Environment Agency

Evidence

Life Cycle Assessment of Supermarket Carrier Bags

Report: SC030148

The Environment Agency is the leading public body protecting and improving the environment in England and Wales.

It’s our job to make sure that air, land and water are looked after by everyone in today’s society, so that tomorrow’s generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry’s impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

This report is the result of research commissioned and funded by the Environment Agency.

Published by:
Environment Agency, Horizon House, Deanery Road, Bristol, BS1 5AH

www.environment-agency.gov.uk

February 2011

This report is printed on Cyclus Print, a 100% recycled stock, which is 100% post consumer waste and is totally chlorine free. Water used is treated and in most cases returned to source in better condition than removed.

Further copies of this report are available from:
The Environment Agency’s National Customer Contact Centre by emailing enquiries@environment-agency.gov.uk or by telephoning 08708 506506.

Author(s):
Dr. Chris Edwards
Jonna Meyhoff Fry

Dissemination Status:
Publicly available

Keywords:
Carrier bags, life cycle assessment, LCA

Research Contractor:
Intertek Expert Services
Cleeve Road
Leatherhead, KT22 7SB

Tel 01372 370900

Environment Agency project manager:
Dr Joanna Marchant
Environment Agency
Kings Meadow House
Kings Meadow Road
Reading, RG 1 8DQ

Tel 0118 9535346

Project: SC030148

Evidence at the Environment Agency

Evidence underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us, helps us to develop tools and techniques to monitor and manage our environment as efficiently and effectively as possible. It also helps us to understand how the environment is changing and to identify what the future pressures may be.

The work of the Environment Agency's Evidence Directorate is a key ingredient in the partnership between research, guidance and operations that enables the Environment Agency to protect and restore our environment.

The Research & Innovation programme focuses on four main areas of activity:

- **Setting the agenda**, by providing the evidence for decisions;
- **Maintaining scientific credibility**, by ensuring that our programmes and projects are fit for purpose and executed according to international standards;
- **Carrying out research**, either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available.

Miranda Kavanagh
Director of Evidence

Advisory Board

This project was informed and assisted by an Advisory Board set up by the Environment Agency.

Iris Anderson	Department of Energy and Climate Change (DECC)
Peter Askew	Department for Business, Innovation and skills (BIS)[1]
Jane Bickerstaffe	Industry Council for Packaging and the Environment (Incpen)
Terry Coleman (Chair)	Environment Agency
Jeff Cooper	Environment Agency[2]
Julia Faria	Local Environmental Quality Division, Department for Environment, Food and Rural Affairs (Defra)[2]
Bob Gordon	British Retail Consortium (BRC)[3]
Keith James	Waste & Resources Action Programme (WRAP)[4]
Marlene Jannink	Department for Business, Enterprise & Regulatory Reform (BERR)[5]
Charlotte Lee-Woolf	Sustainable Consumption and Production, Department for Environment, Food and Rural Affairs (Defra)[3]
Joanna Marchant	Environment Agency
Rob Mynard	Waste Strategy Division, Department for Environment, Food and Rural Affairs (Defra)[2]
Julie Osmond	Welsh Assembly Government[3]
Marc Owen	Waste Strategy, Department for Environment, Food and Rural Affairs (Defra)[3]
Gerry Newton-Cross	Environment Agency[6]
Julian Parfitt	Waste & Resources Action Programme (WRAP)[7]
Nigel Smith	British Retail Consortium (BRC)[2]

---

[1] From January 2007.
[2] Until April 2007.
[3] From December 2009.
[4] From December 2006.
[5] Until December 2006.
[6] Until April 2007.
[7] Until November 2006.

Stakeholder Consultation Group

In addition to the Advisory Board, a Stakeholder Consultation Group was set up to support the project. Membership of the Stakeholder Consultation Group was open to any interested party. The purpose of the Stakeholder Consultation Group was to provide a two-way communication platform for all interested parties, including special interest groups.

Executive Summary

This study assesses the life cycle environmental impacts of the production, use and disposal of different carrier bags for the UK.

In recent years, the relative environmental impacts of lightweight carrier bags and other options has been debated. By the Spring of 2009[8] leading supermarkets had halved the number of single use carrier bags used. However, questions still remain about the environmental significance of lightweight carrier bags, especially with regard to the wider debate on global warming.

The report considers only the types of carrier available from UK supermarkets[9]. It does not examine personal bags nor carriers given out by other high street retailers. The report does not consider the introduction of a carrier bag tax, the effects of littering, the ability and willingness of consumers to change behaviour, any adverse impacts of degradable polymers in the recycling stream, nor the potential economic impacts on UK business.

The following types of carrier bag were studied:

- a conventional, lightweight carrier made from high-density polyethylene (HDPE);
- a lightweight HDPE carrier with a prodegradant additive designed to break the down the plastic into smaller pieces;
- a biodegradable carrier made from a starch-polyester (biopolymer) blend;
- a paper carrier;
- a “bag for life” made from low-density polyethylene (LDPE);
- a heavier more durable bag, often with stiffening inserts made from non woven polypropylene (PP); and
- a cotton bag.

These types of carrier bag are each designed for a different number of uses. Those intended to last longer need more resources in their production and are therefore likely to produce greater environmental impacts if compared on a bag for bag basis. To make the comparison fair, we considered the impacts from the number of bags required to carrying one month’s shopping in 2006/07.

We then calculated how many times each different type of carrier would have to be used to reduce its global warming potential to below that for conventional HDPE carrier bags where some 40 per cent were reused as bin liners. Finally the carriers were compared for other impacts: resource depletion, acidification, eutrophication, human toxicity, fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity and photochemical oxidation (smog formation).

---

[8] Based on 2006 baseline figures.

[9] The study also included a paper carrier bag which are generally not available from UK supermarkets.

The study found that:

- The environmental impact of all types of carrier bag is dominated by resource use and production stages. Transport, secondary packaging and end-of-life management generally have a minimal influence on their performance.
- Whatever type of bag is used, the key to reducing the impacts is to reuse it as many times as possible and where reuse for shopping is not practicable, other reuse, e.g. to replace bin liners, is beneficial.
- The reuse of conventional HDPE and other lightweight carrier bags for shopping and/or as bin-liners is pivotal to their environmental performance and reuse as bin liners produces greater benefits than recycling bags.
- Starch-polyester blend bags have a higher global warming potential and abiotic depletion than conventional polymer bags, due both to the increased weight of material in a bag and higher material production impacts.
- The paper, LDPE, non-woven PP and cotton bags should be reused at least 3, 4, 11 and 131 times respectively to ensure that they have lower global warming potential than conventional HDPE carrier bags that are not reused. The number of times each would have to be reused when different proportions of conventional (HDPE) carrier bags are reused are shown in the table below.
- Recycling or composting generally produce only a small reduction in global warming potential and abiotic depletion.

Type of carrier	HDPE bag (No secondary reuse)	HDPE bag (40.3% reused as bin liners)	HDPE bag (100% reused as bin liners)	HDPE bag (Used 3 times)
Paper bag	3	4	7	9
LDPE bag	4	5	9	12
Non-woven PP bag	11	14	26	33
Cotton bag	131	173	327	393

The amount of primary use required to take reusable bags below the global warming potential of HDPE bags with and without secondary reuse

Contents

Abbreviations

BRC	British Retail Consortium
DEFRA	Department for the Environment, Food and Rural Affairs
GWP	Global Warming Potential
HDPE	High density polyethylene
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
PA	Polyamide
PE	Polyethylene
PET	Polyethylene terephthalate
PLA	Polylactic Acid
PP	Polypropylene
PVC	Polyvinyl chloride
EfW	Energy from Waste
WRAP	Waste and Resources Action Programme
WRATE	Waste and Resources Assessment Tool for the Environment

1 Introduction

1.1 Project background

This study was commissioned by the Environment Agency and assesses the life cycle environmental impacts of the production, use and disposal of different carrier bags for the UK.

In 2008, approximately 10 billion lightweight carrier bags were given away in the UK which equates to around 10 bags a week per household (DEFRA 2009). In recent years, a debate about the relative environmental impacts of these lightweight carrier bags and their alternatives has emerged. This debate has arisen due to a combination of public, media and legislative pressure to reduce the environmental and social impacts of food packaging. In response the UK government, the British Retail Consortium (BRC) and leading supermarkets agreed to cut the number of single use carrier bags used by 50% by the spring of 2009 based on 2006 baseline figures. In July 2009, the Waste and Resources Action Programme (WRAP) announced that this initiative had achieved a reduction of 48% across the UK (WRAP 2009). However, lightweight carrier bags are still seen as an important media and legislative issue and questions still remain on their environmental significance, especially to the wider debate on global warming.

Life Cycle Assessment (LCA) is a standard method for comparing the environmental impacts of providing, using and disposing of a product or providing a service throughout its life cycle (ISO 2006). In other words, LCA identifies the material and energy usage, emissions and waste flows of a product, process or service over its entire life cycle to determine its environmental performance.

Previous studies in several countries have looked at the environmental impacts of different carrier bag options. Their findings are interesting but are not directly applicable to the UK because of their geographical coverage and the assumptions made about the use and disposal of carrier bags by consumers.

This report considers only carriers available from UK supermarkets. It does not examine personal bags nor carriers given out by other high street retailers. The report does not consider the consequences of introducing a carrier bag tax, the effects of littering, the ability to and willingness of consumers to change behaviour, any adverse impacts of degradable polymers in the recycling stream, nor the potential economic impacts on UK industry.

1.2 The different types of carrier bags

The main function of a carrier bag is to carry groceries and goods from the shop to the home. The bag therefore needs to be robust enough to hold a certain quantity of shopping, but at the same time provide a convenient option for the consumer to carry or transport the shopping home. The scope and findings of recent LCA studies of carrier bags are summarised in Annex A.

1.2.1 Supermarket carrier bags studied

Supermarket carrier bags used in the UK have generally been categorised as disposable (i.e. single use) or reusable. However, these descriptions are increasingly becoming blurred as ‘disposable’ plastic carrier bags are now encouraged to be reused both as carrier bags (primary reuse) and also to replace other products such as bin liners (secondary reuse).

Most UK supermarkets offer several types of carrier bag, generally including a conventional, lightweight, HDPE[9] carrier bag (often termed disposable) and a heavy duty LDPE[10] plastic bag often referred to as a ‘bag for life’. These carrier bags vary in terms of weight, capacity and recycled content. Supermarkets now also offer other, more durable, carrier bags, generally made from woven, natural fibres, such as hemp or cotton. Carrier bags recorded as being used in the main UK supermarkets and included in this study are shown in Table 1.1 and are described below. Several of these were not available in UK supermarkets during the reference period of the study but were included because of their potential future use.

Conventional High-density polyethylene (HDPE) bags

This is the lightweight, plastic, carrier bag used in almost all UK supermarkets and often provided free of charge. It is a vest-shaped bag and has the advantage of being thin-gauged and lightweight. It has been termed “disposable” and “single use”

High-density polyethylene (HDPE) bags with a prodegradant additive

This type of lightweight, plastic, carrier bag is made from HDPE with a prodegradant additive that accelerates the degradation process. These polymers undergo accelerated oxidative degradation initiated by natural daylight, heat and/or mechanical stress, and embrittle in the environment and erode under the influence of weathering. The bag looks like the conventional HDPE bag being vest-shaped and thin-gauged.

Low-density polyethylene (LDPE) bags

These are thick-gauged or heavy duty plastic bags, commonly known as ‘bags-for-life’, and are available in most UK supermarkets. The initial bag must be purchased from the retailer but can be replaced free of charge when returned. The old bags are recycled by the retailer.

Non-woven polypropylene (PP) bags

This type of bag is made from spunbonded non-woven polypropylene. The non-woven PP bag is stronger and more durable than a bag for life and is intended to be reused many times. To provide stability to the base of the bag, the bag comes with a semi-rigid insert.

Cotton bags

This type of bag is woven from cotton, often calico, an unbleached cotton with less processing, and is designed to be reused many times.

---

[9] HDPE is high density polyethylene.

[10] LDPE is low density polyethylene.

Table 1.1 Carrier bag types used in UK supermarkets included in this study.

Bag type	Picture example	Weight* [g]	Volume capacity* [litres]
Conventional HDPE bag		**7.5 – 12.6**	**17.9 – 21.8**
HDPE with prodegradant additive		**5.9 – 8.2**	**16 – 19.6**
Heavy duty LDPE bag ('bag for life')		**27.5 – 42.5**	**19.1 – 23.9**
Non-woven PP bag		**107.6 - 124.1**	**17.7 – 21.8**
Paper bag		**55.2**	**20.1**
Biopolymer bag		**15.8**	**18.3**
Cotton bag		**78.7 – 229.1**	**17 – 33.4**

* Some supermarkets have supplied data, others are based on measurements by the authors (see annex B).

Paper bags
These are generally no longer used in UK supermarkets, although they are available from other retail shops. The paper bag was in effect the first "disposable" carrier bag, but was superseded in the 1970s by plastic carrier bags which were seen as the perfect alternative, as they did not tear when wet.

Biopolymer bags
Biopolymer carrier bags are a relatively recent development. They are only available in a few UK supermarkets. The biopolymers are usually composed of either polylactic acid (PLA), made from the polymerisation of lactic acids derived from plant-based starch, or starch polyester blends, which combine starch made from renewable sources such as corn, potato, tapioca or wheat with polyesters manufactured from hydrocarbons (Murphy *et al* 2008). These biodegradable polymers decompose to carbon dioxide, methane, water, inorganic compounds or biomass (Nolan-ITU 2003).

1.2.2 Other options

There are several other types of carrier, none of which have been considered in this study. These include woven polypropylene bags, jute or hemp bags and plastic boxes. Figure 1.1 below shows some examples.

Figure 1.1 Examples of a vacuum formed box, a woven PP bag, a hemp bag, and a jute bag.

Polypropylene (PP) vacuum formed boxes
An alternative to the carrier bag is a rigid box made from vacuum formed polypropylene with separate detachable rigid handles. This is used by one supermarket in store but by many for home deliveries. It is intended to be reused many times.

Woven polypropylene (PP) bags
This type of bag is produced from woven polypropylene “fibres”. Similarly to the non-woven PP and LDPE bags, it is strong and durable and intended to be reused many times. To provide stability to the base of the bag, the bag comes with a semi-rigid insert.

Jute bags
Jute bags are made from jute fibres spun into coarse strong strands making a strong and durable carrier bag. The jute bag is intended to be reused many times.

2 Goal definition

The international standard on lifecycle assessment ISO 14040 (ISO 2006) requires that the goal of an LCA study states the intended application, the reasons for carrying out the study, the intended audience, and whether the results are intended to be used in comparative assertions intended to be disclosed to the public.

2.1 Goal of the study

The goal of this study is to assess the potential life cycle environmental impacts of various current and potential supermarket carrier bags in the UK.

The goal of the study has been split into the following objectives:

- To compile a detailed life cycle inventory of the environmental burdens associated with the production, use and disposal of lightweight plastic carrier bags and three to five other options;
- To use the life cycle inventory data to compare the environmental impacts arising from lightweight plastic carrier bags and the alternatives under the various scenarios considered; and
- To compare the results of this study with other key life cycle studies in this area and identify the main reasons for any significant differences.

The types of carrier bag studied were agreed by the project board, based partly on the market representation in supermarkets, and partly on new materials that were receiving increased attention. A carrier bag is defined in this study as a bag with a capacity of over 15 litres, that could be used at a supermarket checkout. Therefore, this does not include other bags available in supermarkets such as ‘deli’ bags.

The following types of carrier bag were studied:

- conventional high-density polyethylene (HDPE);
- high-density polyethylene (HDPE) with a prodegradant additive;
- starch-polyester (biopolymer) blend;
- paper;
- low-density polyethylene (LDPE);
- non woven polypropylene (PP); and
- cotton.

2.2 Critical review

The study has been critically reviewed in accordance with ISO 14040. The review panel consisted of:

- Mark Goedkoop (chairman), PRé Consultants, Amersfoort, the Netherlands.
- Keith Elstob (co-reviewer), Bunzl Retail, Manchester.
- Jane Bickerstaffe (co-reviewer), INCPEN, Reading.

The chairman of the review panel has been involved in the project from the start by reviewing and commenting on the goal and scope. The co-reviewers were involved at the end of the project. The panel’s report as well as the consultants’ responses to the reviewers’ comments are included in Annex E.

In addition to the critical review, the project was also followed by a Project Advisory Board and a Stakeholder Consultation Group. Members of the Project Advisory Board were invited by the Environment Agency whereas the Stakeholder Consultation Group was open to anybody interested. The members of the board and the stakeholder group were kept informed about the project at regular intervals and were invited to comment and provide information.

2.3 Use of the study and target audience

The results of this life cycle study are intended to provide an independent, unbiased, objective assessment of the environmental impacts of various carrier bags. It should provide evidence for government and supermarkets in devising policies to reduce the environmental impacts of carrier bags. The study also provides a potential baseline to measure the degree of success by supermarkets in reducing the environmental impacts of supermarket carriers.

The target audience for the report is:

- Interested parties such as supermarkets and other retailers, environmental organisations, consumer organisations as well as consumers themselves.
- Public authorities, in particular the Department for Environment, Food and Rural Affairs (DEFRA) responsible for national, environmental policy in England, the Welsh Assembly Government (WAG) who have parallel responsibilities for Wales and WRAP, the Waste and Resources Action Programme.

3 Scope

3.1 Function of the product system and functional unit

A comparison of life cycle environmental impacts should be based on a comparable function (or ‘functional unit’) to allow a fair comparison of the results. The carrier bags studied are of different volumes, weights and qualities. The Environment Agency commissioned a survey[11] which found that, over a 4 weeks period, supermarket shoppers purchased an average of 446 items. The functional unit has therefore been defined as:

Carrying one month’s shopping (483 items) from the supermarket to the home in the UK in 2006/07.

3.2 Reference flow

The reference flow is the number of carrier bags required to fulfil the functional unit (as described in section 3.1). This depends on the volume of the bag, its strength and consumer behaviour when filling and using the bags. Consumer behaviour determines how many items are put into each bag, the number of times a bag is reused (primary reuse), whether the bag is subsequently used to perform an alternative function (secondary reuse), and in part the way they are managed as waste.

The primary[12] reuse of carrier bags was excluded from the reference flow due to a lack of independent data available on the reuse of each type of bag. However, as several types are designed to be reused, we have calculated the primary reuse required to reduce the global warming potential of each reusable bag to below that of the conventional, lightweight HDPE bag The inclusion of primary reuse is detailed in section 3.7

The number of bags required to carry one month’s shopping (483 items) depends whether weight or volume is the limiting factor in carrier bag use, Pira International compared the volume and weight capacity of several carrier bags (detailed in Annex B). We found that the weight capacity of the bags studied was 18 to 19 kg., which is more than an average person can carry. Therefore, volume was selected as the limiting factor for bag use. The average volume of a conventional lightweight (HDPE) carrier bag was 19.1 litres and the average volume of a “bag for life” (LDPE) carrier bag was 21.5 litres.

The consumer survey commissioned by the Environment Agency[13] provided data on the number of items purchased and the number of bags required to carry those items. All the major supermarkets co-operated with the survey which showed that shoppers put an

---

[11] Based on a 2007 survey by TNS Market Research specialists

[12] *Primary* reuse in this study means reuse for the original purpose – to carry shopping from the supermarkrt to the home. This is distinct from *secondary* reuse which here meansd reuse to replace another product, e.g. a bin liner.

[13] *ibid*

average 5.88 items in the conventional HDPE carrier bag and an average 7.96 items into the heavy duty LDPE carrier bag

The average weight, volume and item capacity for each carrier bag type included in this study was then calculated. The material weights of the HDPE prodegradant and starch-polyester bags were adjusted pro-rata to match the average volume of the conventional lightweight HDPE bag (19.1 litres carrying 5.88 items). For the paper, LDPE, non-woven PP and cotton bags, the item capacities were adjusted according to their volumes.

These revised bag capacities were then used to calculate the reference flow[14] for each type of bag as shown in table 3.1. The initial reference flows shown do not include any primary reuse of carrier bags.

Table 3.1 The assumed volume, weight, items per bag and required reference flow for each carrier bag (excluding primary reuse).

Bag type	Volume per bag (litres)	Weight per bag (g)	Items per bag	Refflow – No. bags
Conventional high-density polyethylene (HDPE) bag	19.1	8.12	5.88	82.14
High-density polyethylene (HDPE) bag with a prodegradant additive	19.1	8.27	5.88	82.14
Starch-polyester blend bag	19.1	16.49	5.88	82.14
Paper bag	20.1	55.20	7.43	64.98
Low-density polyethylene (LDPE) bag	21.52	34.94	7.96	60.68
Non-woven polypropylene (PP) bag	19.75	115.83	7.30	66.13
Cotton bag	28.65	183.11	10.59	45.59

Supermarket policies and consumer behaviour have changed since the reference period (2006/07) but there is no evidence to suggest the capacities of HDPE and LDPE bags have changed significantly. However, while data used for starch polyester blend bags were provided by the manufacturer, since the reference period the weight of some of these bags may have been reduced and the effect of this is discussed in section 7.2

3.3 System boundaries

The study is a 'cradle to grave' life cycle assessment. Therefore, the carrier bag systems investigated include all significant life cycle stages from raw material extraction, through manufacture, distribution use and reuse to the final management of the carrier bag as waste. The system boundaries are defined so that all inputs and outputs from the system

---

[14] The reference flow is the number of each type of bag required to fulfil the functional unit (483 items of shopping in one month).

are either elemental flows[15] or materials or energy entering another product life cycle through recycling or energy recovery respectively. Therefore, the study quantifies all energy and materials used, traced back to the extraction of resources, and the emissions from each life cycle stage, including waste management. Recycled content and recycling and composting at end-of-life were excluded from the system boundaries. This was due to the large proportion of bags that contained no recycled content and the wide variation in the amount of bag recycling and composting. The recycled content in carrier bags has increased since the reference period and therefore the results of this study may be worse than the current practice. The inclusion of recycling and composting at end-of-life is considered during the sensitivity analysis. Figure 3.1 shows a simple flow diagram which defines the system boundaries for the study.

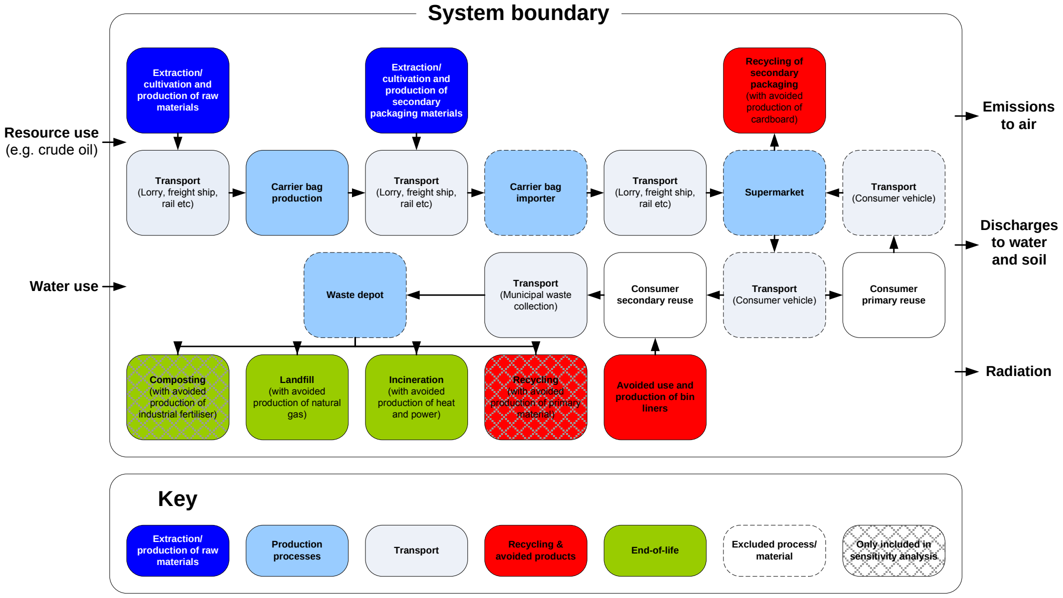


Figure 3.1 System boundaries applied in this study (simplified flow diagram).

The study includes the following life cycle stages:

Extraction/production of raw materials

The extraction of resources, as well as any forestry, agriculture and the processing of resources to produce materials such as HDPE, LDPE, PP, paper, cotton and starch-polyester blend included in the study. The study covers material and energy resources, emissions and waste. Where production data were not available, flows were estimated from similar products.

Packaging

Primary packaging is included. Some secondary packaging (used for the distribution of the bags from the importer to the supermarket distribution centre) has been excluded due to consignments generally being a mix of different supplies depending on the needs of the supermarket. Pallets have also been excluded due to lack of precise data about

---

[15] An elemental flow is material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation (ISO 14040).

their material and reuse rates. However, due to their high reuse, this is not considered to have any significant effect on the results.

Bag production processes

The conversion of the raw materials into carrier bags is included in the study.

Transport

The transport of materials from their producer to the carrier bag manufacturer, and the distribution of the finished carrier bag from the manufacturer to the importer and then to supermarket is included. Transportation by a municipal waste collection vehicle to a waste management facility has also been included.

End-of-life

The management of wastes is included in the study. The choice of end-of-life process reflects the realistic options for each type of bag. The options considered for each bag are shown in table 3.2. Recycling and composting are considered in the sensitivity analysis. The recycling of cotton bags has not been included as no evidence was found to support this. The recycling of HDPE bags with a prodegradant additive has also been excluded due to their negative impact on the quality of recycled HDPE.

Table 3.2 End-of-life processes considered for the different carrier bags investigated.

Bag type	Landfill	Incineration	Mechanical recycling	Composting
Conventional high-density polyethylene (HDPE) bag	✓	✓	✓	
High-density polyethylene (HDPE) bag with a prodegradant additive	✓	✓		
Starch-polyester blend bag	✓	✓		✓
Paper bag	✓	✓	✓	✓
Low-density polyethylene (LDPE) bag	✓	✓	✓	
Non-woven polypropylene (PP) bag	✓	✓	✓	
Cotton bag	✓	✓		

Recycling, reuse & avoided products

The expansion of the system boundaries of the study to include avoided products (described in section 3.4) has been used to model both recycling and secondary reuse. If a material is recycled or reused in another application it can avoid the production of virgin materials. Therefore the benefit of this process is shown by subtracting from the lifecycle inventory the burdens associated with the amount of this product that is avoided by that recycling or reuse.

Avoided products have been included for materials that are recycled during production. Recycling at end-of-life has been included in the sensitivity analysis. It has also been assumed that 40 per cent of the lightweight carrier bags (i.e. the HDPE, HDPE prodegradant and starch-polyester bags) are reused in secondary applications as bin liners and therefore avoids their production. Paper bags were assumed not to be reused as bin liners, as there was no evidence that they could successfully be reused for this purpose.

During the reference period of the study there was no evidence of paper carrier bag use in the main UK supermarkets but we have included them because of interest in their use as a “green” alternative to conventional HDPE carrier bags.

The primary reuse of paper carrier bags was considered alongside other bags such as LDPE, non-woven PP and cotton that are regularly reused to carry shopping. However, the inclusion of reuse for paper carrier bags is intended to illustrate how many times a paper carrier bag would have to be reused to perform better than other bags, it is not a statement that this reuse occurs or that it is feasible. In fact information related to primary reuse for paper bags in the Republic of Ireland indicates that supermarket paper carriers are not reused for shopping[16].. When the primary reuse of any carriers as shopping bags has been included in the study, the required reference flow (as described in section 3.2) has correspondingly reduced.

The primary and secondary data used to model the systems considered in this study are further described in Chapter 4.

3.3.1 Excluded processes and cut-off criteria

Certain elements of the lifecycle have been excluded to ensure the scope of the study remains feasible, although no specific cut-off criteria have been applied. The following materials and processes have been excluded:

Inks and dyes
These materials are used to print the design/brand on each carrier and have been excluded from the study due to a lack of information about the inks and dyes used and the small quantities required.

Retail storage of the carrier bags
Any environmental impacts associated with storage activities at the bag importers and supermarkets have been excluded.

Transport from the supermarket to the consumer
Consumer transportation to and from the supermarket with the carrier bags has been excluded from the study, because the weight of a carrier bag would have little or no effect on vehicle emissions and fuel efficiency.

Capital equipment

---

[16] Personal communication from Marks & Spencer plc to the Environment Agency showing an increase in the number of carrier bags used in M&S in Ireland when HDPE carrier bags were replaced by paper bags.

The environmental impacts linked with the construction and demolition of buildings and the manufacture of machines, equipment and vehicles should in effect be depreciated over the whole of their period of use. These annualised impacts are negligible when compared to the operational burden. Therefore, the construction, maintenance and demolition of industrial buildings and the manufacture of machines, equipment and vehicles have been excluded from the primary data used in this study.

3.4 Allocation and system expansion

Product life cycle systems occasionally yield other products or services as well as the functional unit. The international standard ISO 14044 (ISO, 2006) gives a stepwise procedure for the allocation of material and energy flows as well as environmental releases when this occurs. Allocation should preferably be avoided either through an increase in system detail or through system expansion, where the product system is credited with the avoided burdens delivered by its co-products. Where the system is not expanded, mass should be used to allocate the burdens of shared processes and materials to the product and co-products.

We have used system expansion to show the potential benefits of secondary reuse, recycling, landfill and incineration in this study. System expansion is therefore used for the following processes:

- The avoided production of primary materials when HDPE based materials, LDPE, PP, cardboard and paper are recycled.

- The avoided production of any energy produced from incinerating or landfilling any of the carrier bags.

- The avoided production of bin liners when lightweight carrier bags (i.e. HDPE, HDPE prodegradant and starch polyester bags) are reused in other applications.

We have assumed the recycling of material waste from production and at end-of-life avoids the use of virgin material, which is subtracted from the system. We have also assumed that the avoided material is the same as the input material, although in practice this is not always the case. For example, Schmidt and Strömberg (2006) state that demand and not supply determines the recycling rate of plastics. Therefore, due to the oversupply of post-consumer plastics, recycled material is used in low grade applications which avoid the use of other materials such as wood or concrete. The amount of avoided material included is dependent on performance loss from the recycling process, which is detailed in section 4.5. In the case of post-consumer plastic recycling, the performance loss is greater than post industrial recycling and this is reflected in the study.

Due to the lack of reliable data on recycled content and because of the use of the avoided burden approach to recycling, no recycled content was included in any of the bag types to avoid the double counting of recycling benefits. Although some bags contained recycled content during the reference period, this was not a significant proportion of the carrier bag market.

The generation of electricity from both landfill and incineration are accounted for through the avoided production of grid electricity. None of the bags considered were produced using UK grid electricity and therefore no double counting of the energy benefits of incineration or landfill occurred.

The avoided production of bin liners was also used to reflect the benefits that result from secondary reuse. It was assumed that 40 per cent of the lightweight carrier bags (i.e. the HDPE, HDPE prodegradant and starch-polyester bags) are reused as bin liners and therefore avoid their production and disposal.

In some cases where secondary data are used, allocation has been applied and these are highlighted in the text.

3.5 Data requirements and data quality

3.5.1 Data requirements

A detailed product LCA requires primary data on the materials, energy, waste and emissions specific to the production, use and disposal of the product. The primary data used in this project include the material types and weights to produce carrier bags and primary packaging, the production of carrier bags, transport modes and distances and waste management operations. Secondary data were used for the production of raw materials and waste process emissions (where specific data were not available), electricity generation, fuel production, vehicle emissions and other more minor processes. The data used in this study are described in Chapter 4 and Annex C.

3.5.2 Data quality

Data sources
Most data used in this study are from ecoinvent™ v2. Any other sources are described in the text.

Geographical coverage
The goal of this study is to assess the life cycle environmental impacts of carrier bags used in the UK. In most cases carrier bags are imported from Asia: conventional HDPE, HDPE prodegradant, LDPE and PP bags are produced in China, Indonesia, Malaysia or Turkey. The production of polymers for these bags normally occurs in the same region. However, no datasets were identified for Asia-specific polymer production and European average data have been used instead for all plastic carrier bag systems by adapting the electricity production to the country of origin. However, the amount of electricity used and the efficiency of these production processes is still based on European data.

The paper fibres and the paper bags are assumed to be produced in Europe, due to the high cost of importation from further afield. These are modelled using a European average dataset for paper production. The material used for the biopolymer bags is produced in Italy. The majority of the conversion of biopolymer material into carrier bags takes place in Norway, and the data used also reflect this. Data for cotton grown conventionally[17] in China have been used for the production of cotton. This is considered appropriate as most cotton bags available in supermarkets are generally produced in China, India or other Far East countries.

Data used to model transportation methods are based on European transport efficiencies.

Time-related coverage
At the start of the project a time-related coverage of the year 2005/2006 was set for core datasets and assumptions and a reference period of 10 years for literature datasets.

The literature datasets covering polymer production date from the late 1990s to the early part of this decade. The dataset for Kraft paper production represents the production processes in 2003. The dataset for starch-polyester blend production represent the production processes in 2006. The dataset for cotton represents the period from 2000 to 2005. The datasets used for the production of carrier bags are from 2003 to 2006.

The datasets for transport are representative of the year 2005 for road transport and 2000 for all other forms of transport. The datasets for energy generation represent the period 2004/2005. The datasets for recycling, composting, landfill and incineration have been taken from the WRATE© database and are representative of the current UK waste management options, generally for the period 2003 to 2006.

Technology coverage
The specific data collected for this study reflect current process configurations, operation and performance. The generic data used reflect process configurations, operation and performance at the time of data collection. However, much of the generic data used represent European rather than region-specific technologies.

3.6 Modelling and calculation of inventories and impacts

For the modelling, generation of inventories and calculation of environmental impacts the LCA software tools SimaPro and WRATE© have been used. SimaPro is a software tool specifically designed for LCA (SimaPro 2009). WRATE (Waste and Resources Assessment Tool for the Environment) is a software tool designed for the life cycle assessment of waste management options (WRATE 2009).

3.7 Impact assessment

The impact assessment is divided into two stages:

1. In the first stage we used the IPCC 2007 characterisation factors over a 100 year time horizon (IPCC, 2007) to calculate the global warming potential (GWP) for each carrier bag without any primary reuse, but including secondary reuse as bin

---

[17] That is, not organically grown

liners for lightweight bags. The IPCC method used excludes the impact of biogenic carbon dioxide. Therefore, a zero characterisation factor is assigned to the GWP of biogenic carbon dioxide and carbon dioxide absorbed from the air.

The GWP of the conventional HDPE bag was then used as a baseline and the number of times each heavy duty bag would have to be used for their respective GWPs to drop below this baseline was calculated.

2. For the second stage we used the CML 2 baseline 2000 method (CML, 2001) to calculate the following environmental impact categories:

    - Depletion of abiotic resources
    - Photo-oxidant formation;
    - Eutrophication;
    - Acidification;
    - Human toxicity; and
    - Aquatic and terrestrial toxicity.

The impact categories included are further described in Annex D.

3.8 Sensitivity analysis

A sensitivity analysis allows key variables and assumptions to be changed to test their influence on the results of the impact assessment. We assessed:

- Changing the secondary reuse of the bags;
- an increase in recycling and composting at end-of-life and;
- Using a different impact assessment method.

3.9 Reporting

This report fulfils the requirements of the ISO standard for a third party report supporting comparative assertions intended for publication.

4 Inventory analysis

The following sections outline the data and assumptions used to model the materials, production, transport and end-of-life of the carrier bags considered. Unless otherwise stated, inventory data were taken from the ecoinvent™ database version 2. The lifecycles of each carrier bag system are described in Annex C together with a detailed description of the secondary data used.

4.1 Extraction/production of raw materials

The weight and raw material composition of carrier bags vary depending on the requirements set by the supermarkets and the processing methods used by the producer. The bag weight used here for each carrier bag type is an average based on individual supermarket bag weights and market share (see Annex B) and table 4.1.

Table 4.1 The assumed volume, weight, items per bag and required reference flow for each carrier bag.

Bag type	Volume per bag (litres)	Weight per bag (g)
Conventional high-density polyethylene (HDPE) bag	19.1	8.12
High-density polyethylene (HDPE) bag with a prodegradant additive	19.1	8.27
Starch-polyester blend bag	19.1	16.49
Paper bag	20.1	55.20
Low-density polyethylene (LDPE) bag	21.52	34.94
Non-woven polypropylene (PP) bag	19.75	115.83
Cotton bag	28.65	183.11

The materials used for each carrier bag and its packaging are detailed in Annex C. The material composition of all oil-based polymer bags is based on a combination of data provided by the bag producers and estimates provided by Bunzl Retail[18]. The material composition of the paper bag is based on CEPI Eurokraft & Eurosac data for paper sacks (Weström & Löfgren 2005). The material composition of the starch-polyester blend bag is based on data provided by the bag producer. Inventory data for the starch-polyester blend was collected and compiled by technical experts from the manufacturers, Novamont S.p.A.

---

[18] Bunzl plc is a multinational distribution and outsourcing business. Bunzl Retail, a division of Bunzl plc, is one of the largest suppliers of carrier bags to the UK.

Several substitute materials were also used when existing data on bag materials were not available. For example, limestone data were substituted for those of chalk and the prodegradant additive was assumed to be cobalt stearate with the impacts of 10 per cent cobalt and 90 per cent stearic acid.

Carrier bags are generally supplied in corrugated boxes or, for conventional HDPE bags, in either corrugated boxes or vacuum packed film. It was estimated that approximately 50 per cent of conventional HDPE bags are supplied in corrugated boxes and 50 per cent in vacuum packed film (Elstob 2007). The film is assumed to be composed of two-thirds polyethylene (PE) and one third polyamide (PA). The weights of the corrugated boxes reported by bag producers fluctuated widely, with some producers reporting the box to be heavier than its content. Consequently, we have estimated the weight of corrugated packaging based on discussions with Bunzl Retail and Simpac (Elstob 2007 and Young 2006). For the starch-polyester blend bag, the corrugated box weight reported by the producer was used, although this was heavier than conventional carrier bag packaging.

4.2 Bag production processes

All plastic bags are produced from plastic melt. This is generally blown and sealed to form a bag, except for the non-woven PP bag which is produced from a molten filament using a spun bonded process. The energy demand for these processes is mainly met by grid electricity and this energy consumption depends on the polymer type, density, production equipment and capacity. The energy consumption and waste generated by the production of 1000 bags is shown in table 4.2.

Based on conversations with industry experts we have estimated that 90 per cent of LDPE bags are produced in Turkey and Germany and 10 per cent in China and Malaysia (Elstob 2007) and that all conventional HDPE, HDPE prodegradant and PP bags are imported from the Far East. Therefore, data on conversion of HDPE, HDPE prodegradant, PP and LDPE into carrier bags was provided by bag producers in China and Turkey and modelled based on production in these locations. Data on the production of starch-polyester blend into carrier bags was provided by a bag producer in Norway. All grid electricity use was modelled according to the relevant country (China, Turkey and Norway).

The heat used to produce the LDPE bags was assumed to be generated by natural gas in a non-modulating boiler. The heat used to produce the PP bags was assumed to be generated from burning heavy fuel oil in an industrial furnace based on supplier information. Waste generated during the production of the HDPE, HDPE prodegradant, starch-polyester, LDPE and PP bags is recycled and was in most cases based on data from bag producers. The modelling of the recycling process is discussed in section 4.5. None of the cotton bag producers contacted provided any data on cotton bag production and data on conversion of cotton fabric into carrier bags were estimated. We assumed that the bags were produced in China, using electric sewing machines, and the electricity use was therefore based on previous projects (ERM 2009) and was modelled using Ecoinvent data. All production waste was assumed to be landfilled.

Table 4.2 Energy consumption and waste generation for film and cotton bags (per 1000 bags)

Bag type	Electricity	Heat (from natural gas)	Heat (from heavy fuel oil)	Waste
Conventional high-density polyethylene (HDPE) bag	6.151 kWh (22.144 MJ) (0.758 kWh/kg)			418.4 g
High-density polyethylene (HDPE) bag with a prodegradant additive	6.392 kWh (23.011 MJ) (0.773 kWh/kg)			426.1 g
Starch-polyester blend bag	17.24 kWh (62.064 MJ) (1.045 kWh/kg)			94.8 g
Low-density polyethylene (LDPE) bag	32.58 kWh (117.288 MJ) (0.932 kWh/kg)	13.953 kWh (50.23 MJ) (0.399 kWh/kg)		171.2 g*
Non-woven polypropylene (PP) bag			87.75 kWh (315.9 MJ) (0.758 kWh/kg)	5,850 g
Cotton bag	11 kWh (39.6 MJ) (0.06 kWh/kg) *			1,800 g*

Data used for the conversion of Kraft paper into carrier bags were part of paper sack inventory data published by CEPI Eurokraft and Eurosac (Weström & Löfgren 2005). The data for the production of Kraft paper and the production of paper sacks were aggregated and could not be separated.

4.3 Transport

The transport of raw materials to each bag production site and the delivery of the finished bag from those sites to the UK supermarkets are shown in tables 4.3 and 4.4.

Transport distances were based on estimated production locations from industry experts (Elstob 2007). More than 98 per cent of HDPE and PP bags imported into the UK are produced in Far East countries such as China, Indonesia and Malaysia. Approximately 90 per cent of LDPE bags are produced in Turkey and Germany with the remainder being produced in the Far East. For this study, we assumed that all HDPE and PP bags were produced in the Far East and 90 per cent of the LDPE bags were produced in Turkey and the remainder in China. Transportation by lorry was based on a 16-32 tonne vehicle.

---

[*] These figures are based on industry estimates due to lack of data.

Table 4.3 The transport scenarios for carrier bags.

Bag type	From	To	Transport modes	Distance
Conventional high-density polyethylene (HDPE) bag	Polymer resin producer in Far East	Bag producer in Far East	Lorry	100 km
			Sea freight	500 km
	Titanium oxide and chalk producer in Far East	Bag producer in Far East	Lorry	200 km
			Sea freight	500 km
	Bag producer in Far East	Bag importer in UK	Lorry	100 km
			Sea freight	15,000 km
			Rail	280 km
	Bag importer	Supermarket	Lorry	200 km
High-density polyethylene (HDPE) bag with a prodegradant additive	Polymer resin producer in Far East	Bag producer in Far East	Lorry	65 km
			Sea freight	500 km
	Titanium oxide and chalk producer in Far East	Bag producer in Far East	Lorry	200 km
			Sea freight	500 km
	Bag producer in Far East	Bag importer in UK	Lorry	100 km
			Sea freight	15,000 km
			Rail	280 km
	Bag importer	Supermarket	Lorry	200 km
Starch-polyester blend bag	Polymer resin producer in Italy	Bag producer in Norway	Lorry	3,500 km
	Titanium oxide producer in Europe	Bag producer in Norway	Lorry	200 km
	Bag producer in Norway	Bag importer in UK	Lorry	100 km
			Sea freight	1,200 km
			Rail	200 km
	Bag importer	Supermarket	Lorry	200 km
Paper bag	Bag producer in Europe	Bag importer in UK	Lorry	1,000 km
	Bag importer	Supermarket	Lorry	200 km
Low-density polyethylene (LDPE) bag	Polymer resin producer in Europe	Bag producer in Turkey	Lorry	300 km
	Bag producer in Turkey	Bag importer in UK	Sea freight	5,000 km
			Rail	280 km
	Polymer resin producer in Far East	Bag producer in Far East	Lorry	100 km
			Sea freight	500 km
	Titanium oxide producer in Far East	Bag producer in Far East	Lorry	200 km
			Sea freight	500 km
	Bag producer in Far East	Bag importer in UK	Lorry	100 km
			Sea freight	15,000 km
			Rail	280 km

	Bag importer	Supermarket	Lorry	200 km
Non-woven polypropylene (PP) bag	Polymer resin producer in Far East	Bag producer in Far East	Lorry	100 km
	Bag producer in Far East	Bag importer in UK	Lorry	100 km
			Sea freight	15,000 km
			Rail	280 km
	Bag importer	Supermarket	Lorry	200 km
Cotton bag	Textile producer in China	Bag producer in China	Lorry	100 km
	Bag producer in China	Bag importer in UK	Lorry	100 km
			Sea freight	15,000 km
			Lorry	280 km
	Bag importer	Supermarket	Lorry	200 km

4.4 Reuse, recycling & end-of-life

The secondary use of lightweight plastic carrier bags (i.e. the conventional HDPE bag, the prodegradant HDPE bag and the starch-polyester bag) was modelled using the avoided production of bin liners. A study on lightweight carrier bag usage (WRAP 2005) found that 59 per cent of respondents reused all carrier bags, 16 per cent reused most of them, 7 per cent reused around half of them and 7 per cent reused some of them. Overall it was estimated that 76 per cent of single use carrier bags were reused. The study also asked respondents how they reused carrier bags and found that 53 per cent of respondents said that they used carrier bags as a replacement for kitchen bin liners, as shown in table 4.5.

Table 4.5 The reuse of lightweight carrier bags (WRAP 2005).

Reuse applications	Percentage of respondents that reuse single use carrier bags in each application
Use as a bin liner in kitchen	53%
Use as a bin liner in other rooms	26%
Put rubbish into it then throw it away	43%
For dog / cat / pet mess	11%
Garden refuse	1%
Reuse for supermarket shopping	8%
Reuse for other shopping	10%
To store things at home	14%
For packed lunches	8%
Carry other things in when going out	4%
Put football / Wellington boots in	1%
Give to charity shops	1%
Keep bottles / cans in for recycling	1%
Other uses	2%
Do not have a use / discard	11%

We therefore calculated that 40.3 per cent (53 per cent of 76 per cent) of all lightweight carrier bags avoided the use of bin liners. The volume and weight of an average HDPE bin liner was calculated to be 29.3 litres and 9.3 grams, using the same measurement methods applied to the carrier bags in this study (see annex B). Therefore, for every 19.1 litre lightweight plastic carrier bag that was reused, an avoided burden of 6.1grams of HDPE bin liner was subtracted from the system.

The avoided production of virgin materials through recycling during production was also included in the study, adjusted for any loss in material performance due to the recycling process[19]. In practice, performance loss is often compensated for by the use of an extra amount of recycled material in a product, making it heavier than one produced only from virgin materials. This means that the virgin material avoided is less than the amount of waste material entering the recycling process. The performance loss for recycled production waste was estimated to be 10 per cent for plastic and 20 per cent for paper. Therefore, 90 per cent of the plastic and 80 per cent of the cardboard entering the recycling process is included as avoided product and subtracted from the system. Waste recycled during the production of HDPE, LDPE and PP was estimated to consume 0.6kWh of grid electricity per kilogram recycled. Primary packaging cardboard was assumed to be processed to produce recycled board.

The waste collection and end-of-life scenarios for the all carrier bags (including recycling and composting) were modelled using the Environment Agency LCA software tool WRATE. The assumptions made for end-of-life processing are given in Annex C. At the end-of-life 86 per cent of all bags were assumed to be landfilled and 14 per cent incinerated (DEFRA 2008). Statistics for paper recycling in England (DEFRA 2007) were also used to model the recovery of primary packaging cardboard in supermarkets with 77.3 per cent of cardboard assumed to be recycled. The remaining card was assumed to be split between landfill and incineration as for the carrier bags. Since the reference period (2006/07), in-house supermarket recycling has increased significantly. However, the recycling figures for that period were provided by DEFRA and were not substantially different to general in-house recycling figures reported by supermarket corporate social responsibility reports at that time.

The inclusion of recycling and composting (for the paper and starch-polyester bags) at end-of-life were also studied in a sensitivity analysis which is detailed in section 5.3.2.

When bag recycling at end-of-life was included, it was assumed that all the plastic carrier bags collected at end-of-life for recycling were exported for recycling to China. In the UK in 2005, 65 per cent of plastic film collected for recycling was exported overseas, mainly to China and other Far East countries (BPI 2007). However, carrier bags, whose main recycling route is currently through in-store collection, are likely to end up as back-of-store supermarket waste, of which more than 95 per cent is exported (Maxwell 2007). The inclusion of HDPE bags with prodegradant additive in the HDPE recycling stream is recognised by industry as potentially reducing recyclate quality. Although prodegradant additives were a small proportion of the polyethylene film being recycled, their separation from conventional HDPE is viewed as highly desirable and the recycling of HDPE prodegradant bags at end-of-life has been excluded from the study.

---

[19] This is loss of physical properties (strength or other function) due to the use, collection and recycling of a material.

5 Impact assessment

The first stage of this impact assessment uses IPCC 2007 characterisation factors to provide the Global Warming Potential (GWP or ‘carbon footprint’) for each carrier bag option. This assesses the GWP impact of the lifecycles detailed in the inventory analysis and includes secondary reuse (i.e. reuse of lightweight bags as a bin liner) but excludes the primary reuse for any bag. The number of times each heavy duty bag has to be used for its GWP to drop below this baseline figure for the conventional HDPE bag was then calculated. As discussed in section 3.2, apart from the secondary reuse of conventional HDPE carrier bags, there were no reliable data on the primary reuse of bags. This approach only shows the number of times each heavy duty bag would hypothetically have to be used to reduce its GWP below that of the conventional carrier bag. Actual reuse is governed by consumer use, bag strength and durability. Therefore, some reuse figures are unrealistic. For example, information on the use of paper bags at a major food retailer in the Republic of Ireland, shows no evidence of any reuse[20].

The second stage of the impact assessment calculates impacts for each carrier bag using the CML baseline method and is based on the hypothetical use calculated in stage one. All results and charts shown refer to the functional unit, i.e. the carrier bags required to carry one month’s shopping (483 items) from the supermarket to the home in the UK in 2006/07. The majority of the bar charts show the contribution of each lifecycle stage for each type of carrier bag to an impact category. These lifecycle stages include:

- **The extraction/production of raw materials** (HDPE, LDPE, PP, paper, starch-polyester blend, etc)
- **The production processes** (Energy use during the production of the carrier bag)
- **Transport** (The movement of raw materials to the production site and the finished carrier bag to the supermarket)
- **End-of-life** (Including collection, landfill and incineration)
- **Avoided products and recycling** (The avoidance of virgin materials through secondary reuse or recycling)

Positive values represent an adverse impact. Negative values resulting from ‘recycling & avoided products’ lifecycle stages represent a benefit and reduce the overall impact by the amount shown

A sensitivity analysis is also included in chapter 6 to determine the influence of key variables on the results of the impact assessment. The variables assessed in the sensitivity analysis are:

- Changing consumer behaviour with regards to secondary use of the bags;
- An increase in recycling and composting at end-of-life and;
- Using a different impact assessment method.

---

[20] Personal communication from Marks & Spencer plc to the Environment Agency

5.1 Global warming potential

The GWP (excluding primary reuse) for each lifecycle stage of each carrier bag is shown in figure 5.1. The cotton carrier bag is not shown in figure 5.1, because its GWP is more than ten times that of any other carrier bag. Figure 5.2 includes the cotton bag and shows the results based on the number of times each heavy duty bag would have to be used to reduce its GWP below that for the conventional HDPE bag. In round numbers these are: paper bag - 4 times, LDPE bag - 5 times, non-woven PP bag - 14 times and the cotton bag - 173 times.

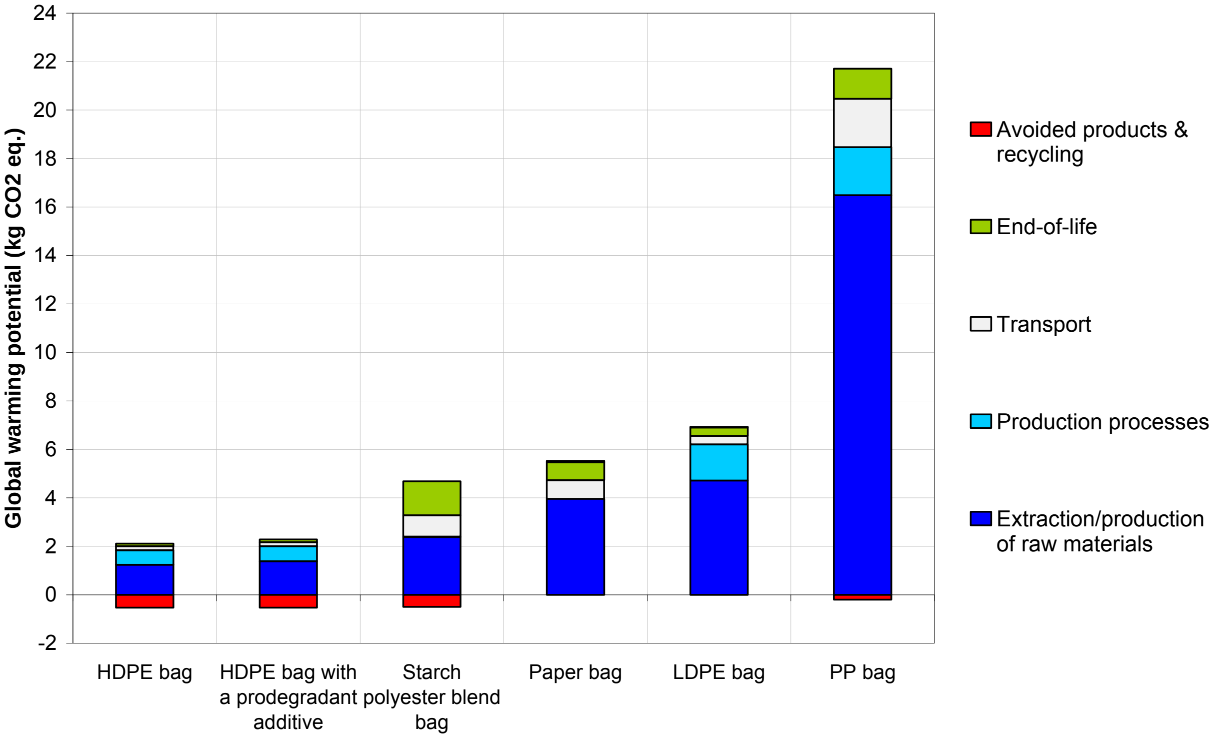


Figure 5.1 The lifecycle impacts of each carrier bag on global warming potential (excluding primary reuse).

The GWP of all of the carrier bags studied is dominated by raw material extraction and production which ranges from 57 per cent of the impact for the starch polyester bag to 99 per cent for the cotton bag. This impact is normally due to the production of the most prevalent material with 64 per cent of the HDPE bag impact generated directly from the extraction and production of HDPE. .

The avoided production of virgin material due to the recycling of post-production waste and primary packaging has a relatively small net effect due to the low proportion of scrap material reprocessed and due to the impacts of cardboard recycling being of similar size to the benefits of avoided production.

Packaging materials generally contribute between 0.4 per cent and 4 per cent of the overall global warming impact for each type of carrier. The GWP from grid electricity used to produce carrier bags varies from 38 per cent of the overall impact for HDPE bags to

0.4 per cent for the starch polyester bag, although the proportion was influenced by the impact of other lifecycle stages such as raw material extraction and production as well as the electricity mix in the country of origin: the HDPE bag is assumed to be produced in China, which relies heavily on electricity generated from burning coal, whereas the starch polyester blend bag is assumed to be produced in Norway where 99 per cent of the grid electricity is generated through hydropower.

The impact of transportation on the total GWP is generally between 0.8 per cent and 14 per cent and is heavily dependent on the road transport distance. The transportation of the starch polyester bag has the highest impact of all carrier transport and transport is also more significant in its lifecycle (21 per cent of total impact) because the starch-polyester blend is carried by road from Italy to Norway and the finished product by road/sea to the UK. In the case of the HDPE, HDPE prodegradant, PP and cotton bags, where bags are shipped from the Far East, the impact of that shipping is between 60-70 per cent of the transport impact.

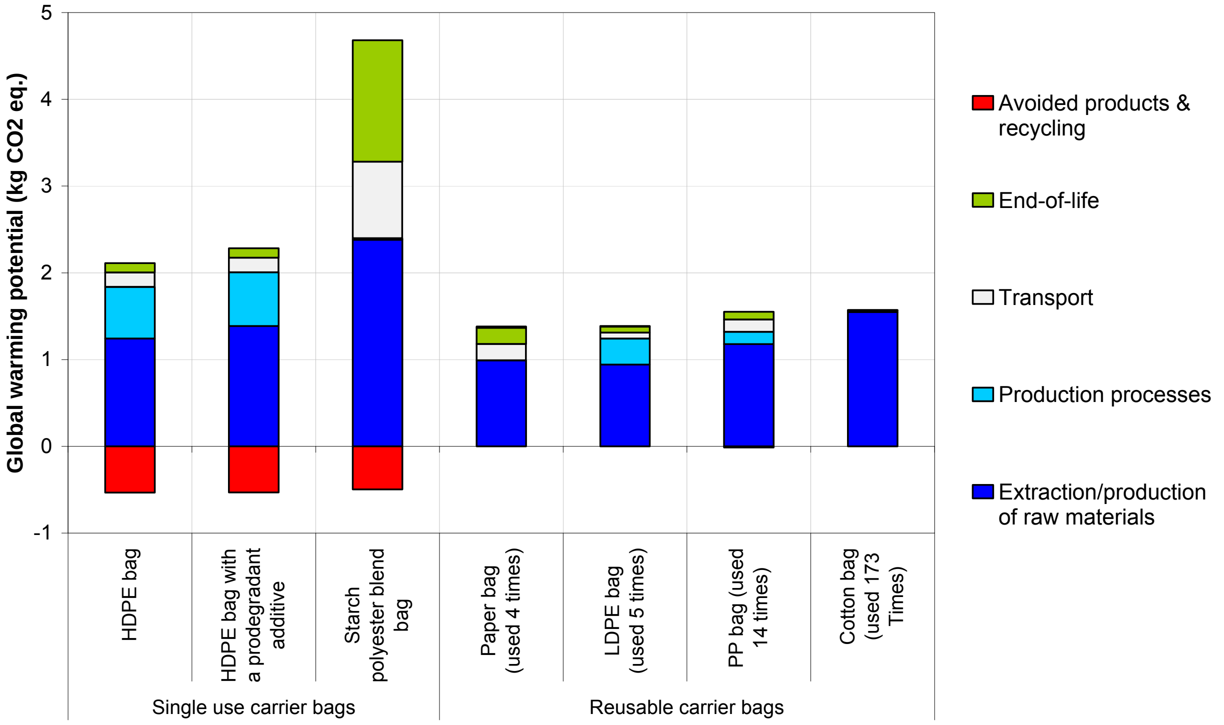


Figure 5.2 **The global warming potential impacts of each type of carrier bag assuming each is reused to outperform a conventional HDPE bag with no reuse).**

The end-of-life impacts of all bags contribute between 0.2 per cent and 33 per cent to overall GWPs. The end-of-life of the plastic carrier bags (the conventional HDPE, HDPE prodegradant, LDPE and PP bags) is generally between 5 per cent and 7 per cent and is dominated by the GWP of plastic incineration. However, the end-of-life of the paper bag and the starch polyester bag is dominated by landfill which contributes over 18 per cent and 29 per cent respectively to the overall impact. Incineration does provide a 5 per cent reduction in the GWP of the paper bag due to the energy from waste incineration which offsets the direct global warming impact .

The influence of the secondary reuse of 40.3 per cent of the lightweight bags is shown in the large reduction created by the avoided products lifecycle stage in both figures. This reuse generates a reduction of 12 per cent for the starch polyester blend bag, 29 per cent for the HDPE prodegradant bag and 32 per cent for the conventional HDPE bag. The exclusion of any primary reuse from figure 5.1 unsurprisingly shows that reusable carrier bags, without primary reuse, have a higher global warming potential than conventional HDPE carrier bags. However, the required reuse shown in figure 5.2 shows that this level is practicable for reusable plastic bags, although for paper bags it remains hypothetical.

5.2 Other impact categories

The CML 2 baseline 2000 method was used to calculate other environmental impacts for each carrier bag, which are considered in turn. The results in each of the following sections show the 8 impact categories considered as well as the GWP results described in section 5.1. These results are presented in bar charts showing the percentage contribution of each life cycle stage to each impact. In some cases the ‘end-of-life’ and ‘recycling & avoided products’ lifecycle stages also reduce the impact. These are therefore shown as negative percentages on the bar charts.

5.2.1 Conventional HDPE carrier bag

The impact assessment results for the conventional HDPE bag are shown in table 5.1 and the relative contributions from each stage of the life cycle are shown in figure 5.3.

In five of the eight impact categories, including acidification, human, aquatic and terrestrial toxicity, the bag production process has the largest lifecycle impact. This results from the use of Chinese grid electricity assumed and/or the disposal of ash from coal burning. However, International Energy Agency statistics (IEA, 2007), show some bag producing countries, such as Malaysia, have a lower reliance on coal and therefore bags produced there would have a lower impact in these categories. The impact of the building, maintenance and use of the transmission network used to deliver grid electricity also influences the terrestrial ecotoxicity of the HDPE bag.

The extraction and production of materials has the largest impact in the other three of the eight impact categories and is influential in a number of others. For toxicity and ecotoxicity, where resource use in not the main influence, the use of titanium dioxide has a significant impact on the material lifecycle stage despite being only 2 per cent of the bags’ weight. For example, the release of vanadium during the extraction and production of titanium dioxide contributes over 19 per cent to the HDPE bags fresh water ecotoxicity. It is important to note that titanium dioxide is only used in opaque bags and therefore clear bags of the same weight would have a lower impact in these categories.

Table 5.1 The environmental impact of the HDPE bag

Method	Impact category	Unit	Total
IPCC 2007	**Global warming potential**	kg CO2 eq	1.578
CML 2 baseline	**Abiotic depletion**	g Sb eq	16.227
	Acidification	g SO2 eq	11.399
	Eutrophication	g PO4--- eq	0.775
	Human toxicity	kg 1,4-DB eq	0.211
	Fresh water aquatic ecotox.	g 1,4-DB eq	66.880
	Marine aquatic ecotoxicity	kg 1,4-DB eq	126.475
	Terrestrial ecotoxicity	g 1,4-DB eq	1.690
	Photochemical oxidation	g C2H4	0.531

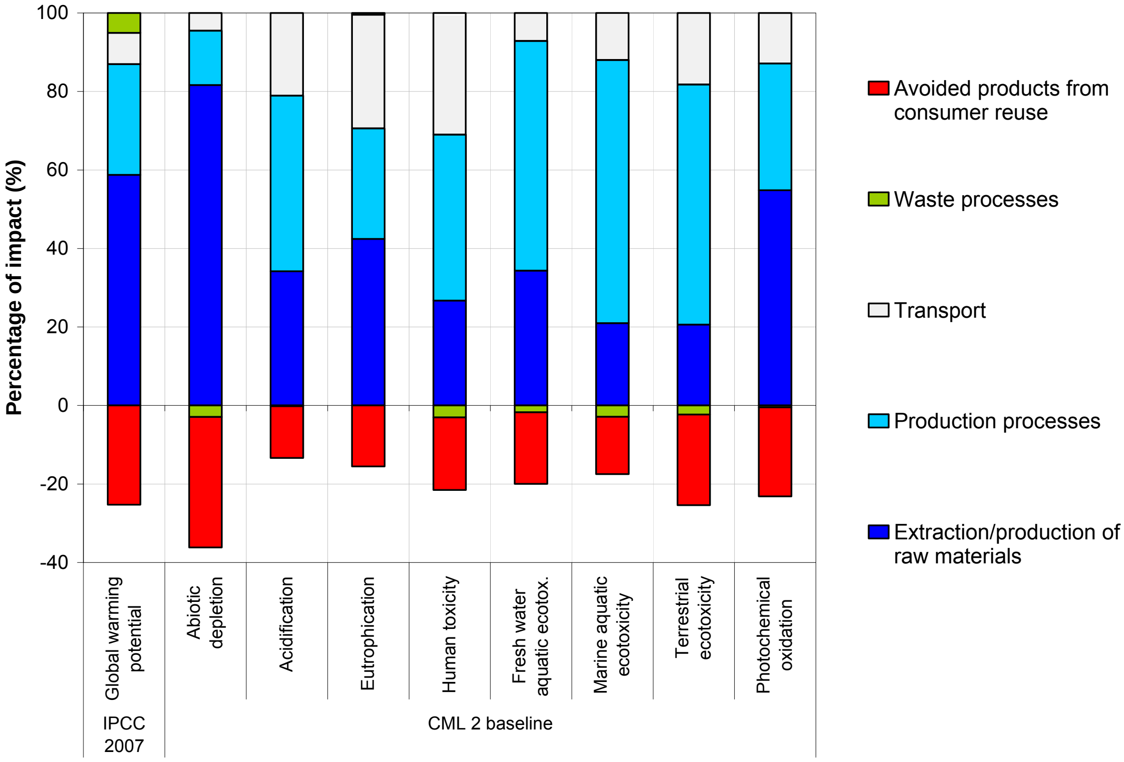


Figure 5.3 The relative contribution of different lifecycle stages to the environmental impacts of HDPE bags.

The distance and mode of transport of the HDPE bags from China to the UK contributes significantly to the impacts of eutrophication and human toxicity due to the emission of nitrogen oxides and polycyclic aromatic hydrocarbons respectively from shipping. The road transport of the raw materials to the carrier bag producer and from the UK importer to the supermarkets has little influence on the results due to the relatively short transport distances assumed (between 100km and 200km). In five of the eight categories, the end-of-life stage reduces the overall impact mainly because the impacts of incineration are outweighed by the impacts avoided from the production of electricity through waste to energy.

The reuse of HDPE carrier bags as bin liners reduces environmental impacts by between 13 per cent and 33 per cent. The reduction in impact from avoided bin liners is greatest in categories where raw material use is the dominant influence. However, in some categories such as human, aquatic and terrestrial ecotoxicity, the benefit of this avoided product is due to the avoided extrusion process rather than avoided resource use.

5.2.2 HDPE carrier bag with a prodegradant additive

The environmental impacts of the HDPE prodegradant bags are shown in table 5.2 and in figure 5.4. The impacts for the HDPE prodegradant bag are very similar to the HDPE bag. The percentage contribution of each lifecycle stage on each impact category is almost identical to the HDPE bag because of their similarity in material content, production, transportation, secondary reuse and end-of-life. In general, the material extraction and production lifecycle stage has a larger impact because the HDPE prodegradant bag is heavier. The reuse of HDPE prodegradant bags as bin liners reduces their overall environmental impact in a similar way to the HDPE bag, although the relative effect of secondary reuse is marginally smaller. The production of the bag is the largest contributor in five of the eight impact categories due to the emissions from the Chinese grid electricity used. Raw material extraction and production is an important stage in categories where energy generation is less influential, such as photochemical oxidation and abiotic depletion.

The production of the prodegradant additive has a minimal impact on most lifecycle categories, although the additive does contribute 4 per cent to the abiotic depletion of the bag due to the impact of the stearic acid used. The impact of transportation on the HDPE prodegradant bag lifecycle is only marginally greater than the HDPE bag (due to the heavier bag). Although the bag contains a prodegradant additive, the end-of-life impacts through incineration and landfill were modelled in the same way as the HDPE bag and are therefore identical. However, there is no evidence to suggest that the disposal of HDPE bags with prodegradant additive has a lower environmental impact than the conventional HDPE bag disposal and the prodegradant additive could actually increase some impacts.

Table 5.2 The environmental impact of HDPE bag with a prodegradant additive

Assessment method	Impact category	Unit	Total
IPCC 2007	**Global warming potential**	kg CO2 eq	1.750
CML 2 baseline	**Abiotic depletion**	g Sb eq	19.331
	Acidification	g SO2 eq	12.276
	Eutrophication	g PO4--- eq	0.839
	Human toxicity	kg 1,4-DB eq	0.228
	Fresh water aquatic ecotox.	g 1,4-DB eq	72.146
	Marine aquatic ecotoxicity	kg 1,4-DB eq	134.264
	Terrestrial ecotoxicity	g 1,4-DB eq	1.797
	Photochemical oxidation	g C2H4	0.581

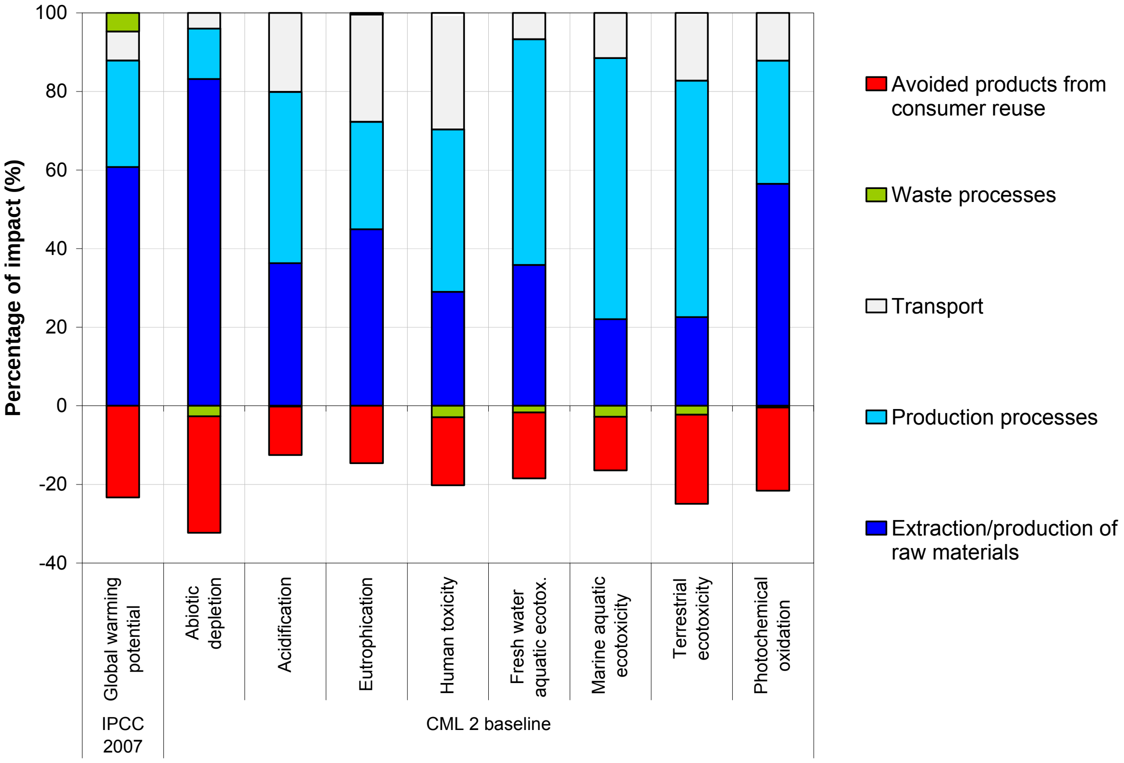


Figure 5.4 The lifecycle impacts of HDPE bag with a prodegradant additive.

5.2.3 Starch-polyester blend carrier bag

The environmental impacts of the starch-polyester blend bags are shown in table 5.3. and in figure 5.5.

Table 5.3 The environmental impact of starch-polyester blend bags.

Assessment method	Impact category	Unit	Total
IPCC 2007	**Global warming potential**	kg CO2 eq	4.184
CML 2 baseline	**Abiotic depletion**	g Sb eq	15.734
	Acidification	g SO2 eq	18.064
	Eutrophication	g PO4--- eq	7.240
	Human toxicity	kg 1,4-DB eq	1.151
	Fresh water aquatic ecotox.	g 1,4-DB eq	199.955
	Marine aquatic ecotoxicity	kg 1,4-DB eq	282.754
	Terrestrial ecotoxicity	g 1,4-DB eq	8.173
	Photochemical oxidation	g C2H4	1.232

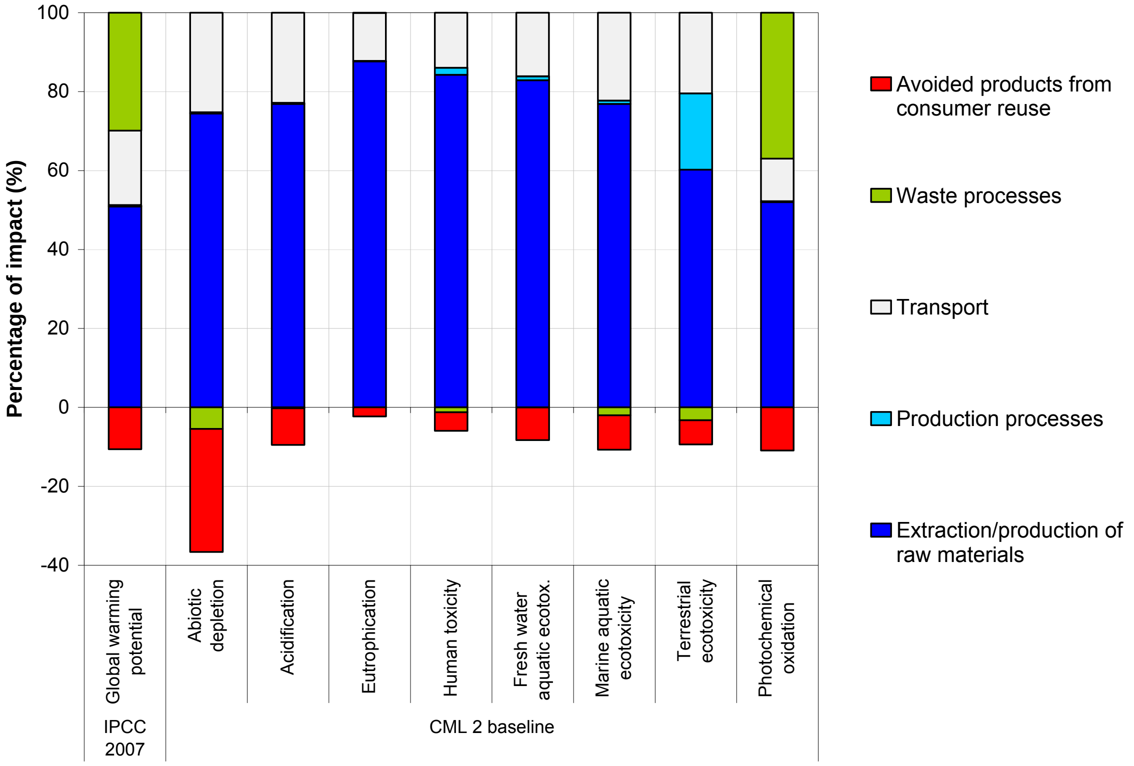


Figure 5.5 The lifecycle impacts of starch-polyester blend bags.

Raw material production is the highest contribution in all of the eight impact categories. However, no specific material or process can be identified other than the production of the starch-polyester due to the aggregated nature of the data provided by Novamont. More information on the origins of this data is available in annex C.

The influence of the transport of raw materials is very similar to that for the conventional HDPE bag. Although the distance is not as great, the materials are transported by lorry from Italy to the north of Norway and this produces a larger impact than sea transport in many categories. The end-of-life of the starch polyester bag only significantly influences its global warming potential and photochemical oxidation due to its degradation in landfill to release methane. This contributes approximately 29 per cent to the GWP impact.

Although bag production requires more energy than the conventional HDPE bag, the production has lower impacts because of the use of Norwegian grid electricity, which has very low impacts. The reuse of carrier bags as bin liners and the benefit of waste to energy at end of life reduce the overall environmental impacts of the starch-polyester blend bags by a similar amount to the other lightweight plastic bags.

5.2.4 Paper carrier bag

The CML 2 baseline impact assessment results for the paper bag are shown in table 5.4 and in figure 5.6. The results in the table include no reuse and the hypothetical four uses calculated in section 5.1. Few supermarkets use paper carriers in the UK, nor are they reused as bin liners (secondary use) as they are not as durable as HDPE bags, being liable to split or tear easily. Currently the only evidence available suggests even where they have been introduced, there is no significant reuse of paper bags.

Table 5.4 The environmental impact of the paper bag.

Assessment method	Impact category	Unit	Total (no reuse)	Total (used 4 times)
IPCC 2007	**Global warming potential**	kg CO2 eq	5.523	1.381
CML 2 baseline	**Abiotic depletion**	g Sb eq	26.697	6.674
	Acidification	g SO2 eq	37.470	9.367
	Eutrophication	g PO4--- eq	5.039	1.260
	Human toxicity	kg 1,4-DB eq	3.247	0.812
	Fresh water aquatic ecotox.	g 1,4-DB eq	150.204	37.551
	Marine aquatic ecotoxicity	kg 1,4-DB eq	244.657	61.164
	Terrestrial ecotoxicity	g 1,4-DB eq	24.719	6.180
	Photochemical oxidation	g C2H4	1.955	0.489

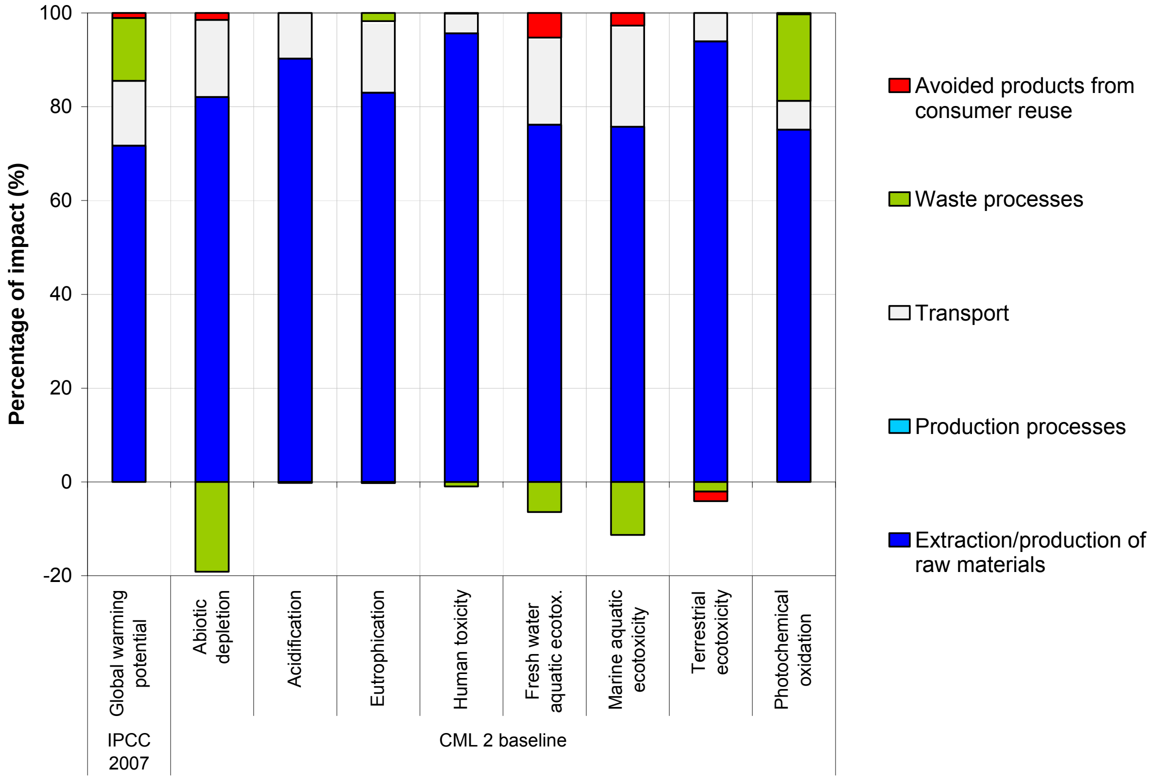


Figure 5.6 The lifecycle impacts of the paper bag.

The lifecycle impacts of the paper bag are dominated by the material extraction and production stages. As the data could not be separated, this combined stage contributes over 70 per cent of the impact in all eight categories. Due to the aggregated nature of the data, it is difficult to identify the processes or materials that contribute to these impacts. More detail on the data used is provided in annex C. However, we analysed the production of similar forms of paper and found the energy required from grid electricity contributed significantly to all impacts. The disposal of ash from paper production also has an impact on eutrophication and fresh water aquatic ecotoxicity. The production of palm oil for use in paper manufacture affects terrestrial ecotoxicity. Although the bags are produced in Europe, the distribution of the bags from the bag producers in to the supermarkets via the UK importer is still noticeable in most impact categories. This is because of the impacts of road transport emissions on acidification, eutrophication, terrestrial ecotoxicity and photochemical oxidation, and the impacts of oil production for diesel on abiotic depletion, human toxicity and aquatic ecotoxicity.

In many cases, the recycling and avoided products stage also produces a net burden (unlike the lightweight plastic bags) because the paper bag is not reused as a bin liner and therefore this stage only represents the recycling of primary packaging at end of life. In this case, the impact of the recycling process is greater than the avoided production of card, creating a net increase. A reduction in impact from end-of-life processing is seen in abiotic depletion and aquatic ecotoxicity, due to the avoided production of electricity through energy from waste incineration. However, waste processing does contribute 18 per cent of photochemical oxidation due to the impact of landfill in that category.

5.2.5 LDPE carrier bag

The environmental impacts of the LDPE bag are shown in table 5.5 and the contribution of each lifecycle stage to each impact in figure 5.7. Raw material production dominates the environmental impacts of the LDPE carrier bag system contributing at least 65 per cent to five of the seven categories. The production of polyethylene contributes most to impacts such as abiotic depletion, GWP and photochemical oxidation. However, the production of titanium dioxide is an important factor for human toxicity and aquatic ecotoxicity impacts.

The burdens from the conversion of LDPE pellets into carrier bags are an important factor in several impact categories. In the case of terrestrial ecotoxicity this impact is due to the effects of the electricity transmission network, but for most impacts it is due to emissions and waste ash produced by coal fired power stations in both of the production locations (assumed to be China and Turkey).

Table 5.5 The environmental impact of the LDPE bag.

Assessment method	Impact category	Unit	Total (no reuse)	Total (used 5 times)
IPCC 2007	**Global warming potential**	kg CO2 eq	6.924	1.385
CML 2 baseline	**Abiotic depletion**	g Sb eq	82.711	16.542
	Acidification	g SO2 eq	29.340	5.868
	Eutrophication	g PO4--- eq	2.576	0.515
	Human toxicity	kg 1,4-DB eq	0.701	0.140
	Fresh water aquatic ecotox.	g 1,4-DB eq	186.726	37.345
	Marine aquatic ecotoxicity	kg 1,4-DB eq	311.810	62.362
	Terrestrial ecotoxicity	g 1,4-DB eq	7.323	1.465
	Photochemical oxidation	g C2H4	1.391	0.278

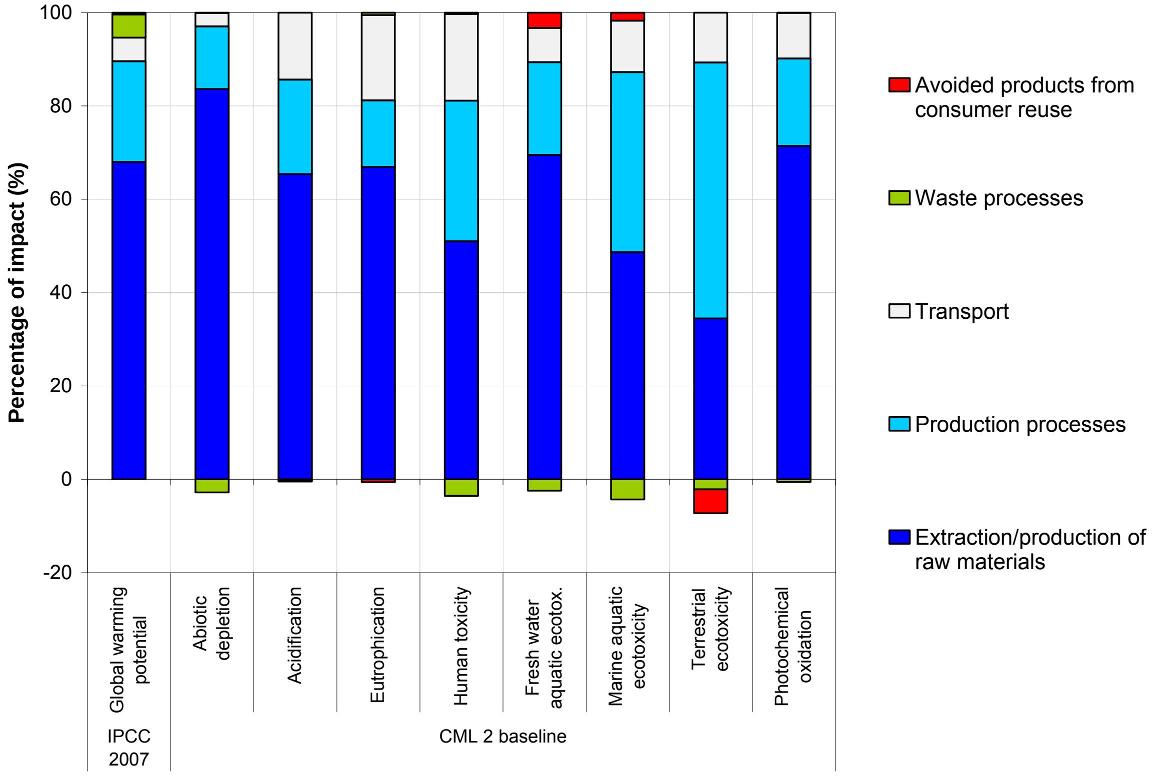


Figure 5.7 The lifecycle impacts of the LDPE bag.

The transport of materials to the carrier bag manufacturer and the distribution of the bag to the supermarket contributes considerably to the human toxicity, acidification and eutrophication impacts. However, these are proportionally smaller than the impact of transport on the HDPE bag due to 90 per cent of the bags being produced in Turkey rather than China. For eutrophication, the impact of transport is evenly split between road and sea transport due to the emission of nitrogen oxides from road vehicles, but for most impacts the contribution of transport is dominated by sea transport mainly due to emissions of nitrogen oxides.

The recycling & avoided products stage covers the recycling of primary packaging including cardboard and, similar to the paper bag, gives a net reduction in terrestrial ecotoxicity and a slight impact in aquatic ecotoxicity. The influence of end-of-life processing is very similar to the HDPE bag having been modelled in the same way.

5.2.6 Non-woven PP carrier bag

The environmental impacts of the non-woven PP bag are shown in table 5.6 and in figure 5.8.

Table 5.6 The environmental impact of the non-woven PP bag.

Assessment method	Impact category	Unit	Total (no reuse)	Total (used 14 times)
IPCC 2007	**Global warming potential**	kg CO2 eq	21.510	1.536
CML 2 baseline	**Abiotic depletion**	g Sb eq	274.764	19.626
	Acidification	g SO2 eq	101.314	7.237
	Eutrophication	g PO4--- eq	14.579	1.041
	Human toxicity	kg 1,4-DB eq	3.046	0.218
	Fresh water aquatic ecotox.	g 1,4-DB eq	467.717	33.408
	Marine aquatic ecotoxicity	kg 1,4-DB eq	1411.312	100.808
	Terrestrial ecotoxicity	g 1,4-DB eq	50.812	3.629
	Photochemical oxidation	g C2H4	5.247	0.375

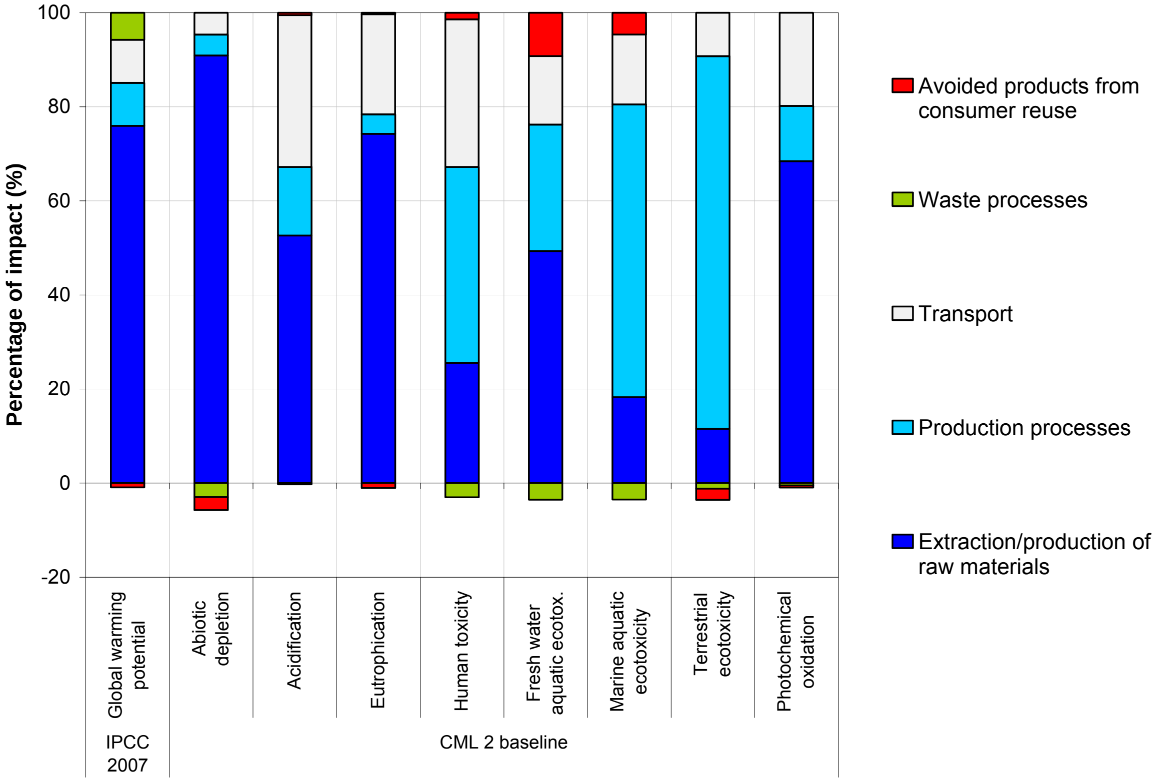


Figure 5.8 The lifecycle impacts of the non-woven PP bag.

The results for the non-woven PP bag are similar to the impacts for both types of polyethylene bags. Material extraction and production for the non-woven PP bag contributes more than half of the impacts for abiotic depletion, acidification, fresh water aquatic ecotoxicity, photochemical oxidation and eutrophication. For abiotic depletion, the contribution of resource use and material production is greater than bag production. The production of cotton fibre used in the non-woven bag contributes almost one third of the eutrophication impacts due to the release of nitrogen from cotton cultivation. Primary packaging also contributes more to the human toxicity and fresh water ecotoxicity impacts when compared to other bags, because of the amount of corrugated board used and the impact of its production on these categories. The influence of raw materials on toxicity and ecotoxicity is limited due to the greater burdens created from emissions of nickel and vanadium from burning heavy fuel oil in an industrial furnace, which is uniquely used for the production of this type of bag.

The importance of the recycling & avoided products lifecycle stage is reduced, because it only includes the recycling of primary packaging (similar to the same stage of the paper and LDPE bags). The recycling process does have a greater impact on categories such as fresh water ecotoxicity because of the large impact of card recycling and production on those catagories and the greater amount of primary packaging for the non-woven PP bag,

The effects of the transport of the bag and the end-of-life processing of its materials are also in similar proportions to the HDPE bag due to similar distances and transport methods plus the use of the same data for the end-of-life scenarios. The road transport distances are almost identical and, although the PP bag does have lower pre-production shipping distances, this has a limited impact on most impact categories. Therefore, the only substantial differences are due to the different weight of material used.

5.2.7 Cotton carrier bag

The environmental impacts of the cotton bag (used 173 times) are shown in table 5.9. The impact category results for the cotton bag show material extraction and production contributes more than 98 per cent to all the impact categories. This contribution is partly due to the assumption that the raw material is woven cotton textile. The energy required to process cotton into cotton yarn is the main contributor to abiotic resource depletion, acidification, human toxicity, freshwater and marine ecotoxicity, and photochemical oxidation. For eutrophication, cotton growing is the main contributor, from the use and production of fertilizer. Cotton growing and the energy consumed during cotton processing contribute almost equally to terrestrial ecotoxicity.

Table 5.9 The environmental impact of the cotton bag (used 173 times).

Assessment method	Impact category	Unit	Total (no reuse)	Total (used 173 times)
IPCC 2007	**Global warming potential**	kg CO2 eq	271.533	1.570
CML 2 baseline	**Abiotic depletion**	g Sb eq	1519.838	8.785
	Acidification	g SO2 eq	2787.681	16.114
	Eutrophication	g PO4--- eq	304.486	1.760
	Human toxicity	kg 1,4-DB eq	66.254	0.383
	Fresh water aquatic ecotox.	g 1,4-DB eq	23477.073	135.706
	Marine aquatic ecotoxicity	kg 1,4-DB eq	44716.601	258.477
	Terrestrial ecotoxicity	g 1,4-DB eq	3208.855	18.548
	Photochemical oxidation	g C2H4	95.114	0.550

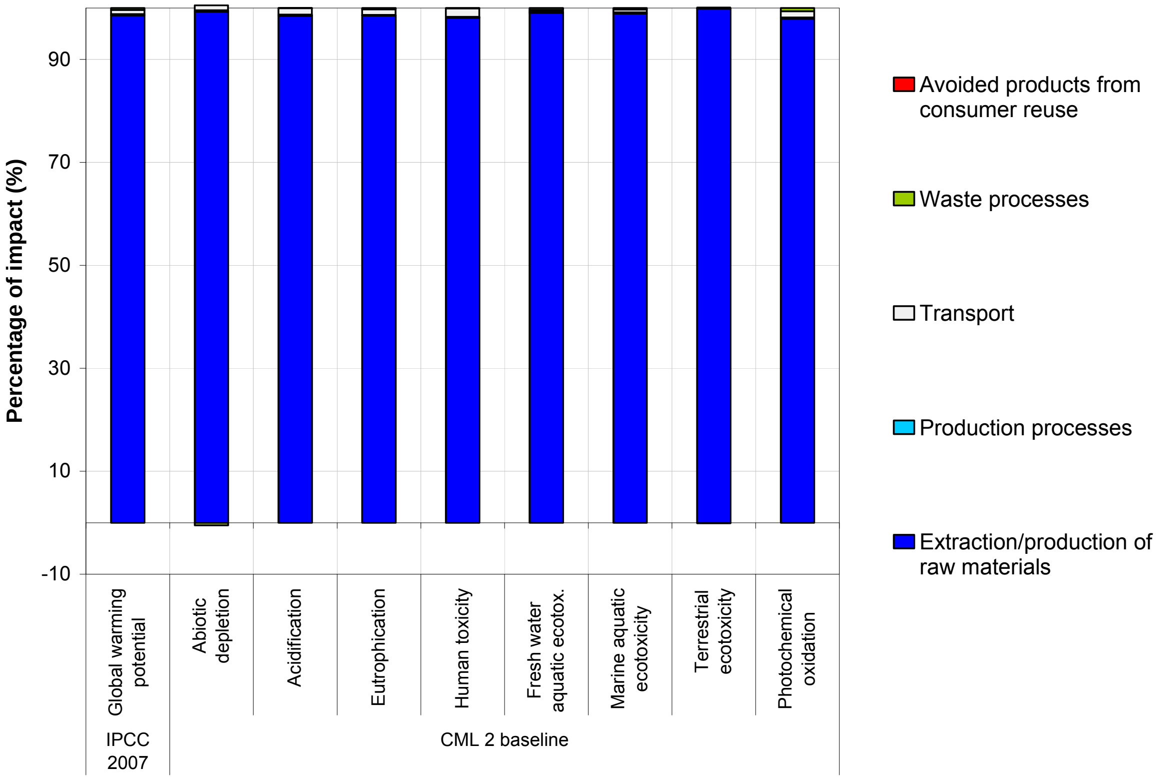


Figure 5.8 The lifecycle impacts of the cotton bag.

6 Sensitivity Analysis

The sensitivity analysis on the results focuses on three key areas:

- the secondary use of the bags by consumers;
- increasing recycling and composting at end-of-life; and
- using an alternative impact assessment method.

The reuse of conventional HDPE bags for shopping and its effect on the relative impacts is discussed in section 7.2

6.1 Secondary use of lightweight bags

We investigated the effects of changes in the secondary use of lightweight bags on all of the impact categories. Secondary use is the reuse of carrier bags in alternative applications replacing the need for other products. This was modelled in the study through the avoided production of bin liners for approximately 40 per cent of the bags used. Generally only lightweight carrier bags (i.e. the HDPE, HDPE prodegradant and starch-polyester blend bags) are reused in this way. In this sensitivity analysis, secondary use was applied to zero and 100 per cent of the bags

Table 6.1 shows the GWP for the lightweight carrier bag required to achieve the reference flow (as stated in section 3.2) with secondary use levels of zero, the original 40.3 per cent and 100 per cent. Figure 6.1 shows the influence of these changes in secondary use on all of the impacts for the conventional HDPE bag

Table 6.1 The effect of secondary reuse on the global warming potential of single use carrier bags.

Bag type	Sensitivity changes	IPCC 2007 Global warming potential (kg CO2 eq)
HDPE bag	No secondary use	2.082
	40.28% secondary use	1.578
	100% secondary use	0.830
HDPE prodegradant bag	No secondary use	2.254
	40.28% secondary use	1.750
	100% secondary use	1.003
Starch-polyester bag	No secondary use	4.691
	40.28% secondary use	4.184
	100% secondary use	3.433

The abiotic depletion of all lightweight carrier bags was reduced by between 70 per cent (for the HDPE prodegradant bag) and 81 per cent (for the starch-polyester blend bag) with a change from no reuse to 100 per cent reuse. The larger reduction in the impact of the starch-polyester bag is because this bag has a lower abiotic depletion impact compared to the other lightweight options and the amount of resource avoided is the same for each bag. Secondary use of bags is also highly influential on other impact categories such as GWP, toxicity, ecotoxicity and photochemical oxidation for both the conventional HDPE and HDPE prodegradant bags. A change from no reuse to 100 per cent reuse reduces these impacts by between 41 per cent and 60 per cent. The change in these impacts is much lower for the starch-polyester blend bag due to the higher contribution of the rest of its lifecycle on these categories.

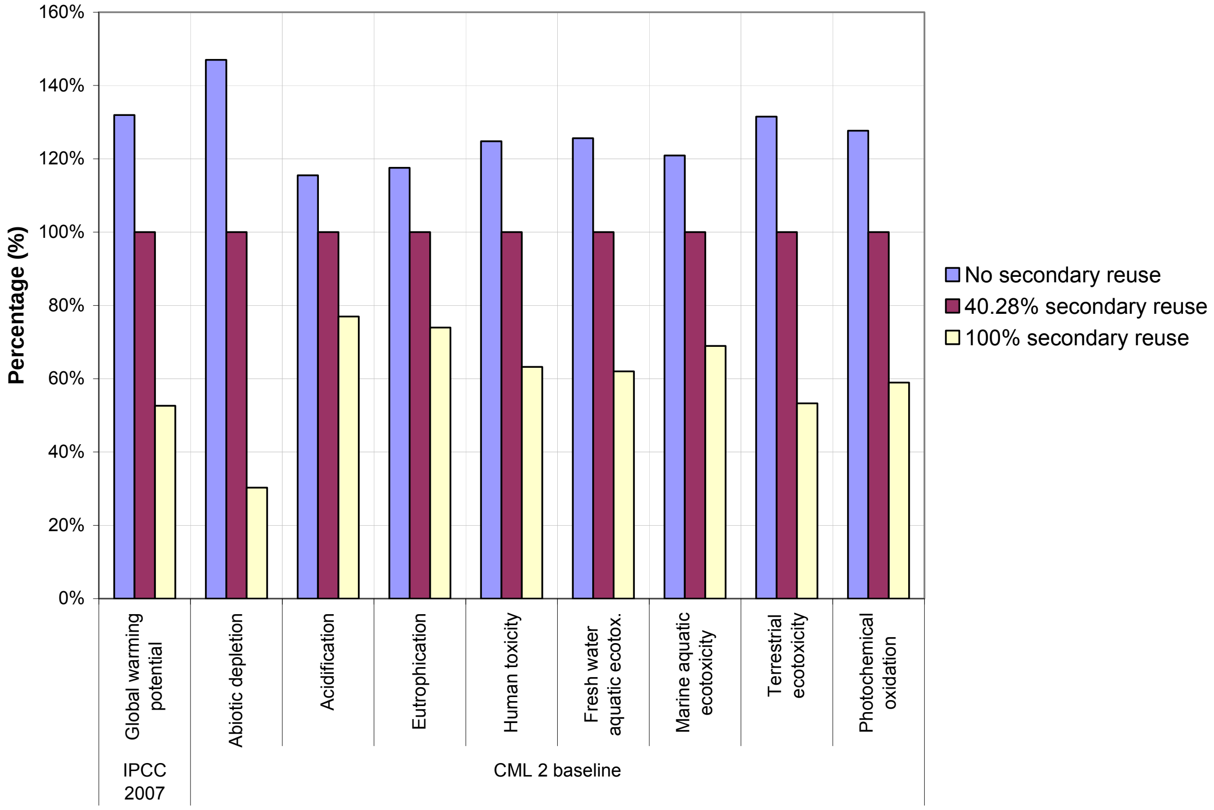


Figure 6.1 **The influence of secondary reuse on the lifecycle impacts of the conventional HDPE bag.**

The more bags that are reused, the greater the reduction in all the environmental impacts considered.

The number of times each of the heavy duty bags (i.e. all other bag types) had to be used for shopping to reduce the GWP below that of the HDPE bag was also considered for both low and high secondary reuse of the HDPE bag. Without secondary use the global warming potential of the conventional HDPE bags required to achieve the reference flow increased to 2.08 kg CO2 eq. This reduced the number of times the heavier bags needed to be used to drop below this baseline to 3 uses for the paper bag, 4 uses for the LDPE bag, 11 uses for the PP bag and 131 uses for the cotton bag. However, if all conventional HDPE bags were reused as bin liners the number of uses would rise to 7 for the paper bag, 9 for the LDPE bag, 26 for the PP bag and 327 for the cotton bag.

6.2 An increase in recycling and composting at end-of-life

We investigated the effect of increased recycling and composting at end-of-life on all the impact categories considered. All of the lightweight carrier bags were considered with and without secondary reuse. The 40 per cent of lightweight carrier bags that are reused as bin liners are therefore managed as residual municipal waste, leaving almost 60 per cent to go to recycling or composting. When secondary reuse is excluded we have assumed all bags are recycled or composted. The inclusion of HDPE bags with prodegradant additive in the HDPE recycling stream is recognised by industry as a potential problem for recyclate quality.and the recycling of HDPE prodegradant bags at end-of-life has not been considered. Table 6.2 shows the GWP for the different carrier bags (for the reference flow stated in section 3.2) with different levels of recycling and composting.

Table 6.2 The effect of recycling and composting on the global warming potential of carrier bags.

Bag type	Sensitivity changes	IPCC 2007 Global warming potential (kg CO2 eq)
HDPE bag	Baseline	1.578
	Recycling	1.400
	Recycling (no reuse)	1.785
HDPE prodegradant bag	Baseline	1.750
Starch-polyester bag	Baseline	4.184
	Composting	2.895
	Composting (no reuse)	3.329
Paper bag (4 uses)	Baseline	1.381
	Recycling	1.090
	Composting	1.256
LDPE bag (5 uses)	Baseline	1.385
	100% Recycling	1.196
PP bag (14 uses)	Baseline	1.536
	100% Recycling	1.292
Cotton bag (172 uses)	Baseline	1.579

The baseline figure for each carrier bag on table 6.2 represent the GWP described in section 5.1 which for all carriers includes average residual municipal waste processing for England (86 per cent to landfill, 14 per cent to incineration). Figure 6.2 shows how these changes alter the impacts of the conventional HDPE bag relative to the baseline results set to 100 per cent.

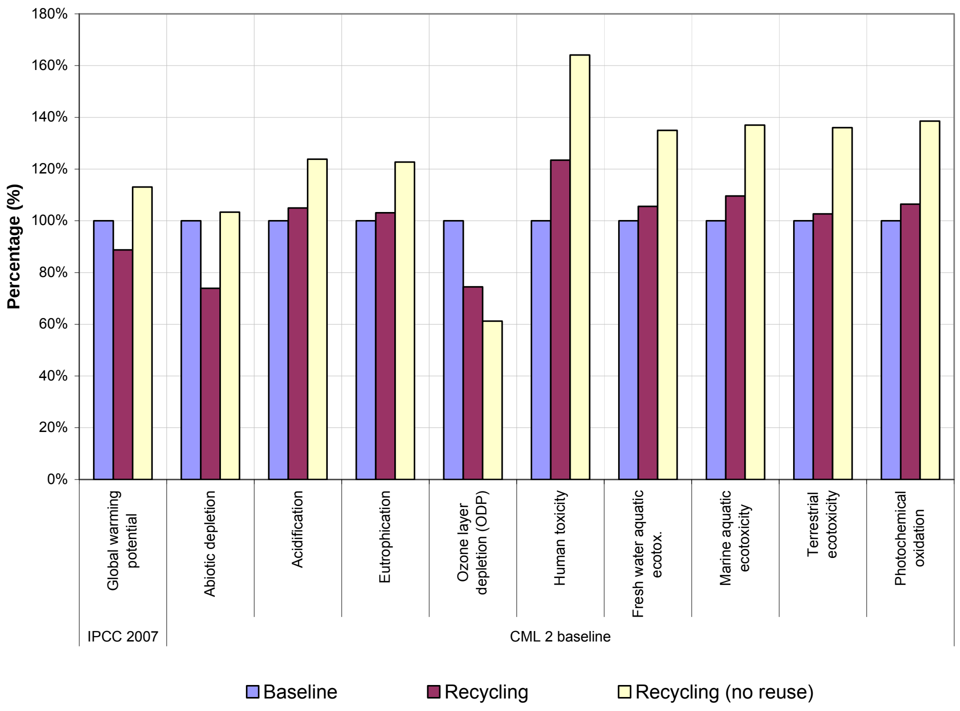


Figure 6.2 The influence of recycling on the lifecycle impacts of the HDPE bag.

Recycling conventional HDPE bags which are not reused as bin liners instead of disposing of them reduces GWP and abiotic depletion but substantially increases human toxicity and marginally increases all other impact categories. The large increase in potential human toxicity is due to the reduction in incineration which means more electricity has to be generated from coal and gas, and also an increased contribution from transport due to the shipping of the waste plastic to the Far East for recycling. If all HDPE bags are recycled, there is no benefit from avoided bin liners resulting in a rise in all impact categories. The results for all plastic carrier bags including the HDPE prodegradant bag, the LDPE bag and the PP bag are similar.

Figure 6.3 shows the influence of composting on the results for the starch-polyester blend bag. The use of composting at the end of the life for the 59.7 per cent of starch-polyester bag that are not reused changes most impact categories by less than 5 per cent. However, unlike the recycling of the conventional HDPE bag where an avoided product is created, composting the starch-polyester blend bags produces only carbon dioxide and water. Therefore, there is no reduction in resource use and a slight increase in abiotic depletion. Global warming potential and photochemical oxidation are both substantially reduced because composting avoids the impact of landfill, which has a considerable effect on these categories.

When no starch-polyester bags are reused as bin liners and all bags are composted, seven of the nine impacts are increased. This is more significant for abiotic depletion and photochemical oxidation where the avoided production of bin liners was particularly important.

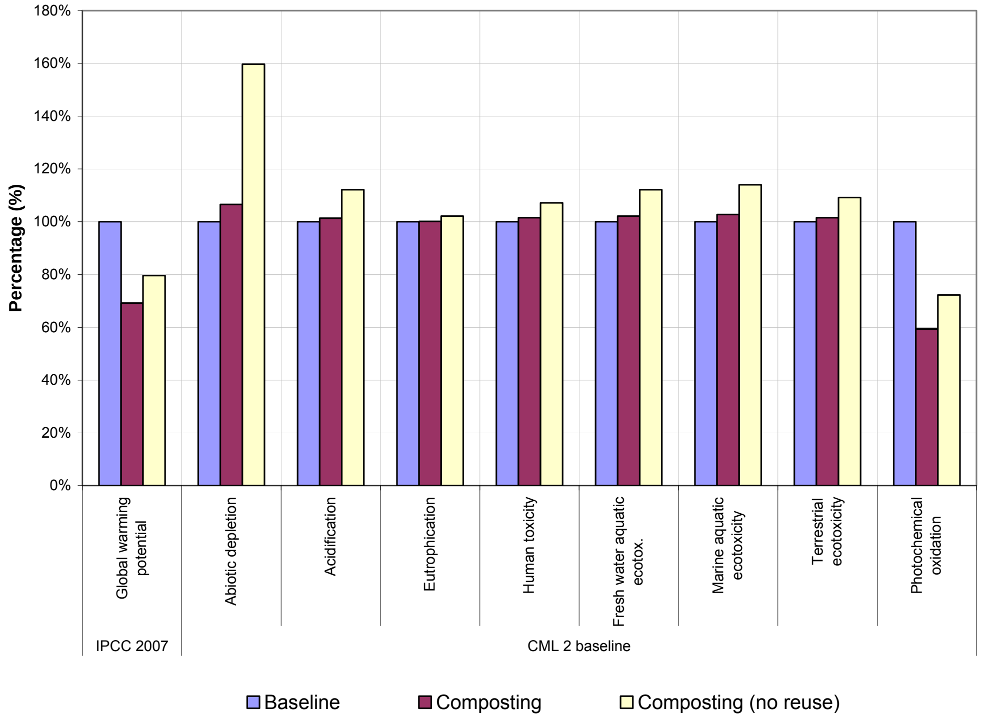


Figure 6.3 The influence of composting on the lifecycle impacts of the starch-polyester blend bag.

Figure 6.4 shows the effect of increased recycling and composting on the impacts of the paper bag. The recycling of the paper bag reduces the impact in six of the impact categories considered, including a 21 per cent reduction in GWP.

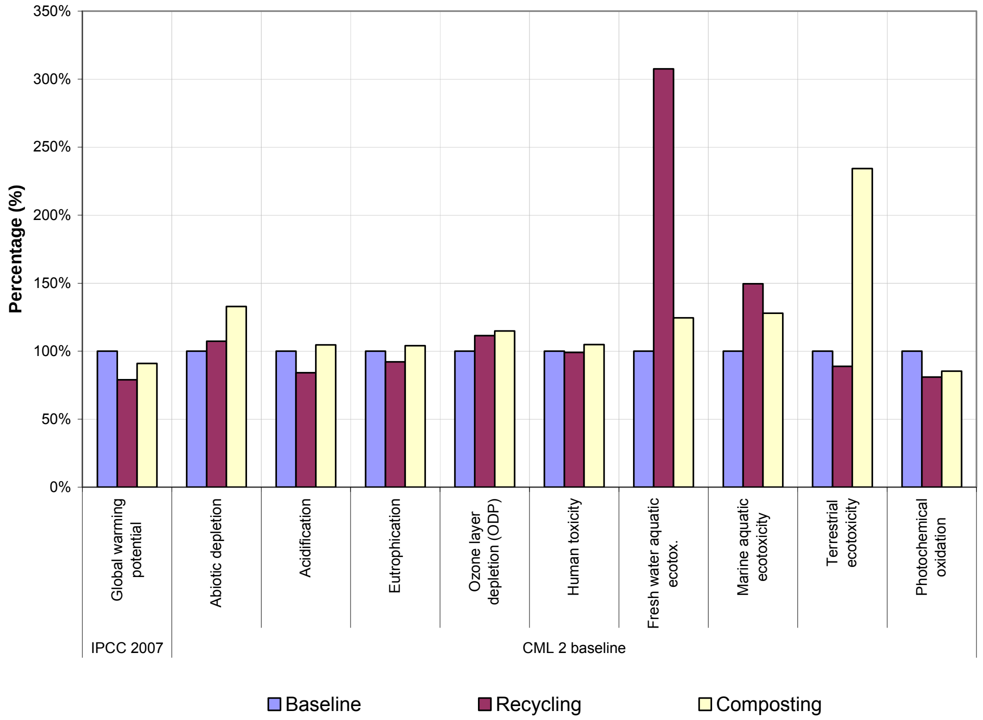


Figure 6.4 The influence of composting and recycling on the lifecycle impacts of the paper bag.

However, recycling increases fresh water ecotoxicity due to the release of copper to the water during recycling and terrestrial ecotoxicity from composting due to the release of metallic contaminants to soil and water.

Generally, when secondary reuse is reduced and replaced by recycling, impacts such as GWP and abiotic depletion are increased. Impact catagoires such as human toxicity are also affected by increases in recycling because of reduced incineration and the energy recovered resulting in an increase in electricity generated by coal and gas combustion. The composting of the starch-polyester and paper bags also increases many of the impacts of these carrier bags, although the recycling and composting of the paper bag and the composting of the starch polyester bag reduced GWP by avoiding the generation of methane associated with landfill.

6.3 Changing the impact assessment method employed

We conducted an alternative impact assessment using the eco-indicator 99 method and the results were compared to the original impact assessment discussed in chapter 5. These are shown in figure 6.5 and the eco-indicator 99 method results are shown over 10 impact categories in figure 6.6. Several of the impact categories are the same but a number of other impact categories such as land use are considered. One of the key differences is the inclusion of biogenic carbon dioxide in the calculation of global warming potential by assigning a characterisation factor of 1 to the GWP of biogenic carbon dioxide and a characterisation factor of -1 to carbon dioxide absorbed from the air by biomass (such as trees). This method therefore includes biogenic carbon dioxide that is absorbed and released during the natural carbon cycle.

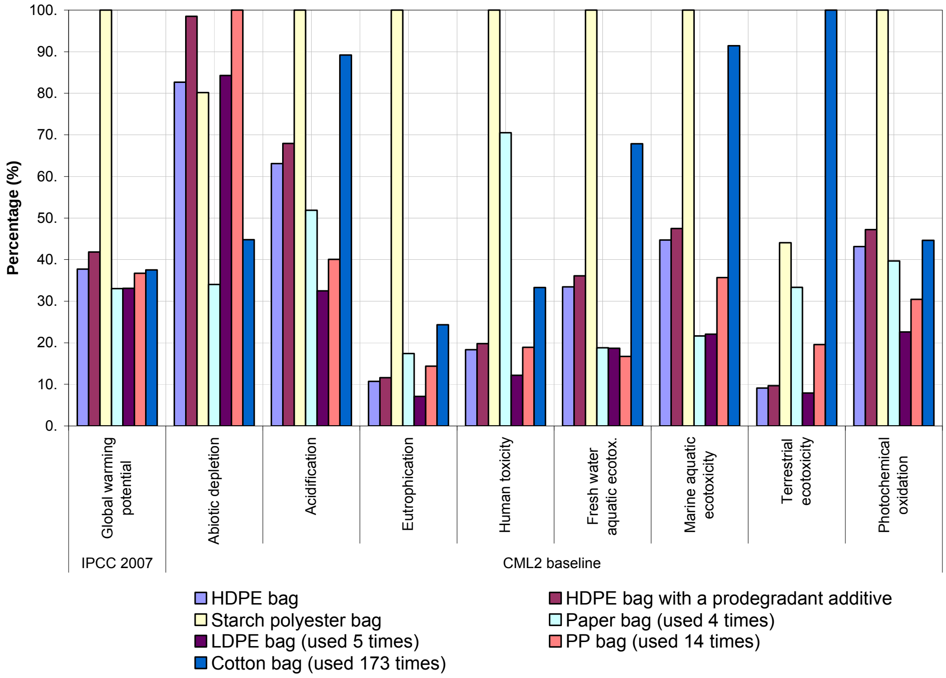


Figure 6.5 The results of the impact assessment when the IPCC 2007 and CML 2 baseline methods were used.

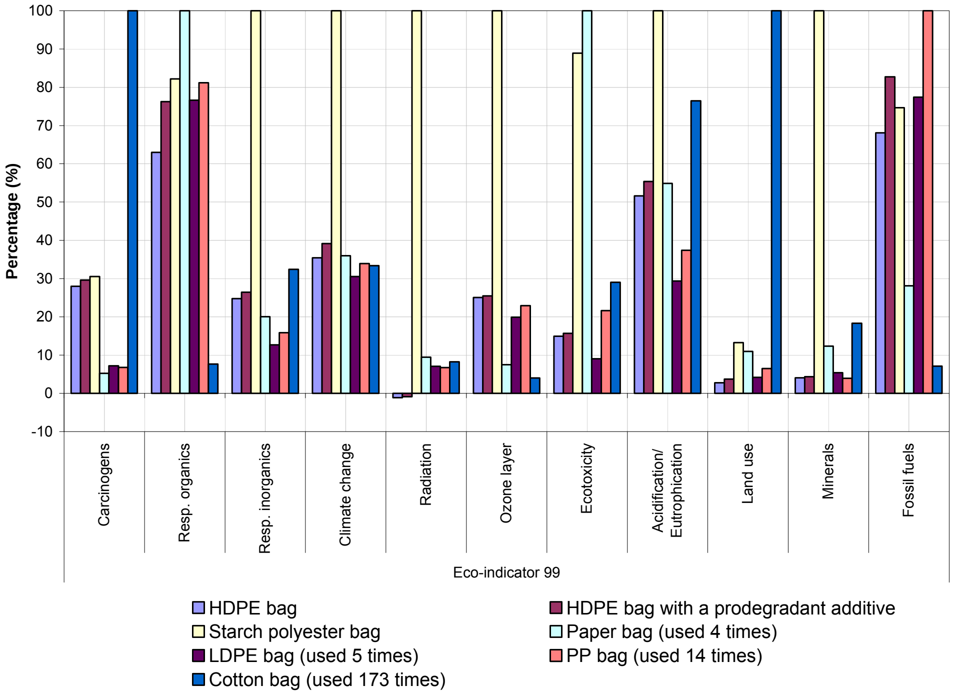


Figure 6.6 The results of the impact assessment when the eco-indicator 99 method was used.

The inclusion of biogenic carbon dioxide in the eco-indicator results increases the impact of the starch-polyester blend bag and the paper bag in comparison to the other carrier bag options. The amount of biogenic carbon dioxide equivalents emitted at the end-of-life of these bag lifecycle is greater than the biogenic carbon dioxide equivalents absorbed during production, therefore providing a marginal net increase in the GWP impact.

The starch-polyester bag degrades fully to methane and carbon dioxide in landfill, producing a higher global warming impact from the end-of-life than the paper bag, which does not fully degrade in landfill.

The results for fossil fuel, abiotic depletion and acidification are very similar to the CML method. The impacts from radiation are related to the life cycle of nuclear fuel used to contribute to the grid electricity used to produce each bag type. The comparatively high radiation impact of the starch-polyester blend bag is due to the higher proportion of nuclear produced electricity used in the manufacture of the starch polyester. The reduction in radiation for the conventional HDPE and HDPE prodegradant bags is due to the reduced energy required from the extrusion of bin liners that are avoided.

The cotton, starch-polyester blend and paper bags have the highest land use due to the land required for the growth of raw materials, although the impact of land use on starch-polyester bag is dominated by the use of corrugated board for packaging with only 20 per cent of the land use impact from the production of the starch polyester.

7 Discussion

7.1 Comparison with other studies

To check the results of this study we compared the impact assessment to other LCA studies of carrier bags, some of which are described in annex A. It is difficult to make detailed comparisons between the studies due to differences in system boundaries, functional unit and impact assessment methods. However, a common feature in all the studies is the inclusion of GWP as an impact category and therefore a basic data comparison can be made by dividing the global warming potential of each bag by its reference flow weight. This should remove any difference due to bag capacities and reuse and highlight any disparities in the data used. Figure 7.1 shows the results of this and three other studies based on the weight of CO2 equivalents generated per kg of each bag. The results for each study are relative to the baseline of the HDPE carrier bag in that study which is set at 100 per cent.

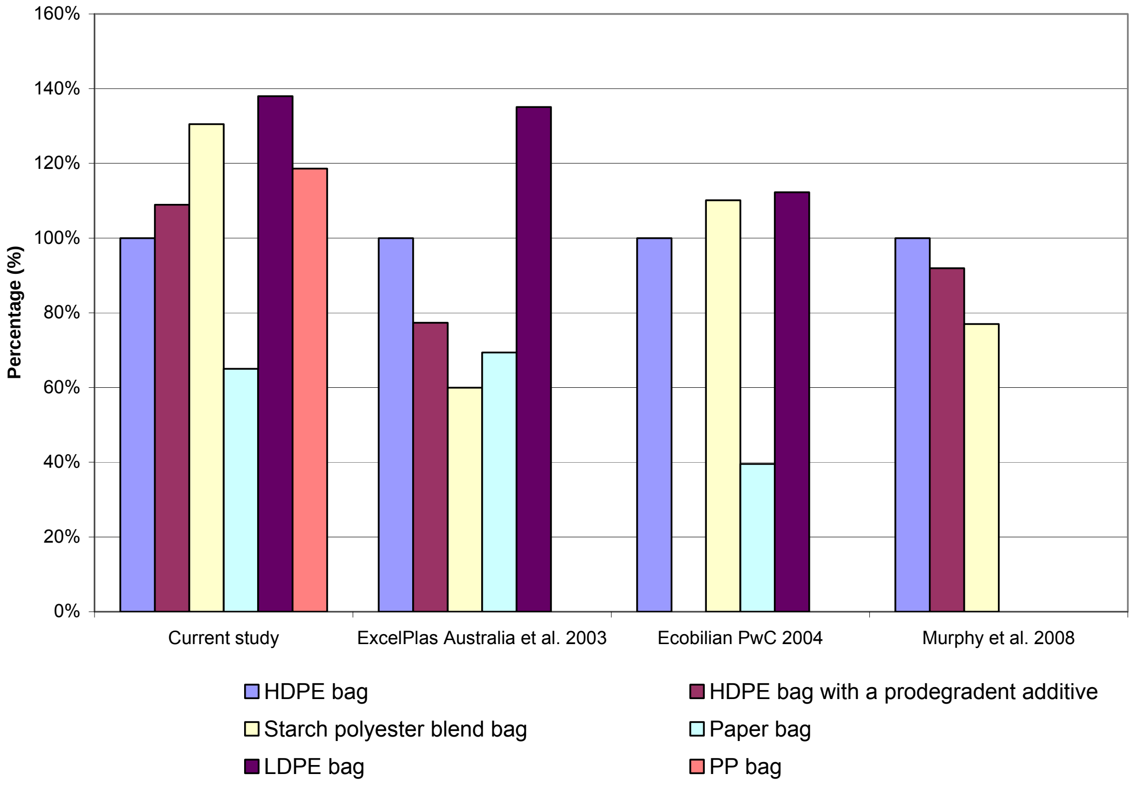


Figure 7.1 A comparison of the global warming potential of each bag type in each report based on the kg CO2 eq. produced per kg of bag weight.

Each report provides only a limited amount of information regarding the assumptions made and there are differences in material content, production, transport and end-of-life processing, so it is difficult to identify the sources of difference between each study. Generally, other studies have found that the impact of HDPE bags with prodegradant have a lower global warming potential when compared to conventional HDPE bags. This may be due to differences in the material content of the bags. Murphy et al (2008) assumed that the HDPE bag was produced using only HDPE, whilst the HDPE prodegradant bag contained 96 per cent HDPE and 4 per cent catalyst. The prodegradant additive was modelled as an organic chemical with a lower GWP impact than HDPE from the ETH database. This study used a more complex combination of materials, including chalk and titanium oxide, and used a surrogate for the prodegradant additive (90% stearic acid, 10% cobalt) which had a larger impact when compared to HDPE.

The global warming potential of the paper bag was lower than the HDPE bag in three of the four studies when compared by material weight. The LDPE reusable bag had a higher global warming potential than the baseline HDPE bag in the three studies. The results of this study generally lie between the results of the other studies for these formats.

The impact of the starch polyester blend varies considerably between studies. Both ExcelPlas Australia et al. (2003) and Murphy et al. (2008) show a lower gram for gram impact of the starch polyester bag than HDPE. However, the Ecobilian PwC (2004) and this study both show a higher impact by weight from the starch polyester bag. This is partially due to the impact of the material in landfill at the end-of-life

Figure 7.2 compares the grams of material used per litre for each bag type relative to the HDPE bag which was set at 1 for each study.

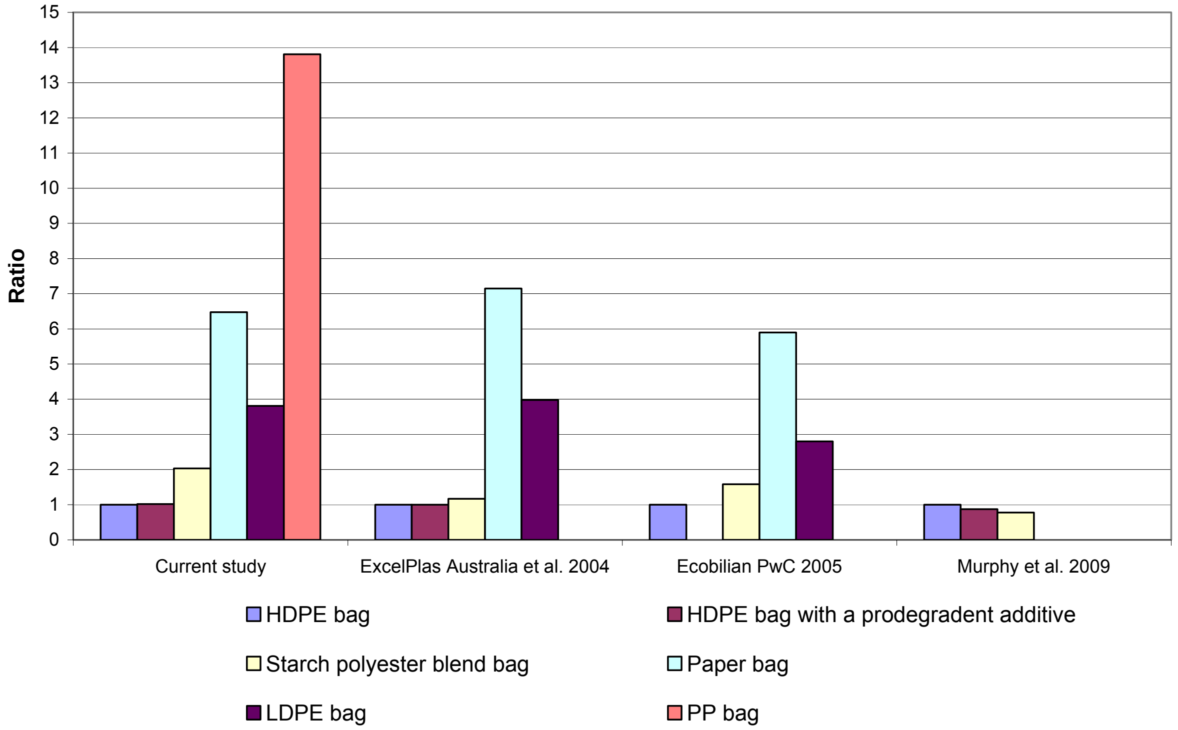


Figure 7.2 **A comparison of the grams of material used per litre in each report based on a baseline of 1 for single use HDPE bags.**

The ratios of material per litre capacity for the HDPE prodegradant bag, the paper bag and the LDPE bag relative to the HDPE bag in each report are comparable. However, there are differences between the grams per litre used for starch-polyester blend bags. Murphy et al. (2008) is the only study which assumes that both the prodegradant bag and the starch-polyester bag require less material per unit volume than the HDPE bag. The difference is almost certainly linked to the different samples used to generate the weight and capacity data. Although the data used here was supplied by manufacturers the results of this report only represent the reference period, 2007. There is evidence that biopolymer materials have improved since that period and weights have been reduced[21].

All the reports agree that the extraction and production of raw materials has the greatest effect on the environmental performance of the carrier bags studied. Ecobilan PwC (2004) found that improvements were seen when secondary reuse was considered for conventional HDPE bags and that reducing weight and reuse were the best options for improving the environmental performance of the carrier bags. The level of reuse required for LDPE bag to be superior to the conventional HDPE bag was also found to be similar to this study. Nolan-ITU (2003) reported that reusable bags had a lower environmental impact, although they assumed reuse was significantly higher than the other studies at 10 uses for the LDPE bag. Nolan-ITU also found that degradable bags have a similar environmental impact to conventional lightweight HDPE bags and that starch-polyester blend bags have higher eutrophication and acidification impacts. Like this study, Murphy et al. (2008) reported that the recycling of HDPE bag reduces both abiotic depletion and global warming potential and the composting of starch-polyester bags increases the impact in those categories. However, this study shows that recycling greater effects on both eutrophication and acidification. This is probably due to the transport of recyclates to China included in this report which increases the impact in these categories.

7.2 Discussion of results

The goal of this study was to investigate and compare the environmental impact of carrier bags made from HDPE, LDPE, non-woven PP, HDPE with prodegradant additives, paper, a starch-polyester blend and cotton using life cycle assessment (LCA). The assessment used the IPCC 2007 and CML 2 baseline method to provide the environmental impacts of these carrier bag systems in nine environmental categories.

Each type of carrier bag is designed for a different number of uses. Those intended to last longer need more resources in their production. To make the comparison fair, the environmental impacts of the carriers bags were considered in relation to carrying the same amount of shopping over a period based on studies of their volumes and the number of items consumers put into them. Resource use, primary and secondary reuse and end-of-life recovery play a pivotal role in the environmental performance of the carrier bags studied. The analysis showed that the environmental impacts of each type are significantly affected by the number of times a carrier is used.

---

[21] Personal communication from the Co-op to the Environment Agency.

When each bag was compared with no primary reuse (i.e. no reuse as a carrier bag), the conventional HDPE bag had the lowest environmental impacts of in eight of the nine impact categories, because it was the lightest bag considered. The HDPE prodegradant bag had a larger impact than the HDPE bag in all categories considered. Although the bags were very similar, the prodegradant bag weighed slightly more and therefore used slightly more energy and resources during production and distribution. The lifecycle impact of both these types of carrier bags was dominated by raw material extraction and the production of the carrier bags, with the use of Chinese grid electricity produced from coal burning significantly affecting the acidification and ecotoxicity impacts of the bag.

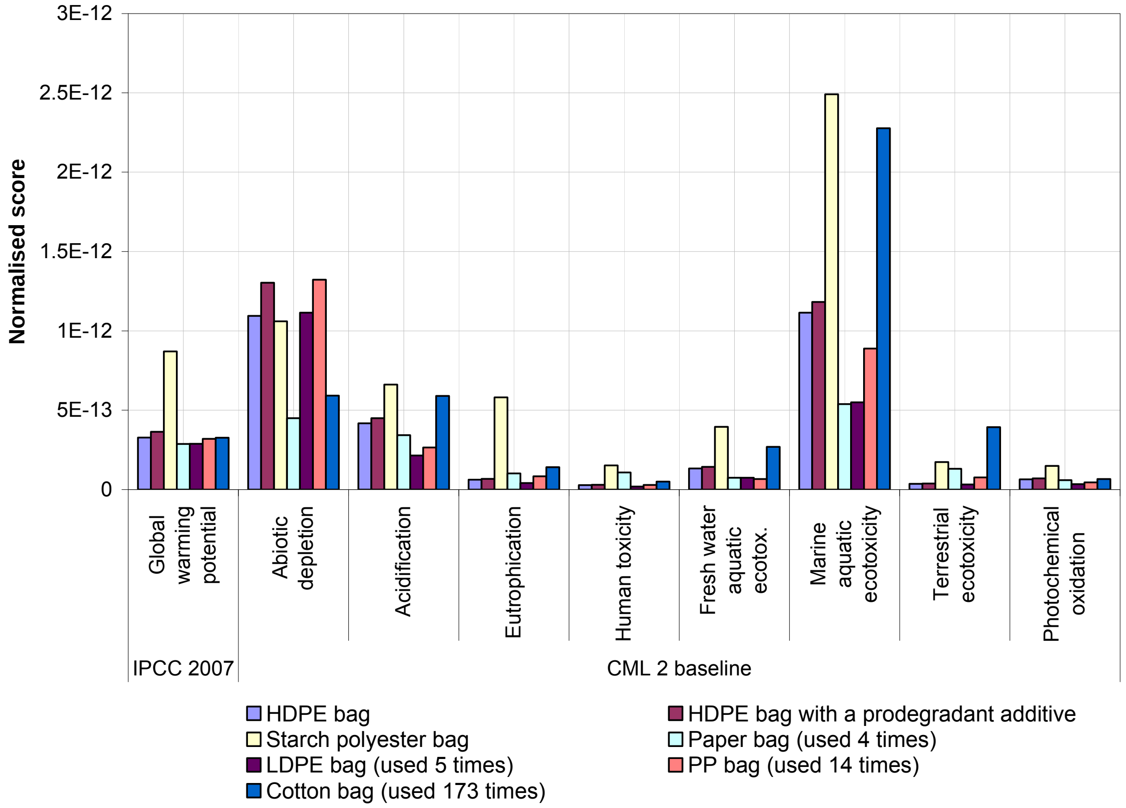


Figure 7.1 The normalised results of the impact assessment when the IPCC 2007 and CML 2 baseline methods were used.

The normalised results of the impact assessment are shown in figure 7.1. Normalisation divides the results in each category by a reference value to provide a measure of their relative important. The figure shows the relative importance of global warming potential, abiotic depletion, acidification and marine aquatic ecotoxicity. However, some impact categories, particularly human toxicity and aquatic and terrestrial ecotoxicity, are difficult to quantify with LCA because their local impacts makes them difficult to aggregate with the traditional global impact categories used. However, the impact categories are still widely used, and have therefore been included in the assessment as issues of interest.

We have avoided calling lightweight bags “single use” or “disposable”, because consumers are increasingly reusing lightweight carriers for shopping. Additionally a high proportion were used during the reference period as a genuine replacement for another product and the secondary reuse of these bags plays an important part in reducing their global warming potential.

This study does not compare the real functionality of the bags, which is partially dependent on consumer use. This would require a large survey to establish average primary reuse rates for each bag. Instead, we have calculated the ‘required reuse’ to reduce the global warming potential of each type of bag to below that of the conventional bag, which will be unrealistic for some bag types. This provides a better and more practical understanding of the consumers’ role in the environmental impact of reusable bags.

The results show that durable carrier bags have to be reused several times to have a lower global warming potential than the conventional HDPE carrier bags. Whether this reuse is achieved depends both on the physical properties of the bag and consumer behaviour.

Most of the impacts were related to the extraction and production of the raw materials and analysis of the results shows that there are three key factors in the assessment of the impacts of different types of carrier bag:

- the amount of material necessary to carry a fixed amount of shopping;
- the way they are used (number of reuses or secondary use); and
- to a lesser extent, the way they are managed at the end-of-life.

The manufacturing of the bags is normally the most significant stage of the life cycle, due to both the material and energy requirements. The impact of the energy used is often exacerbated by their manufacture in countries where the electricity is produced from coal-fired power stations. Generally, bags that are designed to be used many times are heavier and contain more raw materials and require more energy in their production than lightweight carrier bags. For any carrier bag, including lightweight bags, the impacts of manufacture can be reduced by using a carrier bag several times – for example, if a carrier is used three times, the impacts will be one-third of a similar bag which is used only once.

Therefore if conventional HDPE carrier bags are reused as carrier bags three times followed by reusing 40 per cent as bin liners, an LDPE “bag for life” would have to be reused some 14 times and a cotton bag more than 500 times to reduce their GWP to below the level of the conventional bag with this reuse. This is quite feasible for the LDPE bag but less likely for the cotton bag.

When the lightweight carrier bags are compared, the starch polyester bag has the largest impact on GWP due to:

- its greater weight in comparison with the conventional HDPE and HDPE prodegradant bags
- the large transport distance by road; and
- the impacts from its landfil.

The starch-polyester carrier bags considered were based on manufacturer’s data and weighed almost twice as much as conventional HDPE carrier bags. They had the highest impacts of the lightweight carrier bags in every category apart from abiotic resource depletion.

Since the reference period, the weight of starch polyester bags has been reduced by manufacturers to similar to that of the conventional HDPE bag. On a weight for weight basis this suggests that the global warming potential, acidification and photochemical oxidation impacts of the starch-polyester bag would be similar to conventional HDPE carrier bags, as indicated in other reports on the subject. However, the impacts of global warming potential, eutrophication, toxicity and ecotoxicity for the starch-polyester blend bag studied would still be worse than conventional plastic bags due to the high impacts of raw material production, transport and landfill on those categories.

The sensitivity analysis showed that, not counting primary reuse, the secondary reuse of lightweight carrier bags was fundamental to their environmental performance, particularly in terms of abiotic depletion, global warming potential, toxicity, ecotoxicity and photochemical oxidation. In the case of the HDPE bag, a change from no reuse to 100 per cent reuse decreased these impacts by between 43 per cent and 79 per cent. The environmental benefit of recycling HDPE and HDPE prodegradant bags was also affected by secondary reuse. The recycling of these bags was found to be beneficial to global warming potential and abiotic depletion in combination with secondary reuse. However, when HDPE bags are recycled instead of being reused it increases most of their environmental impacts.

The sensitivity study also found that composting starch polyester bags reduce only their global warming potential. Recycling and composting reduced the global warming potential of the paper bag by 21 per cent and nine per cent respectively, but could also cause significant rises in aquatic and terrestrial ecotoxicity.

8 Conclusions

8.1 Conclusions related to individual carrier bags

The following sections outline the results shown in figure 7.1 for each of the bag types considered in this study. The comparisons include the secondary reuse of 40 per cent of lightweight bags (HDPE, HDPE prodegradant and starch-polyester) as bin liners.

8.1.1 Conventional HDPE bag

The conventional HDPE bag had the lowest environmental impacts of the lightweight bags in eight of the nine impact categories. The bag performed well because it was the lightest bag considered. The lifecycle impact of the bag was dictated by raw material extraction and bag production, with the use of Chinese grid electricity significantly affecting the acidification and ecotoxicity of the bag.

8.1.2 HDPE bag with prodegradant additive

The HDPE prodegradant bag had a larger impact than the HDPE bag in all categories considered. Although the bags were very similar, the prodegradant bag weighed slightly more and therefore used more energy during production and distribution.

8.1.3 Starch-polyester bag

The starch-polyester bag had the highest impact in seven of the nine impact categories considered. This was partially due to it weighing approximately twice that of the conventional HDPE bags but also due to the high impacts of raw material production, transport and the generation of methane from landfill.

8.1.4 LDPE bag

The LDPE bag has to be used five times to reduce its GWP to below that of the conventional HPDE bag. When used five times, its impacts were lower in eight of nine of the impact categories. The impact was also substantially lower than the HDPE bag in terms of acidification, aquatic ecotoxicity and photochemical oxidation due to lower shipping distances and the use of grid electricity which is less reliant on coal.

8.1.5 Non-woven PP bag

The non-woven PP bag had to be used fourteen times to reduce its GWP to below that of the conventional bag. With this level of reuse it was also superior to the conventional HDPE bag in five of the nine categories. However, the PP bag was significantly worse than the baseline in terms of terrestrial ecotoxicity due to the emissions associated with use of a heavy fuel oil in an industrial furnace. When recycling was considered global warming potential and abiotic depletion impacts were reduced similar to the HDPE bag.

8.1.6 Paper bag

The paper bag has to be used four or more times to reduce its global warming potential to below that of the conventional HDPE bag, but was significantly worse than the conventional HDPE bag for human toxicity and terrestrial ecotoxicity due to the effect of paper production. However, it is unlikely the paper bag can be regularly reused the required number of times due to its low durability.

8.1.7 Cotton bag

The cotton bag has a greater impact than the conventional HDPE bag in seven of the nine impact categories even when used 173 times (i.e. the number of uses required to reduce the GWP of the cotton bag to that of the conventional HDPE bag with average secondary reuse). The impact was considerably larger in categories such as acidification and aquatic & terrestrial ecotoxicity due to the energy used to produce cotton yarn and the fertilisers used during the growth of the cotton.

8.2 General conclusions

The following bullet points provide general conclusions to the study.

- The environmental impact of carrier bags is dominated by resource use and production. Transport, secondary packaging and end-of-life processing generally have a minimal influence on their environmental performance.

- The key to reducing the impact of all carrier bags is to reuse them as much as possible and where reuse for shopping is not practical, secondary reuse in application such as bin liners is beneficial.

- The reuse of conventional HDPE and other lightweight carrier bags for shopping and/or as bin-liners can substantially improve their environmental performance.

- Reusing lightweight carrier bags as bin liners produces greater benefits than recycling bags due to the benefits of avoiding the production of the bin liners they replace.

- For the impacts categories considered, the HDPE bag with prodegradant additives increased the environmental impacts from those of the conventional HDPE bag.

- Starch-polyester blend bags have a higher global warming potential than conventional polymer bags, due to the increased weight of material in a bag, higher material production impacts and a higher end-of-life impact in landfill.

- Recycling or composting generally produces only a small reduction in global warming potential and abiotic depletion. The reduction is greatest for the biodegradable bags – paper and starch-polyester. Composting of starch-polyester bags significantly reduces the contribution of the end-of-life stage to global warming.

- The paper, LDPE, non-woven PP and cotton bags should be reused at least four, five, 14 and 173 times respectively to ensure that they have lower global warming potential than conventional HDPE carrier bags. The number of times each would have to be reused when the conventional carrier bag is reused in different ways is shown in table 8.1.

Table 8.1 The amount of primary use required to take reusable bags below the global warming potential of HDPE bags with and without secondary reuse.

	HDPE bag (No secondary reuse)	HDPE bag (40.3% reused as bin liners)	HDPE bag (100% reused as bin liners)	HDPE bag (Used 3 times)
Paper bag	3	4	7	9
LDPE bag	4	5	9	12
Non-woven PP bag	11	14	26	33
Cotton bag	131	173	327	393

9 References

British Polythene Industries (BPI), 2007. *Environmental Facts,* Retrieved 17th August 2009, from, http://www.bpipoly.co.uk/downloads/bpi_enviro2.pdf

Centre for Environmental Studies (CML), 2001. *CML Impact Assessment Characterisation Factors*, University of Leiden, More information on http://www.leidenuniv.nl/interfac/cml/ssp/lca2/index.html

Department for Environment Food and Rural Affairs (DEFRA), 2007. *Packaging Waste Recovery and Recycling achieved in 2006*, 29th March 2007.

Department for Environment Food and Rural Affairs (DEFRA), 2008. *Municipal Waste Statistics*. Retrieved 17th August 2009, from, http://www.defra.gov.uk/environment/statistics/wastats/bulletin08.htm

Department for Environment Food and Rural Affairs (DEFRA), 2009. *Local environmental quality: carrier bags*. Retrieved 17th August 2009, from, http://www.defra.gov.uk/ENVIRONMENT/localenv/litter/bags/

EcoBilan PwC, 2004. Évaluation des impacts environnementaux des sacs de caise Carrefour – Analyse du cycle de vie de sacs de caise en plastique, papier et matériau biodegradable (Evaluation of the environmental impacts of Carrefour supermarket carrier bags – Analysis of the life cycle of plastic, paper and biodegradable carrier bags), Carrefour, France.

Elstob, K., 2007. *Personal communication,* Bunzl Retail Supplies Ltd.

ERM, 2009. *Personnal communication*, Environmental Resource Management Ltd.

Intergovernmental Panel on Climate Change (IPPC), 2007. *IPCC Fourth Assessment Report. The Physical Science Basis.* More information on http://www.ipcc.ch/ipccreports/ar4-wg1.htm

International Energy Agency (IEA), 2007. Electricity/heat in Malaysia in 2007. Retrieved 4th February 2010, from http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=MY

International Organization for Standardization (ISO), 2006. *ISO 14040:2006 Environmental management – Life cycle assessment – Principles and framework.*

Maxwell, M., 2007. *Personal communication,* British Polythene Industries PLC.

Murphy. R.J. Davis. G. Payne. M., 2008. Life Cycle Assessment (LCA) of Biopolymers for single-use carrier bags. A research report for the National Non-Food Crops Centre (NNFCC), Imperial College London, September 2008.

Nolan-ITU. 2003. The impacts of degradable plastic bags in Australia, Final report to Department of the Environment and Heritage. Nolan-ITU, Centre for Design at RMIT, ExcelPlas Australia. September 2003.

Schmidt, A. and K. Strömberg, 2006. *Genanvendelse I LCA – systemudvidelse* [Recycling in LCA – system expansion], Miljønyt No. 81 2006, Danish Environmental Protection Agency, Denmark.

SimaPro, 2009. *SimaPro LCA software, version 7.1.4*, Pré Consultants.

Waste and Resources Action Programme (WRAP), 2005. *Carrier Bag Usage and Attitudes. Benchmark and Target Market Study*.

Waste and Resources Action Programme (WRAP), 2006. *Choose to Reuse.* Retrieved 17th August 2009, from http://www.wrap.org.uk/downloads/Choose_to_Reuse_Report_-_June_2006.74570e05.2998.pdf

Waste and Resources Action Programme (WRAP), 2009. *New figures show single use carrier bags cut by 48%*, 17th July 2009. Retrieved 17th August 2009, from http://www.wrap.org.uk/wrap_coporate/news/new_figures_show.html

Weström, P. and Löfgren, C., 2005. *Life Cycle Inventory for paper sacks*, CEPI Eurokraft and Eurosac, Sweden.

WRATE, 2009. *Waste and Resources Assessment Tool for the Environment, version 1.0.1.0,* Environment Agency.

Young, N., 2006. *personal communication,* Simpac Ltd.

Annex A - A summary of selected life cycle assessments of carrier bags

A.1 Introduction

Life cycle assessments of carrier bags have been carried out in several countries and regions to aid the local debate on carrier bag use. Recent LCA studies on carrier bags have been streamlined and their scope has therefore been limited. For most of them this has included limiting the environmental impacts assessed. Yet in addition to the environmental impacts, several of the studies have also included various social impacts, such as potential impacts on littering, industry, recycling, and consumers.

Generally, these LCA studies found that reusable bags have a lower environmental impact when compared to single use bags, including both conventional HDPE and prodegradent bags (Ecobilan PwC 2004). Degradable bags were shown to have similar global warming potential to conventional HDPE bags, and tended to have much higher eutrophication potential related to fertilizing the crops used as the basis for the polymer. Conversely, bags produced from conventional oil based polymers have higher abiotic resource depletion potential. Where degradable materials are composted and thereby kept out of landfill, the impacts are slightly reduced. The global warming potential of biodegradable bags was attributed to their starch content which resulted in higher methane emissions during landfill degradation.

The main issues identified in previous studies as having a significant influence on the results were:

- The weight/volume of groceries to be held by each type of carrier bag;
- The number of uses; and
- The alternative uses for lightweight carrier bags.

The following sections outline each of the reports considered in more detail.

A.2 Évaluation des impacts environnementaux des sacs de caisse Carrefaux. Analyse du cycle de vie de sacs de caisse en plastique, papier, et matériau biodegradable* (Ecobilan PwC 2004)

* Evaluation of the environmental impacts of Carrefour supermarket carrier bags. Analysis of the life cycle of plastic, paper and biodegradable carrier bags.

Description of the study

This 2004 study was conducted by Ecobilan for the French supermarket chain Carrefour. The aim of the study was to quantify the environmental impacts associated with Carrefour carrier bags in the different countries where Carrefour is represented (mainly France, Belgium, Spain and Italy). The results were intended for use in Carrefour policy development. The study was carried out in conformance with ISO 14040 and included a crital review conducted by the French Environment Agency (ADEME). The carrier bags involved in the study are shown in table A.2.1 which includes bag weight and usable volume.

Table A.2.1 The carrier bags included in the study.

	HDPE bag	LDPE bag	Paper bag	Biodegradable bag
Materials	HDPE, virgin LLDPE TiO2 Ink Adhesive	LDPE, virgin TiO2 Ink	Paper, recycled Ink Adhesive	50% starch 50% PCL Ink
Weight	6.04 g	44 g	52 g	17 g
Useable volume	14 ltr	37 ltr	20.48 ltr	25 ltr
Country of manufacture	Malaysia, France, Spain	France	Italy	Italy
Re-use scenarios	No Yes, in sensitivity analysis (re-used as bin liner)	Yes (reuse rates of 1, 2, 3, 4 and 20 investigated)	Generally no. Yes, in sensitivity analysis	No

The functional unit for the study was the carrier bags required for the packing of 9,000 litres of purchases. This was based on the typical annual volume of purchased goods per customer. The study is representative of France and primary data was collected from suppliers of bags to Carrefour and supplemented using secondary data from the Ecobilan database. The modelling of end-of-life activities was based French household waste processing which was split between landfill (51%) and incineration (49%). A recycling rate of 45% was included for waste paper.

The Impact categories/indicators considered were the consumption of non-renewable energy resources, water, the emission of greenhouse gases, atmospheric acidification, the formation of photochemical oxidants, eutrophication, residual solid waste and littering. A sensitivity analysis was also carried out on the following parameters:

- Re-use of 32.5% and 65%, respectively, of HDPE bags as bin liners;
- Re-use of paper bags once;
- 100% landfill of used bags;
- 100% incineration of used bags, with an without energy recovery; and
- Recycling of 30% of used LDPE bags.

Results

The relative performances of the different carrier bags against the environmental indicators assessed are shown in table A.2.2.

Table A.2.2. The results of the study over 8 indicators (>1 equals worse than HDPE bag, <1 equals superior to HDPE bag)

Impact categories	HDPE bag	LDPE bag			Paper bag	Bio-degradable bag
		Used 2x	Used 4x	Used 20x		
Consumption of non-renewable energy sources	1	1.4	0.7	0.1	1.1	0.9
Consumption of water	1	1.3	0.6	0.1	4	1
Emission of greenhouse gases	1	1.3	0.6	0.1	3.3	1.5
Atmospheric acidification	1	1.5	0.7	0.1	1.9	1.8
Formation of photochemical oxidants	1	0.7	0.3	0.1	1.3	0.5
Eutrophication of water	1	1.4	0.7	0.1	14	12
Production of solid waste	1	1.4	0.7	0.1	2.7	1.1
Risk of littering	High	Average to low			Low	Average to low

The study found that when the LDPE bag was reused a minimum of four times it offered the best environmental performance compared to the other bags studied. The HDPE bag was found to be better than the paper and biodegradable bags for most indicators, except photochemical oxidant formation and the risk of littering. In relation to the HDPE bag, the paper bag performed better with regards to the risk of littering, equivalent with regards to the consumption of non-renewable energy resources and the formation of photochemical oxidants, and worse by at least 80 per cent for the other five indicators studied. In relation to the HDPE bag, the biodegradable bag performed better with regards to the risk of littering and the formation of photochemical oxidants, equivalent for three indicators, and worse for the emission of greenhouse gases, atmospheric acidification and eutrophication.

In the sensitivity analysis, results were not found to change significantly although improvements were seen when the HDPE bag was reused as bin liner and when the paper bag was reused. However, the LDPE bag remained the best option against all indicators when reused between four to seven times.

The dominant source of environmental impacts for all the bag types studied and most indicators was the extraction and production of the materials (polyethylene, paper, starch, etc.). Overall transport contributed very little to the environmental impacts and the production of the bags generally resulted in smaller impacts than those associated with the production of the materials used. However, production of the bags may nevertheless be an important source of photochemical oxidants when the inks used are solvent-based. The end-of-life stages contributed to the impacts of risk of littering, production of solid waste and emission of greenhouse gases and dioxins.

Based on these results, it was concluded that the best options for improving the performance of carrier bags was to minimise weight (while maintaining technical properties) and reuse the bags.

A.3 Plastic Shopping Bags – Analysis of Levies and Environmental Impacts (Nolan-ITU *et al* 2002)

Description of the study

A 2002 streamlined LCA study carried out by Nolan-ITU in association with the RMIT Centre for Design and Eunomia Research and Consulting Ltd aimed to explore various shopping bag options and their associated potential environmental and economic impacts for the Australian Department of the Environment and Heritage. The results were intended to inform policy decisions with regards to plastic bags and enable decision making. The carrier bags studied are shown in table A.3.1.

Table A.3.1 The carrier bags included in the study with specification and major assumptions.

Bag material	Composition	Weight	Relative capacity	Expected life	Production location
HDPE, singlet	HDPE	6 g	1	Single use	67% southeast Asia, 33% locally
50% recycled HDPE, singlet	HDPE (50% post-consumer content)	6 g	1	Single use	67% southeast Asia, 33% locally
Boutique LDPE (single use)	LDPE	18.1 g	0.8	Single use	34% southeast Asia, 66% locally
Reusable LDPE	LDPE	35.8 g	1.5	12 trips	34% southeast Asia, 66% locally
Coles calico	Cotton	125.4 g	1.1	52 trips	100% Pakistan
Woven HDPE swag	HDPE	130.7 g	3	104 trips	100 % Taiwan
PP fibre 'Green Bag'	PP	PP 65.6 g Nylon base 50.3 g	1.2	104 trips	n/a
Kraft paper – Coles handled	Kraft virgin paper	42.6 g	1	Single use	n/a
Solid PP 'Smart Box'	PP	250 g	2	156 trips	100% Scotland
Biodegradable – starch based (Mater-Bi)	Starch based biodegradable polycaprolactone (PCL)	7 g	1	Single trip	100% Italy

The functional unit for the study was the carrying of approximately 70 grocery items home from a supermarket each week for 52 weeks. The study was representative of Australia and the data used was from publicly available life cycle inventory datasets. The study also took into account the carrying capacity and expected life of the bags as well as the avoided impact created by using less virgin material and by using the carrier bags as bin liners in the home. The impact categories/indicators considered were material consumption, Litter (reported as mass of material finding its way into the litter stream, area of ground covered by litter, and the persistence of litter), global warming and primary energy use.

Results

The results of the study are shown in table A.3.2.

Table A.3.2. The results of the study over 6 impact categories.

Bag type	Material consumption (kg)	Litter (g)	Litter (m^2)	Litter (m^2/y)	Greenhouse (CO_2 eqv.)	Primary energy use (MJ)
HDPE, singlet	3.12	15.6	0.144	0.72	6.08	210
50% recycled HDPE, singlet	3.12	15.6	0.144	0.72	4.79	117
Boutique LDPE (single use)	11.77	58.8	0.195	0.975	29.8	957
Reusable LDPE	0.96	4.8	0.0121	0.0603	2.43	78
Calico	1.14	5.7	0.0041	0.0819	2.52	160
Woven HDPE swag	0.22	1.1	0.00148	0.00743	0.628	18.6
PP fibre ‘Green Bag’	0.48	2.4	0.00187	0.00934	1.96	46.3
Kraft paper – handled	22.15	111	0.156	0.078	11.8	721
Solid PP ‘Smart Box’	0.42	NA	NA	NA	1.1	38.8
Biodegradable – starch based (Mater-Bi)	6.5	32.5	0.156	0.078	6.61*	61.3

* Assumed to break down into carbon dioxide

The results showed that the heavy duty reusable plastic bags with a long usable life achieved the greatest environmental benefits. Of the heavy duty reusable plastic bags, the woven HDPE bag was the preferred option although no significant difference was identified for the reusable bags. The woven HDPE bag performed better for the impact categories material consumption, embodied energy, global warming, litter (using persistence as the measure), and primary energy use.

The environmental benefits from reusable bags were closely linked to the life expectancy of the bags, their weight-to-capacity ratio and their final destination. The woven HDPE bag assessed had a capacity three times that of the HDPE singlet bag. With a smaller capacity, the environmental impact of the woven HDPE bag came much closer to, and was in some cases exceeded by, the PP box and the PP bag.

When single use bags were compared, the biodegradable and paper bags performed better than conventional HDPE and LDPE bags on litter persistence. The biodegradable bag has a lower contribution to global warming and lower embodied energy than the paper bag.

The biodegradable bag was also found to consume less energy than the conventional HDPE bag, and was roughly equivalent in global warming potential. It used more material because the reference bag used was double the weight of the single-use HDPE bag, and it had a lower impact on litter due to the faster rate of degradation. However, It must be highlighted that due to the limited LCA work done on starch based plastics, the data used for the modelling of biodegradable plastic bag was the least reliable of all the inventory data used in the analysis.

A.4 The Impacts of Degradable Plastic Bags in Australia (Nolan-ITU 2003)

Description of the study

A 2003 streamlined LCA study carried out by ExcelPlas Australia, the Centre for Design at RMIT and Nolan-ITU for the Australian Department of the Environment and Heritage investigated the impacts of introducing degradable plastic bags into the Australian market. In particular, it aimed to examine the effects on national recycling efforts, local manufacturing, and landfills. The LCA considered six bags manufactured from degradable polymers. These were compared with the streamlined LCA results for lightweight HDPE bags, paper bags, reusable plastic bags and calico bags from a previous Australian study (Nolan *et al* 2002). The carrier bags studied are shown in table A.4.1.

Table A.4.1 The carrier bags included in the study with specification and major assumptions.

Bag material	Composition	Weight	Relative capacity	Expected life	Production location
Starch polybutylene succinate / adipate (PBS/A)	50% starch from maize 25% 1,4-butanediol 12.5% succinic acid 12.5% adipic acid	6 g	1	Single use	Japan
Starch with polybutylene adipate terephthalate (PBAT)	50% starch from maize 25% 1,4-butanediol 12.5% adipic acid 12.5% terephthalate acid	6 g	1	Single use	50% Germany, 50% USA
Starch-polyester blend	50% starch from maize 50% polycaprolactone (PCL)	8.1 g	1	Single use	Italy
Starch-polyethylene blend	30% starch from cassava (tapioca) 70% HDPE	6 g	1	Single use	Malaysia
Polyethylene and prodegradant	97% HDPE 3% additive	6 g	1	Single use	Additive from Canada, 50% of bag from Malaysia
Polylactic acid (PLA)	100% PLA	8.1 g	1	Single use	50% USA, 50% Japan
Lightweight HDPE	HDPE	6 g	1	Single use	Hong Kong
Kraft paper (with handle)	Kraft virgin pulp	42.6 g	1	Single use	n/a
PP fibre “green bag”	PP Nylon base	65.6 g 50.3 g	1.2	104 uses	n/a
Woven HDPE “swag bag”	HDPE	130.7 g	3	104 uses	Taiwan
Calico	Cotton	125.4 g	1.1	52 uses	Pakistan
LDPE	LDPE	40 g	2	10 uses	Hong Kong

The functional unit for the study was the carrying of approximately 70 grocery items home from a supermarket each week for 52 weeks. The study was representative of Australia and the data used was from publicly available life cycle inventory datasets. The end-of-life waste management options modelled in the baseline scenario were 70.5% to landfill (anaerobic environment), 10% to composting with source separated organics, 19% reused as bin liners and 0.5% as litter.

The Impact categories considered included the greenhouse effect, (Abiotic) resource depletion, eutrophication, litter aesthetics and litter marine biodiversity.

Results

The results of the study are shown in table A.4.2.

Table A.4.2. The results of the study over 6 impact categories.

Bag type	Material use (kg)	Greenhouse gases (kg CO_2 eq.)	Abiotic depletion (kg Sb eq.)	Eutrophication (kg PO_4^{3-} eq.)	Litter marine biodiversity (kg*yr)	Litter aeshetics (m^2*yr)
Starch-PBS/A	3.12	2.5	0.00487	0.00273	4.26E-05	0.078
Starch-PBAT	3.12	2.88	0.023	0.00406	4.26E-05	0.078
Starch-polyester	4.21	4.96	0.0409	0.00494	5.75E-05	0.078
Starch-PE	3.12	4.74	0.0694	0.00258	0.0078	0.078
HDPE & additive	3.12	6.31	0.101	0.00236	0.0039	0.078
PLA	4.212	16.7	0.0776	0.00911	5.75E-05	0.078
Lightweight HDPE	3.12	6.13	0.102	0.00246	0.0078	0.312
Kraft paper	22.152	30.2	0.285	0.0266	0.000302	0.078
PP fibre	0.209	1.95	0.023	0.00126	0.000241	0.00187
Woven HDPE	0.216	0.216	0.00934	0.000231	0.000107	0.00148
Calico	1.141	6.42	0.0177	0.00795	3.09E-06	0.00164
LDPE	1.04	2.76	0.0422	0.00114	0.00257	0.00746

The overall conclusion was that reusable bags have lower environmental impacts than all the single-use bags, including both lightweight HDPE bags and degradable bags. This supported the findings of Nolan-ITU *et al* 2002. The study found that degradable bags generally had similar greenhouse effect impacts to lightweight HDPE bags, and depending on the source of the raw material may have much higher eutrophication impacts from farming activities. On the other hand, the conventional polymers have higher resource depletion impacts (abiotic depletion).

Degradable polymers with starch content had higher greenhouse effect impacts due to methane emissions from the degradation of the materials in landfills (i.e. anaerobic conditions) and nitrous oxide emissions from fertilizer application to crops. Degradable polymers manufactured from renewable resources (e.g. crops) also had a greater impact upon eutrophication due to the application of fertilizer to land.

The benefits of degradable bags were found to be the lower consumption of non-renewable resources (abiotic resource depletion) and faster rate of degradation in the litter stream (with potential benefits for wildlife as less plastics are ingested by fish and marine mammals).

A.5 Life Cycle Assessment (LCA) of Biopolymers for single use carrier bags (Murphy *et al* 2008)

Description of the study

A full peer reviewed LCA study comparing the environmental impacts of bioplastic carrier bags to conventional bags was conducted by Imperial College London on behalf of the National Non-Food Crops Centre (NNFCC) from 2006 to September 2008. The LCA considered four single use bags; a lightweight HDPE bag, an oxo-degradable HDPE bag, a starch polyester biopolymer bag and a PLA/Ecofoil biopolymer bag. The carrier bags studied are shown in table A.5.1.

Table A.5.1 The carrier bags included in the study with specification.

Bag type	Material	Weight (g)	Capacity (75% full) (l)	Quantitiy of bags for FU	Mass of material (kg)
HDPE	HDPE	8.6	11.7	855	7.35
Mater-bi	Starch (corn) 50%, Polycaprolactone	9.15	16	625	5.72
Octopus (prototype 1)	PLA 60%, Ecofoil 40%	9	11.7	855	7.7
Oxo-degradable	HDPE, Catalyst	7.5	11.7	855	6.41

The functional unit for the study was the carrying of 10,000 litres of grocery items from a supermarket to the home in carrier bags filled to 75% of the nominal bag volume. The study was representative of the production and use of these bags in the UK . Primary data concerning the processing of the polymers and their transportation and distribution was obtained from the manufacturers and distributor websites. Raw material production data was obtained from the BUWAL 250 and APME databases with surrogate materials used to represent Ecofoil, Polycaprolactone and the oxo-degradable bags catalyst material.

Use and reuse of bags, ink production, secondary packaging, anti-slip agents and transportation from the supermarket to the home were all excluded from the study. End-of-life scenarios included the consideration of 100% landfill, 100% incineration with energy from waste, 100% material recycled (for the HDPE bag only) and 100% municipal composting (for the biopolymer bags only) to facilitate the identification of the most appropriate disposal route for each bag type. The recycling process assumed the avoided production of 90% of the material entering the process.

The Impact assessment used the CML baseline 2002 methodology alongside the eco-indicator 99 method (providing a single score using a heirarchist/average perspective.

Results

The results of the study are shown in table A.5.2.

Table A.5.2. The results of the study over 4 impact categories.

Bag type	End-of-life processing	Global warming (kg CO_2 eq.)	Abiotic depletion (kg Sb eq.)	Acidification (kg SO_2 eq.)	Eutrophication (kg PO_4 eq.)
HDPE	EfW	31.7	0.258	0.111	0.0115
	Landfill	22.7	0.28	0.131	0.0121
	Recycling	19.1	0.175	0.129	0.00841
Oxo-degradable	EfW	26.1	0.0704	0.114	0.00473
	Landfill	18.2	0.0903	0.131	0.00519
Mater-bi	EfW	21.1	0.179	0.116	0.0236
	Landfill	13.6	0.195	0.13	0.0391
	Compost	24.3	0.197	0.13	0.0239
Octopus	EfW	23.1	0.238	0.207	0.0464
	Landfill	13.7	0.258	0.225	0.0672
	Compost	27.4	0.262	0.224	0.0466

The overall conclusion was that the results indicated that there is scope to gain environmental benefits, especially in terms of resource efficiency, from the use of biopolymer bags when compared with fossil based equivalents. However, these benefits will only be achieved through the use of effective disposal routes such as energy from waste or municipal composting. The study found that the environmental impacts were dominated by the extraction and production of raw materials and that the waste management scenario had a significant influence on the environmental profile of different materials. Energy from waste offered the best solution, especially for biopolymer bags, but the recycling of HPDE bags showed promise if it resulted in the avoidance of virgin polymer production.

In terms of global warming potential, the starch polyester blend bag provided the best alternative when landfilled. However, this assumed a low degradation rate of 30% resulting in the sequestration of the majority of carbon held within the bag. The study also found that the composting of biodegradable bags was subject to major uncertainty due to the use of a composting framework that was estimated from published data. Thee results of the eco-indicator 99 single score method indicated that the recycled HDPE bag offered the best option followed by the starch polyester biopolymer and oxo-degradable bags respectively.

Annex B - A study of carrier bag weight, volume and item capacity

B.1 Introduction

In January 2008 Test Research conducted a survey of supermarket carrier bag use. The data derived from this study was used in conjunction with a study on carrier bag weight and volume conducted by Pira International in March 2008 to ascertain the average weight, volume and item capacity for 7 carrier bag types which are listed below.

The following carriers were studied:

- A high-density polyethylene (HDPE) bag;
- A high-density polyethylene (HDPE) bag with a prodegradent additive; and
- A starch-polyester (biopolymer) blend bag.
- A paper bag;
- A low-density polyethylene (LDPE) bag;
- A non woven polypropylene (PP) bag; and
- A cotton bag.

The weight and volume of an average bin liner was also calculated during the study. The following report outlines how this study was conducted.

B.2 Test Research Study: January 2008

Test Research interviewed 1,149 shoppers in-store at 30 major supermarkets throughout the country between the 21st November and 9th December 2007. Table B.2.1 shows the structure of the sample.

Table B.2.1 The structure of the Test Research sampling

Supermarket	Interviews	Day	Interviews/day
Asda (6 stores)	246	Monday	181
Co-op (5 stores)	203	Tuesday	225
Morrisons (4 stores)	171	Wednesday	170
Sainsbury’s (6 stores)	195	Thursday	120
Somerfield (2 stores)	57	Friday	110
Tesco (5 stores)	168	Saturday	238
Waitrose (2 stores)	109	Sunday	145
Total	1,149	Total	1,149

Four questions were asked during the survey:

- How many bags have you used to do your shopping and what types are they?
- How many items have you purchased?
- Is this a main food shopping trip or a smaller “top-up” shopping trip?

How will you transport your shopping home from the supermarket today?

The findings of the study provided a sample profile of shoppers and an analysis of the usage of different types of bags. This analysis found that the average number of items per bag for all bag types was 20.7 items, as shown in table B.2.2. The study found that 2,490 single use carrier bags were used to carry 14,651 items by the shopper surveyed providing an average of 5.88 items per bag. 72 LDPE ‘bags for life’ were also used to carry 573 items providing an average of 7.96 items.

Table B.2.2 The number of items per bag

	Total	Asda	Co-op	Morrisons	Sainsbury’s	Somerfield	Tesco	Waitrose
Base: All respondents	**1149**	**246**	**203**	**171**	**195**	**57**	**168**	**109**
Average number of items	20.7	32	7.6	31.1	7.6	10.3	26.5	22.8
Average number of bags	3.1	4.8	1.5	4.3	1.5	2.4	3.6	3
Average number of items per bag	6.6	6.7	5.2	7.3	5	4.3	7.3	7.5

B.3 Pira International study: March 2008

The study conducted by Pira International in March 2008 measured the weight, volume and weight capacity of a number of sample carrier bags to understand whether weight capacity or volume capacity was the limited factor in carrier bag use. Carrier bags were collected from major retails and bag producers during the reference period of the study. Table B.3.1 shows the carrier bags sampled from UK supermarkets. Starch-polyester blend and paper bags were sourced from producers. Due to the variety of different capacities available for these bags, a single paper bag and starch-polyester bag were selected based on their similarity, in terms of volume and strength, to the other bags considered. In addition premium, handled and value bin liners were sourced from supermarkets.

Table B.3.1 The supermarket carrier bags sampled

Bag type	Supermarket samples
High-density polyethylene (HDPE) bag	Sainsbury's, Waitrose, Asda, Iceland, Morrisons
High-density polyethylene (HDPE) bag with a prodegradant additive	Tesco, Somerfield, Co-op
Low-density polyethylene (LDPE) bag	Tesco, Sainsbury's, Waitrose, Asda, Iceland, Morrisons, Somerfield
Non woven polyproylene (PP) bag	Asda, Greengocer
Cotton bag	Sainsbury's, Asda, Co-op, Marks & Spencer

Volume testing

The study used expanded polystyrene beads (as shown in figure B.3.1) to measure the volume of the HDPE, HDPE prodegradant and LDPE carrier bags. The use of these low weight beads above other mediums such as sand reduced any potential damage to the sample bags before weight capacity testing. Each bag was filled to capacity (up to in line with its handles) and then the volume of beads used was measured. The test found that an average single use bag (i.e. HDPE and HDPE prodegradent bags) had a capacity of 20.7 litres whilst the average LDPE bag had a capacity of 21.3 litres.

Figure B.3.1 Expanded polystyrene beads

Weight testing

The study used a jog testing machine to measure the weight capacity of the HDPE, HDPE prodegradant and LDPE carrier bags. The machine accurately simulates the movement of walking by moving the bag up and down in a walking motion. The study began by jog testing the sample bag for 4 minutes with a 5 kg load. An additional weight of 1 kg was then added every minute until the bag failed. The final weight and time were then logged. The study found that an average single use bag (i.e. HDPE and HDPE prodegradant bags) had a capacity of 18.22 kilograms and lasted for 17 minutes and 32 seconds. The average LDPE bag had a capacity of 19 kilograms and lasted 18 minutes and 30 seconds.

Analysis of the volume and weight capacity results

The results of the volume and weight testing showed that there were only slight differences in the volume and weight capacity of conventional single use bags and reusable bags. However, the average weight capacity of both bag types was found to be significantly higher than the weight an average person could comfortably carry. Therefore, volume was selected as the limiting factor for bag use.

B.4 The calculation of bag weight, volume and number of items

Based on the findings of the two studies, the average weights and volumes of each bag type was calculated using market share data. This was then related to the average number of items found in conventional HDPE carrier bags and LDPE bags for life.

The average volume of conventional HDPE and HDPE prodegradant bags was calculated using market share data (TNS Global 2006) and the carrier bag volumes measured during the Pira International study. The market share of the top 8 supermarkets was calculated and then combined with the relevant bag volume to give an average volume of 19.1 litres, as shown in table B.4.1. Although the Sainsbury sample contained recycled content, the bag was included due to the importance of Sainsburys market share. However, this did not significantly affect the average weight and volume calculated.

Table B.4.1 The calculation of the average volume of single use carrier bags

Supermarket source	Market share	HDPE & HDPE prodegradent bag volume (litres)
Sainsbury	17.98%	17.90
Waitrose	4.22%	20.80
Asda	18.42%	19.60
Iceland	2.00%	32.20
Morrisons	12.43%	21.80
Tesco	33.74%	17.90
Somerfield	5.99%	16.00
Co-op	5.22%	19.60
Average		19.1

The volume and item capacity for all single use carrier bags (HDPE, HDPE prodegradent and starch polyester bags) was therefore assumed to be 19.1 litres and 5.88 items respectively. To ensure that the correct bag weight was used to model each of these carriers, the average volume and weight of each carrier bag type was measured and an average ‘grams per litre’ ratio calculated. This figure was then multiplied by the average single use carrier bag volume (19.1 litres) to give an accurate weight for each bag type.

The calculated ratios are shown in table B.4.2. The average ratio for a HDPE bag, a HDPE prodegradant bag and a starch polyester blend bag gave bag weights of 8.116 grams, 8.266 grams and 16.491 grams respectively for a 19.1 litre bag of each type.

Table B.4.2 The calculation of an average grams per litre ratio for each single use bag type.

Bag type	Supermarket source	Market share	Share for bag type	Volume (litres)	Weight (grams)	Grams per litre
High-density polyethylene (HDPE) bag	Sainsbury	17.98%	32.66%	17.90	8.830	0.49
	Waitrose	4.22%	7.66%	20.80	8.670	0.42
	Asda	18.42%	33.47%	19.60	7.480	0.38
	Iceland	2.00%	3.63%	32.20	12.620	0.39
	Morrisons	12.43%	22.58%	21.80	8.980	0.41
	Total	55.05%	100%			
	Average			**20.09**	**8.537**	**0.42**
High-density polyethylene (HDPE) bag with a prodegradent additive	Tesco	33.74%	75.06%	17.90	8.240	0.46
	Somerfield	5.99%	13.33%	16.00	5.890	0.37
	Co-op	5.22%	11.60%	19.60	6.480	0.33
	Total	44.95%	100%			
	Average			**17.84**	**7.722**	**0.43**
Starch polyester blend bag	**Supplier**			**18.30**	**15.800**	**0.86**

The average volume of an LDPE bag was calculated using market share data (TNS Global 2006) and the carrier bag volumes measured during the Pira International study. The market share of the 7 supermarkets that provided LDPE carrier bags for the study was calculated and then combined with the relevant bag volume to give an average volume of 21.52 litres, as shown in table B.4.3.

Table B.4.3 The calculation of the average volume of LDPE carrier bags

Supermarket source	Market share	LDPE bag volume (litres)
Sainsbury	18.97%	20.20
Tesco	35.60%	23.90
Waitrose	4.45%	23.90
Iceland	2.11%	20.60
Somerfield	6.32%	21.70
Morrisons	13.12%	19.10
Asda	19.44%	19.60
Average		21.52

The volume and item capacity for an average LDPE bag was therefore assumed to be 21.52 litres and 7.96 items respectively. Unlike the calculation used for the single use carrier bags, where the same volume and number of items were assumed for all bag types, the volume and number of items for all reusable bags was varied. This was due to the Test Research data which defined reusable bags by type but did not identify single use bag as prodegradant or non prodegradant. It was therefore assumed that, whilst the single use bag data represented all single use bag types, the reusable bag data specifically represented the use of LDPE bags. To adapt the LDPE bag data for other reusable bag types, the number of items per litre was calculated (0.37 items per litre). The volume and weight of all other reusable bags considered was then measured (as shown in table B.4.4) and, based on the items per litre ratio, a number of items per bag type was calculated. This was found to be 7.43 items for the paper bag, 7.3 items for the non woven PP bag and 10.59 items for the cotton bag. The volume, weight and items per bag for every bag type are shown in table B.4.5.

Table B.4.4 The volume and weight of all other reusable bag types

Bag type	Supermarket source	Volume (litres)	Weight (grams)	Grams per litre
Paper bag	**Supplier**	**20.10**	**55.200**	**2.75**
Non woven polyproylene (PP) bag	Asda	17.7	124.080	7.01
	Greengrocer	21.8	107.580	4.93
	Average	**19.75**	**115.830**	**5.86**
Cotton bag	Sainsbury	17.00	195.680	11.51
	Asda	32.10	229.050	7.14
	Co-op	33.40	78.660	2.36
	M&S	32.10	229.050	7.14
	Average	**28.65**	**183.11**	**7.03**

Table B.4.5 The volume, weight and items per bag for all bag types

Bag type	Volume (litres)	Weight (grams)	Items per bag
High-density polyethylene (HDPE) bag	19.10	8.116	5.88
High-density polyethylene (HDPE) bag with a prodegradent additive	19.10	8.266	5.88
Starch polyester blend bag	19.10	16.491	5.88
Paper bag	20.10	55.200	7.43
Low-density polyethylene (LDPE) bag	21.52	34.945	7.96
Non woven polyproylene (PP) bag	19.75	115.830	7.30
Cotton bag	28.65	183.110	10.59

The average volume, weight and ‘grams per litre’ ratio was also calculated for bin liners using the same methods. Three liners were measured; a premium liner, a liner with handles and a value liner. The liners selected had similar volumes to the carrier bags investigated within this study and were smaller than conventional black bin liners used for household refuse. The calculated weights and volumes are shown in table B.4.6.

Table B.4.6 The volume and weight of bin liners.

Liner type	Volume (litres)	Weight (grams)	Grams per litre
Premium bin Liner	37.07	15.820	0.43
Bin liner with handles	30.13	8.490	0.28
Value bin liner	20.70	3.490	0.17
Average	**29.3**	**9.3**	**0.32**

Annex C - Description of inventory data

C.1 Extraction and production of raw materials

The materials and weights shown in table C.1.1 are used for the carrier bag systems outlined in the study.

Table C.1.1 The material specification and primary packaging of each carrier bag.

Bag type	Bag specifications		Primary packaging	
High-density polyethylene (HDPE) bag	HDPE, virgin	6.09 g	Corrugated box	390 g/1000 bags
	LLDPE, virgin	0.89 g	Or	
	Titanium dioxide	0.16 g	Vacuum film	55 g/1000 bags
	Chalk	0.81 g		
	Ink	*<0.16 g*		
	TOTAL	8.12 g		
High-density polyethylene (HDPE) bag with a prodegradant additive	HDPE, virgin	6.45 g	Corrugated box	600 g/2000 bags
	LDPE, virgin	0.83 g		
	LLDPE, virgin	0.5 g		
	Titanium dioxide	0.17 g		
	Chalk	0.25 g		
	Prodegradant	0.002 g		
	Ink	<0.07 g		
	TOTAL	8.27 g		
Starch-polyester blend bag	Mater-Bi	16.08 g	Corrugated box	434 g/500 bags
	Titanium dioxide	0.33 g	Vacuum film	8.5 g/500 bags
	Ink	*0.08 g*	*Pallet*	*360 g/500 bags*
	TOTAL	16.49 g		
Paper bag	Kraft virgin paper	52.99 g	Corrugated box	620 g/200 bags
	Glue	1.44 g	Stretch film	17 g/250 bags
	Ink	*0.66 g*	*Pallet*	*525 g/250 bags*
	Dye	*0.11 g*		
	TOTAL	55.20 g		
Low-density polyethylene (LDPE) bag	LDPE, virgin	32.85 g	Corrugated box	640 g/250 bags
	LLDPE, virgin	0.7 g	*Pallet*	*525 g/250 bags*
	Titanium dioxide	1.05 g		
	Ink	*<0.35 g*		
	TOTAL	34.94 g		
Non-woven polypropylene (PP) bag*	PP, virgin	114.9 g	Corrugated box	564 g/50 bags
	PP/cotton thread	0.93 g	Paper lining	10.44 g/50 bags
	TOTAL	115.83 g		
Cotton bag*	Cotton textile	181.81 g	Corrugated box	1000 g/50 bags
	Cotton thread	1.3 g		
	TOTAL	183.11 g		

*Ink content data was not available for these bag types

Specific data for polymer production in the Far East was sought but no such data were identified. As a consequence, inventory datasets (eco-profiles) for HDPE, LDPE, LLDPE and PP published by Plastics*Europe* have been used (Boustead 2005a-c). The datasets were compiled by Ian Boustead by collating data collected directly from the European plastics industry. The Plastics*Europe* eco-profile versions in the ecoinvent database were used. The PlasticsEurope dataset cover the production of HDPE from the cradle to the polymer factory gate. The polymerisation data refer to the year 1999 and were acquired from 24 polymerisation plants producing 3.87 million tonnes of HDPE annually. This represents 89.7 per cent of all Western European production.

The PlasticsEurope dataset cover the production of LDPE from the cradle to the polymer factory gate. The polymerisation data refer to the year 1999 and were acquired from 27 polymerisation plants producing 4.48 million tonnes of LDPE annually. This represents 93.5 per cent of all Western European production. The Plastics*Europe* dataset covers the production of PP from the cradle to the polymer factory gate. The polymerisation data refer to the year 1999 and were acquired from 28 polymerisation plants producing 5.69 million tonnes of PP annually. This represents 76.9 per cent of all Western European production.

The Kraft paper bag is produced from chemical pulp using the sulphate process. Wood chips are cooked with chemicals in a digester at high pressure and temperature to remove the lignin and break up the wood into cellulose fibres. The sulphate process uses caustic soda and sodium sulphide to cook the wood chips. The pulp is washed and screened and the cooking liquor is drained off, concentrated and burnt off for steam production. The wet pulp is adjusted with auxiliary chemicals and additives and fed into the paper machine, where the pulp is squirted as a thin film across the machine width onto a moving wire section. In the wire section the paper is shaped and dewatered, after which it passes through a series of presses to dewater the paper further. Final drying is done in the dryer section, where the paper passes around a series of heated cylinders. At the bag producer’s the kraft paper is then printed, formed, glued, cut and pressed into individual bags.

The unbleached uncoated paper sack inventory dataset has been extracted by STFI-Packforsk specifically for this study from the paper sack inventory dataset published by CEPI Eurokraft and Eurosac (Weström & Löfgren 2005). The data were compiled by STFI-Packforsk by combining data collected directly from European pulp and paper mills. The overall quality of the inventory data has been assured by internal review. No independent third party review has been conducted. Although the data refers to paper sacks excluding refuse sacks and carrier / shopping bags, CEPI Eurokraft has confirmed that it can be considered representative of these types of bags as well (Hill 2006).

The CEPI Eurokraft and Eurosac dataset covers the production of paper sacks from the cradle to the paper sack mill gate. The dataset covers the production of kraft paper and the production of paper sacks, and it is not possible to separate the two processes. The collected data is based on plant production data for the year 2003 and is estimated to be valid for about 5-6 years ahead.

The data about sack paper and paper sack production was acquired from a total of 13 pulp and paper plants in seven different European countries and five paper sack plants in four different European countries, respectively. It is not known how many of these cover unbleached uncoated kraft sack paper. The five paper sack plants contributing with data only account for a small proportion of European production.

For the CEPI Eurokraft & Eurosac data, the production of a number of chemicals and additives where the quantities used account of less than 1-2 per cent of the total material in the sack paper is excluded (Weström and Löfgren 2005). Instead, these flows are simply reported as non-elementary inputs[22]. The amount of non-elementary inputs is less than 4 per cent of the total input weight (excluding water).

For some of the chemicals and additives reported as non-elementary inputs in the kraft paper sack inventory data, LCI data was identified in the ecoinvent database. Where this was the case, these were used.

The starch-polyester blend inventory dataset has been provided by Novamont S.p.A. The data were collected and compiled by technical experts from Novamont. The overall quality of the inventory data has been assured by Novamont, however it is not known if there has been any independent third party review of the dataset.

The Novamont dataset covers the production of the starch-polyester blend granulates from the cradle to the Novamont gate. The dataset covers the production of the fossil oil monomers i.e. oil extraction and refining, conversion into monomers, and production of the vegetable oil monomers i.e. the growing of corn and oil-seed crops, milling and extraction, and finally the polymerisation with addition of the fossil monomer. It has been estimated that 0.59 kilograms of carbon dioxide is absorbed from the atmosphere for every kilogram of mater-bi produced based on Novamont (2008).

The data refers to the year 2006 and relates to one production site in Terni, Italy. As a consequence, Italian electricity has been used.

Inventory data for the production of titanium dioxide is derived from the ecoinvent database. The titanium dioxide is manufactured by processing titanium-containing rutile and ilmenite minerals, based on confidential data. There is no information about the geographical or time-related coverage of the data.

The cotton fibres used in the non-woven PP bag was modelled using data from the IDEMAT 2001 database. This data is based on the production of cotton in the United States and was recorded in 1992.

Substitute materials were used to model the production of chalk, glue and the prodegradant additive. For chalk, the SimaPro substance of calcite has been used. Chalk was modelled as Limestone using ecoinvent data based on the production of limestone at one Swiss company during 2001. The process includes mining, mineral preparation, calcination, hydration and packaging and loading.

---

[22] A non-elementary input is an input from the technosphere which has been processed in some way. Thus, it has not been followed back to the cradle.

The production of glue for the paper bag lifecycle was based on inhouse data and consisted of 32% ABS, 48% phenolic resin and 20% paraffin. The glue was assumed to be produced in Germany and used 0.42 kg of steam per kg, 0.25kwh of grid electricity per kg and generated 0.26kg of waste per kg which was assumed to be incinerated. All of these processes and materials were modelled using ecoinvent data.

Due to lack of information, the prodegradant additive was assumed to be cobalt stearate and consists of 10 per cent cobalt and 90 per cent stearic acid. The ecoinvent process for Cobalt was used whilst data for stearic acid was sourced from the IVAM LCA 4.04 dataset, based on Western European production in the period of 1995-99.

The cotton bag was modelled using data from the ecoinvent database as described in the Ecoinvent Report No. 21 (Althaus et al 2007). The ecoinvent dataset is collated from a number of sources, with the main sources being two reports, one by the Öko-Institute (Wiegmann, 2002) and another by the Wageningen University (Kooistra et al, 2006). The ecoinvent dataset is for conventional production with an average net yield of 1100 kg fibres / ha for Chinese cotton production and represent data for the time period of 2000 to 2007. The dataset includes the processes of soil cultivation, fertilisation, application of pesticides, irrigation, harvesting, ginning and related transport. Further processing include yarn production, textile refinement and weaving.

Ecoinvent data for the production of cardboard was used to model any cardboard boxes used as secondary packaging. This was based on the production of fresh fibre, single walled corrugated board. The main source of raw material data within Ecoinvent is the European database for corrugated board life cycle studies from FEFCO, Groupment Ondule and Kraft Institute (2006).

Vacuum film was modelled using ecoinvent data based on a combination of 70% LDPE and 30% Nylon and the extrusion of plastic. Similarly, stretch film was modelled using ecoinvent data based on LDPE and the extrusion of plastic The ecoinvent data on the extrusion of films was based on a Swiss packaging study representing one Swiss company in 1993 (Habbersatter et al. 1998) and a PlasticsEurope conversion report representing averages of upto 8 companies (Boustead, 1997). Wastage from this process was 2.4% and all waste was incinerated.

C.2 Bag production processes

Plastic film bags, such as the HDPE and HDPE prodegradant carrier bags, are produced through the blown film extrusion or co-extrusion process. Plastic melt is extruded through a vertical circular die and air is introduced to create a “bubble-like” expansion forming a thin walled tube. The film tube is cooled and passed through nip rolls to flatten the film. The film is then heat sealed and cut or perforated to make each bag. This is done either in line with the blown film process or at a later stage.

The non-woven PP bag is produced using a spun bonded process. Plastic melt is extruded through a coat hanger die, feeding the spinneret which forms a curtain of filaments. The filaments are cooled by air and then deposited on the wire mesh belt as a random non-woven material. This is transferred to the heat bonding calendar, which by heat and pressure determines the physical properties of the material, and then cooled by water-cooled rolls and wound up. The material is then folded and cut to size, and sewn into bags. The bags have a semi-rigid base insert for stabilisation generally made from PET, PP or PVC.

Data on conversion of HDPE with prodegradant into carrier bags was provided by a bag producer in China. This process was adapted for the conversion of HDPE bags based on the weight of material processed. Information on the conversion processes refer to the year 2006.

Data used for the conversion of kraft paper into carrier bags were paper sack inventory data published by CEPI Eurokraft and Eurosac (Weström & Löfgren 2005). Kraft sack paper is converted into sacks by the processes of forming, gluing, cutting and pressing. The energy demand is met partly by electricity and partly by various fuel types. As described in section 4.2, the dataset covers the production of kraft paper and the production of paper sacks, and it is not possible to separate the two processes.

Data on conversion of LDPE, PP and starch-polyester blend into carrier bags was provided by bag producers in Turkey, China and Norway respectively. Information on the conversion processes refer to the time period 2006/07.

Due to a lack of information from bag producers, data on conversion of cotton textile into carrier bags was estimated based on in-house confidential data.

Table C.2.1 Overview of conversion data used in this LCA study

Polymer / paper	Publication date	Reference year	Number of plants included
Anonymous bag producers			
HDPE bag	Not publicly available	2006	1
LDPE bag	Not publicly available	2006	1
HDPE bag with prodegradant	Not publicly available	2006	1
PP bag	Not publicly available	2006/07	1
CEPI Eurokraft & Eurosac			
Paper bag	2005	2003	5
Biobag International AS			
Starch-polyester bag	Not publicly available	2006/07	1

Due to confidentiality, the conversion data used are not shown in the report. The energy mix for grid electricity at each production location is shown in table C.2.2. The generation of energy from coal, oil, natural gas, hydropower, biomass and nuclear in China and Turkey was based on existing Ecoinvent processes representing average European production. The generation of heat from natural gas for the production of the LDPE bag was based on the Ecoinvent process for a <100kw non modulating fan burner boiler. The generation of heat from heavy fuel oil for the non-woven PP bag was based on the Ecoinvent process for a 1MW industrial furnace.

Table C.2.2 Overview of grid electricity mix in production locations.

	Production location		
Energy type	**Norway**	**Turkey**	**China**
Coal		23.0%	78.0%
Oil		5.0%	3.0%
Natural gas	0.3%	41.0%	0.5%
Hydropower	99.1%	31.0%	16.0%
Wind power	0.3%		
Cogen	0.3%		
Biomass			0.5%
Nuclear			2.0%

C.3 Transport

The eco-invent datasets for European transport have been used in this study. Due to the lack of representative data, the European transport data has been used for all transport scenarios.

The transport modes considered are road, rail and sea transport. The vehicle operation data refer to the year 2000 and excludes any return trips.

The eco-invent dataset for heavy good vehicle transport in Europe is based on the European research project Copert III. The datasets are a function of the direct process of vehicle operation and the indirect processes of vehicle fleet (fleet production, maintenance, and disposal) and road infrastructure. The transportation method was assumed to be by a 16 – 32 tonne Euro 3 efficiency lorry with an average load of 10 tonnes. Based on parameters on lorry size, load and road category, the fuel consumption and emissions as a function of the distance are then calculated.

The eco-invent dataset for rail transport in Europe is based on several rail transport studies. The datasets are a function of the direct process of rail operation and the indirect processes of rail equipment (train production, maintenance, and disposal) and rail infrastructure.

The ecoinvent dataset for sea transport is based on a number of sea transport studies. The datasets are a function of the direct process of vessel operation and the indirect processes of vessel fleet (vessel production, maintenance, and disposal) and port infrastructure.

Table C3.1 Eco-invent transoceanic freight ship description and fuel assumptions

Vessel category	Engine	Average load assumed	Fuel consumption assumed	
Transoceanic freight ship, dry bulk carrier	Average of slow speed engine and steam turbine propulsion	~50,000 dwt	2.5 g/tkm	Heavy fuel oil

dwt = dry weight tonnes

C.4 End-of-life

The end of life processes were modelled using WRATE (Waste and Resources Assessment Tool for the Environment) which is the Environment Agency software that compares the environmental impacts of different municipal waste management systems. WRATE uses life cycle assessment to include the resources used, waste transportation and operation of a whole range of waste management processes with their environmental costs and benefits. The assumptions used when modeling the end of life processes in WRATE for this LCA are detailed below.

C.4.1 Landfill

Collection - 140 litre wheeled bin for household waste and 500kg of household waste/inhabitant per year. Assumes bag waste constitutes 0.5% of waste stream over year.

Waste transport - 25km one way road transport direct to site using Refuse Collection Vehicle – ultra-low sulphur diesel fuel refuse collection vehicle (6 x 4 RCV) using with waste compaction.

Landfill description - Landfill with a clay liner and clay cap with a 25000 tonne per annum capacity. Well engineered, Landfill Directive compliant landfill. It is based on modelling from LandSim v2.5 and GasSim 1.5, supplemented with other information concerning capital and operational burdens. The modelling periods were 20,000 years for leachate using LandSim and 150 years for landfill gas. The model includes landfill treatment and landfill gas capture (equivalent 75% over its lifetime) for landfill gas recovery and landfill gas burned in engines generating electricity which offsets the marginal mix for electricity production of 50 per cent coal and 50 per cent natural gas.

Waste is deposited either at the top or base of the waste face depending upon direction of tipping at the time. A steel-wheeled landfill compactor is used on the operational areas to level and compact the waste. A suitable machine is used in the construction of cell walls, the placement of daily cover and as a back-up in the event of breakdown of the compactor. A number of passes are made over the waste by the compactor, or other suitable equipment, to achieve satisfactory compaction of the wastes.

The surface of the landfill area is covered progressively with inert materials, including imported waste materials free from biodegradable waste, so that at the end of the working day the surface, face and flanks of the area are free from uncovered biodegradable and loose paper or other similar materials which may be wind blown.

The modelling of leachate emissions has been undertaken using LandSim Version 2.5, which was developed for use by the Environment Agency to provide probabilistic quantitative risk assessments of specific landfill site performance in relation to groundwater protection. The models have been run for a 20,000 year period, during which time the degradation of both the engineered liner and the low permeability cap have been incorporated.

Groundwater flow from the base of the engineered barrier through the unsaturated zone to the water table has been modelled assuming that the leaking fluid displaces the existing pore water, changing neither volume nor properties of the soil water. The discharge of leachate to a leachate treatment plant has also been included in the assessment of the overall environmental burdens. The total loading to the environment resulting from the production of leachate is represented as the sum of the total mass loading to groundwater and the total mass loading to sewer following treatment over the life of the landfill, for each contaminant

Modelling of gaseous emissions has been undertaken using GasSim v1.5. GasSim is a probabilistic performance assessment model that includes a gas generation, partitioning between collection, migration, surface emissions and biological methane oxidation as well as incorporating combustion plant and atmospheric dispersion and impact.

Biological methane oxidation was assumed for 10% of the emissions that passed directly through the cap. Flare capacity was provided to account for gas generation down to a maximum of 250 m3/h. Filling rates were selected to allow each of the landfill sizes to be filled in a 20 year period. Progressive capping of the site was assumed so that gas collection was optimised to a level consistent with current industry practice. As well as the emission of bulk and trace gases through the landfill surface, gases collected and passed through the combustion plant will be partially destroyed and converted to appropriate combustion products (with the exception of carbon dioxide) and certain new gases will be created.

C.4.2 Incineration

Collection - 140 litre wheeled bin for household waste and 500kg of household waste/inhabitant per year. Assumes bag waste constitutes 0.5% of waste stream over year.

Waste transport - 50km to regional plant (one way trip) using ultra-low sulphur diesel fuel refuse collection vehicle (6 x 4 RCV) with waste compaction.

Description - 225ktpa moving grate incinerator with electricity generation. It is assumed that integrated bottom ash is recycled for road aggregate and that there is 50km one way down stream transport by Roll-on-off for Air Pollution Control residues to landfill. Incoming municipal waste vehicles discharge their loads into the municipal waste storage bunker, kept under negative pressure to avoid the release of dust and odour.

Waste is mixed and moved by means of grabs mounted on two travelling cranes. The crane and grab have been designed to transfer the plant's daily waste burning capacity into the feed hopper and to carry out moving, mixing and stacking of waste in the storage bunker. Municipal waste is fed by the crane into the feed hopper and feed chute. Combustion conditions are continuously monitored and controlled to avoid the release of dioxins and furans. Dry urea is injected into the furnace for NOx abatement.

The ERF has an inclined reverse-acting grate capable of burning a broad range of waste calorific values without the need for any auxiliary fuel. The bottom ash is quenched and ferrous metals recovered by an overband magnet. After this the residues can be recycled for construction with the non-ferrous metals recovered for recycling.

Flue gas from the combustion process passes to a boiler which converts the energy from the hot gases into steam at 45bar, 400°C. The steam from the boiler feeds a steam turbine which generates around 8MWs of electricity at 11,000volts (overall electrical efficiency is approximately 21 per cent). Following the turbine, the steam is condensed using an air cooled condenser and the condensate returned to the boiler.

The flue gas treatment system uses semi-dry design that neutralises the acid gases, ie hydrochloric acid, hydrogen fluoride, sulphur dioxide and sulphur trioxide. The plant is designed to be upgraded if required to meet future emissions standards. Lime injected into the flue gases as a suspension in water. The flue gases are therefore both cooled and treated. Powdered activated carbon is injected into the flue gas to adsorb residual dioxins, cadmium and mercury.

Particulate material is removed from flue gas with bag house filter. The bags are held vertically, with the gas flow through the bags being from the outside with the resultant clean gases emerging from within. FGT residues are recovered at the bottom of the gas scrubber vessel and the bag house filter and transported by screw conveyors to storage in a silo.

During normal operations, wastewater is routed to a wastewater treatment plant which is designed to allow the water to be recycled within the process.

C.4.3 Composting

Collection -140 litre bring bank located at supermarket

Waste transport - 25km one way road transport using ultra-low sulphur diesel fuel refuse collection vehicle (6 x 4 RCV) with waste compaction.

Description - In vessel composting of 50% green and 50% food waste with feedstock assumed to degrade to PAS100 standard compost. The process comprises aerated high temperature phase composting (21 days), agitation and windrow composting (63 days). For the compost offset a soil conditioning and inorganic fertiliser benefit are accounted for based on physico-chemical characteristics of typical PAS100 compost (e.g. bulk density characteristics and nutrient properties) and the typical UK soil conditioner market. Emissions to soil and ground water are estimated from elemental limit values for PAS 100 composts, and the carbon content of the compost assuming carbon dioxide air emissions over 150 years and species specific assumptions concerning the compartmentalisation of minerals after 150 years.

This composting system provides for the rapid high temperature composting of organic wastes in a continuous flow plant. The insulated silos, each with a capacity of 32 m^3, are suspended above a concrete base in a large steel structure. A single silo-cage bank consists of between 8 and 28 silos, depending on the annual input or output requirements. For larger operations, multiple silo-cage banks are run in parallel. A silo-cage bank has a front-end mixer and loading system. An unloading system and side conveyor remove the composted material from the silo-cage. The back end of the silo-cage can be equipped with a screen and bagging line or the composted material can be collected and taken to a maturation barn to fully mature.

Feedstock Delivery

The organic waste is mixed with selected amendments in a predetermined ratio to give a feedstock that is ideal for composting. The amendment may need to be nitrogen-rich (e.g. manure) or carbon-rich (e.g. wood shavings) depending on the chemical composition of the waste. Amendment selection is crucial to ensuring that the feedstock material is bulky with sufficient airspace to support the aerobic microbial activity in all parts of the organic material. Each silo receives an amount appropriate to operation's requirements – typically about 3 m^3 per silo per day. The feedstock material is 'sprinkled' on top of the previous day's load. The material drops no more than about half a metre into the silo and so its open structure is maintained.

Composting Silos

The feedstock material sits on the hotter lower layers. It quickly warms, accelerating microbial activity and is rapidly colonised by micro-organisms from the already composting organic material below. As the silo is unloaded, the composting organic material gradually and evenly descends the silo and passes through a series of temperature bands. To monitor the progress of the process, the temperature in each silo is continuously measured by temperature probes and recorded on a pc-based data logger. The hottest layers in the silo tend to be between one and two metres from the top. As well as air in the bulky organic material, the vertical temperature gradient in the organic material creates a chimney effect and air is drawn up into the material from the open base of the silo. There is therefore no need for costly forced aeration, turning or agitation of the organic material. The feedstock characteristics and the end-product specifications determine the residence time in the silos, which can vary between 10 and 21 days.

Unloading Composting Silos

An unloading mechanism traverses beneath the silo-cage and extracts the bottom layer of composted organic material from the silos. The material is still warm (about 45°C) and side conveyors carry it to the end collection points. From here it may be dispatched straight to land or it may go to storage for maturation and further stabilisation in static piles before bagging.

C.5 Avoided products & recycling

The processing of recycled waste during the production of plastic is based on an estimate of 0.6kwh of grid electricity and was model using the grid electricity mix of the country of production. The performance loss was estimated to be 10 per cent for plastic and 20 per cent for paper and the avoided products were modelled using ecoinvent data on for the production and extraction of the recycled material.

The recycling of bag materials at end-of-life was based on data generated through the WRATE software tool. The following sections outline the assumptions made.

Collection -140 litre bring bank at supermarket.

Waste transport -, 25 km one way trip from supermarket to transfer station using ultra-low sulphur diesel fuel refuse collection vehicle (6 x 4 RCV) with waste compaction., then 250 km one-way trip using intermodal road transport for onward transport to recycling facility.

Description – plastic film Mechanical recycling - Plastic film recycling. The process relates to the operations of the BPI recycled products process in Dumfries accepting agricultural plastic film (75% of feedstock) and commercial LDPE (25%). According to Danish LCA methodology 10% by weight are material rejects (that are sent to Landfill) and a 20% performance loss is also assumed for the offset of LLDPE granulate. The plastic film is recycled into Plaswood, a sustainable wood substitute.

Description – paper Mechanical recycling - Bag made from recycled paper in first instance ("paper, recycling at plant process") replacing corrugated board packaging from mixed fibre ("corrugated board, mixed fibre, single wall at plant"). A 14.5% material loss is assumed with a mixed residual waste material disposed to landill 10km away and a 10% performance loss is assumed over new corrugated board, based on Danish LCA methodology.

It is assumed that all the plastic carrier bags collected at end-of-life for recycling are exported for recycling to China. This was modelled using the ecoinvent transoceanic freight ship data describe in section C.3.

The avoided production of bin liners was modelled using ecoinvent data on the production of HDPE and the use of an average European extrusion process. The data was subtracted from the model to represent the avoided production of the bin liner.

C.6 Lifecycle diagrams

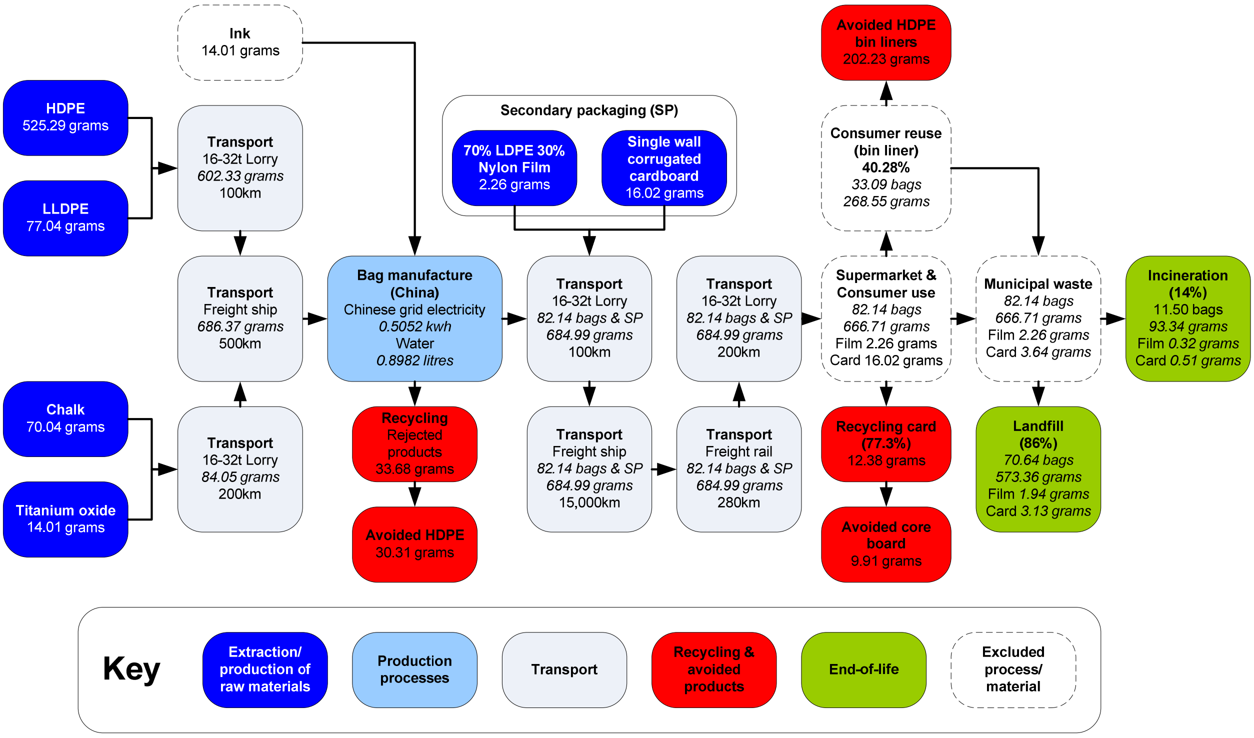


Figure C.6.1 The lifecycle of the HDPE bag.

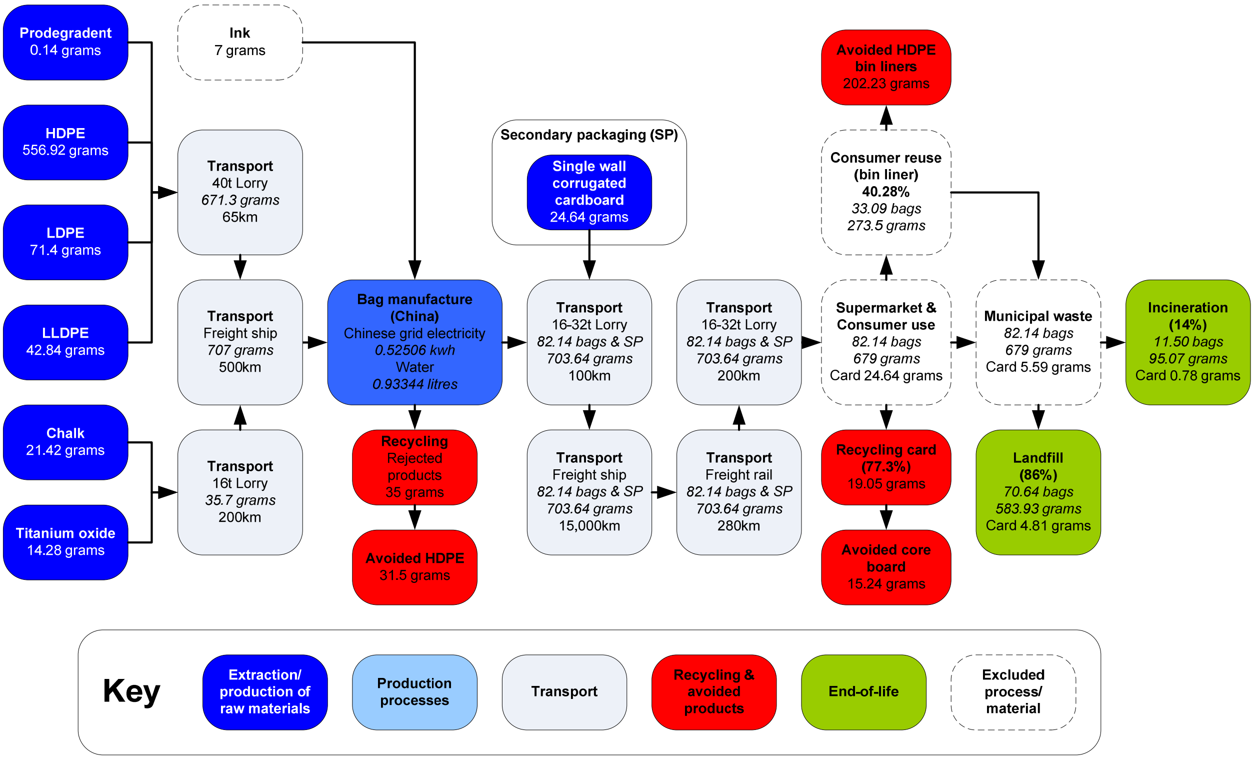


Figure C.6.2 The lifecycle of the HDPE bag with a prodegradant additive.

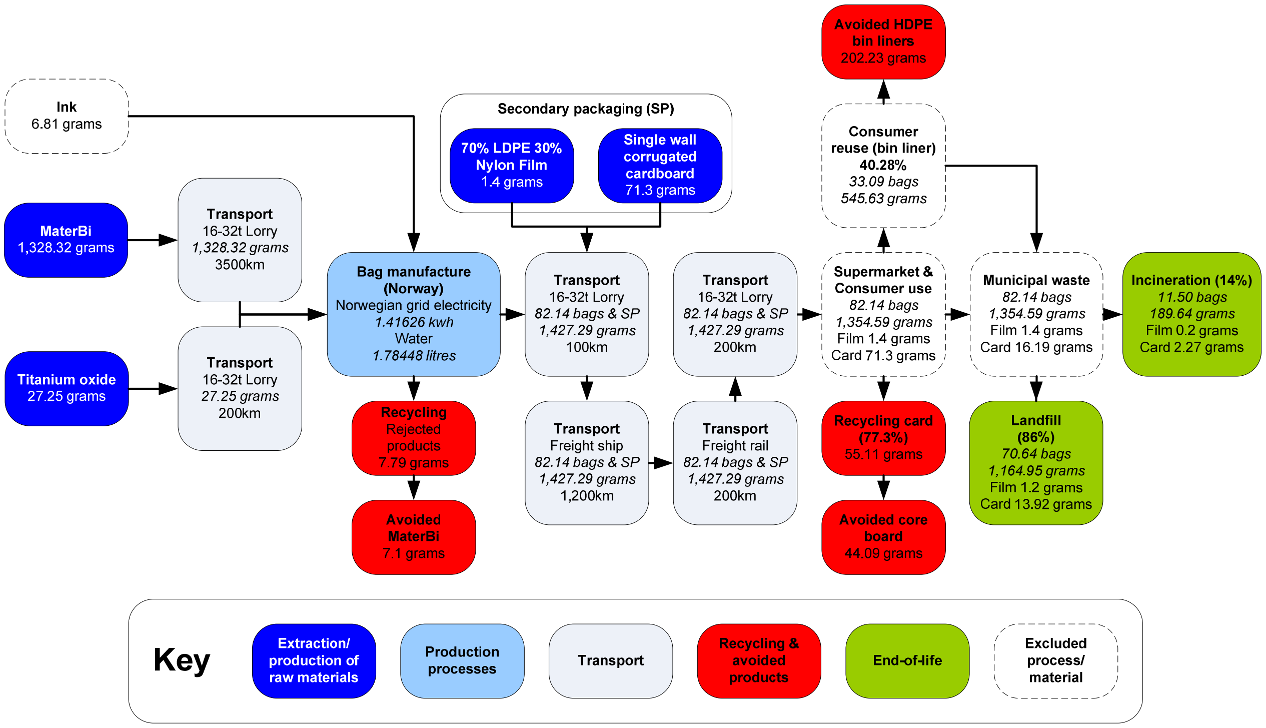


Figure C.6.3 The lifecycle of the starch-polyester blend bag.

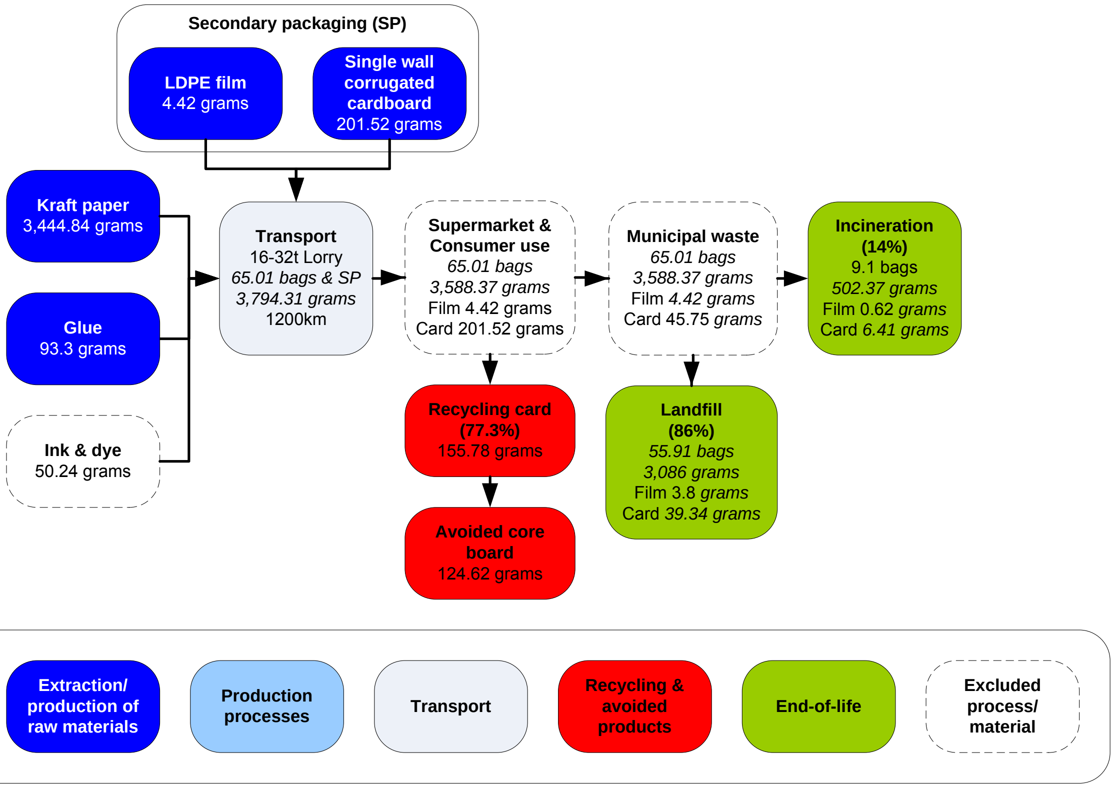


Figure C.6.4 The lifecycle of the paper bag.

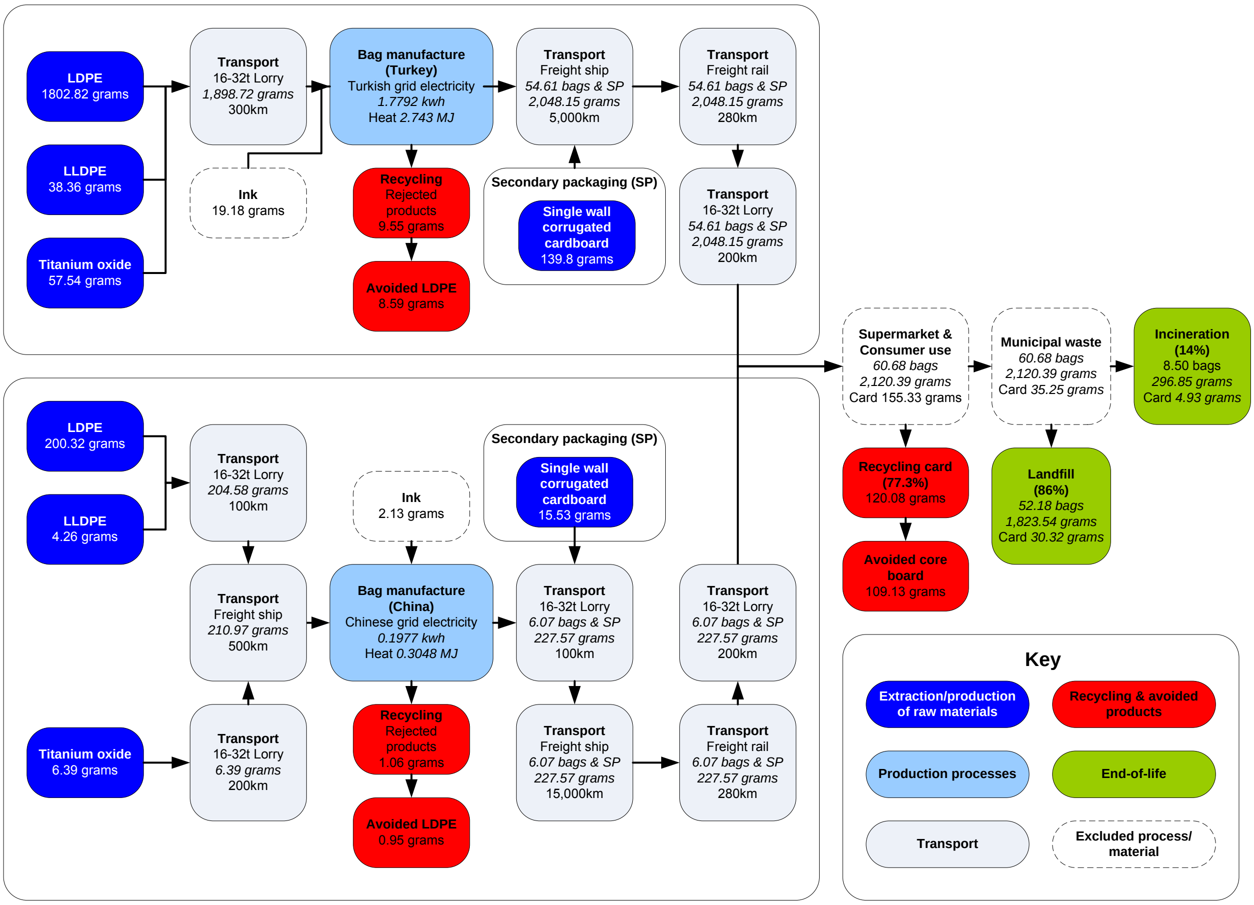


Figure C.6.5 The lifecycle of the LDPE bag.

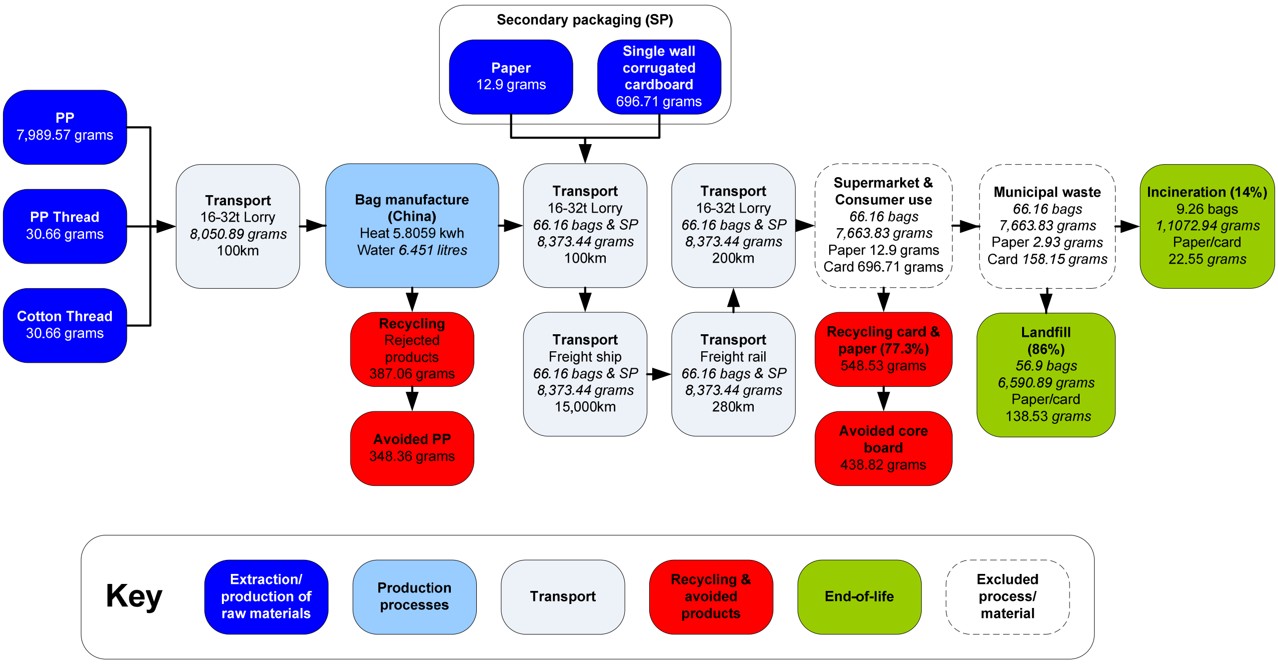


Figure C.6.6 The lifecycle of the non-woven PP bag.

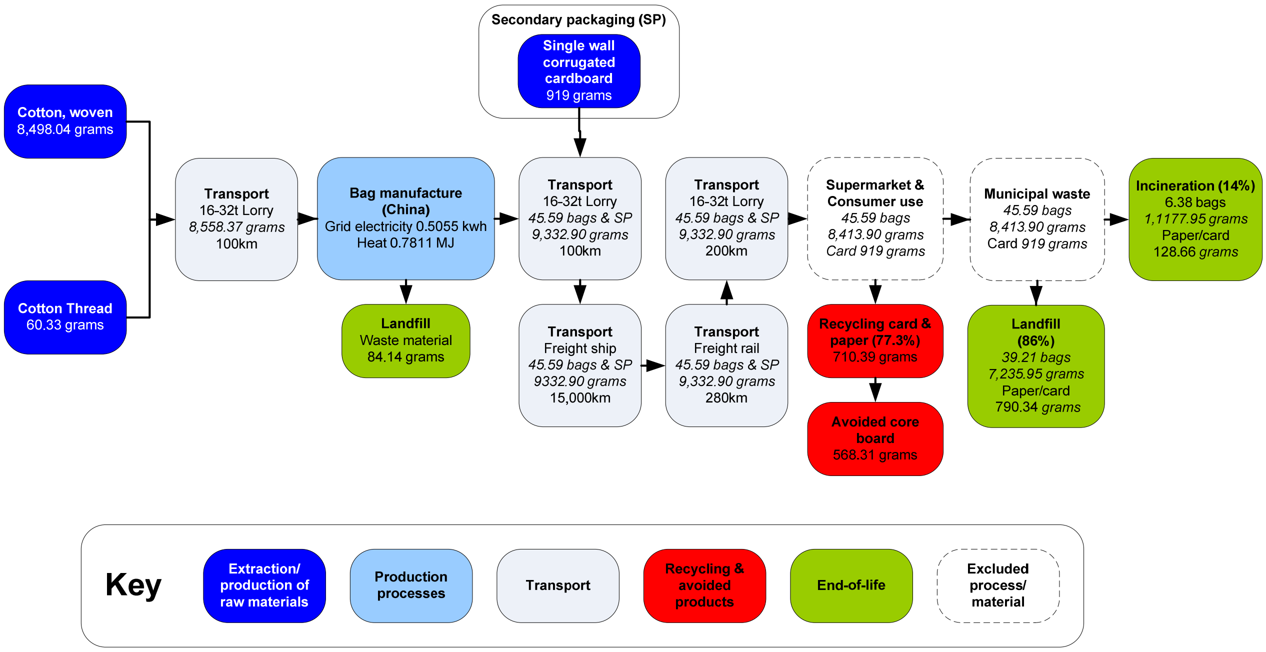


Figure C.6.7 The lifecycle of the cotton bag.

C.7 References

Althaus H.-J., Werner F., Stettler C., and Dinkel F. (2007) *Life Cycle Inventories of Renewable Materials*, v2.0, Ecoinvent Report No. 21, Switzerland.

Boustead, I. (1997) *Eco-profiles of the European Plastics Industry.* Polymer Conversion. Report 10, Brussels.

Boustead, I. (2005) *Eco-profiles of the European Plastics Industry,* Plastics*Europe*, Belgium.

Hill, U., CEPI Eurokraft, *personal email communication* (July 2006 and April 2007).

FEFCO, Groupment Ondule and Kraft Institute (2006) *European database for corrugated board life cycle studies, Paris.*

Habersatter et al. (1998) *Okoinventare fur Verpackungen.* BUWAL Schriftenreihe Umwelt Nr. 250, BUWAL, Bern.

Kooistra K.J., Pyburn R., Termorshuizen A.J. (2006) *The sustainability of cotton, consequences for man and environment*, Wageningen University Report 223, The Netherlands.

Novamont (2008) Environmental Product Declaration of Mater-Bi NF07U (EPD Validated) Retrieved from http://bio4eu.jrc.ec.europa.eu/documents/e_epd102.pdf

Weström, P. and Löfgren, C., 2005. *Life Cycle Inventory for paper sacks*, CEPI Eurokraft and Eurosac, Sweden.

Wiegmann K. (2002) *Anbau und Verarbeitung von Baumwolle – Dokumentation der GEMIS Daten*, Öko-Institut e.V., Germany.

Annex D - Description of impact categories

Abiotic depletion

What is it? This impact category refers to the depletion of non living (abiotic) resources such as fossil fuels, minerals, clay and peat.

How is it measured? Abiotic depletion is measured in kilograms of Antimony (Sb) equivalents.

Global warming potential

What is it? Global warming potential is a measure of how much of a given mass of a green house gas (for example, CO_2, methane, nitrous oxide) is estimated to contribute to global warming. Global warming occurs due to an increase in the atmospheric concentration of greenhouse gases which changes the absorption of infra red radiation in the atmosphere, known as radiative forcing leading to changes in climatic patterns and higher global average temperatures.

How is it measured? Global warming potential is measured in terms of CO_2 equivalents.

Photochemical oxidation

What is it? The formation of photochemical oxidant smog is the result of complex reactions between NOx and VOCs under the action of sunlight (UV radiation) which leads to the formation of ozone in the troposphere. The smog phenomenon is very dependent on meteorological conditions and the background concentrations of pollutants.

How is it measured? It is measured using photo-oxidant creation potential (POCP) which is normally expressed in ethylene equivalents.

Eutrophication

What is it? This is caused by the addition of nutrients to a soil or water system which leads to an increase in biomass, damaging other lifeforms. Nitrogen and phosphorus are the two nutrients most implicated in eutrophication.

How is it measured? Eutrophication is measured in terms of phosphate ($PO_4{}^{3-}$) equivalents.

Acidification

What is it? This results from the deposition of acids which leads to a decrease in the pH, a decrease in the mineral content of soil and increased concentrations of potentially toxic elements in the soil solution. The major acidifying pollutants are SO_2, NOx, HCL and NH_3.

How is it measured? Acidification is measured in terms of SO2 equivalents.

Toxicity

What is it? Toxicity is the degree to which something is able to produce illness or damage to an exposed organism. There are 4 different types of toxicity; human toxicity, terrestrial ecotoxicity, marine aquatic ecotoxicity and fresh water aquatic ecotoxicity.

How is it measured? Toxicity is measured in terms of dichlorobenzene equivalents.

Annex E – Peer review comments

E.1 General comments

We believe this is a very well presented and clear study, conducted in a very professional way; the results are presented in a balanced way. We have found a few major issues, relating to:

- The assumptions on recycling, and especially how the benefits of recycling are taken into account
- The lack of the consideration of land use and water consumption

E.2 Comments per chapter

The following sections outline the specific comments made in the peer review. The response of the authors is shown in red.

E.2.1 Chapter 1 Introduction

Comment 2.1.1 - Selection of alternatives.
Why wasn't a HDPE bag with recycled content included? The Sainsbury's bag sampled in the report would have been a 33% recycled bag (it was launched in Sept 06 and went nation wide early 2007). This coincides with the timing when the reference flow was defined (Paragraph 3.1), so this may be the reason, but it should be explained. However, upon further analysing we found that according to pages 77 & 78 – the "structure of the test research sampling' was done between 21st November and 9th December 2007. In B.3 it says the measuring of bags by Pira was in March 2008 – this would indicate the actual Sainsbury's bag should have been a recycled one.

The aim of the study was to provide an analysis of an average HDPE carrier bag during the reference period. The structure of the report aims to provide an accurate analysis of 2006/07 carrier bags and a theoretical idea of how recycling would affect those results. Therefore, no recycled contents has been included in any of the bags considered but the avoidance of like for like materials during recycling at end-of-life has been included to show both the implications of recycling and recycled content. It is clear that this required greater clarification within the report and therefore we have stated that the aim of the sensitivity analysis was to show the effect of recycling at both the start and end of life. A comment has also been added to state that recycled content was not included in the inventory and why.

Comment 2.1.2 - Market shares, and representativity
It is unclear from the report if the product studied are "real" alternatives. Some, like the paper or starch bag seem to have a very low (if any) real market share. This makes us wonder how realistic the data are regarding user behavior and some of the data representing production and logistics. It would add value if the real market shares can be added, and discussed.

Both the paper bag and the starch bag were not used in UK supermarkets during the reference period. The report acknowledged that these bag types have played or could play a role in carrier bag use and therefore required attention. Their inclusion was not influenced by current use or market share and this has been made more explicit within the report. Due to their low use it was also difficult to find accurate samples. The samples used were selected based on the similarity of their capacity to current supermarket carrier bags and therefore represent the most accurate reference possible. This information has also been added to the report.

Comment 2.1.3 - Other bags

There is no mention of produce / deli bags; we are not sure if they are worthy of mention? A consequence of not mentioning them could lead to “supermarket carrier bags” being an all encompassing definition. Obviously the very thin gauge bags are used to avoid cross contamination from meat, cheese, and fish – the HDPE type bag is infinitely less weight than other options. They are also used to pack fresh fruit to avoid the need to have only pre-packed products in trays and flow-wraps or blister cartons. In Ireland for their carrier bag tax they differentiated these by means of dimensions of the bag. In a report meant to be used as a basis of policymaking, it would be very useful to make explicit that this study is not relevant for other types of bags.

The report has been amended to clarify the difference between carrier bags and produce/deli bags.

E.2.2 Chapter 2 Goal definition

Comment 2.2.1 – Critical review process (section 2.2)

Please clarify the term integrated in the last sentence of 2.2; I think it is better to simply state the chairman reviewed and commented the goal and scope.

The report has been amended to include this change.

E.2.3 Chapter 3 Scope

Comment 2.3.1 - Reference flow (section 3.2)

The reference flow refers to the situation 4 years ago, which we understand is due to the long time needed for the study. It would be good to make a generic comment describing to what extend this is still representative for now.

A generic comment has been added to state that although bag compositions have changed in the recent years, the reference flows for common bag types will not have significantly changed. Bag use may have reduced since the reference period but this is due to bag reuse rather than changes in other consumer habits (e.g. buying less). A comment has also been added to mention the large development in biopolymers which could have resulted in the most significant change.

Comment 2.3.2 - Items per bag (Table 3.1)

We do not understand how the data for this table was collected. The text and annex B show a very detailed study on HDP and LDPE bag (which is really unique in itself), but how the number of items in a paper or starch based bag was determined is unclear. This is of course important as this is the basis for comparison.

A reference has been made in this section to annex B and more detail has been added to the annex regarding the calculation of the paper and starch bag capacities and weights. This states that, as neither the paper or starch polyester bag were available in UK supermarkets and both were used in a variety of different applications and therefore had a wide range of weight and volume characteristics, a single bag was selected with similar physical attributes to the other bags considered to represent each of these bag types.

Comment 2.3.3 – Allocation (section 3.4)

The text in this section is not really representative of what is actually done in the study, as described in 4.5, in which much more detail and specificity is provided; we recommend to bring these in line. Or at least refer to 4.5

The report has been amended to ensure that section 4.5 is reference in section 3.4 and more detail is provided on the allocation methods used.

Comment 2.3.4 – Allocation (section 3.4)

The primary reuse is not discussed for HDPE/Starch bags, but in 4.5 this seems to be taken into account.

The third bullet point in this section states that system expansion is included for “The avoided production of bin liners when carrier bags are reused in other applications”. Within the report this is defined as secondary reuse (i.e. reuse in another application) and therefore an additional sentence has been added stating this with reference to the HDPE and starch bags.

Comment 2.3.5 – Allocation (section 3.4)

The choice to assume a one to one avoidance of primary production when plastic is recycled, is highly optimistic. For several reasons:

- The paper of Schmidt and Stömberg mentioned in the text, refers to the problem that in plastic recycling the demand and not the collection and supply determine the recycling rate of plastic.
- The “oversupply” of collected plastics is used to make very low value products, like poles and street furniture. At best they avoid the production of wood and concrete, but they will not avoid significant amounts of virgin plastic production. In chapter 4.5 the methodology is described better, stating assumptions on material and quality losses with partially addresses these observations. Reference is made to an operation in Dumfries, that is said to “accept” commercial LDPE, but it is unclear what this facility produces.
- Postconsumer shopping bags are printed, and probably often containing some unwanted materials; this would make it very difficult to use shopping bags as a high value plastics. Plastic waste created during the shopping bag production, like the waste occurring when handles are punched out can indeed be reused, and are often reused in the shopping bag extrusion again. In that case closed loop assumptions can be made and that type of recycling does avoid virgin material use
- In this study there are no alternatives made of recycled plastic (unless the Sainsbury bag is included). If this would have been the case, one would see a

> double count. A bag, made of recycled plastic would in the end avoid virgin plastic. This can lead to the strange conclusion that the environmental load of this recycled bag, is negative.[23] This is counter intuitive as it implies the more bags are used, the cleaner the environment gets.

For paper the assumption is more realistic, recycled paper can indeed replace virgin paper to some extend.

One of the purposes of including the avoided production of plastics during the sensitivity analysis was to show the impact of recycling and also the potential effect of recycled content. As stated in the peer review comments, the inclusion of recycled content in the inventory would have double counted this effect. To provide greater simplicity it was therefore decided to only include the effect of recycling at end-of-life and within a separate sensitivity analysis therefore presenting a 'worst case' for each bag type in the main results. This has been made clear in the report. Greater details on the end-of-life assumptions for post consumer recycling, such as performance loss, have therefore been added to give greater clarity on this issue. The reference of the Schmidt and Stromberg paper has also been placed in a clearer context within the report. The reasons behind the inclusion of the avoided production of plastic from carrier bag recycling is outline in the response to comment 2.5.2.

Comment 2.3.6 – Allocation (section 3.4)

Waste incineration indeed leads to energy production, but also here it is unclear why this would be taken into account. The energy reclamation is a virtue of the waste incinerator and not of the plastic bag. There is also a double count, as the energy from waste incineration is also included in the production mix of energy (although the share is small, so this effect is limited)

None of the bags considered was produced in the UK and all were used to generate energy in UK incinerators. Therefore, these bags would not be used as feedstock in WtE plants in the countries of production. This has been made more explicit in the report as well as providing more information on the background data used to model waste incineration.

Comment 2.3.7 – Allocation (section 3.4)

Table 3.2 also refers to composting, it is not clear if any benefit is claimed for the compost produced.

This has been clarified in the report.

Comment 2.3.8 – Impact assessment: GWP (section 3.7.1)

It is unclear why a discussion on reuse is started in this section.

---

[23] Suppose the production of virgin material has a load of 100 points per kg, and the collection and recycling of secondary plastic has a load of 20 points. If all the other processes in the entire lifecycle has an environmental load of 30 points, the total environmental load would become 20 + 30 - 100 = - 50. So the more bags are used the cleaner the environment gets.

A discussion of the exclusion/inclusion of primary reuse has been added earlier in the report.

Comment 2.3.9 – Impact assessment: GWP (section 3.7.1)

Biogenic carbon uptake is apparently been excluded and a statement is made that biogenic carbon is seen as carbon neutral. We would like to see some more detail; is for instance biogenic methane also excluded. Or is the fact that generation of biogenic methane does significantly contribute to the climate change effect

The alteration of different characterisation factors has been made clear within this section.

Comment 2.3.10 – Impact assessment: Other impact categories (section 3.7.2)

We think it is difficult to accept the exclusion of the impacts of land-use in a study were also paper, PLA and cotton products are involved, and similarly the impact of water use is missing. The CML method does recommend a simple way of dealing with this, by simply adding the land occupation as area* time.

The Environment Agency made it clear that land and water use were not impact categories of interest to them in this study, because of difficulties in getting precise, verified data . However, land use has been included in the sensitivity analysis with the use of the eco-indicator 99 method and this has been stated in the text.

Comment 2.3.11 – Critical review (section 3.10)

This paragraph discusses the same topic as in chapter 2; we suggest to either discuss it here or in chapter 2.

The section on the critical review process has been moved to chapter 2.

E.2.4 Chapter 4 Inventory analysis

Comment 2.4.1 – Material specifications (Table 4.1)

Whilst specs are wide ranging, and this item represents bags from the sampling done, but – if the vacuum pack for 1,000 HDPE bags is 55g, then 8.5g for 500 starch bags (which are thicker) 8.5g seems erroneous – perhaps this should in fact be 85g??

The HDPE bag is packaged using 390 grams of cardboard and 55 grams of film per 1000 bags. In contrast the starch bag is packaged using 868 grams of cardboard and 17 grams of film per 1000 bags. Although the film is lower the cardboard is significantly higher and we therefore feel that if all secondary packaging is considered it provides a fair indication of each bags requirement.

Comment 2.4.2 – Material specifications (section 4.1)

As noted in Chapter 1, some alternatives, like paper and starch-polyester seem to have a very low market share, how representative are these data? For instance, is Kraft strong enough to be used for a paper carrier bag. It would have to be laminated and, to be equivalent to the other bags, have handles, which would significantly increase its weight.

The weight represents the total amount of material required to provide the stated capacity for each bag type based on the samples used. As stated, more detail has been added to annex B about how the samples were selected.

Comment 2.4.3 – Material specifications (Table 4.1)

Editorial; Ink is missing from the bottom two central boxes, and probably cotton thread is missing, in the lowest

This table has now been moved to the annex and has been amended.

Comment 2.4.4 – Bag production processes (section 4.2)

Paragraph 3, line 3. Should read .. 90% of LDPE bags are produced in Europe especially Turkey and Germany, and 10% in the Far East especially Malaysia and China. The last sentence referring to use of hand sewing machines seems inappropriate.

The text in this section has been changed. However, the aim of this sentence was to set out the assumptions made on bag manufacture locations, not to reference the exact quote given (i.e. this was "based on conversations with industry experts"). Therefore, only Turkey and China were modelled and this has now been made clear in the text. The reference to hand sewing has also been removed.

Comment 2.4.5 – Bag production processes (section 4.2)

Paragraph 2, line 4 should read … Europe is the main producer especially Turkey and Germany.

The text has been changed.

Comment 2.4.6 – Bag production processes (Table 4.2)

It is not clear what happens with the waste reported in the last column; often plastic waste, especially if it is white and not coloured is reused, which avoids primary production; please clarify.

Production waste for all of the bag options (excluding the paper and cotton bags) is recycled and includes avoided products, as highlighted in the process diagrams in Annex C. This has been referenced and commented on in the text.

Comment 2.4.7 – End-of-life (section 4.4)

If the DEFRA stats are for UK paper recycling (applied for cardboard) are general figures, then when considering Supermarkets alone the 77.3% may be understated. This is because many stores have compactors / bailers, and sell the corrugated scrap – due to this commercial activity We would expect the % recycled by supermarkets to be higher (unless some of the recycled scrap sent to recycling is unrecyclable and therefore ends up in landfill??); please clarify

A comment regarding the statistics used has been added to the report. This states that, since the reference period, in-house cardboard recycling has increased significantly. However, the best card recovery figures provided for that period were by Defra and were not significantly different to general in-house recycling figures reported by supermarket CSR reports.

Comment 2.4.8 – End-of-life (section 4.4)

Page 29: there must be a mistake on the size of incinerator – 225,000 not 225 tonnes.

This error has been amended.

Comment 2.4.9 – Avoided products & recycling (section 4.5)

Please describe what the Dumfries facility produces, and how realistic it is that this avoids virgin plastic production; then assess what these outputs actually would displace on the market.
The estimates for losses of plastic (10% and paper 20%) seem not to be based on any specific choice.

More detail has been added to the report regarding the end-of-life recycling assumptions made.

Comment 2.4.10 – End-of-life (section 4.4)

The HDPE prodegradant containing materials and the starch based materials, can indeed seriously disrupt recycling operations if these bags become a successful product. The argument that they have a small share now, is not too convincing, as no shares are given, and information is lacking if even a small share can have a negative impact on recycling. It is strange that the comment is only made referring to the prodegradant containing material and not the starch based material.
In table 3.2 we saw that Starch polyester was not assumed to be mechanical recyclable, and we think the same holds true for bags with a prodegradant additive. These bags should be considered as unrecyclable, and even worse as disrupting recycling.

The report has been adapted to exclude prodegradant bags from recycling.

E.2.5 Chapter 5 & 6 Impact assessment & sensitivity analysis

Comment 2.5.1 – Impact assessment comparison

The reviewers have a problem with the way the bags are compared, as no comparison basis has been defined, and thus there is no comparison on the basis of a functional unit. The problem is caused by the lack of actual reuse estimates. The number of reuses is computed on the basis of the carbon footprint, but this has nothing to do with the real number of reuses and it is unclear if these numbers can actually be achieved. Reusing a PP “bag for life” 14 times seems realistic, reusing a paper bag 4 times does not. Reusing a cotton bag 173 times seems very ambitious.
We understand that it is difficult to determine actual number of reuses we are aware of the WRAP, Choose to Reuse study http://www.wrap.org.uk/downloads/Choose_to_Reuse_Report_-_June_2006.c694423a.2998.pdf that tries to describe the actual reuse rates, but we have seen that also that study does not provide a clear answer.
The problem of presenting these numbers without any comments, the reader still does not know what the best bag is. One could interpret however that, the bag for life is a

good alternative of the HDPE bag for people who actually use the bag for life on a regular basis. At the same time the study can conclude that the paper bag is not a good alternative, as it is not plausible to assume it can be reused, and certainly not 4 times. In other words the second objective of the study, as defined in chapter 2.1 is not met; there is not even an attempt to try to compare products on the basis of a clearly defined functional unit, and this is a rather fundamental requirement in the ISO standard:

- Paragraph 4.1.4 of the 14040 standard clearly defines all impact assessment results are related to the functional unit
- Paragraph 4.2.3.7 of the 14044 standard clearly confirms this in the case of comparisons

As we already acknowledge the difficulty to determine the reuse rates, we would like to see a clear description of this limitation, and we would also like to see a clear statement that in fact the study failed to make a comparison due to the impossibility to define a realistic functional unit.

The Author agrees with the peer review findings that a true functional unit is not provided as this would require a set amount of reuse to accurately measure the bags function. A discussion of this has been included in chapter 3 (Scope) to provide a greater understanding of the exclusion of primary reuse. This has also been referenced in chapter 5 and the limitations of the results in meeting a functional unit have been acknowledged in the discussion. Efforts have also been made to reduce the influence of the reuse figures calculated in the impact assessment of GWP, such as including results that exclude primary reuse for the other impact categories.

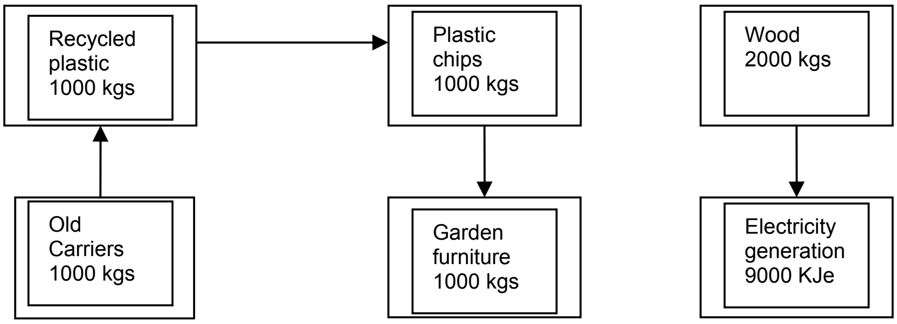
Comment 2.5.2 – Impact assessment (avoided products)

General, we do not agree with the way credits are determined in the case of secondary recycling, we think the assumption that primary materials are avoided is way too optimistic, and we would like to see this assumption replaced by a more realistic assumption. For the production of energy for waste incineration, we also do not agree; energy reclamation is a virtue of the incinerator, and the electricity grid, and has nothing to do with the plastic bag lifecycle. We would like to see this credit removed. As far as we can see such changes would not have significant impact on the conclusions.

We would like to credit the carrier system with the relevant credits from waste management. This is in line with government policy here and with the revised Waste Framework Directive, which gives a higher position to incineration with energy recovery.

The Dumfries plant handles recycled agricultural film (80 per cent) and plastic carriers (20 per cent). The Dumfries plant was included in our waste management data because it was the only plant for which we could get good data. Generally we believe plastic carriers are now recycled into further carriers. However, if we assume that garden furniture (fencing, tables, chairs, decking) is produced from the Dumfries plant, then we have the following:

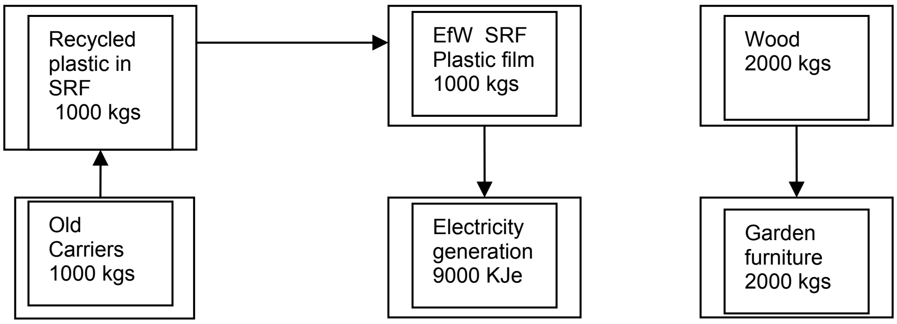
System A: Carriers recycled to garden furniture, wood burnt to generate electricity.



This assumes that the demand for garden furniture and for electricity is constant and for simplification that there are no losses of materials in the system.

The alternative scenario is shown in system B. Here the plastic carriers are collected for a waste fuel, SRF. This waste is burned in an energy from waste plant which generates electricity. To simplify things, because plastic is lighter than wood we can assume that our 1000 kgs plastic will make the same amount of furniture as 2000 kg of wood. Additionally, the amount of electricity generated is assumed to be the same, because the CV of plastic is 3 times that of wood, which makes up for the reduced weight and an overall efficiency of 24% for the EfW plant compared with 35% for the wood-fired power station.

Scenario B: Carriers burnt to produce electricity, wood used to make furniture



The two systems in Scenario A and B therefore have overall equivalence – each producing the same amount of electricity and garden furniture (even though the plastic furniture is lighter, it still performs the same *function* as the wood).
The LCA is not just about what carriers should be made, it's much more about which carriers people should choose, depending on their lifestyle, how they should use them to minimise the impacts and then the difference that different end-of-life choices make.

The type of bag (degradable or non-degradable) makes a real difference if they are landfilled. In WRATE, the landfill model is derived from another and the gas recovery and energy offset cannot be varied. Therefore the landfill model will show the effects of methane emissions and also the benefits of energy recovery from landfill gas. For consistency, this needs to be included for all waste management options.

Terry Coleman/Jo Marchant

16 February 2010

Comment 2.5.3 – Impact assessment

On several places reference is made to production in China, while actually China and Malaysia are meant.

Malaysia was not included as a production location in the inventory analysis and therefore the reference to Chinese and not Malaysian grid electricity is correct. This has been made clear in the Inventory analysis.

Comment 2.5.4 – Impact assessment methods (GWP)

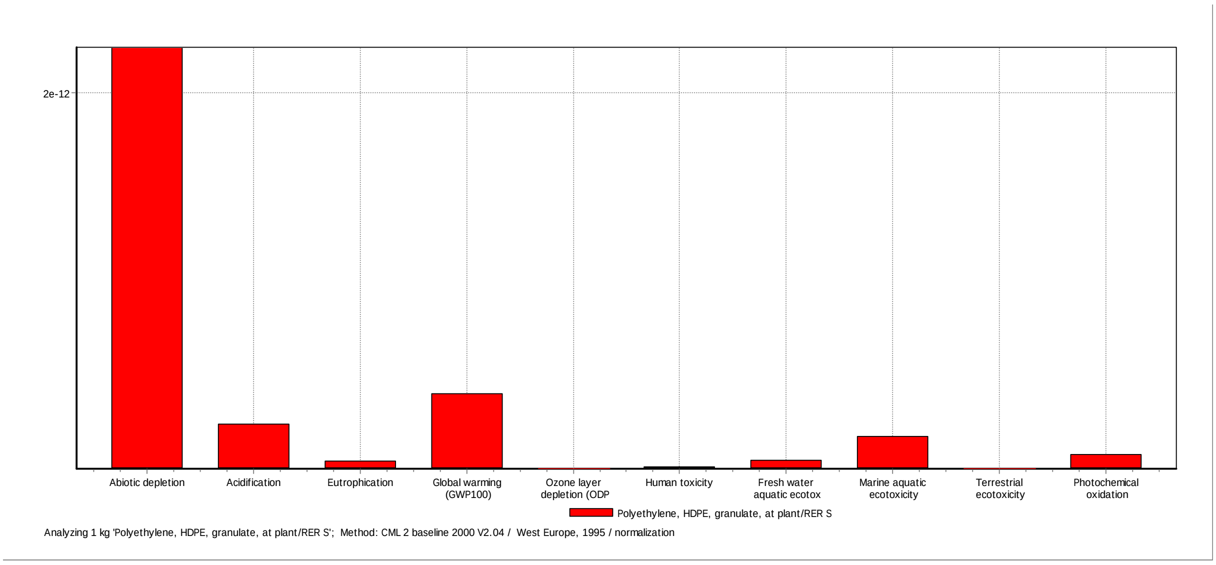
As noted under 3.7 it is unclear how biogenic carbon has been dealt with. Later in chapter 5, when the eco-indicator is used, suddenly carbon uptake is taken into account. Why have the authors not attempted to apply one consistent way, and use a variant in the sensitivity.

Biogenic carbon was excluded from the main results of the study. However, to show its effect, the sensitivity analysis used the eco-indicator method to show the implications of using a methodology which includes biogenic carbon. The exclusion of biogenic carbon from the main results and the inclusion of biogenic carbon within the sensitivity analysis will be made more explicit throughout the report.

Comment 2.5.5 – Other Impact categories (section 5.2)

This chapter is lengthy and, although well done, not overly interesting to read. The results are given per bag type, and it is very hard to put the statements into perspective. As a reader, I would be very interested to start with a comparison between the different bags. As discussed above it seems to be impossible to give a real comparison on the basis of a real functional unit, but we suggest to give a direct comparison without any reuses, like in figure 5.1. If the authors consider such a direct comparison in chapter 5.1, why not repeat this in 5.2. In the same way a figure analogue to figure 5.2 could be given. This figure is now presented in 6.2.

In general the observations made are clear and relevant, although it is not so clear why impact categories that would hardly have any relevance after normalisation, such as ozonelayer depletion are discussed as if they are relevant in this context. Below we copy the normalised results of LDPE production to illustrate the point; ozonelayer depletion levels are far too low to be ever relevant.



Analyzing 1 kg 'Polyethylene, HDPE, granulate, at plant/RER S'; Method: CML 2 baseline 2000 V2.04 / West Europe, 1995 / normalization

We suggest explaining the reader that the 100% score for each column does not imply each impact category has the same order of magnitude or importance, we suggest to illustrate this by using normalised results in the final comparison which is now in figure 6.1. We understand that the approach chosen is not wrong.

In response to the peer review comments, the results per bag type have been simplified to give a more concise analysis of each bags result and ozone layer depletion has been excluded as an impact category. The conclusion and discussion sections have now been separated to provide a better discussion of the overall results. In addition, figure 6.2 has been replaced with a bar chart showing a normalised comparison of the bags with reuse.

Comment 2.5.6 – Other Impact categories (section 5.2)

5.2.1 Titanium Dioxide is only used in opaque bags, some of the main supermarkets in the UK (Asda, Morrisons, Somerfield) use a clear bag - therefore the impact of some HDPE bags would be overstated in terms of fresh water ecotoxicity.

This has been added to the text in this section.

Comment 2.5.7 – Paper carrier bag (section 5.2.4)

Surprised how low the transport element is in figure 5.6, given its relative bulk, given what is stated in paragraph 2, perhaps the true bulk of the product has not been correctly taken into account?

The transportation of the paper bag includes the weight of just over 65 bags travelling a distance of 1200km journey from bag producer to supermarket. Although the impact of transportation is proportionately smaller than other bags in figure 5.6 (due to the higher impact of the extraction and production of raw materials) the actual impact of transportation is larger than other formats. For example, 14% (the proportional impact of transport on the paper bag) of 5.523 kg CO2 eq. (the GWP of the paper bag with no reuse) is 773 g CO2 eq. However, for the HDPE bag, 8% (transport impact) of 1.578 kg CO2 eq. (GWP impact) is 126 g CO2 eq.

Comment 2.5.8 – LDPE carrier bag (section 5.2.5)

Paragraph 3 needs to add reference to Germany.

Only Turkey was included as a production location in Europe in the inventory and therefore Germany should not referenced in this section. The text now makes it clear that this is an assumption.

Comment 2.5.9 – Starch-polyester blend carrier bag (section 5.2.3)

In the paragraph below figure 5.5 reference is made to the way data was presented/collected; it would be very useful to have a short explanation what this means, and how this data was aggregated. The same applies for the first paragraph on the paper bag.

A reference will be added to Annex C which contains more information on the inventory data used.

Comment 2.5.10 – Sensitivity analysis (section 6)

In several graphs the captions are missing

All captions have been included.

Comment 2.5.11 – Sensitivity analysis (section 6.1)

The title is somewhat confusing, as secondary use seems to be equivalent with primary recycling.

The title has been changed to 'Secondary use of lightweight bags'. Secondary use is discussed throughout the report as the reuse of lightweight carrier bags in secondary applications such as for bin liners. The inventory analysis also states how this has been modelled by including the avoided production of bin liners. Greater reference to this has now been added to this section to make this clear.

Comment 2.5.12 – Sensitivity analysis (section 6.2)

As noted we do not agree with the way the benefits of secondary recycling are computed. We also do not agree that bags with prodegradant bags can be assumed to be recyclable. On the contrary they may make it impossible to recycle other bags, in case the different bag types are mixed.

The prodegradant bag has been excluded from recycling within the sensitivity analysis.

Comment 2.5.13 – Sensitivity analysis (section 6.3)

We think the way carbon storage is described is confusing, and we do not understand the second paragraph after figure 5.15. Also here we suggest to start with a comparison like in figure 5.1

The paragraph describing carbon storage has been reworked to provide a better explanation of its inclusion in the impact assessment.

E.2.6 Chapter 7 & 8 Discussion and conclusions

Comment 2.6.1 – Discussion and conclusion

The comparison with other studies is very interesting and provides a very nice background, and addresses objective 3 in chapter 2.1 nicely.

The second paragraph, contains a note to the authors, for internal use. In fact it addresses the problem we have, that is there is no real comparison, and thus that objective 2 of the study could not be reached, at least a comparison as meant in ISO 14040, using a distinct functional unit was not possible due to the lack of information on reuses.

We think it is still possible to make more concrete recommendations if three classes are chosen:

1. Relatively favourable solutions are the HDPE bag (preferably not opaque) and the PP bag for life, as the number of reuses required to score better seem realistic.
2. The prodegradant additive, does not seem to add much benefits, and has a negative impact is it increases the weight of the bag (which is not clear). If a recycling system is developed for bags, it should not be used. The Starch polyester bag also has no benefits.
3. The paper bag is not a good alternative, as it is more realistic to assume people will reuse such a bag 4 times or more.
4. The cotton bag does not seem to be a good alternative due to the high impact of cotton production

We are aware of the fact that reviewers are not supposed to draw conclusions, so this proposal should be seen as an example of what seems possible.

The discussion and conclusion have been reworked to include greater clarity in the conclusions made. A discussion of the issue surrounding the functional unit has also been added.

E.3 Final review statement

We believe this is a very well presented and clear study, conducted in a very professional way. The review took place in two major stages. At the end of 2009 a first version was produced and reviewed. Many comments have been taken into account, and a new version was produced in the summer of 2010.

The review panel has checked this version and have seen most comments have been properly addressed The major improvements between the first and second study were:

- More realistic assumptions on post consumer recycling, and especially how the benefits of recycling were taken into account, which were too optimistic; in the final study this has been properly addressed, and we agree on the approach.

- A better clarification on the selection of alternatives under investigation.

- Overall improvements in the data collection.

There are also a number of comments that could not be addressed, such as, the lack of consideration for land-use and water consumption in the case of cotton and biobased materials which is difficult to justify, but we accept the problems in data collection.
The reviewers have difficulty understanding why the results were presented in a relatively complex way. There is no clear comparison on the basis of a functional unit, while much work has been done to get information on a comparison basis. Instead a comparison is made on the basis of the required reuse (section 7.2). Whether the required number of reuses are realistic is left over to the reader to assess. We do understand the sensitive nature when the comparison is presented in a more clear and directly comparable way, and we can accept this, even though the ISO standards do require to base comparisons on a clear functional unit.

Overall we think the study in its final form fulfils the requirements in the ISO 14040 standards; in particular:

- the methods used to carry out the LCA are consistent with this 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, and
- the study report is transparent and consistent.

The reviewers:
Mark Goedkoop; PRé consultants B.V.
Keith Elstob, Bunzl Retail
Jane Bickerstaffe, INCPEN, Reading

Would you like to find out more about us, or about your environment?

Then call us on

08708 506 506* (Mon-Fri 8-6)

email

enquiries@environment-agency.gov.uk

or visit our website

www.environment-agency.gov.uk

incident hotline 0800 80 70 60 (24hrs)
floodline 0845 988 1188

* Approximate call costs: 8p plus 6p per minute (standard landline).
Please note charges will vary across telephone providers

Environment first: This publication is printed on recycled paper.