this life cycle stage (e.g. lightweighting or increased recycled content) may result in the biggest environmental gains.
- For the pouches, the life cycle stages contributing the most to the environmental performance of these packaging systems are distribution packaging production followed by pouch production. For certain impact categories, the impact of the distribution packaging is significantly higher than that of the pouch itself. This is partly a result of the minimal weight of the pouch, which means that the other elements of the pouch systems contribute proportionally more. The relatively high contribution from the distribution packaging may suggest, if functionality requirements allow, that improvements to the distribution packaging stage (e.g. lightweighting) may result in the biggest environmental gains.
- For the cartons, the life cycle stages contributing the most to the environmental performance of these packaging systems are laminate production followed by cap production and distribution packaging production. For example, for climate change, the contribution of the laminate for the carton with screwcap is 37%, cap production 27% and distribution packaging is 14%. For the gable-top carton, the contributions to climate change are 47%, 16% and 17% respectively. If functionality requirements allow, this does suggest that improvements at the laminate production stage (i.e. lightweighting) may result in the biggest environmental gains. However, the contribution of one single life cycle stage is not as significant as for some of the other milk container systems assessed.

Figure 6.1 The waste hierarchy



6.2 Uncertainty analysis

Any LCA is to a large extent based on assumptions and estimations, which may affect the results. These occur in: the goal and scope definition, where processes are identified and included or excluded; in the inventory where the inputs and outputs of the processes are quantified; and in the impact assessment where different characterisation factors are applied.

Scoping the project implies making assumptions about the systems studied. The assumptions are reflected in the way the systems are described and in the elements included in the system boundaries. Using a sensitivity analysis, key input parameters about which there may be uncertainty, or for which a range of values may exist, are reconsidered and the influence on the results is tested. The general uncertainties in the inventory can be estimated by performing a statistical analysis, but this will not add any new knowledge compared to the sensitivity analysis.

The factors used for the characterisation in the impact assessment reflect a cause-effect reaction in the environment. International consensus has been reached with regard to most of the impact categories. As explained in the scope section, it must be stressed that the impact categories of LCA are **potential impacts**. That is, they express what would happen if the cause-effect relationship is enacted. In practice, it is not known if, for example, each and every cancer-triggering molecule enters a human body and does, in fact, cause cancer.

6.3 Sensitivity analysis

The sensitivity analysis contains the results of further investigations on the parameters about which there may be significant uncertainty or that have been found to be of most influence to the results.

The areas that have been identified for sensitivity analysis are:

- allocation approach for recycled content and recycling at end-of-life;
- exclusion of milk wastage through the supply chain;
- assumptions regarding avoided materials; and
- assumptions on jug reuse rates for pillow pouch system.

In addition, system equivalence to selected other milk container examples is investigated. These include:

- transport step between HDPE bottle converting plant and dairy; and
- pillow pouches in multi-pack.

A number of assumptions have been made in the study which are not investigated in this sensitivity analysis. This may either be because their influence on the overall results is minor or that alternative scenarios have not been identified. This is the case for, for example, the gable-top carton system where assumptions have been made regarding the secondary and transit packaging to dairy.

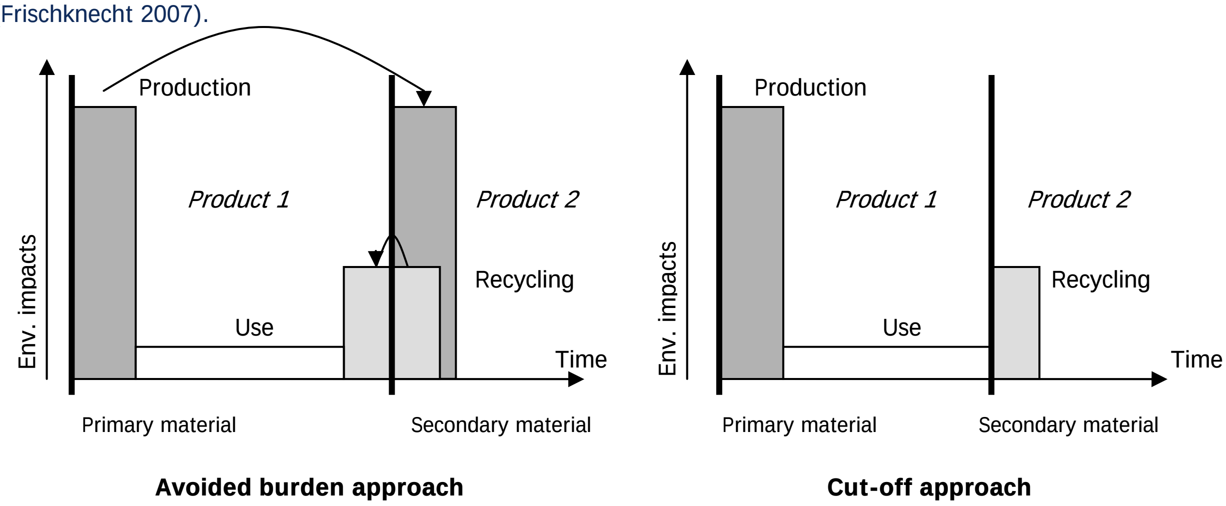
6.3.1 System boundary settings

This study has used the avoided burdens approach in setting system boundaries. This approach considers the end of life fate of the material by expanding the system to include the avoided alternative production of these outputs. This means that all the benefits of recycling are allocated to the material being recycled. To ensure that the approach is consistent for outflows as well as inflows to the system, the material input to the system bears the environmental impacts of primary production, irrespective of whether or not it has a recycled content.

The avoided burdens approach allows for evaluating the full environmental potential of the waste management process chosen. For example, the method allows for the full benefit of recycling and thereby avoiding the production of virgin raw materials to be investigated. This therefore supports WRAP in its efforts to encourage and to fund the increased recycling of materials after use. However, due to all benefits being awarded at end-of-life, the method is not well suited to evaluating the environmental potential of incorporating recycled material into a product, an additional area of significant support and funding from WRAP. For this purpose, another approach, the cut-off approach (or recycled content approach), is considered.

The cut-off approach considers the share of recycled material in the manufacture of a product. The environmental impacts of extraction and processing of the primary material are attributed to the first use of that material (see *Figure 6.2*). The second use of the material bears the environmental impacts of transportation and recycling of the material, but no environmental load from the primary production activities. Recycling at end of life will only incur the environmental burdens of collection. Similarly, for energy from waste only the environmental burdens of collection are included; with the burdens of incineration allocated to the electricity generated. Landfill still incurs the environmental burdens of collection and landfilling but no benefits from the use of landfill gas. This is consistent with the approach as set out in initial drafts of the publicly available standard for product carbon footprinting, PAS 2050 developed by BSI, Defra and the Carbon Trust (PAS 2050:2008).

Figure 6.2 Schematic representation of the avoided burden approach and the cut-off approach (Frischknecht 2007).



HDPE bottle

Using this approach for the HDPE bottle, the impact assessment results for bottle-to-bottle recycling are shown in *Table 6.1* below.

Table 6.1 Impact assessment results for the HDPE bottle scenarios using the cut-off approach - with bottle-to-bottle recycling in the UK as the waste management option (closed-loop) (per functional unit)

Impact category	Unit	HDPE bottle, 100% virgin, BtB recycling	HDPE bottle, 30% rHDPE, BtB recycling	HDPE bottle, 50% rHDPE, BtB recycling
Abiotic resource depletion	kg Sb eq	0.626	0.524	0.456
Climate change	kg CO_2 eq	48.1	43.9	41.2
Photo-oxidant formation	kg C_2H_4 eq	0.0436	0.0341	0.0278
Acidification	kg SO_2 eq	0.0164	0.0150	0.0142
Eutrophication	kg PO_4^{3-} eq	0.144	0.123	0.110
Human toxicity	kg 1,4-DB eq	6.63	5.71	5.11
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	0.836	0.779	0.741

Table 6.2 below shows the percentage difference in the impact assessment results achieved using the cut-off approach.

Table 6.2 Differences in impact assessment results achieved for the HDPE bottle scenarios using the cut-off approach - with recycling as the waste management option (per functional unit)

Impact category	Percentage difference – 100% vHDPE vs 30% rHDPE	Percentage difference – 100% vHDPE vs 50% rHDPE
Abiotic resource depletion	16%	27%
Climate change	8.6%	14%
Photo-oxidant formation	22%	36%
Acidification	8.4%	14%
Eutrophication	14%	24%

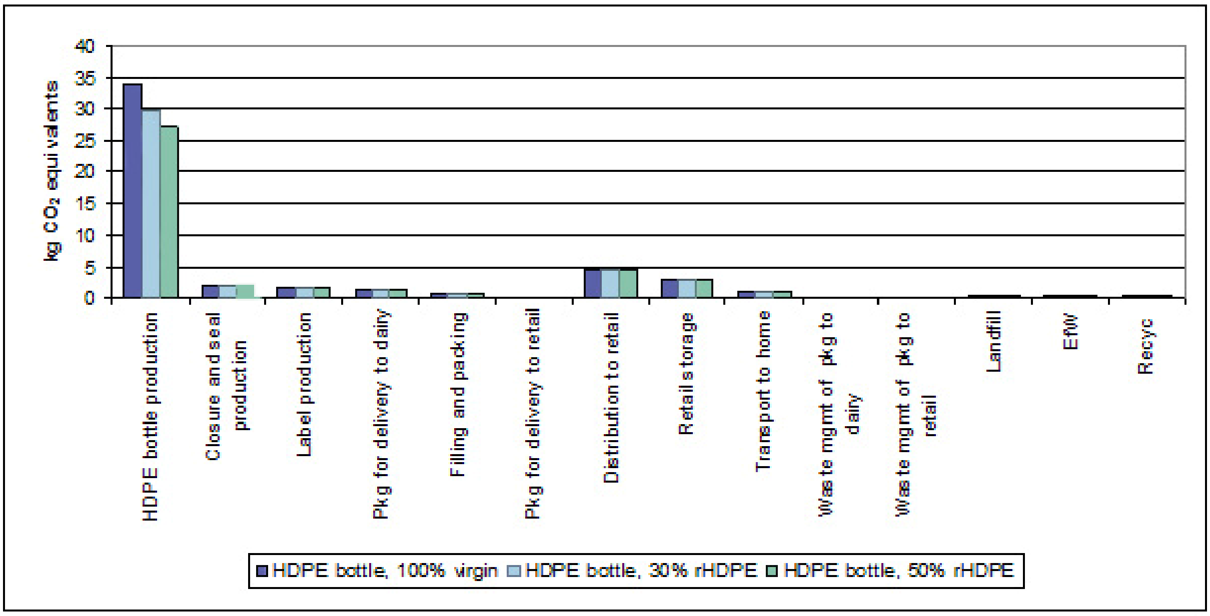
Impact category	Percentage difference – 100% vHDPE vs 30% rHDPE	Percentage difference – 100% vHDPE vs 50% rHDPE
Human toxicity	14%	23%
Freshwater aquatic eco-toxicity	6.8%	11%

Points of note

- Using the cut-off approach, significant differences are seen between the results of the HDPE bottle systems with varying recycled content.
- When considering the waste management option of bottle-to-bottle recycling, increasing the recycled content to 30% reduces the potential environmental impact from climate change by 8.6% compared to the bottle with no recycled content. For photo-oxidant formation, the impact category showing the largest difference, the difference is 22%, and for freshwater aquatic eco-toxicity, the impact category showing the smallest different, it is 6.8%.
- When considering the waste management option of bottle-to-bottle recycling, increasing the recycled content to 50% reduces the potential environmental impact from climate change by 14% compared to the bottle with no recycled content. For photo-oxidant formation the difference is 36%, and for human toxicity it is only 11%.

The environmental impacts associated with the different life cycle stages for the HDPE bottle system using the cut-off approach, with bottle-to-bottle recycling as the waste management option for the primary packaging, are shown in *Figure 6.3* below for the impact category of climate change as an example.

Figure 6.3 Impact profile for the HDPE bottle scenarios using the cut-off approach – climate change

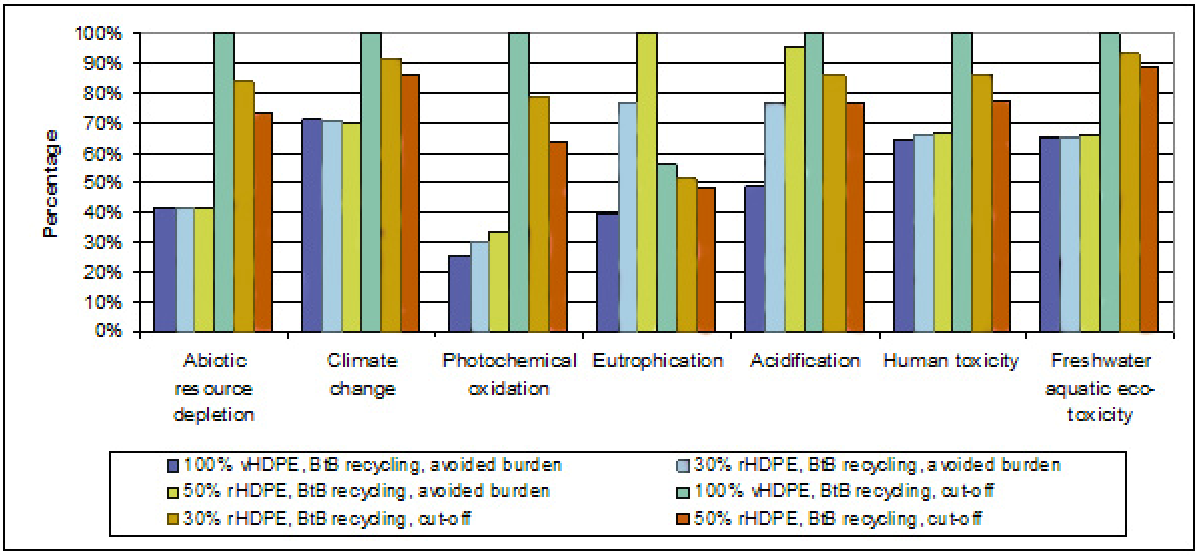


Points of note

- Bottle production is the predominant contributor to the impact category of climate change.
- Impacts in virgin HDPE production are primarily incurred through the consumption of fossil fuels and fossil fuel derived electricity in the raw material stage.
- Impacts in the production of rHDPE are primarily incurred through the consumption of natural gas and fossil fuel derived electricity in the recycling process.
- As illustrated in Tables 6.1 and 6.2, increasing the recycled content reduces the impacts associated with bottle production considerably when using the cut-off approach.
- The life cycle stages associated with cap and label production, secondary and transit packaging production and its subsequent waste management, filling and packing, distribution, retail, transport to the home and bottle-to-bottle recycling contribute relatively little to the impact profile for this category.
- Due to the cut-off approach used, the benefit of recycling at end of life is minimal.

Figure 6.4 below compares the impacts using the cut-off approach and the avoided burden approach. The results are presented per impact category as 100% scaled columns.

Figure 6.4 Scaled comparison of the avoided burden and cut-off approach for the HDPE bottle system with bottle-to-bottle recycling as the waste management option



The significant differences in results between the two system boundary approaches are illustrated in the figure. As can be seen, the results can be said to be sensitive to the system boundary approach taken.

PET bottle

Using the cut-off approach for the PET bottle, the impact assessment results for bottle-to-bottle recycling are shown in *Table 6.3* below.

Table 6.3 Impact assessment results for the PET bottle scenarios using the cut-off approach - with bottle-to-bottle recycling in the UK as the waste management option (closed-loop) (per functional unit)

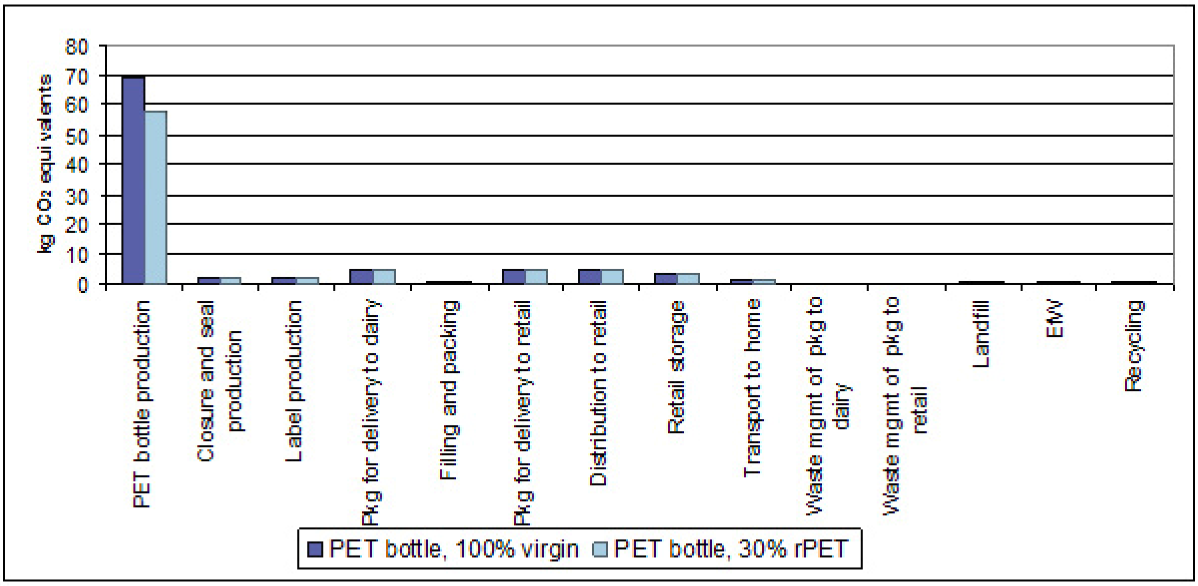
Impact category	Unit	PET bottle, 100% virgin, BtB recycling	PET bottle, 30% rHDPE, BtB recycling	Percentage difference – 100% vPET vs 30% rPET
Abiotic resource depletion	kg Sb eq	1.08	0.907	16%
Climate change	kg CO_2 eq	92.4	81.7	12%
Photo-oxidant formation	kg C_2H_4 eq	0.0580	0.0488	16%
Acidification	kg SO_2 eq	0.0848	0.0664	22%
Eutrophication	kg PO_4^{3-} eq	0.322	0.274	15%
Human toxicity	kg 1,4-DB eq	22.4	17.6	21%
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.89	2.36	18%

Points of note

- Using the cut-off approach, significant differences are seen between the results of the PET bottle systems with varying recycled content.
- When considering the waste management option of bottle-to-bottle recycling, increasing the recycled content to 30% reduces the potential environmental impact from climate change by 12% compared to the bottle with no recycled content. This is the impact category showing the smallest difference. The impact category showing the largest difference is acidification with a difference of 22%.

The environmental impacts associated with the different life cycle stages for the PET bottle system using the cut-off approach, with bottle-to-bottle recycling as the waste management option for the primary packaging, are shown in *Figure 6.5* below for the impact category of climate change as an example.

Figure 6.5 Impact profile for the PET bottle scenarios using the cut-off approach – climate change

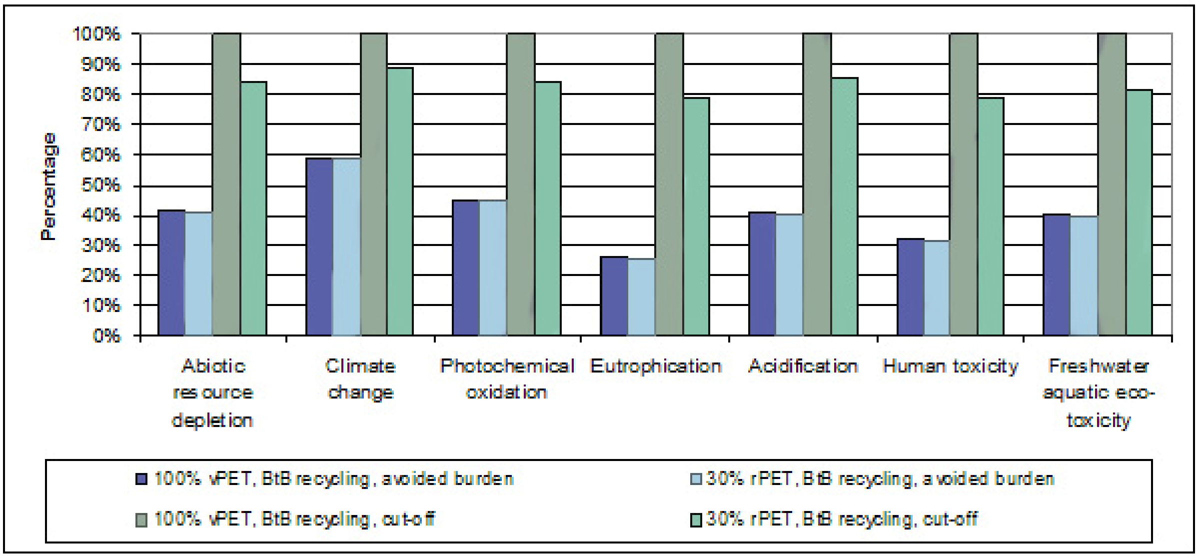


Points of note

- Bottle production is the predominant contributor to the impact category of climate change.
- Impacts in virgin PET production are primarily incurred through the consumption of fossil fuels and fossil fuel derived electricity in the raw material stage.
- Impacts in the production of rPET are primarily incurred through the consumption of natural gas and fossil fuel derived electricity in the recycling process.
- As illustrated in Table 6.3, increasing the recycled content reduces the impacts associated with bottle production considerably when using the cut-off approach.
- The life cycle stages associated with cap and label production, secondary and transit packaging production and its subsequent waste management, filling and packing, distribution, retail, transport to the home and bottle-to-bottle recycling contribute relatively little to the impact profile for this category.
- Due to the cut-off approach used, the benefit of recycling at end of life is minimal.

Figure 6.6 below compares the impacts using the cut-off approach and the avoided burden approach. The results are presented per impact category as 100% scaled columns.

Figure 6.6 Scaled comparison of the avoided burden and cut-off approach for the PET bottle system with bottle-to-bottle recycling as the waste management option



As seen for the HDPE bottle system, significant differences in results between the two system boundary approaches are illustrated in the figure. The results can be said to be sensitive to the system boundary approach taken.

6.3.2 Exclusion of milk wastage through the supply chain

Due to a lack of data, milk wastage as a result of filling and packaging failure was excluded. The environmental impacts associated with the production of milk are generally higher than those of the packaging, and as a result the production impacts of different wastage rates for the different milk container types might be significant.

Average milk wastage rates in retail are reported to be at a level of approximately 0.1% (Chris Foster 2008). Milk production was not considered as part of this study, but has been investigated in various projects. *Table 6.4* below compares life cycle impact results of 0.1% milk wastage with those of the 100% vHDPE bottle with landfill as the waste management option. The milk results are data reported as part of the Milk Roadmap project. Please note, not all the impact categories as assessed in this study were reported for milk and in calculating the results no allocation was given to beef production.

Table 6.4 Comparison of life cycle impact assessment results of 0.1% milk wastage and HDPE bottles, 100% vHDPE (per functional unit)

Impact category	Unit	Liquid milk, 0.1% wastage[1]	HDPE bottle, 100% virgin, landfill	Percentage increase, total results
Abiotic resource depletion	kg Sb eq	0.00170	0.623	0.27%
Climate change	kg CO_2 eq	0.648	48.0	1.3%
Photo-oxidant formation	kg C_2H_4 eq		0.0431	
Acidification	kg SO_2 eq	0.00966	0.0162	37%
Eutrophication	kg PO_4^{3-} eq	0.00341	0.141	2.4%
Human toxicity	kg 1,4-DB eq		7.59	
Freshwater aquatic eco-toxicity	kg 1,4-DB eq		0.843	

Table 6.4 above indicates that an assumed milk wastage rate of 0.1% will have a limited impact on the overall result, except for acidification where the impact will increase by 37%.

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[1] *Foster et al 2007.*

6.3.3 Assumptions regarding avoided materials

Where materials are recycled at end-of-life, it has been assumed that the recycled material substitutes a virgin material, i.e. the production of virgin material is avoided. In practice, the recycled material could also displace another recycled material, no material at all or a different material. This is, for example, the case when HDPE bottles are recycled into park benches, thereby displacing wood.

A sensitivity test was carried out to determine the influence on results should the HDPE bottle after use be recycled into park benches and thereby replace wood.

Figure 6.5 below compares the impacts of the HDPE bottle system assuming the HDPE bottle substitutes virgin material and wood. The results are presented per impact category as 100% scaled columns.

Figure 6.5 Scaled comparison of assumptions about material substitution for recycling

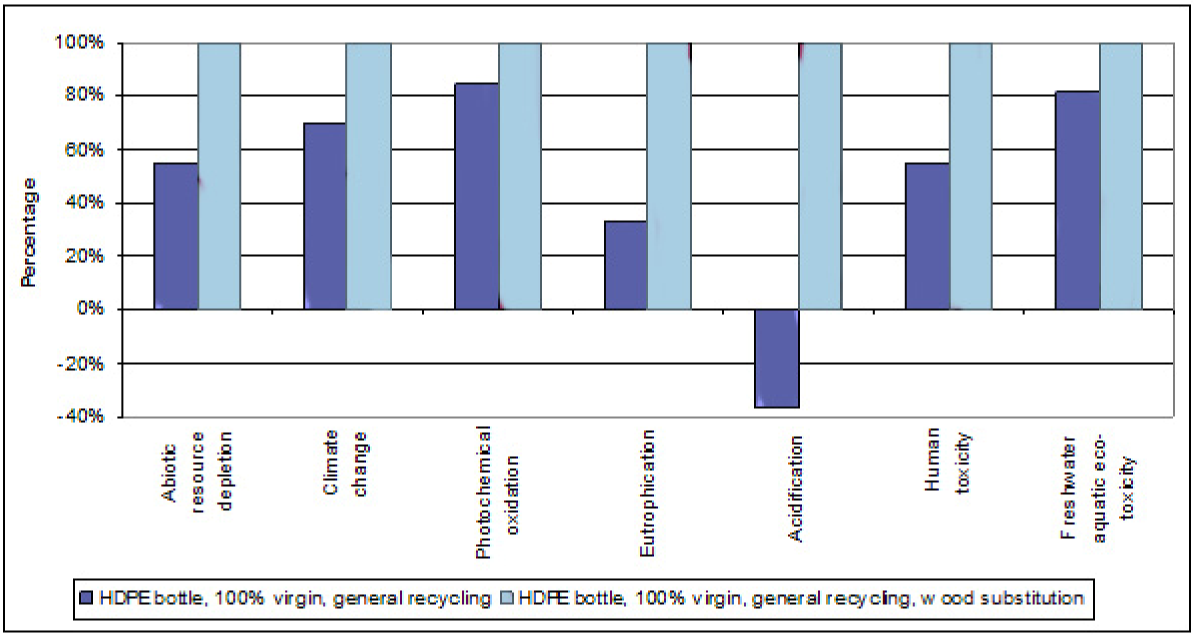


Figure 6.5 shows that the assumptions regarding substituted material when recycling the HDPE bottles after use have significant influence on the HDPE bottle environmental impact profile, with acidification and human toxicity showing the greatest differences.

6.3.4 Assumptions on the jug reuse rate for the pillow pouch system

No data were available on the average use and life span of the jug used to aid pouring of milk from pillow pouches. Instead, it was assumed that the jug was used for two years by an average household size and then replaced. Based on statistical information about average milk consumption and average household size in the UK, this meant that 1.43 jugs were required to fulfil the functional unit of 1,000 pints of milk.

A sensitivity test was carried out to determine the influence on results should the jug only be used for one year and six months, respectively.

Figure 6.6 below compares the impacts of the pillow pouch system assuming the jug is used for two years, one year, and six months. The results are presented per impact category as 100% scaled columns.

Figure 6.6 Scaled comparison of jug used for two years, one year, and six months

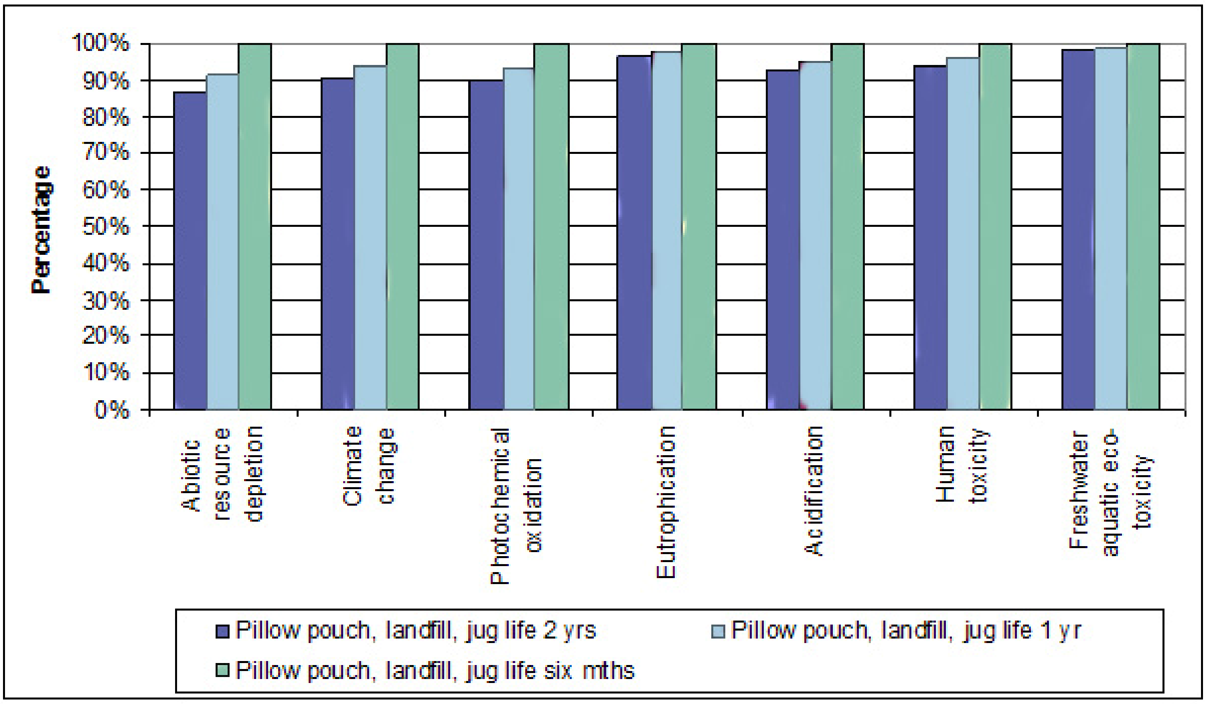


Figure 6.6 shows the jug life span has limited influence on the pillow pouch environmental impact profile, with abiotic resource depletion showing the greatest difference.

6.3.5 System equivalence to selected other milk container examples

The milk containers studied as part of this project, are examples of milk containers available on the UK market. Some of them exhibit specific characteristics that do not apply to similar milk containers on the market. The influence of some of these characteristics is assessed in the following.

Transport step between HDPE bottle converting plant and dairy
The HDPE bottle system studied as part of this project represents a HDPE bottle produced at a converting plant located adjacent to the dairy. To investigate the contribution the transport would have for a dairy not adjacent to the converting plant, a transport step between the converting plant and the dairy has been included.

A distance of 200 km between the converting plant and the dairy has been assumed. Since the volume of the bottles will be the limiting factor for the number of bottles transported per lorry, the data have been amended to reflect this. According to a dairy, a lorry can hold 68,442 two pint blown HDPE bottles.

Additional transit packaging has also been assumed. For the purposes of this analysis, all bottles are assumed to be packaged in a plastic bag, as is currently the case for 36% of the bottles produced at the converting plant adjacent to the dairy. It is assumed that the plastic is recycled after use. No other packaging is assumed.

Figure 6.7 below compares the impacts of the 100% virgin HDPE bottle system assuming a distance of 200 km between the converting plant and the dairy. The results are presented per impact category as 100% scaled columns.

Figure 6.7 Scaled comparison of no transport and 200 km between converting plant and dairy (100% vHDPE with landfill as the waste management option)

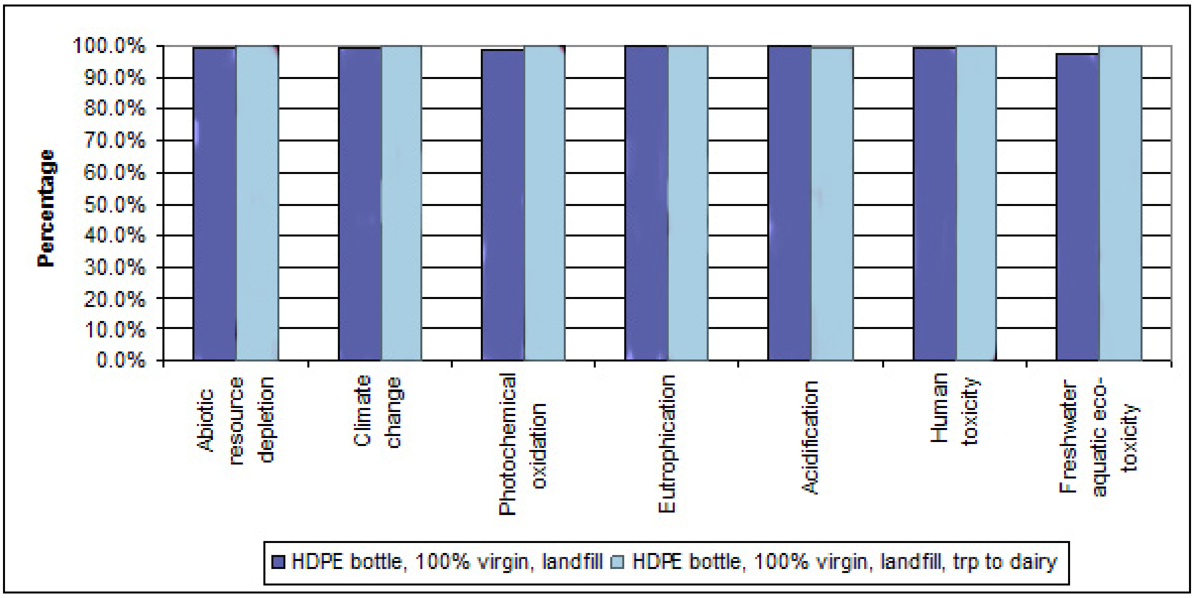
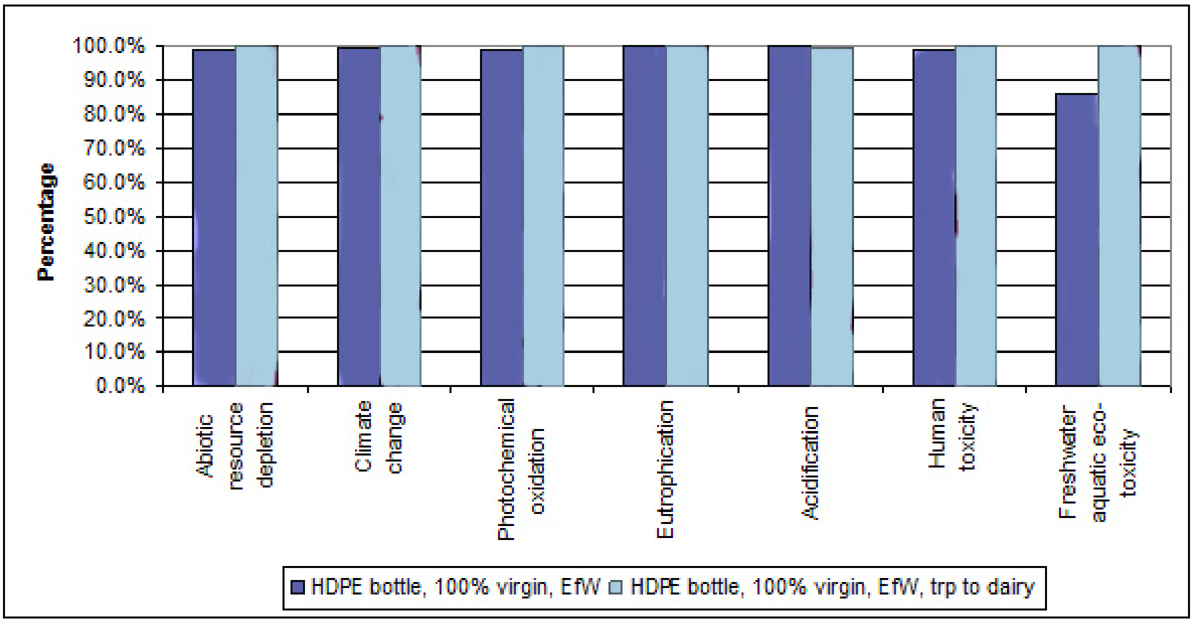


Figure 6.7 shows that adding a transport step between the converting plant and the dairy has a limited influence on the environmental profile of the HDPE bottle with landfill as the waste management option. However, this does somewhat depend on the impact results associated with the other life cycle processes. For example, if incineration with energy recovery is assumed for the end-of-life process for the bottle, the acidification impacts for transporting the bottles between the converting plant and the dairy are significantly higher than the other life cycle processes leading to a difference of 14%, as shown in *Figure 6.8* below.

Figure 6.8 Scaled comparison of no transport and 200 km between converting plant and dairy (100% vHDPE with energy from waste as the waste management option)



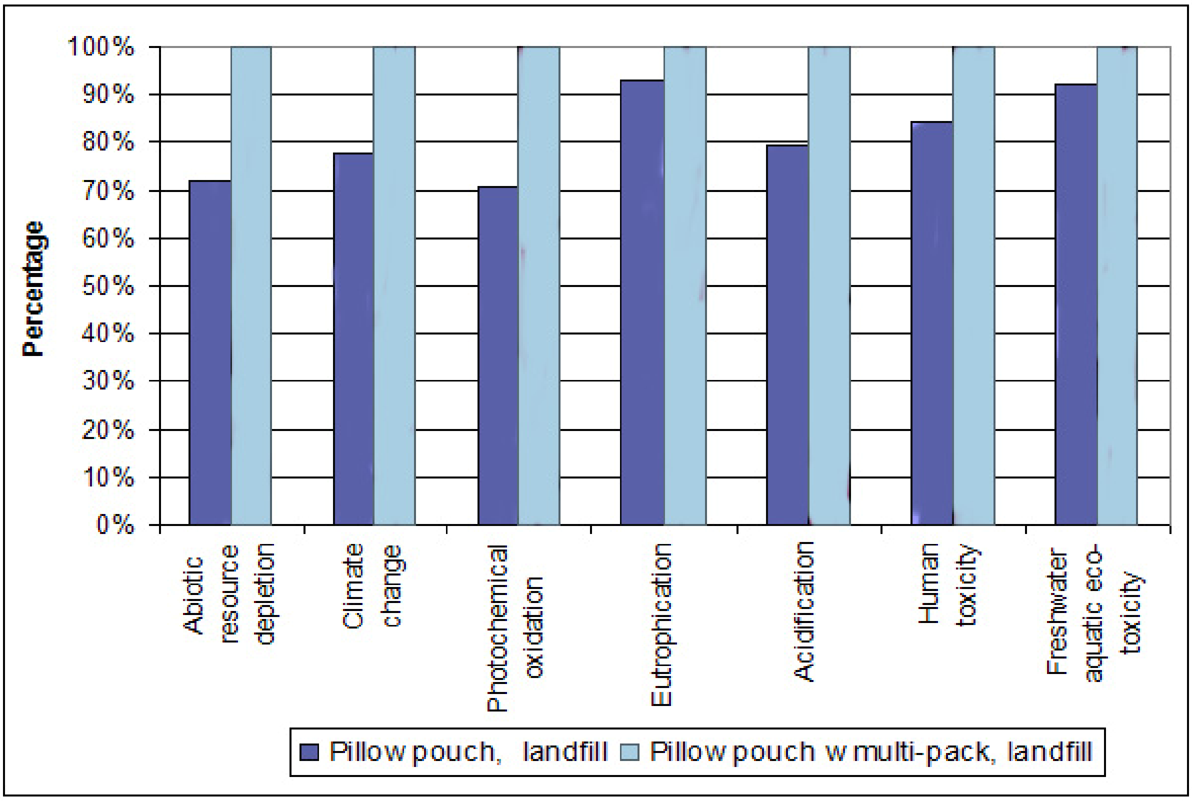
Pillow pouches in multi-packs

In other countries, pillow pouches are also available in multi-packs. It was therefore considered of interest to investigate the impacts if a multi-pack of three pouches was assumed.

The multi-pack is assumed to be an LDPE bag weighing 14.14 g based on an actual multi-pack used in Canada. No amendments to the secondary and transit packaging are assumed. It is assumed that the multi-pack is disposed of as general household waste after use.

Figure 6.9 below compares the impacts of a multi-pack on the pillow pouch system. The results are presented per impact category as 100% scaled columns.

Figure 6.9 Scaled comparison of pillow pouch system with and without a multi-pack (pillow pouch with landfill as the waste management option)



Showing a greater than 20% difference in system impacts across several impact categories, it is considered that packing the pouches in multi-packs affects the environmental impact profile of the pillow pouch significantly.

7.0 Conclusions and recommendations

This study investigates the relative life cycle environmental impacts of different examples of packaging for pasteurised milk available on the UK market. Two separate distribution systems have been assessed: a retail system (supermarkets); and a doorstep system. This report covers the retail system.

The study investigated the following milk packaging systems identified as being of interest to the client:

- HDPE bottle – with 0%, 30% and 50% recycled content as well as a lightweight scenario;
- PET bottle – with 0% and 30% recycled content as well as a lightweight scenario;
- pillow pouch, including serving jug – a 100% virgin and a lightweight scenario;
- stand-up plastic pouch– a 100% virgin and a lightweight scenario;
- cartons with screwcap– a 100% virgin and a lightweight scenario; and
- gable top cartons– a 100% virgin and a lightweight scenario.

7.1 Study limitations

The conclusions drawn from this study must be seen in the context of the limitations of the study.

The study is an assessment of example packaging systems for chilled pasteurised milk. It was intended that the study should cover average milk packaging systems as available on the UK market. However, despite considerable efforts, it was not possible to obtain data from all parties operating on the UK market. Therefore, the results of this study cannot be said to reflect market average performance or be used in drawing specific conclusions relating to the relative performance of all milk packaging.

The results of the study are limited by the data collected, the assumptions made where data gaps occurred, and the systems assessed. Data gaps were evident for all packaging systems assessed, especially with regard to the distribution and retail stages of the life cycle, but also for secondary and transit packaging, and the filling and packing stage for some of the packaging systems.

As a result of the limited data obtained for the distribution and retail stages of the life cycle, the study cannot be used as the basis for assessing the efficiency of packaging formats for logistics systems or in the retail environment. The study does include an estimate of the distances travelled and energy consumed in distribution and retail. The use of these estimates is limited to judging the significance of these life cycle stages in the context of the full life cycle.

7.2 Overall conclusions

A number of conclusions can be drawn from the study that applies across the milk packaging systems. This applies to the fact that the extraction or growing of raw material and the processing of these into packaging formats, whether this be the primary or secondary or transit packaging, is found to contribute the most to the environmental profile of the milk container systems. This means that the largest relative environmental savings are achieved through the improvement of these life cycle stages.

Overall, the findings are found to support the waste hierarchy. This means that the results indicate that significant relative environmental savings can be achieved through minimisation, i.e. lightweighting. These savings, of course, are dependent on lightweighting being achievable without compromising the functionality of the milk container. Recycling, i.e. the recycling of materials after use, is also shown to provide considerable environmental savings. This is followed by energy recovery and then disposal in landfill.

The support of the waste hierarchy is only valid for the systems where the avoided burdens approach has been used for setting the system boundaries. The avoided burdens approach allows for evaluating the full environmental potential of the waste management process chosen. The cut-off approach, if investigated for all waste management options, would show similar results for energy to waste and recycling, as only the initial collection of the waste is included within the system boundaries.

<u>HDPE bottle system</u>

The production and associated raw material extraction for the HDPE bottle is the predominant contributor to the impact categories assessed, except for freshwater aquatic eco-toxicity. Part of the reason for the bottle’s significant contribution is the weight of the bottle compared to the weights of the cap, seal, label and secondary and transit packaging used in the system.

Comparing the different waste management options, the results indicate that recycling is the best option for HDPE bottles. Recycling bottles back into bottles provides the lowest impacts for the categories of abiotic resource depletion, climate change, and photo-oxidant formation. General recycling provides the lowest impacts for the categories of eutrophication and acidification.

Lightweighting the bottle by 10% shows fewer potential environmental impacts for all impact categories assessed. For example, with landfill as the waste management option, the potential impacts are 5.7% and 7.2% less for climate change and abiotic resource depletion, respectively.

As explained above, the overall results have been shown to be sensitive to the system boundary settings. To investigate this, the avoided burdens approach was compared to a cut-off approach in the sensitivity analysis. Using the avoided burdens approach, only minor differences in the potential environmental impacts are observed when comparing different recycled content scenarios. This was expected because of the system boundary assumptions made. Using the cut-off approach, increasing the recycled content leads to significant improvements in potential environmental impacts. For example, a bottle with 30% rHDPE content provides potential environmental impacts of 8.6% and 16% less to that life cycle stage than those of a 100% virgin HDPE bottle for the impact categories of climate change and abiotic resource depletion, respectively.

PET bottle system
The production and associated raw material extraction for the PET bottle is the predominant contributor to all of the impact categories assessed. The main reason for this is the weight of the bottle compared to the weights of the cap, seal, label and secondary and transit packaging used in the system.

Comparing the different waste management options, the results indicate that recycling is the best option for PET bottles. Recycling bottles back into bottles provides the lowest impacts for the categories of abiotic resource depletion, climate change, and eutrophication. General recycling provides the lowest impacts for the categories of photo-oxidant formation and acidification.

Lightweighting the bottle by 10% shows fewer potential environmental impacts for all impact categories assessed. For example, with landfill as the waste management option, the potential impacts are 7.2% and 7.8% less for climate change and abiotic resource depletion, respectively.

As for the HDPE bottle system, the overall results have been shown to be sensitive to system boundary assumptions. Using the avoided burdens approach, only minor differences in the potential environmental impacts are observed when comparing different recycled content scenarios. This was expected because of the system boundary assumptions made. Using the cut-off approach, increasing the recycled content leads to significant improvements in potential environmental impacts. For example, a bottle with 30% rPET content provides potential environmental impacts of 12% and 16% less to that life cycle stage than those of a 100% virgin PET bottle for the impact categories of climate change and abiotic resource depletion, respectively.

Pillow pouch system
The life cycle stages contributing the most to the environmental performance of the pillow pouch are the production of the pouch and distribution packaging production.

The jug, investigated with different reuse rates, makes a minimal contribution to the overall results.

Comparing the different waste management options, the results indicate that recycling is the best option for the impact categories of climate change, eutrophication, and acidification. For the impact categories of abiotic resource depletion and photo-oxidant formation, energy from waste has the lowest potential environmental impacts.

Lightweighting the pouch by 10% shows fewer potential environmental impacts for all of the impact categories assessed. For example, with landfill as the waste management option, the potential impacts are 2.8% and 4.7% less for climate change and abiotic resource depletion, respectively.

Stand-up pouch system
The life cycle stages contributing the most to the environmental performance of the stand-up pouch are the production of the stand-up pouch and the distribution packaging.

Comparing the different waste management options, the results indicate that recycling is the best option for the impact categories of climate change, eutrophication, and acidification. For the impact categories of abiotic resource depletion and photo-oxidant formation, energy from waste has the lowest potential environmental impacts.

Lightweighting the pouch by 10% shows fewer potential environmental impacts for all of the impact categories assessed. For example, with landfill as the waste management option, the potential impacts are 5.4% and 7.4% less for climate change and abiotic resource depletion, respectively.

Carton with screwcap system

The life cycle stages contributing the most to the environmental performance of the carton with screwcap system are the production of the laminate, followed by cap production and distribution packaging production.

Comparing the different waste management options, the results indicate that recycling is the best option for the impact categories of photo-oxidant formation, eutrophication, and acidification. For the impact categories of abiotic resource depletion and climate change, energy from waste has the lowest potential environmental impacts.

Lightweighting the liquid paper board by 10% shows fewer potential environmental impacts for all of the impact categories assessed. For example, with landfill as the waste management option, the potential impacts are 3.5% and 1.3% less for climate change and abiotic resource depletion, respectively.

Gable-top carton system

The life cycle stages contributing the most to the environmental performance of the gable-top carton system are the production of the laminate, followed by cap production and distribution packaging production.

Comparing the different waste management options, the results indicate that recycling is the best waste option for the impact categories of photo-oxidant formation, eutrophication, and acidification. For the impact categories of abiotic resource depletion and climate change, energy from waste has the lowest potential environmental impacts.

Lightweighting the liquid paper board by 10% shows fewer potential environmental impacts for all of the impact categories assessed. For example, with landfill as the waste management option, the potential impacts are 4.6% and 2.1% less for climate change and abiotic resource depletion, respectively.

7.3 Opportunities for improving environmental impacts

The study has demonstrated the potential for reducing the environmental impacts of milk packaging through lightweighting, diversion to recycling at end of life, and by increasing the recycled content. This must, of course, be seen in the context of the functionality requirements of the packaging. The authors consider that the benefits displayed for the example milk container systems investigated in this study can be replicated for the wider milk container market.

With no allocation of the burdens from their initial life, recycled HDPE and PET have been shown to have lower environmental impacts than the corresponding virgin materials.

The benefit of recycling at end of life is dependent on the assumption that virgin material production is avoided. In practice, the recycled material could displace another recycled material, no material at all or a different material. This is, for example, the case when HDPE bottles are recycled into park benches thereby displacing wood. If this is the case, the benefit of recycling would be less, possibly even resulting in environmental impacts from the recycling process.

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Appendix 1 Impact Assessment Method

Extracted from SimaPro.

CML 2 baseline 2000

Introduction

This method is an update from the CML 1992 method. This version is based on the spreadsheet version 2.02 (September 2001) as published on the CML web site and replaces the preliminary version.

The CML 2 baseline method elaborates the problem-oriented (midpoint) approach. The CML Guide provides a list of impact assessment categories grouped into
A: Obligatory impact categories (Category indicators used in most LCAs)
B: Additional impact categories (operational indicators exist, but are not often included in LCA studies)
C: Other impact categories (no operational indicators available, therefore impossible to include quantitatively in LCA)

In case several methods are available for obligatory impact categories, a baseline indicator is selected, based on the principle of best available practice. These baseline indicators are category indicators at "mid-point level" (problem oriented approach)". Baseline indicators are recommended for simplified studies. The guide provides guidelines for inclusion of other methods and impact category indicators in case of detailed studies and extended studies.

Only baseline indicators are available in the CML method in SimaPro (based on CML Excel spreadsheet with characterisation and normalisation factors). In general, these indicators do not deviate from the ones in the spreadsheet. In case the spreadsheet contained synonyms of substance names already available in the substance list of the SimaPro database, the existing names are used. A distinction is made for emissions to agricultural soil and industrial soil, indicated with respectively (agr.) or (ind.) behind substance names emitted to soil. Emissions to seawater are indicated with (sea), while emissions to fresh water have no addition behind their substance name (we assume that all emissions to water in existing process records are emissions to fresh water).

Depletion of abiotic resources

This impact category indicator is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of deaccumulation.

Climate change

The characterisation model as developed by the Intergovernmental Panel on Climate Change (IPCC) is selected for development of characterisation factors. Factors are expressed as Global Warming Potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission.

Human toxicity

Characterisation factors, expressed as Human Toxicity Potentials (HTP), are calculated with USES-LCA, describing fate, exposure and effects of toxic substances for an infinite time horizon. For each toxic substance HTP's are expressed as 1,4-dichlorobenzene equivalents/ kg emission.

Fresh-water aquatic eco-toxicity

Eco-toxicity Potential (FAETP) are calculated with USES-LCA, describing fate, exposure and effects of toxic substances. Characterisation factors are expressed as 1,4-dichlorobenzene equivalents/ kg emission.

Marine aquatic ecotoxicity

Marine eco-toxicity refers to impacts of toxic substances on marine ecosystems (see description fresh water toxicity).

Photo-oxidant formation

Photochemical Ozone Creation Potential (POCP) (also known as summer smog) for emission of substances to air is calculated with the UNECE Trajectory model (including fate), and expressed in kg ethylene equivalents/kg emission.

Acidification

Acidification Potentials (AP) is expressed as kg SO_2 equivalents/ kg emission.

Eutrophication

Nutrification potential (NP) is based on the stoichiometric procedure of Heijungs (1992), and expressed as kg PO_4^{3-} equivalents/ kg emission.

May 01 Characterisation for sum parameters metals added. October 2001 Version 2.02 update.

Appendix 2 Life Cycle Impact Assessment Detailed Results

The HDPE bottle system

Table A2.1 Life cycle impact assessment results for the HDPE bottle system, 100% vHDPE (per functional unit)

Impact category	Unit	Bottle production	Cap production	Label production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Bottle-to-bottle recycling UK	Recycling UK	Recycling China
Abiotic resource depletion	kg Sb eq	4.99E-01	3.53E-02	2.25E-02	1.08E-02	4.01E-03	4.93E-03	2.75E-02	2.07E-02	6.09E-03	-4.44E-03	-4.62E-03	1.56E-03	-2.68E-01	-3.60E-01	-2.77E-01	-2.57E-01
Climate change	kg CO_2 eq	3.39E+01	2.37E+00	1.80E+00	1.13E+00	5.48E-01	5.63E-01	4.37E+00	2.82E+00	9.68E-01	-2.58E-01	-5.33E-01	3.46E-01	1.35E+01	-1.35E+01	-1.21E+01	-9.03E+00
Photo-oxidant formation	kg C_2H_4 eq	3.42E-02	2.58E-03	1.56E-03	7.19E-04	7.11E-05	4.36E-04	2.46E-03	3.66E-04	1.13E-03	-1.12E-04	-4.06E-04	3.00E-05	-1.28E-03	-3.19E-02	-6.69E-03	-2.38E-03
Acidification	kg SO_2 eq	8.24E-03	7.48E-04	5.75E-04	9.54E-04	7.45E-05	4.54E-04	4.69E-03	3.83E-04	4.14E-04	-1.95E-04	-4.31E-04	3.17E-04	-1.34E-03	-4.19E-03	-1.06E-02	-4.81E-03
Eutrophication	kg PO_4^{3-} eq	9.75E-02	7.92E-03	5.57E-03	3.85E-03	6.80E-04	2.48E-03	2.12E-02	3.50E-03	2.73E-03	-3.44E-03	-2.26E-03	9.52E-04	-2.64E-02	-6.97E-02	-1.88E-01	-1.26E-01
Human toxicity	kg 1,4-DB eq	4.39E+00	1.35E+00	2.69E-01	2.11E-01	4.58E-02	1.45E+00	3.85E-01	2.36E-01	4.82E-01	-4.28E-02	-1.42E+00	2.29E-01	-1.09E+00	-3.08E+00	-3.23E+00	-1.50E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	3.92E-01	1.35E-01	2.29E-02	8.48E-02	4.15E-03	4.21E-01	3.32E-02	2.14E-02	8.03E-03	4.72E-02	-4.16E-01	8.88E-02	-6.34E-01	-2.10E-01	-9.50E-04	2.97E-02

Table A2.2 Life cycle impact assessment results for the HDPE bottle system, 30% rHDPE (per functional unit)

Impact category	Unit	Bottle production	Cap production	Label production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Recycling UK	Recycling China
Abiotic resource depletion	kg Sb eq	4.98E-01	3.53E-02	2.25E-02	1.08E-02	4.01E-03	4.93E-03	2.75E-02	2.07E-02	6.09E-03	-4.44E-03	-4.62E-03	1.56E-03	-2.68E-01	-2.77E-01	-2.57E-01
Climate change	kg CO$_2$ eq	3.38E+01	2.37E+00	1.80E+00	1.13E+00	5.48E-01	5.63E-01	4.37E+00	2.82E+00	9.68E-01	-2.58E-01	-5.33E-01	3.46E-01	1.35E+01	-1.21E+01	-9.03E+00
Photo-oxidant formation	kg C$_2$H$_4$ eq	3.42E-02	2.58E-03	1.56E-03	7.19E-04	7.11E-05	4.36E-04	2.46E-03	3.66E-04	1.13E-03	-1.12E-04	-4.06E-04	3.00E-05	-1.28E-03	-6.69E-03	-2.38E-03
Acidification	kg SO$_2$ eq	8.14E-03	7.48E-04	5.75E-04	9.54E-04	7.45E-05	4.54E-04	4.69E-03	3.83E-04	4.14E-04	-1.95E-04	-4.31E-04	3.17E-04	-1.34E-03	-1.06E-02	-4.81E-03
Eutrophication	kg PO$_4^{3-}$ eq	9.69E-02	7.92E-03	5.57E-03	3.85E-03	6.80E-04	2.48E-03	2.12E-02	3.50E-03	2.73E-03	-3.44E-03	-2.26E-03	9.52E-04	-2.64E-02	-1.88E-01	-1.26E-01
Human toxicity	kg 1,4-DB eq	4.38E+00	1.35E+00	2.69E-01	2.11E-01	4.58E-02	1.45E+00	3.85E-01	2.36E-01	4.82E-01	-4.28E-02	-1.42E+00	2.29E-01	-1.09E+00	-3.23E+00	-1.50E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	3.91E-01	1.35E-01	2.29E-02	8.48E-02	4.15E-03	4.21E-01	3.32E-02	2.14E-02	8.03E-03	4.72E-02	-4.16E-01	8.88E-02	-6.34E-01	-9.50E-04	2.97E-02

Table A2.3 Life cycle impact assessment results for the HDPE bottle system, 30% rHDPE (closed-loop) (per functional unit)

Impact category	Unit	Bottle production	Cap production	Label production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Bottle-to-bottle recycling UK
Abiotic resource depletion	kg Sb eq	3.68E-01	3.53E-02	2.25E-02	1.08E-02	4.01E-03	4.93E-03	2.75E-02	2.07E-02	6.09E-03	-4.44E-03	-4.62E-03	-2.32E-01
Climate change	kg CO_2 eq	2.64E+01	2.37E+00	1.80E+00	1.13E+00	5.48E-01	5.63E-01	4.37E+00	2.82E+00	9.68E-01	-2.58E-01	-5.33E-01	-6.39E+00
Photo-oxidant formation	kg C_2H_4 eq	2.43E-02	2.58E-03	1.56E-03	7.19E-04	7.11E-05	4.36E-04	2.46E-03	3.66E-04	1.13E-03	-1.12E-04	-4.06E-04	-2.00E-02
Acidification	kg SO_2 eq	6.13E-03	7.48E-04	5.75E-04	9.54E-04	7.45E-05	4.54E-04	4.69E-03	3.83E-04	4.14E-04	-1.95E-04	-4.31E-04	8.49E-03
Eutrophication	kg PO_4^{3-} eq	7.15E-02	7.92E-03	5.57E-03	3.85E-03	6.80E-04	2.48E-03	2.12E-02	3.50E-03	2.73E-03	-3.44E-03	-2.26E-03	-3.56E-03
Human toxicity	kg 1,4-DB eq	3.30E+00	1.35E+00	2.69E-01	2.11E-01	4.58E-02	1.45E+00	3.85E-01	2.36E-01	4.82E-01	-4.28E-02	-1.42E+00	-1.92E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.94E-01	1.35E-01	2.29E-02	8.48E-02	4.15E-03	4.21E-01	3.32E-02	2.14E-02	8.03E-03	4.72E-02	-4.16E-01	-1.10E-01

Table A2.4 Life cycle impact assessment results for the HDPE bottle system, 50% rHDPE (per functional unit)

Impact category	Unit	Bottle production	Cap production	Label production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Recycling UK	Recycling China
Abiotic resource depletion	kg Sb eq	4.98E-01	3.53E-02	2.25E-02	1.08E-02	4.01E-03	4.93E-03	2.75E-02	2.07E-02	6.09E-03	-4.44E-03	-4.62E-03	1.56E-03	-2.68E-01	-2.77E-01	-2.57E-01
Climate change	kg CO_2 eq	3.37E+01	2.37E+00	1.80E+00	1.13E+00	5.48E-01	5.63E-01	4.37E+00	2.82E+00	9.68E-01	-2.58E-01	-5.33E-01	3.46E-01	1.35E+01	-1.21E+01	-9.03E+00
Photo-oxidant formation	kg C_2H_4 eq	3.41E-02	2.58E-03	1.56E-03	7.19E-04	7.11E-05	4.36E-04	2.46E-03	3.66E-04	1.13E-03	-1.12E-04	-4.06E-04	3.00E-05	-1.28E-03	-6.69E-03	-2.38E-03
Acidification	kg SO_2 eq	8.07E-03	7.48E-04	5.75E-04	9.54E-04	7.45E-05	4.54E-04	4.69E-03	3.83E-04	4.14E-04	-1.95E-04	-4.31E-04	3.17E-04	-1.34E-03	-1.06E-02	-4.81E-03
Eutrophication	kg PO_4^{3-} eq	9.65E-02	7.92E-03	5.57E-03	3.85E-03	6.80E-04	2.48E-03	2.12E-02	3.50E-03	2.73E-03	-3.44E-03	-2.26E-03	9.52E-04	-2.64E-02	-1.88E-01	-1.26E-01
Human toxicity	kg 1,4-DB eq	4.37E+00	1.35E+00	2.69E-01	2.11E-01	4.58E-02	1.45E+00	3.85E-01	2.36E-01	4.82E-01	-4.28E-02	-1.42E+00	2.29E-01	-1.09E+00	-3.23E+00	-1.50E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	3.91E-01	1.35E-01	2.29E-02	8.48E-02	4.15E-03	4.21E-01	3.32E-02	2.14E-02	8.03E-03	4.72E-02	-4.16E-01	8.88E-02	-6.34E-01	-9.50E-04	2.97E-02

Table A2.5 Life cycle impact assessment results for the HDPE bottle system, 50% rHDPE (closed-loop) (per functional unit)

Impact category	Unit	Bottle production	Cap production	Label production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Bottle-to-bottle recycling UK
Abiotic resource depletion	kg Sb eq	2.82E-01	3.53E-02	2.25E-02	1.08E-02	4.01E-03	4.93E-03	2.75E-02	2.07E-02	6.09E-03	-4.44E-03	-4.62E-03	-1.47E-01
Climate change	kg CO_2 eq	2.13E+01	2.37E+00	1.80E+00	1.13E+00	5.48E-01	5.63E-01	4.37E+00	2.82E+00	9.68E-01	-2.58E-01	-5.33E-01	-1.64E+00
Photo-oxidant formation	kg C_2H_4 eq	1.77E-02	2.58E-03	1.56E-03	7.19E-04	7.11E-05	4.36E-04	2.46E-03	3.66E-04	1.13E-03	-1.12E-04	-4.06E-04	-1.21E-02
Acidification	kg SO_2 eq	4.72E-03	7.48E-04	5.75E-04	9.54E-04	7.45E-05	4.54E-04	4.69E-03	3.83E-04	4.14E-04	-1.95E-04	-4.31E-04	1.70E-02
Eutrophication	kg PO_4^{3-} eq	5.42E-02	7.92E-03	5.57E-03	3.85E-03	6.80E-04	2.48E-03	2.12E-02	3.50E-03	2.73E-03	-3.44E-03	-2.26E-03	4.05E-02
Human toxicity	kg 1,4-DB eq	2.56E+00	1.35E+00	2.69E-01	2.11E-01	4.58E-02	1.45E+00	3.85E-01	2.36E-01	4.82E-01	-4.28E-02	-1.42E+00	-1.14E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.29E-01	1.35E-01	2.29E-02	8.48E-02	4.15E-03	4.21E-01	3.32E-02	2.14E-02	8.03E-03	4.72E-02	-4.16E-01	-4.36E-02

Table A2.6 Life cycle impact assessment results for the HDPE bottle system, 100% vHDPE lightweight (per functional unit)

Impact category	Unit	Bottle production	Cap production	Label production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Recycling UK	Recycling China
Abiotic resource depletion	kg Sb eq	4.55E-01	3.53E-02	2.25E-02	1.08E-02	4.01E-03	2.73E-02	2.07E-02	5.57E-03	4.93E-03	-4.44E-03	-4.62E-03	1.42E-03	-2.44E-01	-2.51E-01	-2.31E-01
Climate change	kg CO_2 eq	3.13E+01	2.37E+00	1.80E+00	1.13E+00	5.48E-01	4.34E+00	2.82E+00	8.85E-01	5.63E-01	-2.58E-01	-5.33E-01	3.15E-01	1.23E+01	-1.10E+01	-7.91E+00
Photo-oxidant formation	kg C_2H_4 eq	3.09E-02	2.58E-03	1.56E-03	7.19E-04	7.11E-05	2.44E-03	3.66E-04	1.03E-03	4.36E-04	-1.12E-04	-4.06E-04	2.73E-05	-1.17E-03	-6.07E-03	-1.76E-03
Acidification	kg SO_2 eq	7.45E-03	7.48E-04	5.75E-04	9.54E-04	7.45E-05	4.66E-03	3.83E-04	3.79E-04	4.54E-04	-1.95E-04	-4.31E-04	2.89E-04	-1.22E-03	-9.65E-03	-3.82E-03
Eutrophication	kg PO_4^{3-} eq	8.83E-02	7.92E-03	5.57E-03	3.85E-03	6.80E-04	2.11E-02	3.50E-03	2.49E-03	2.48E-03	-3.44E-03	-2.26E-03	8.66E-04	-2.40E-02	-1.71E-01	-1.08E-01
Human toxicity	kg 1,4-DB eq	4.02E+00	1.35E+00	2.69E-01	2.11E-01	4.58E-02	3.82E-01	2.36E-01	4.41E-01	1.45E+00	-4.28E-02	-1.42E+00	2.08E-01	-9.95E-01	-2.93E+00	-1.20E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	3.59E-01	1.35E-01	2.29E-02	8.48E-02	4.15E-03	3.30E-02	2.14E-02	7.35E-03	4.21E-01	4.72E-02	-4.16E-01	8.08E-02	-5.77E-01	-8.64E-04	2.98E-02

Table A2.7 Life cycle impact assessment results for the HDPE bottle system, 100% vHDPE lightweight (closed-loop) (per functional unit)

Impact category	Unit	Bottle production	Cap production	Label production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Bottle-to-bottle recycling UK
Abiotic resource depletion	kg Sb eq	3.38E-01	3.53E-02	2.25E-02	1.08E-02	4.01E-03	2.73E-02	2.07E-02	5.57E-03	4.93E-03	-4.44E-03	-4.62E-03	-2.07E-01
Climate change	kg CO_2 eq	2.46E+01	2.37E+00	1.80E+00	1.13E+00	5.48E-01	4.34E+00	2.82E+00	8.85E-01	5.63E-01	-2.58E-01	-5.33E-01	-5.01E+00
Photo-oxidant formation	kg C_2H_4 eq	2.20E-02	2.58E-03	1.56E-03	7.19E-04	7.11E-05	2.44E-03	3.66E-04	1.03E-03	4.36E-04	-1.12E-04	-4.06E-04	-2.00E-02
Acidification	kg SO_2 eq	5.64E-03	7.48E-04	5.75E-04	9.54E-04	7.45E-05	4.66E-03	3.83E-04	3.79E-04	4.54E-04	-1.95E-04	-4.31E-04	-1.81E-03
Eutrophication	kg PO_4^{3-} eq	6.54E-02	7.92E-03	5.57E-03	3.85E-03	6.80E-04	2.11E-02	3.50E-03	2.49E-03	2.48E-03	-3.44E-03	-2.26E-03	-3.74E-02
Human toxicity	kg 1,4-DB eq	3.04E+00	1.35E+00	2.69E-01	2.11E-01	4.58E-02	3.82E-01	2.36E-01	4.41E-01	1.45E+00	-4.28E-02	-1.42E+00	-1.76E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.72E-01	1.35E-01	2.29E-02	8.48E-02	4.15E-03	3.30E-02	2.14E-02	7.35E-03	4.21E-01	4.72E-02	-4.16E-01	-8.56E-02

The PET bottle system

Table A2.8 Life cycle impact assessment results for the PET bottle system, 100% vPET (per functional unit)

Impact category	Unit	Bottle production	Cap production	Label production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Bottle-to-bottle recycling UK	Recycling UK	Recycling China
Abiotic resource depletion	kg Sb eq	8.33E-01	4.01E-02	2.56E-02	5.28E-02	4.01E-03	6.86E-02	2.96E-02	2.07E-02	1.03E-02	-2.46E-02	-2.32E-02	2.63E-03	-2.24E-01	-5.92E-01	-4.64E-01	-4.30E-01
Climate change	kg CO$_2$ eq	6.86E+01	2.70E+00	2.05E+00	4.43E+00	5.48E-01	5.05E+00	4.69E+00	2.83E+00	1.64E+00	-1.27E+00	-1.22E+00	5.84E-01	3.18E+01	-3.60E+01	-2.17E+01	-1.65E+01
Photo-oxidant formation	kg C$_2$H$_4$ eq	3.89E-02	2.93E-03	1.78E-03	3.75E-03	7.11E-05	5.15E-03	2.64E-03	3.67E-04	1.91E-03	-5.91E-04	-4.59E-04	5.06E-05	-9.49E-04	-3.04E-02	-1.09E-02	-3.63E-03
Acidification	kg SO$_2$ eq	7.26E-02	8.50E-04	6.53E-04	2.52E-03	7.45E-05	1.79E-03	5.04E-03	3.84E-04	7.00E-04	-9.82E-04	-6.42E-04	5.37E-04	1.54E-03	-6.08E-02	-1.75E-02	-7.67E-03
Eutrophication	kg PO$_4^{3-}$ eq	2.39E-01	9.00E-03	6.32E-03	1.62E-02	6.80E-04	1.98E-02	2.28E-02	3.51E-03	4.61E-03	-1.72E-02	-5.63E-03	1.60E-03	-8.42E-03	-1.68E-01	-3.07E-01	-2.02E-01
Human toxicity	kg 1,4-DB eq	1.82E+01	1.53E+00	3.06E-01	7.98E-01	4.58E-02	2.22E+00	4.13E-01	2.36E-01	8.15E-01	-2.68E-01	-1.55E+00	3.85E-01	3.15E-01	-1.56E+01	-5.37E+00	-2.44E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.14E+00	1.54E-01	2.60E-02	2.33E-01	4.15E-03	5.56E-01	3.57E-02	2.14E-02	1.36E-02	8.52E-02	-4.15E-01	1.50E-01	-4.66E-01	-1.70E+00	-1.22E-01	-7.01E-02

Table A2.9 Life cycle impact assessment results for the PET bottle system, 30% rPET (per functional unit)

Impact category	Unit	Bottle production	Cap production	Label production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Recycling UK	Recycling China
Abiotic resource depletion	kg Sb eq	8.34E-01	4.01E-02	2.56E-02	5.28E-02	4.01E-03	6.86E-02	2.96E-02	2.07E-02	1.03E-02	-2.46E-02	-2.32E-02	2.63E-03	-2.24E-01	-4.64E-01	-4.30E-01
Climate change	kg CO_2 eq	6.88E+01	2.70E+00	2.05E+00	4.43E+00	5.48E-01	5.05E+00	4.69E+00	2.83E+00	1.64E+00	-1.27E+00	-1.22E+00	5.84E-01	3.18E+01	-2.17E+01	-1.65E+01
Photo-oxidant formation	kg C_2H_4 eq	3.90E-02	2.93E-03	1.78E-03	3.75E-03	7.11E-05	5.15E-03	2.64E-03	3.67E-04	1.91E-03	-5.91E-04	-4.59E-04	5.06E-05	-9.49E-04	-1.09E-02	-3.63E-03
Acidification	kg SO_2 eq	7.28E-02	8.50E-04	6.53E-04	2.52E-03	7.45E-05	1.79E-03	5.04E-03	3.84E-04	7.00E-04	-9.82E-04	-6.42E-04	5.37E-04	1.54E-03	-1.75E-02	-7.67E-03
Eutrophication	kg PO_4^{3-} eq	2.40E-01	9.00E-03	6.32E-03	1.62E-02	6.80E-04	1.98E-02	2.28E-02	3.51E-03	4.61E-03	-1.72E-02	-5.63E-03	1.60E-03	-8.42E-03	-3.07E-01	-2.02E-01
Human toxicity	kg 1,4-DB eq	1.83E+01	1.53E+00	3.06E-01	7.98E-01	4.58E-02	2.22E+00	4.13E-01	2.36E-01	8.15E-01	-2.68E-01	-1.55E+00	3.85E-01	3.15E-01	-5.37E+00	-2.44E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.15E+00	1.54E-01	2.60E-02	2.33E-01	4.15E-03	5.56E-01	3.57E-02	2.14E-02	1.36E-02	8.52E-02	-4.15E-01	1.50E-01	-4.66E-01	-1.22E-01	-7.01E-02

Table A2.10 Life cycle impact assessment results for the PET bottle system, 30% rPET (closed-loop) (per functional unit)

Impact category	Unit	Bottle production	Cap production	Label production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Bottle-to-bottle recycling UK
Abiotic resource depletion	kg Sb eq	6.00E-01	4.01E-02	2.56E-02	5.28E-02	4.01E-03	6.86E-02	2.96E-02	2.07E-02	1.03E-02	-2.46E-02	-2.32E-02	-3.63E-01
Climate change	kg CO_2 eq	5.05E+01	2.70E+00	2.05E+00	4.43E+00	5.48E-01	5.05E+00	4.69E+00	2.83E+00	1.64E+00	-1.27E+00	-1.22E+00	-1.80E+01
Photo-oxidant formation	kg C_2H_4 eq	2.82E-02	2.93E-03	1.78E-03	3.75E-03	7.11E-05	5.15E-03	2.64E-03	3.67E-04	1.91E-03	-5.91E-04	-4.59E-04	-1.99E-02
Acidification	kg SO_2 eq	5.25E-02	8.50E-04	6.53E-04	2.52E-03	7.45E-05	1.79E-03	5.04E-03	3.84E-04	7.00E-04	-9.82E-04	-6.42E-04	-4.10E-02
Eutrophication	kg PO_4^{3-} eq	1.76E-01	9.00E-03	6.32E-03	1.62E-02	6.80E-04	1.98E-02	2.28E-02	3.51E-03	4.61E-03	-1.72E-02	-5.63E-03	-1.06E-01
Human toxicity	kg 1,4-DB eq	1.30E+01	1.53E+00	3.06E-01	7.98E-01	4.58E-02	2.22E+00	4.13E-01	2.36E-01	8.15E-01	-2.68E-01	-1.55E+00	-1.05E+01
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	1.53E+00	1.54E-01	2.60E-02	2.33E-01	4.15E-03	5.56E-01	3.57E-02	2.14E-02	1.36E-02	8.52E-02	-4.15E-01	-1.09E+00

Table A2.11 Life cycle impact assessment results for the PET bottle system, 30% rPET lightweight (per functional unit)

Impact category	Unit	Bottle production	Cap production	Label production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Recycling UK	Recycling China
Abiotic resource depletion	kg Sb eq	7.54E-01	4.01E-02	2.56E-02	5.28E-02	4.01E-03	6.86E-02	2.92E-02	2.07E-02	9.29E-03	-2.46E-02	-2.32E-02	2.38E-03	-2.04E-01	-4.20E-01	-3.89E-01
Climate change	kg CO_2 eq	6.23E+01	2.70E+00	2.05E+00	4.43E+00	5.48E-01	5.05E+00	4.63E+00	2.83E+00	1.47E+00	-1.27E+00	-1.22E+00	5.29E-01	2.87E+01	-1.97E+01	-1.49E+01
Photo-oxidant formation	kg C_2H_4 eq	3.52E-02	2.93E-03	1.78E-03	3.75E-03	7.11E-05	5.15E-03	2.61E-03	3.67E-04	1.72E-03	-5.91E-04	-4.59E-04	4.59E-05	-8.68E-04	-9.87E-03	-3.24E-03
Acidification	kg SO_2 eq	6.56E-02	8.50E-04	6.53E-04	2.52E-03	7.45E-05	1.79E-03	4.97E-03	3.84E-04	6.32E-04	-9.82E-04	-6.42E-04	4.87E-04	1.37E-03	-1.59E-02	-6.89E-03
Eutrophication	kg PO_4^{3-} eq	2.16E-01	9.00E-03	6.32E-03	1.62E-02	6.80E-04	1.98E-02	2.25E-02	3.51E-03	4.16E-03	-1.72E-02	-5.63E-03	1.45E-03	-7.86E-03	-2.78E-01	-1.82E-01
Human toxicity	kg 1,4-DB eq	1.65E+01	1.53E+00	3.06E-01	7.98E-01	4.58E-02	2.22E+00	4.08E-01	2.36E-01	7.35E-01	-2.68E-01	-1.55E+00	3.49E-01	2.72E-01	-4.86E+00	-2.19E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	1.94E+00	1.54E-01	2.60E-02	2.33E-01	4.15E-03	5.56E-01	3.52E-02	2.14E-02	1.22E-02	8.52E-02	-4.15E-01	1.36E-01	-4.26E-01	-1.10E-01	-6.25E-02

Table A2.12 Life cycle impact assessment results for the PET bottle system, 30% rPET lightweight (closed-loop) (per functional unit)

Impact category	Unit	Bottle production	Cap production	Label production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Bottle-to-bottle recycling UK
Abiotic resource depletion	kg Sb eq	5.43E-01	4.01E-02	2.56E-02	5.28E-02	4.01E-03	6.86E-02	2.92E-02	2.07E-02	9.29E-03	-2.46E-02	-2.32E-02	-3.29E-01
Climate change	kg CO_2 eq	4.59E+01	2.70E+00	2.05E+00	4.43E+00	5.48E-01	5.05E+00	4.63E+00	2.83E+00	1.47E+00	-1.27E+00	-1.22E+00	-1.63E+01
Photo-oxidant formation	kg C_2H_4 eq	2.55E-02	2.93E-03	1.78E-03	3.75E-03	7.11E-05	5.15E-03	2.61E-03	3.67E-04	1.72E-03	-5.91E-04	-4.59E-04	-1.80E-02
Acidification	kg SO_2 eq	4.73E-02	8.50E-04	6.53E-04	2.52E-03	7.45E-05	1.79E-03	4.97E-03	3.84E-04	6.32E-04	-9.82E-04	-6.42E-04	-3.69E-02
Eutrophication	kg PO_4^{3-} eq	1.59E-01	9.00E-03	6.32E-03	1.62E-02	6.80E-04	1.98E-02	2.25E-02	3.51E-03	4.16E-03	-1.72E-02	-5.63E-03	-9.65E-02
Human toxicity	kg 1,4-DB eq	1.18E+01	1.53E+00	3.06E-01	7.98E-01	4.58E-02	2.22E+00	4.08E-01	2.36E-01	7.35E-01	-2.68E-01	-1.55E+00	-9.49E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	1.38E+00	1.54E-01	2.60E-02	2.33E-01	4.15E-03	5.56E-01	3.52E-02	2.14E-02	1.22E-02	8.52E-02	-4.15E-01	-9.79E-01

The pillow pouch system

Table A2.13 Life cycle impact assessment results for the pillow pouch system, 100% virgin (per functional unit)

Impact category	Unit	Pillow pouch production	Pkg for delivery to dairy	Filling and packing	Jug	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Recycling UK	Recycling China
Abiotic resource depletion	kg Sb eq	1.01E-01	9.61E-04	4.08E-04	1.01E-02	9.37E-02	2.80E-03	2.07E-02	1.11E-03	-3.27E-04	-2.26E-02	3.14E-04	-5.41E-02	-3.22E-02	-2.82E-02
Climate change	kg CO_2 eq	6.83E+00	1.01E-01	5.58E-02	7.80E-01	1.41E+01	4.44E-01	2.82E+00	1.77E-01	-2.15E-02	-2.18E+00	6.97E-02	2.71E+00	-1.19E+00	-5.65E-01
Photo-oxidant formation	kg C_2H_4 eq	6.48E-03	8.04E-05	7.23E-06	5.67E-04	8.51E-03	2.50E-04	3.66E-04	2.06E-04	-4.69E-06	-6.00E-04	6.04E-06	-2.58E-04	-1.57E-04	7.14E-04
Acidification	kg SO_2 eq	3.18E-03	1.15E-04	7.57E-06	2.63E-04	2.15E-02	4.77E-04	3.83E-04	7.58E-05	-1.09E-05	-1.29E-03	6.39E-05	-2.70E-04	-4.40E-04	7.38E-04
Eutrophication	kg PO_4^{3-} eq	3.23E-02	4.57E-04	6.91E-05	2.46E-03	7.17E-02	2.16E-03	3.50E-03	4.99E-04	-1.89E-04	-2.27E-02	1.92E-04	-5.33E-03	-7.48E-03	5.11E-03
Human toxicity	kg 1,4-DB eq	1.21E+00	2.54E-02	4.66E-03	1.21E-01	4.08E+00	3.91E-02	2.36E-01	8.82E-02	-1.93E-03	-8.64E-02	4.61E-02	-2.21E-01	-2.62E-01	8.90E-02
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.43E-01	5.98E-03	4.22E-04	1.20E-02	9.71E-01	3.38E-03	2.14E-02	1.47E-03	6.17E-03	8.86E-01	1.79E-02	-1.28E-01	-1.52E-03	4.68E-03

Table A2.14 Life cycle impact assessment results for the pillow pouch system, 100% virgin lightweight (per functional unit)

Impact category	Unit	Pillow pouch production	Pkg for delivery to dairy	Filling and packing	Jug	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Recycling UK	Recycling China
Abiotic resource depletion	kg Sb eq	9.11E-02	9.61E-04	4.08E-04	1.01E-02	9.37E-02	2.76E-03	2.07E-02	1.04E-03	3.74E-05	-2.26E-02	2.85E-04	-4.91E-02	-2.93E-02	-2.57E-02
Climate change	kg CO_2 eq	6.21E+00	1.01E-01	5.58E-02	7.80E-01	1.41E+01	4.37E-01	2.82E+00	1.65E-01	5.94E-03	-2.18E+00	6.33E-02	2.46E+00	-1.08E+00	-5.13E-01
Photo-oxidant formation	kg C_2H_4 eq	5.83E-03	8.04E-05	7.23E-06	5.67E-04	8.51E-03	2.47E-04	3.66E-04	1.93E-04	3.35E-06	-6.00E-04	5.48E-06	-2.34E-04	-1.49E-04	6.43E-04
Acidification	kg SO_2 eq	2.83E-03	1.15E-04	7.57E-06	2.63E-04	2.15E-02	4.70E-04	3.83E-04	7.08E-05	6.38E-06	-1.29E-03	5.80E-05	-2.45E-04	-4.07E-04	6.65E-04
Eutrophication	kg PO_4^{3-} eq	2.94E-02	4.57E-04	6.91E-05	2.46E-03	7.17E-02	2.12E-03	3.50E-03	4.66E-04	2.88E-05	-2.27E-02	1.74E-04	-4.83E-03	-6.94E-03	4.49E-03
Human toxicity	kg 1,4-DB eq	1.11E+00	2.54E-02	4.66E-03	1.21E-01	4.08E+00	3.85E-02	2.36E-01	8.23E-02	5.22E-04	-8.64E-02	4.18E-02	-2.00E-01	-2.39E-01	7.96E-02
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	2.24E-01	5.98E-03	4.22E-04	1.20E-02	9.71E-01	3.32E-03	2.14E-02	1.37E-03	4.51E-05	8.86E-01	1.62E-02	-1.16E-01	-1.31E-03	4.33E-03

The stand-up pouch system

Table A2.15 Life cycle impact assessment results for the stand-up pouch system, 100% virgin (per functional unit)

Impact category	Unit	Stand-up pouch production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Recycling UK	Recycling China
Abiotic resource depletion	kg Sb eq	2.29E-01	1.09E-03	9.04E-03	7.80E-02	3.53E-03	2.07E-02	3.80E-03	-4.18E-04	-1.88E-02	9.65E-04	-1.66E-01	-9.73E-02	-8.50E-02
Climate change	kg CO_2 eq	1.78E+01	1.18E-01	1.23E+00	1.17E+01	5.60E-01	2.83E+00	6.03E-01	-2.54E-02	-1.81E+00	2.14E-01	8.33E+00	-3.61E+00	-1.70E+00
Photo-oxidant formation	kg C_2H_4 eq	1.65E-02	9.22E-05	1.87E-04	7.08E-03	3.16E-04	3.67E-04	7.03E-04	-1.04E-05	-4.99E-04	1.86E-05	-7.94E-04	-2.89E-04	2.39E-03
Acidification	kg SO_2 eq	7.08E-03	2.49E-04	1.86E-04	1.79E-02	6.02E-04	3.84E-04	2.58E-04	-1.85E-05	-1.07E-03	1.97E-04	-8.31E-04	-1.12E-03	2.51E-03
Eutrophication	kg PO_4^{3-} eq	5.55E-02	5.21E-04	2.14E-03	5.96E-02	2.72E-03	3.51E-03	1.70E-03	-3.52E-04	-1.89E-02	5.90E-04	-1.64E-02	-1.77E-02	2.10E-02
Human toxicity	kg 1,4-DB eq	2.63E+00	2.92E-02	1.16E-01	3.39E+00	4.93E-02	2.36E-01	3.01E-01	-3.36E-03	-7.19E-02	1.42E-01	-6.79E-01	-7.62E-01	3.19E-01
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	4.89E-01	7.23E-03	1.98E-02	8.08E-01	4.26E-03	2.14E-02	5.01E-03	7.07E-03	7.37E-01	5.50E-02	-3.93E-01	-6.97E-03	1.21E-02

Table A2.16 Life cycle impact assessment results for the stand-up pouch system, 100% virgin lightweight (per functional unit)

Impact category	Unit	Stand-up pouch production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Recycling UK	Recycling China
Abiotic resource depletion	kg Sb eq	2.05E-01	1.09E-03	9.04E-03	7.80E-02	3.38E-03	2.07E-02	3.80E-03	-4.18E-04	-1.88E-02	8.68E-04	-1.50E-01	-8.76E-02	-7.65E-02
Climate change	kg CO_2 eq	1.60E+01	1.18E-01	1.23E+00	1.17E+01	5.37E-01	2.83E+00	6.03E-01	-2.54E-02	-1.81E+00	1.93E-01	7.50E+00	-3.25E+00	-1.53E+00
Photo-oxidant formation	kg C_2H_4 eq	1.49E-02	9.22E-05	1.87E-04	7.08E-03	3.03E-04	3.67E-04	7.03E-04	-1.04E-05	-4.99E-04	1.67E-05	-7.15E-04	-2.61E-04	2.15E-03
Acidification	kg SO_2 eq	5.95E-03	2.49E-04	1.86E-04	1.79E-02	5.77E-04	3.84E-04	2.58E-04	-1.85E-05	-1.07E-03	1.77E-04	-7.48E-04	-1.01E-03	2.26E-03
Eutrophication	kg PO_4^{3-} eq	4.82E-02	5.21E-04	2.14E-03	5.96E-02	2.61E-03	3.51E-03	1.70E-03	-3.52E-04	-1.89E-02	5.31E-04	-1.47E-02	-1.60E-02	1.89E-02
Human toxicity	kg 1,4-DB eq	2.41E+00	2.92E-02	1.16E-01	3.39E+00	4.73E-02	2.36E-01	3.01E-01	-3.36E-03	-7.19E-02	1.27E-01	-6.11E-01	-6.85E-01	2.87E-01
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	4.44E-01	7.23E-03	1.98E-02	8.08E-01	4.08E-03	2.14E-02	5.01E-03	7.07E-03	7.37E-01	4.95E-02	-3.54E-01	-6.27E-03	1.09E-02

The carton with screwcap system

Table A2.17 Life cycle impact assessment results for the carton with screwcap system, 100% virgin (per functional unit)

Impact category	Unit	Laminate production	Cap production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Recycling Sweden
Abiotic resource depletion	kg Sb eq	1.33E-01	1.50E-01	1.91E-03	3.31E-02	6.86E-02	3.72E-03	2.07E-02	7.77E-03	-8.56E-04	-2.30E-02	-1.59E-02	-1.87E-01	-1.41E-01
Climate change	kg CO_2 eq	1.36E+01	1.00E+01	2.41E-01	4.50E+00	5.05E+00	5.91E-01	2.83E+00	1.23E+00	5.15E-02	-1.20E+00	3.56E+00	-1.91E+00	2.85E+00
Photo-oxidant formation	kg C_2H_4 eq	1.19E-02	1.10E-02	1.75E-04	7.56E-04	5.15E-03	3.33E-04	3.67E-04	1.44E-03	-2.90E-06	-4.42E-04	-3.37E-04	8.64E-04	-2.33E-03
Acidification	kg SO_2 eq	1.32E-02	3.08E-03	3.62E-04	7.22E-04	1.79E-03	6.35E-04	3.84E-04	5.28E-04	2.00E-05	-6.25E-04	6.82E-04	8.87E-04	-7.59E-03
Eutrophication	kg PO_4^{3-} eq	6.48E-02	3.66E-02	1.08E-03	8.87E-03	1.98E-02	2.87E-03	3.51E-03	3.48E-03	-2.74E-05	-5.53E-03	-9.96E-05	-8.81E-03	-3.54E-02
Human toxicity	kg 1,4-DB eq	3.86E+00	1.75E+00	6.77E-02	7.48E-01	2.22E+00	5.20E-02	2.36E-01	6.15E-01	-1.81E-03	-1.50E+00	5.83E-02	-6.20E-01	-1.46E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	7.42E-01	1.72E-01	1.85E-02	1.06E-01	5.56E-01	4.49E-03	2.14E-02	1.02E-02	-3.90E-04	-3.98E-01	8.89E-03	-3.64E-01	-5.69E-01

Table A2.18 Life cycle impact assessment results for the carton with screwcap system, 100% virgin lightweight (per functional unit)

Impact category	Unit	Laminate production	Cap production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Recycling Sweden
Abiotic resource depletion	kg Sb eq	1.27E-01	1.50E-01	1.91E-03	3.31E-02	6.86E-02	3.50E-03	2.07E-02	7.26E-03	-8.56E-04	-2.30E-02	-1.42E-02	-1.80E-01	-1.38E-01
Climate change	kg CO_2 eq	1.26E+01	1.00E+01	2.41E-01	4.50E+00	5.05E+00	5.56E-01	2.83E+00	1.15E+00	5.15E-02	-1.20E+00	3.22E+00	-1.14E+00	3.19E+00
Photo-oxidant formation	kg C_2H_4 eq	1.14E-02	1.10E-02	1.75E-04	7.56E-04	5.15E-03	3.13E-04	3.67E-04	1.34E-03	-2.90E-06	-4.42E-04	-3.02E-04	7.22E-04	-2.10E-03
Acidification	kg SO_2 eq	1.19E-02	3.08E-03	3.62E-04	7.22E-04	1.79E-03	5.97E-04	3.84E-04	4.94E-04	2.00E-05	-6.25E-04	6.28E-04	7.40E-04	-6.83E-03
Eutrophication	kg PO_4^{3-} eq	5.98E-02	3.66E-02	1.08E-03	8.87E-03	1.98E-02	2.70E-03	3.51E-03	3.25E-03	-2.74E-05	-5.53E-03	-4.87E-05	-9.07E-03	-3.26E-02
Human toxicity	kg 1,4-DB eq	3.55E+00	1.75E+00	6.77E-02	7.48E-01	2.22E+00	4.89E-02	2.36E-01	5.74E-01	-1.81E-03	-1.50E+00	6.23E-02	-6.05E-01	-1.35E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	6.74E-01	1.72E-01	1.85E-02	1.06E-01	5.56E-01	4.22E-03	2.14E-02	9.57E-03	-3.90E-04	-3.98E-01	1.18E-02	-3.55E-01	-5.39E-01

The gable-top carton system

Table A2.19 Life cycle impact assessment results for the gable-top carton system, 100% virgin (per functional unit)

Impact category	Unit	Laminate production	Cap production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Recycling Sweden
Abiotic resource depletion	kg Sb eq	1.35E-01	7.00E-02	2.71E-03	1.65E-02	6.86E-02	3.55E-03	2.07E-02	7.35E-03	-1.18E-03	-2.30E-02	-1.80E-02	-1.51E-01	-1.01E-01
Climate change	kg CO_2 eq	1.43E+01	4.78E+00	3.45E-01	2.24E+00	5.05E+00	5.63E-01	2.83E+00	1.17E+00	6.56E-02	-1.20E+00	3.90E+00	-5.01E+00	7.53E-02
Photo-oxidant formation	kg C_2H_4 eq	1.84E-02	5.05E-03	2.44E-04	3.39E-04	5.15E-03	3.17E-04	3.67E-04	1.36E-03	-4.85E-06	-4.42E-04	-3.82E-04	1.24E-03	-2.59E-03
Acidification	kg SO_2 eq	1.43E-02	1.46E-03	5.11E-04	3.33E-04	1.79E-03	6.05E-04	3.84E-04	4.99E-04	2.47E-05	-6.25E-04	6.93E-04	1.28E-03	-8.45E-03
Eutrophication	kg PO_4^{3-} eq	6.92E-02	1.72E-02	1.52E-03	3.76E-03	1.98E-02	2.73E-03	3.51E-03	3.29E-03	-7.35E-05	-5.53E-03	-3.15E-04	-4.18E-03	-3.57E-02
Human toxicity	kg 1,4-DB eq	4.92E+00	8.58E-01	9.50E-02	2.21E-01	2.22E+00	4.96E-02	2.36E-01	5.81E-01	-2.56E-03	-1.50E+00	1.61E-02	-4.57E-01	-1.47E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	8.27E-01	8.59E-02	2.70E-02	3.36E-02	5.56E-01	4.28E-03	2.14E-02	9.68E-03	9.09E-04	-3.98E-01	-9.10E-03	-2.70E-01	-5.02E-01

Table A2.20 Life cycle impact assessment results for the gable-top carton system, 100% virgin lightweight (per functional unit)

Impact category	Unit	Laminate production	Cap production	Pkg for delivery to dairy	Filling and packing	Pkg for delivery to retail	Distribution to retail	Retail storage	Transport to home	Waste mgmt of pkg to dairy	Waste mgmt of pkg to retail	Landfill	EfW	Recycling Sweden
Abiotic resource depletion	kg Sb eq	1.28E-01	7.00E-02	2.71E-03	1.65E-02	6.86E-02	3.30E-03	2.07E-02	6.75E-03	-1.18E-03	-2.30E-02	-1.62E-02	-1.43E-01	-9.82E-02
Climate change	kg CO$_2$ eq	1.33E+01	4.78E+00	3.45E-01	2.24E+00	5.05E+00	5.24E-01	2.83E+00	1.07E+00	6.56E-02	-1.20E+00	3.52E+00	-4.15E+00	4.54E-01
Photo-oxidant formation	kg C$_2$H$_4$ eq	1.77E-02	5.05E-03	2.44E-04	3.39E-04	5.15E-03	2.95E-04	3.67E-04	1.25E-03	-4.85E-06	-4.42E-04	-3.43E-04	1.08E-03	-2.33E-03
Acidification	kg SO$_2$ eq	1.29E-02	1.46E-03	5.11E-04	3.33E-04	1.79E-03	5.62E-04	3.84E-04	4.59E-04	2.47E-05	-6.25E-04	6.32E-04	1.11E-03	-7.61E-03
Eutrophication	kg PO$_4^{3-}$ eq	6.34E-02	1.72E-02	1.52E-03	3.76E-03	1.98E-02	2.54E-03	3.51E-03	3.02E-03	-7.35E-05	-5.53E-03	-2.58E-04	-4.46E-03	-3.26E-02
Human toxicity	kg 1,4-DB eq	4.58E+00	8.58E-01	9.50E-02	2.21E-01	2.22E+00	4.61E-02	2.36E-01	5.34E-01	-2.56E-03	-1.50E+00	2.05E-02	-4.41E-01	-1.34E+00
Freshwater aquatic eco-toxicity	kg 1,4-DB eq	7.51E-01	8.59E-02	2.70E-02	3.36E-02	5.56E-01	3.98E-03	2.14E-02	8.90E-03	9.09E-04	-3.98E-01	-5.82E-03	-2.60E-01	-4.68E-01

Appendix 3 Critical Review

"Life Cycle Assessment of Example Packaging Systems for Milk - Retail"

Critical Review

according to ISO 14040 and 14044

prepared for

Waste & Resources Action Programme
(WRAP)

by

Walter Klöpffer (Chair)

Chris Foster

and

Andreas Detzel

April 2009

1 General Aspects of this Critical Review

This critical review was commissioned by the Waste & Resources Action Programme (WRAP, The Commissioner) in November 2007 to a critical review team chaired by Walter Klöpffer. The LCA study to be reviewed has been performed by Environmental Resources Management (ERM), Oxford, UK (The Practitioner).

Since the chair has been involved from the start of the study, the critical review can be considered as (at least partly) interactive review, as recommended by SETAC [1]. The performance of critical review studies in the accompanying mode is not requested by ISO 14040 [2], but preferable to the a posteriori mode out of experience [3]. The chair of the panel reviewed the Goal & Scope chapter submitted November 14, 2007. He and Chris Foster were invited to attend the mid-term meeting of the project March 31, 2008 in the ERM office in London.

According to the international (and British) LCA-standards, this critical review is a review by “interested parties” (panel method), see ISO 14040 Section 7.3.3 [2] and ISO 14044 Section 6.3 [4]. The co-reviewers invited to join the panel were selected under the aspects of competence and special knowledge about the UK market, packaging LCI data and LCA methodology. The reviewers also fulfil, beyond competence, the requirement to be neutral and independent from particular commercial interests. It was therefore not necessary to invite other interested parties into the critical review panel; such parties are involved, however, in the steering committee of this project for the Commissioner. Furthermore, since WRAP is a neutral and not for profit organization striving to better recycling and waste options only, no unfair treatment of any particular product system is to be expected.

With the exception of the March 2008 meeting in London (1st draft report by ERM) there were no face-to-face meetings during this review, but frequent exchange of comments via email and an intense and decisive data check by Andreas Detzel via internet/phone-connection with the Practitioner which showed considerable data quality issues. Those have meanwhile been partly overcome by the practitioner, a fact which has also been reflected in the updated report versions sent to the review team. Yet, they have not been fully solved.

A major change in the structure of the study with severe consequences for the reporting occurred during the final phase (after the mid-term meeting) and came as a surprise to the review team: the topic was split according to the mode of distribution into a retail part and a doorstep part. This means that two final reports and consequently two critical review reports have to be written. Since this procedure was not planned – not even mentioned as a possible variant – at the beginning, and therefore could not be calculated properly by the reviewers, the two reports will be very similar (nearly identical) with the exception of a few aspects that are specific to the doorstep distribution system. This critical review report refers to the retail report.

[PRACTITIONER’S COMMENTS: The decision to split the report into two was done on the request of the steering committee. Members of the steering committee were concerned that the reader would make comparisons between the two distribution systems if provided in one report whereas it could be argued that they are non-comparable (ie providing different functions). The possibility of two reports had not been discussed in great detail previously in the steering committee. The request was agreed to by the commissioner and the practitioner, and discussed with the critical review chair. Due to this occurring in the latter stages of the project, the two reports are very similar in both text and layout.]

The Final Draft Report (distribution via the supermarket) was delivered December 4, 2008. The second report (distribution via doorstep delivery) followed December 16, 2008 (see separate critical review report). The statements contained in this critical review report are based on the December 04 report and additional material delivered by the Practitioner (February 2009) and commented in detail by Andreas Detzel. This was followed by another draft report containing additional information (March 2009).

The critical review process took place in an open and constructive atmosphere. It should be greatly acknowledged that the practitioner provided additional information until the last minute despite severe budget restrictions.

The resulting critical review report is consensus between the reviewers.

2 General Comments

The original plan of the work, as laid down in the reviewed Goal & Scope chapter, was a very ambitious one and so was the time schedule, as stated in the critical review report. Budgetary constraints of the Commissioner lead to a formal end of the review contracts March 31 2008, which were, of course, fulfilled also beyond this date.

Data acquisition turned out to be the major – and only partly solved – problem of this LCA study. The original aim, to compare the packaging systems for milk (for retail and doorstep distribution) under environmental aspects, was abandoned and only the aspects of recycling and waste management were included in the final report(s). This constitutes clearly a severe deviation from the original goal and scope of the study. Here it is appropriate to remind that such a change is allowed by the LCA standards (iterative procedure), as long as the changes are done in written form. Since the goal of a study is not to be scrutinized by the critical reviewers, we can only accept this decision. There remains nevertheless the feeling that exactly this change was strived for by those interested parties not delivering the detailed data needed for the accomplishment of the original goal. It is no excuse at all to claim that the data are not available; LCI-relevant data are always available in the companies, they have only to be transformed into a format useful for LCA. This needs some work and good will, evidently absent in this case (in contrast to so-called “Carbon Footprint” (GWP) studies [7,8] which are rather popular in the UK and – if properly done - need roughly the same data-set as full LCAs). It should be added that it is difficult to transform a comparative LCA study into a recycling and waste management study. If this was the aim from the beginning, another methodology of the study would have been adopted from the beginning.

Apart from this lack of original data the Practitioner did his/her best to bring the study to an acceptable result. We appreciate this and acknowledge that WRAP, too, tried to save what could be saved. The great breakthrough in environmental improvement of British packaging – here in the market of milk containers – was missed however. The study, which we would like to scale down to an exploratory LCA, still offers many items useful to think about and get advise for improvements. It should be upgraded to a full comparative LCA in the future, including all aspects of “end-of-life”, once the data situation will have been improved. The methodology should be unified (cradle-to-point of sale + end-of-life phases) into one in order to create homogenous cradle-to-grave systems.

The ISO standard puts particular focus on transparency and reproducibility of a LCA study. The separation in two part-LCAs, and using two different softwares (here: Simapro and Wrate), is adverse to those requirements and should not be a permanent solution.

[PRACTITIONER'S COMMENTS: We agreed that there are limitations to the transparency and reproducibility of the study due to the sensitivity (or perceived sensitivity) of data made available, the data itself, and the complications due to the use of WRATE. We recognise that there may be an opportunity to revisit the project and improve on these issues if the data providers are willing to collaborate more closely on the project.]

3 Statements by the reviewers as required by ISO 14040

According to the LCA-framework standard ISO 14040 [2]

"The critical review process shall ensure that:

- *the methods used to carry out the LCA are consistent with the international Standard;*
- *the methods used to carry out the LCA are scientifically and technically valid;*
- *the data used are appropriate and reasonable in relation to the goal of the study;*
- *the interpretations reflect the limitations identified and the goal of the study;*
- *the study report is transparent and consistent."*

In the following sections 3.1 to 3.5 these items are discussed to our best judgment based on the revised ISO standards 14040 [2] and 14044 [4]. These standards superseded the familiar old series ISO 14040-43 (1997-2000) in October 2006. The two standards are linked in such a way that it is not possible to use the LCA framework (14040) without using the strict rules (the "shalls") contained in 14044, see also [5].

It is the right of both Commissioner and Practitioner to comment on this critical review or parts of it; these comments are also part of the final report.

3.1 Are the methods used to carry out the LCA consistent with the International Standard?

In the final report it is claimed that this study has been performed according to the international standards ISO 14040 and 14044 [2,4]. This includes that the structure of LCA [2] as well as the detailed rules for the four components [4] had to be observed.

Concerning the structure it can be said the main chapters 2/3 to 6 of the report correspond to the four components "Goal and scope definition" (2/3), "Inventory analysis" (4), "Impact assessment" (5) and "Interpretation" (6) of LCA. They are rounded up by a short introduction (1), a short chapter "conclusions and recommendations" (7) and three appendices. Not only the structure, but also the content follows the standards with a few exceptions mentioned below.

Life cycle inventory (LCI) of a full LCA requires the modelling of the product system from cradle-to-grave, from raw material extraction to the end-of-life (EOL) phase, i.e. waste management including recycling. In this LCI, two models were used: one, the Sima Pro software model for the upstream part of the product tree and the WRATE waste model (EOL). This procedure, although not forbidden by the standards (ISO makes no detailed prescriptions about the calculations), introduces difficulties into the modelling and the presentation of results. Confusions are thus difficult to avoid.

[PRACTITIONER'S COMMENTS: We agree that using two software tools, SimaPro and WRATE, has caused some problems in presented data and results in a transparent and coherent manner. WRATE was used since there is no LCI data available that is as comprehensive and specific to UK waste management processes as WRATE. It is normal LCA practice to combined LCI data from different sources. The difference here is that instead of importing the LCI data from one tool to another, the LCI data is appraised in the source software using the same impact methods. The WRATE software is compatible to SimaPro in the sense that it produces complete life cycle inventories and uses the same secondary data sources (ecoinvent) and impact methods. However, the tools are not wholly compatible in that it is not possible to transfer data electronically from WRATE to SimaPro. Instead, the inventories of the various processes would have had to be entered manually into SimaPro. This was outside the scope and budgetary restraints of this project and was therefore not done.]

Life cycle impact assessment (LCIA) is performed according to the CML (Centre for Environmental Science, Leiden University) method, the most widely used "mid-point" method. Normalization, an optional component of LCIA, is not included in this study.

In the LCA component Life cycle interpretation, the method of sensitivity analysis has been used together with other methods of comparison. An explicit data uncertainty analysis was not carried out. The final report is comprehensive enough to be recognized as third party report according to the standards.

The new requirement by ISO 14044 [4] saying that the critical review panel shall consist of at least three experts was accomplished.

We can therefore state that the methods used are consistent with the international standard.

3.2 Are the methods used to carry out the LCA scientifically and technically valid?

One methodological weak point has been mentioned in the previous section: the use of two not fully compatible LCI calculation methods. Although both methods are valid in their own right, the combination poses problems and the transparency suffers. Additional effort was spent by the Practitioner to improve the results and to make the report more transparent.

The method originally designed was aimed at the first goal of the study (November 2007): a comparative assessment of the most used packaging systems for milk distribution via the retail path. This goal has been abandoned for reasons of data availability (see section 3.3) and waste management including recycling without a comparison of the packaging systems for the filling, distribution and use phases has been declared as the new goal. Here it should be noted that a waste management study would have been designed in a different way, for instance as a system expansion method, such as the "basket of benefits" method [6] much used for EOL LCA studies (comparison of different recycling vs. incineration methods).

[PRACTITIONER'S COMMENTS: On project start, great effort was expended on getting all major parties involved in the supply of milk to consumers to take part in this project. This was to a large extent achieved and as such the parties committed to supplying data for this study account for the majority market share of milk currently available on the UK market. This is especially the case for the packaging manufacturers involved in the project, however less so for the dairies where only one of the major dairies was able to provide data.

Based on an assessment of the gaps and inconsistencies of data made available by the various packaging producers and fillers, the commissioner and practitioner concluded that any comparison would not be fair and conclusive. It was therefore decided to change to goal of the study to be non-comparative. This was agreed and accepted by the steering committee, and was further communicated to the critical review chair for discussion.]

In conclusion, it can be stated that the methods used are scientifically and technically valid with the restrictions mentioned.

3.3 Are the data used appropriate and reasonable in relation to the goal of the study?

This question is the most serious item in this LCA study and it should be noted that the practitioner made great efforts to collect original foreground data. This was not successful in most cases. There are few, if any, average data (posing no confidentiality problems), but several original data from single providers anxious about their anonymity. This is clearly an unsatisfactory situation which will not change until a broad and consistent programme on original data acquisition will be performed in UK – either as a voluntary action by the industry, or performed or at least co-ordinated by DEFRA. This being said, it should be acknowledged that the practitioner as well as the commissioner tried hard to obtain the necessary data, but the data situation for the different packaging systems remained asymmetric – evidently the main reason for changing the original goal of the study.

The background data (generic data) used are those of eco-invent as part of the Sima Pro software (upstream) and of WRATE (downstream, EOL), a peer reviewed UK waste management software. It is hoped that some results with regard to the Global Warming Potential which seem to be incomprehensible (landfill vs. incineration with energy reclaim) will be fully explained in the final version of the report. This may well be a methodological and not a data problem.

It can be stated that the data situation is disappointing and below the expectations raised by the original Goal & Scope of the study. Great efforts will be necessary to create a data base which will meet the standard already achieved in many other industrialised countries.

For the reduced goal of waste management it can be stated that the data are now sufficient with the caveats discussed in this critical review report.

3.4 Do the interpretations reflect the limitations identified and the goal of the study?

Six sensitivity analyses (the best instrument to quantify uncertainties with regard to assumptions, allocation rules, data etc.) have been performed in this study, including the one sensitivity analysis on open-loop recycling (OLR) required by the standard as a minimum. In this case, the main OLR allocation (called avoided burden approach) has been replaced by the cut-off rule. Since the latter favours in general the secondary material accepting system – in contrast to “avoided burden” - strong differences are to be expected and indeed observed. What this means in practice can only be decided during use of the data; neither one of the approaches is true or false, they represent different ways of looking at the same system.

The sensitivity analyses mentioned above have been carried out for all packaging systems investigated. Further explanations and an outlook are given in a section 7 “Conclusions and recommendations”.

In the conclusions section of the LCA report sentences like “For the impact categories of eutrophication, acidification and human toxicity, general recycling provides the lowest impacts” can be found. Based on the underlying data quality and the methodological concerns regarding the toxicity impact categories it must be doubted whether those findings are robust enough to be presented in this way to the reader. It is recommended to use a more careful wording here (or to even omit conclusions on e.g. human toxicity from this section).

[PRACTITIONER’S COMMENTS: Conclusions regarding human toxicity and freshwater aquatic eco-toxicity have been omitted from the executive summary and the conclusions section.]

Within the limitations of the study, it can be stated that the interpretations reflect the limitations identified and the goal of the study.

3.5 Is the study report transparent and consistent?

The report is well written and the length seems to be appropriate for the systems studied. The transparency of the report overall is acceptable. Yet certain limitations to transparency exist. They are due to the data policy and the modelling approach of the WRATE software used for disposal processes. The latter does not allow to distinguish between the environmental loads caused by disposal processes and the environmental credits obtained. For this reason the result graphs in the report only show the net result of both. Especially in the field of packaging disposal and the related assumptions have a considerable influence on the final LCA results. The contribution of disposal processes and credits therefore should be shown separately in the graphs.

The report includes an executive summary.

Overall, the report is sufficiently transparent and consistent.

4 Recommendations

This report, together with the “doorstep” report should be used to obtain a baseline for the situation at the packaging market for milk and to learn from the great difficulties encountered in this study with regard to the broader field of packaging. It should be cleared up, how substantial LCAs can be made in the future, how can the data base be improved, who is going to lead the further development etc. LCA has a great tradition in UK, from the beginnings in the 1970s [9], companies and university institutes engaging in LCA, as Unilever, P&G, Rowland Clift and his school and others. Fortunately, ERM has taken up the challenge to create a new LCA consulting culture and also WRAP is to be praised for using LCA to solve problems of waste management and recycling.

Greater government involvement and more open industry response will be needed if comparative LCAs as a basis for decision-making are to lead to major environmental improvement in the UK context.

References:

[1] Society of Environmental Toxicology and Chemistry (SETAC): Guidelines for Life Cycle Assessment: A "Code of Practice". Edition 1. From the SETAC Workshop held at Sesimbra, Portugal, 31 March - 3 April 1993. Brussels, Belgium, and Pensacola, Florida, USA, August 1993

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Frankfurt/M, 29.04.2009

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