3 Life cycle assessment of paper and plastic checkout carrier bags

3.1 Overview of the life cycle analysis approach and findings

This section has been approached by means of an introduction to life cycle analysis (LCA) followed by a description of a generic life cycle analysis methodology, a discussion of the limitations of LCA's, descriptions of the lifecycles of paper and plastic checkout carrier bags, a description of the research approach, a description of the limitations of the research, the presentation of the research found and a statement of conclusions.

The objective of this section was to present a summary of the findings of a literature review into studies previously undertaken of the life cycles of plastic (polyethylene), paper and cloth checkout carrier bags. The review found no data relating to cloth carrier bags. Two studies dealing with the comparison of, firstly, paper and plastic checkout grocery bags in the United States and, secondly, paper and plastic animal feed distribution sacks in Europe were found.

A comparison of the two studies indicates that the results are contradictory. Literature found suggests that the discipline of life cycle analysis is highly sensitive to internal variables including the project scope, methodology, objectives and environmental and geographic context in which the studies are undertaken. This therefore suggests that the studies are limited in both comparison to one another and interpretation in the South African context. It is therefore concluded that in order to generate an understanding of which product life cycle has the greater environmental impact (in South Africa) a South African LCA comparison must be completed.

3.2 Introduction to life cycle analysis

A life cycle analysis (LCA) provides a framework and methods for identifying and evaluating environmental burdens associated with the complete life cycles of products and services, i.e. from the product cradle to the grave.

3.3 What is Life Cycle Analysis?

The life cycle assessment (LCA) method deals with the complex interaction between the provision of a product or service, through all stages of its life cycle, and the environment. The LCA attempts to predict the overall environmental burdens associated with the provision of the product and identify particularly burdensome or wasteful processes therein.

The United States Environmental Protection Agency defines a Life Cycle assessment as 'an objective process used to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment, and

...to evaluate and implement opportunities to affect environmental improvements[3] The purpose of following the product life cycle from the cradle to the grave is to limit or eliminate impact displacement.

Typically a life cycle assessment would determine the energy and raw material utilisation and solid, liquid and gaseous emissions generated at each stage of the life cycle. Generally the second-generation impacts of the system are ignored (e.g. the energy used to fire the bricks that are used to build the kiln would typically not be included).

The basis of an LCA study is an inventory of all the inputs and outputs of industrial processes that occur during the life cycle of a product. The inventory process is simple, in principle. In practice, however, it is subject to a number of practical and methodological problems, as listed below:

- System boundaries
- Processes that generate more than one product
- Avoided impacts
- Geographical variations
- Data quality
- Choice of technology

3.4 Generic methodology

The life cycle of a product or service includes extraction of natural resources, production of raw materials, transport, production of the product, use, and waste management/recycling. In a life cycle assessment, the environmentally relevant input and output flows of the life cycle of the studied products, and the environmental impacts that these cause are calculated and evaluated.

Currently ISO 14040-43 defines a life cycle as comprising of four phases, namely:

Phase 1: Goal and scope assessment

The purpose of the study is described. This description includes the intended application and audience, and clearly states the reasons for carrying out the study. The scope of the study is described, which includes the limitations, the functions of the systems investigated, the functional unit, the systems investigated, the system boundaries, the allocation approaches, the data requirements, the key assumptions, the impact assessment method, the interpretation method and the type of reporting.

---

[3] Vignon B W, Tolle D A, Cornaby B W, Latham H C, Harrison C L, Boguski T L, Hunt R G and Sellers J D, 1993, 'Life-Cycle Assessment: Inventory Guidelines and Principles', United States Environmental Protection Agency, Cincinnati, USA.

Phase 2: Inventory analysis

Data is collected and interpreted, calculations are made and the inventory results are calculated and presented. Mass flows and environmental input and output flows are calculated and presented.

Phase 3: Impact assessment

The production system is examined from an environmental perspective using category indicators, such as global warming, acidification and eutrophication.

Phase 4: Interpretation

Herein the results are analysed in relation to the goal of the study. Conclusions are drawn, limitations of the results are presented and recommendations are provided based on the findings of the preceding phases. The conclusions should be compatible with the goals and quality of the study.

Practical constraints of life cycle assessments

A continuing concern of LCA methodology development bodies is the time and cost required to complete LCAs. Some have questioned whether the LCA community has established a methodology that is beyond the reach the majority of potential users. Others have questioned the relevance of the LCA to the actual decisions that potential users must make.

Collection of Life Cycle Inventory (LCI) data can be extremely costly and time consuming and often results in LCA studies being abandoned or proving inadequate because of poor and inconsistent LCI data. Good LCA's demand sound LCI's that subsequently contribute to making good judgments about environmental matters. The build up of a LCI puts together a whole series of smaller process data sets, either for individual processes or collections of individual processes.

In an attempt to facilitate the completion of LCIs numerous industry segments have undertaken and made available 'cradle-to-gate' or 'gate-to-gate' LCI studies. These are prepared by many of the specific industry groupings for the connected processes that are under their control. Such 'block' collections of industry data are known as 'eco-profiles'. A collection of Eco-profiles can then be added together to form a complete LCI. This procedure serves to reduce costs, save time, provide reliable and accurate data and makes LCA studies easier to complete, be more widely applicable, and as a consequence, assists with sound decisions on environmental management by interested parties. The profiles are, however, highly dependent on the context in which they where developed and use in different contexts introduces risk of incompatibility.

There are a number of organizations marketing eco-profiles in the form of LCA databases however these have been found to vary considerably in[4]:

- Level of detail
- Flexibility of data manipulation
- Data quality
- Purchase costs

3.5 Limitations of LCAs

As with any scientific method the LCA methodology suffers from limitations that must be understood. Several basic principles and practicalities remain to be defined:

- Data details differ for each supplier, specific processes used, location, dominant methods of primary production
- Analysis of multi-product manufacturing systems provide complex allocation problems
- The impact assessment stages are not fully developed and cannot provide a full decision support system
- The impact assessment depends on environmental priorities of the industry segment and data provided
- Interpretation is subjective in its ranking of impacts

In this light LCAs have been shown to rarely produce clear winners and losers but rather serve to detail environmental implications and illustrate tradeoffs[5].

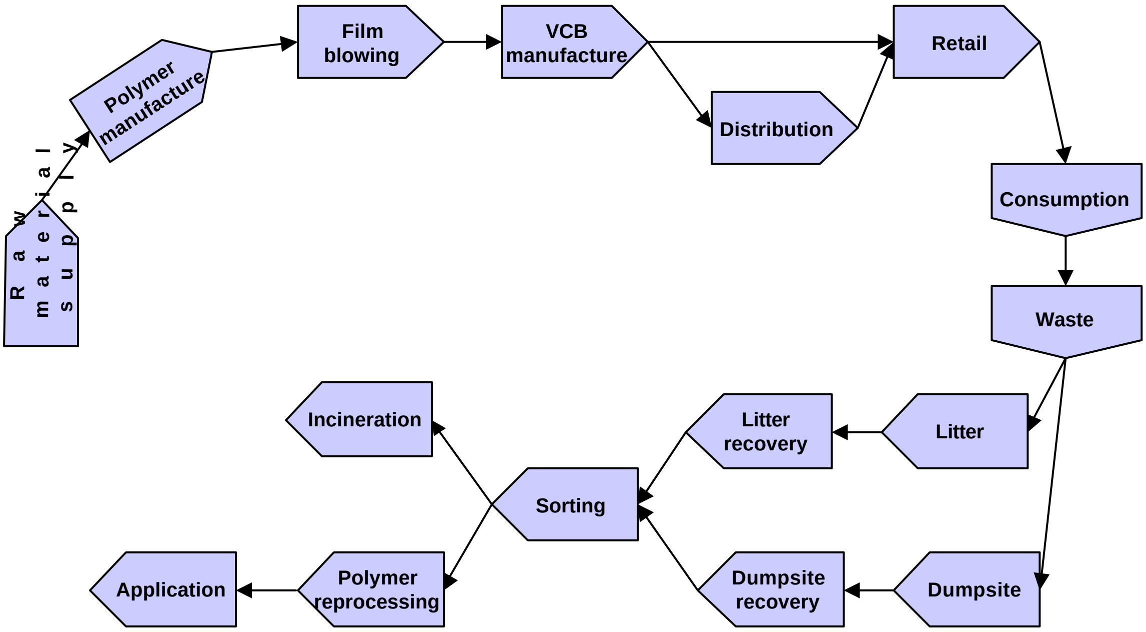
---

[4] LCA – Help or Headache?, Estelle Hook, http://www.co-design.co.uk/ehook.htm

[5] Use of Life Cycle Assessment (LCA) as a Policy Tool in the Field of Sustainable Packaging Waste Management, A EUROPEN Discussion Paper – September 1999, http://www.europen.be/issues/lca/lca_revised.html

3.6 Generic Life Cycle of Plastic Carrier Bags

The life cycle of plastic vest type carrier bags is illustrated in the diagram below.



Raw material supply and polymer production

Polymers used in the plastic resin and manmade fiber industries either occur naturally, such as cellulose, or are formed during polymerization when bond-forming reactions cause small repeating molecules to join together. Polymers are typically made from one type of simple chemical unit, or monomer.

Polymers are central to plastic resin manufacture. Many grades of different polymers are produced, each with different physical characteristics such as strength and ease of flow when melted. These different physical characteristics are achieved by changing operating parameters or by using different polymerization processes to change properties, such as polymer density or molecular weight. Polymers, which have been dried and formed into pellets, are called plastic resins. These resins are further processed at plastics processing facilities that create plastic products of different shapes, sizes and physical properties.

There are several steps that are important to polymerization. First, reactants are purified prior to polymerization. During polymerization, catalysts, heat, pressure and reaction time are all optimized to maximize polymer conversion and speed the reaction. Finally, the polymer is extruded and palletized for packaging and shipment. Various supporting steps are important to note because of their potential effect on the environment. These supporting steps include unloading and storage of chemicals and equipment cleaning.

Conversion of plastic film

Polymer resins are delivered to converters either in bulk tankers or in plastic sacks. Molten polymer is extruded as a continuous tube. As it leaves the extrusion die, the tube is inflated with air to form a bubble and when the bubble reaches the appropriate size it is cooled by air that changes it into a solid film. The region where the solidification occurs is known as the 'frost line', is the region where the required film thickness is reached. The tube is then guided by collapsing boards and gradually flattened and gusseted as it approaches the pinch rolls. When the film passes between them, the top of the bubble is effectively sealed.

The flat film is fed to the winding equipment via a pre-treatment and slitting unit. Slitting and trimming is a continuous operation. The flat film is then wound onto rolls.

Machinery for the extrusion of HDPE and LDPE differ significantly due to the different nature of the molten polymer. The differences prevail primarily in cooling, dye units and screws.

VCB manufacture

The gusseted wound film is unwound and passed through a series of rollers. Depending on the printing requirements the film may be passed under ultra violet lights to serve as preparation for printing and print curing. The film may then be printed.

Printed film is passed through rollers, sealed and cut at predetermined lengths. Lengths of film are then stacked and punched to form the handles of the vest type carrier bag. Bags are then bundled and baled for distribution.

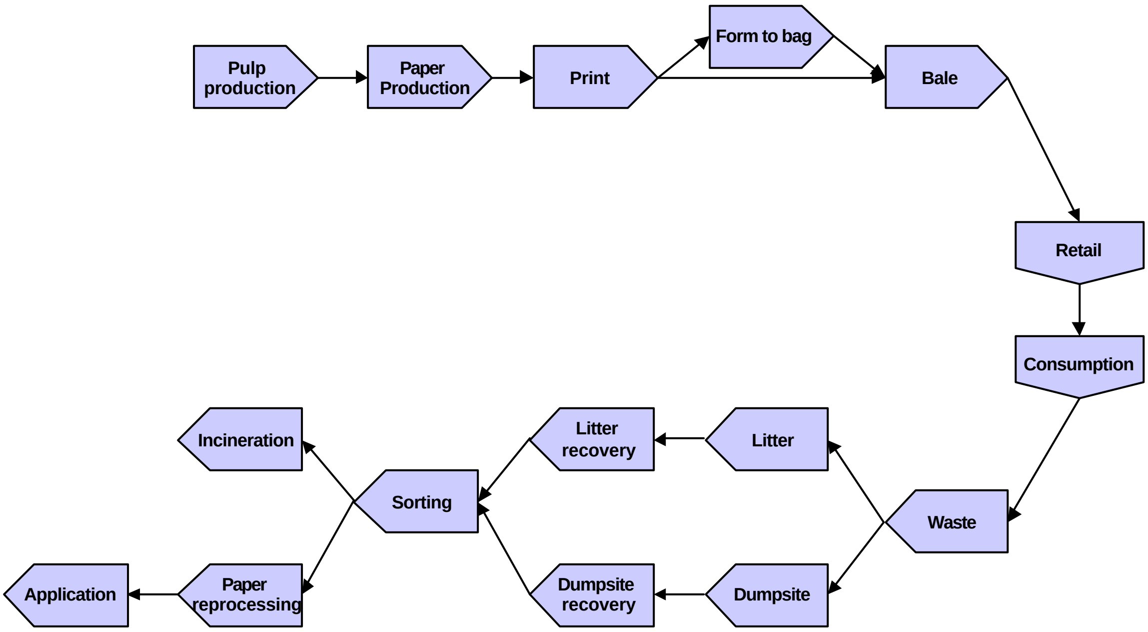
Distribution and consumption

Vest type carrier bags are distributed to formal and informal retailers though numerous mechanisms including hawkers, distributors and direct delivery. Carrier bags are used on checkout to hold purchased goods. On completion of use the carrier bag is thrown away or reused in numerous ways such as bin liners and carriers.

Waste management

The sources of materials for recyclers typically comprise in-house film that is collected and sorted by polymer grade. Collectors obtain materials from those not wishing to recycle their own materials and may also wish to obtain material from dumps by means of teams of pickers. Materials are then sorted and baled. Materials collected generally comprise post consumer waste and in process waste. Sorted and baled materials are passed through a granulator, agglomerator and then pelletised.

3.7 Generic Life Cycle of Paper Carrier Bags



Raw material production

Paper is manufactured by applying a watery suspension of cellulose fibres to a screen which allows the water to drain and leaves the fibrous particles behind in a sheet. Most modern paper products contain non-fibrous additives, but otherwise fall within this general definition. Only a few paper products for specialized uses are created without the use of water, via dry forming techniques. The watery fibrous substrate formed into paper is called pulp. The production of pulp is the major source of environmental impacts in the pulp and paper industry.

Processes in the manufacture of paper and paperboard can, in general terms, be split into three steps: pulp making, pulp processing, and paper/ paper board production. First, a stock pulp mixture is produced by digesting a material into its fibrous constituents via a chemical, mechanical, or a combination of chemical and mechanical means. In the case of wood, the most common pulping material, chemical pulping actions release cellulose fibres by selectively destroying the chemical bonds in the glue-like substance (lignin) that binds the fibres together. After the fibres are separated and impurities have been removed, the pulp may be bleached to improve brightness and processed to a from suitable for paper-making equipment. At the paper-making stage, the pulp can be combined with dyes, strength building resins, or texture adding filler materials, depending on its intended end product. Afterwards, the mixture is dewatered, leaving the fibrous constituents and pulp additives on a wire or wire-mesh conveyor. Additional additives may be applied after the sheet-making step. The fibers bond together as they are carried through a series of presses and heated rollers. The final paper product is then spooled on large rolls to be passed on to subsequent steps.

Conversion

Self opening bags are produced on S.O. bag machines, some of which have their own in line printing presses. These presses are used when the number of colours or type of design do not justify pre-printing. After printing, the plies pass trough slitters which pre-cut the bottom of the bag, and a cross pasting station where the plies are pasted together at regular intervals. A nozzle then applies adhesive to the longitudinal seam. The plies are then folded over one another and the pre-pasted seams allowed to adhere to the form a tube. This tube is immediately flattened, gussets being formed in the process. The tube now passes between a revolving knife and a stationary knife which cut with a scissor action, and separate the tube into individual lengths for converting into bags. The pre-slit bottom section of each length is opened up with the aid of suction cups and forming guides after which adhesive is applied. Bottom pasters ensure that adhesive is transferred to the required position on the bottom. The bottom is then closed by means of formers and rollers. The completed bags are compressed between a series of rollers before being counted, bundled and palletized.

Distribution and consumption

Paper checkout bags are distributed to retailers through numerous channels including distributors and direct supply. Paper checkout bags are primarily used by boutique stores and distributed free of charge to consumers at checkout. Currently paper bags make up approximately 9% of bags distributed by small retailers. However the percentage of grocery checkout carrier bags is significantly smaller than that (currently estimated at less than 1%).

Waste management

After use bags can enter the sorting phase by one of two mechanisms namely from litter or the dumpsite. After collection the waste is then sorted and depending on quality and condition is either disposed of by incineration or dumping or recycled.

3.8 Research approach for the life cycle assessment

Publicly available literature relating to LCAs of plastic, paper and cloth check out bags was sought from the following sources:

- ECOINVENT (Energy-materials-environment Group)
- BUWAL 250 (ETH Swiss Federal Institute of Technology)
- Eco-profile of the European plastics industry (APME)
- IVAM (IVAM Environmental Research)
- FEFCO
- STFI
- VITO (Flemish Institute for Technological Research)
- KCL ECODATA (The Finnish Pulp and Paper Research Institute)
- PEMS (Packaging Industry Research Association)

The review managed to identify numerous point sources of inventory data in the form of 'eco-profiles'. Lack of data continuity prevented the production of a Life Cycle Inventory, it was therefore necessary to resort to studies in which the complete life cycle for products had been analysed. Since the scope and objectives of LCAs greatly affect results, in order to provide comparisons between product types it was necessary to target comparative studies.

Review of the relevant literature revealed two studies that dealt with direct comparisons between paper and plastic sacks.

The first study, undertaken in the United States, is an LCA based comparison of LDPE and Paper "1/6 barrel grocery sacks" and was undertaken by Franklin Associates.

The second study undertaken in Europe dealt with the distribution of agricultural filling goods in different distribution systems, namely paper, plastic, semi-bulk and bulk. The distribution systems are 25 kg (capacity) sacks made of 140 micron Low Density Polyethylene and 70 g/m^2 two ply unbleached paper.

No data was found relating to the life cycle of biodegradable plastics. Industry experts however felt that biodegradable plastics offer no real life cycle benefit since production is on a smaller scale than polyethylene therefore production facilities are not as efficient per kilogram of polymer. In addition due to lack of local production facilities of biodegradable resins therefore require shipping thereby significantly affecting the life cycle profile. None of the alternative biodegradable polymers would have a density lower than polyethylene; therefore equivalent bags would require more resin thereby attracting a life cycle penalty[6].

No life cycle inventory data, or life cycle analyses were found for cloth bags this therefore has been left out of the report.

3.9 Limitations of the research approach

There are a number of issues affecting the comparison of the above studies both to the South African environment and to one another, for example:

- Geographies
    - Temperature
    - Availability of land
    - Annual rainfall
- Product life cycle
    - Raw material source (e.g. coal vs. oil)
    - Sources of energy (nuclear, coal, hydro electric power stations)
    - Production processes (Cracking and extrusion technologies, emission controls)
    - Conversion processes (Modern and antiquated technology)
    - Consumer processes (propensity for reuse, propensity to recycle, waste management, is the product used as a source of energy?)
    - Waste management processes
- Objectives and scope
    - Definition of system parameters
    - Definition of objectives
    - Data collection methodology

The issues listed above are indicative of the factors that may, or may not, cause significant differences in LCAs for similar products in different circumstances. These factors compromise the ability to use the above studies in the South African context. The two studies are, however, presented in the following section and conclusions drawn.

---

[6] Email communications with Tony Kingsbury, President of the International Biodegradable Products Institute, 27th August 2001.

3.10 Presentation of relevant literature

The functional unit

The functional unit of an LCA is the amount of product or material for which the environmental loadings are quantified. When comparisons are performed it is important that the products to be compared fulfil the same function, therefore the unit of comparison in both the following studies is 10,000 uses.

Study 1: Title: **"Resource and Environmental Profile Analysis of Polyethylene and Unbleached Paper Grocery Sacks,"** Franklin Associates, Ltd., 1990.

Franklin Associates, an independent Life Cycle Analysis and Solid Waste Management consultancy undertook the study.

Background

Packaging materials, in the United States, had come under the scrutiny of a wide range of interest groups as a result of decreasing landfill capacity, an inability to find new landfill sites and the large percentage by volume of packaging materials in landfills.

Objectives

The objective of this study is stated as the determination of energy and environmental discharges of polyethylene and paper grocery sacks.

Scope

Grocery bags examined in the study were the:

- 1/6 barrel polyethylene (HDPE and LLDPE) vest type grocery sacks; and
- 1/6 barrel 70 pound base weight single ply unbleached paper grocery sack.

Details of the sacks considered.

Bag type	Micron/ g/m^2	Dimensions (cm)	Similar to	Indicative pricing
1/6 Barrel Polyethylene	unknown	51 x 30.5 x 20	Maxi VCB	$ 45/ 1000
1/6 Barrel Paper	110	44 x 18 x 31	Shopper paper checkout bag	$ 70/ 1000

These sacks were regarded as being standard issue plastic and paper sacks used in grocery stores in the United States.

The utilisation ratio of polyethylene to paper sacks was identified as critical to the project. It was identified that there was no representative industry ratio indicating the number of uses of polyethylene grocery sacks that fill the same role as paper grocery sacks. The results of the analysis are presented at ratios of 1.5:1 and 2:1, i.e. 1.5 plastic sacks filling the same role as 1 paper sack. It is however recognized that the plastic sack has a greater reuse capability.

Methodology

A cradle to the grave approach was used to determine the energy and environmental discharges of the packages, this quantified energy consumption and environmental emissions at each stage of the product's life cycle beginning at the point of raw material extraction and proceeding through processing, manufacture, use and final disposal, or reuse.

Energy use was presented in the report in British Thermal Units but has been converted to Mega Joules for the purposes of this report.

Government documents as well as federal regulations, technical literature and confidential industry sources form the basis of the data.

Three broad environmental categories were considered, namely solid wastes, atmospheric emissions and waterborne wastes.

Both paper and polyethylene sacks were considered to participate in an "open loop" recycling system, in that recycled materials would replace virgin materials in the manufacture of other goods (e.g. in the case of polyethylene recycled material would go to the manufacture of pipes, etc.).

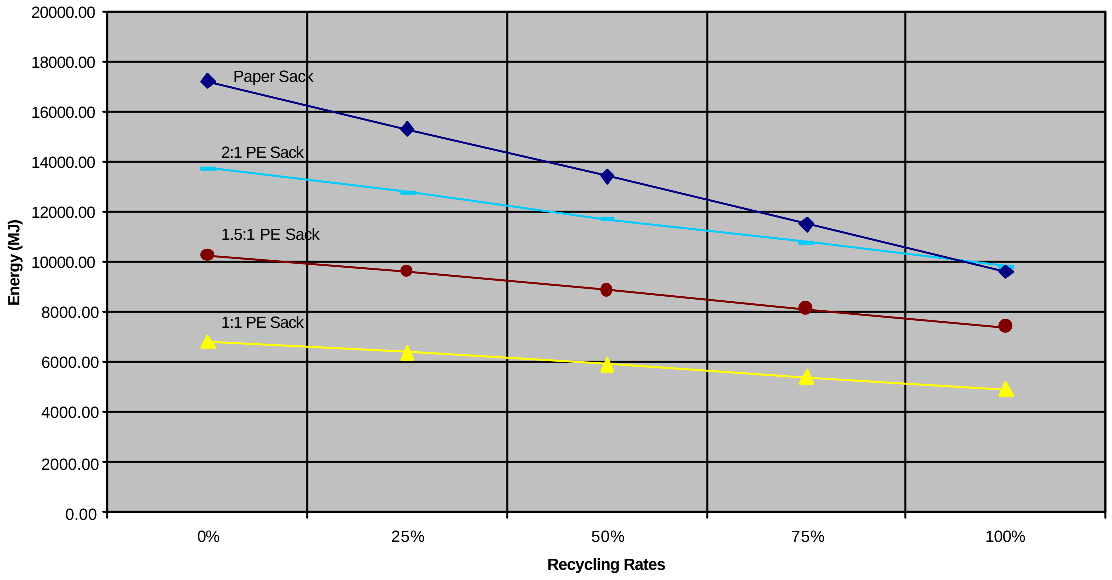
Findings of the study

Energy requirements

Energy requirements for 1/6 Barrel PE and Paper Grocery Sacks at Various Recycling Rates (MJ/10 000 bags)					
Sack type	**Recycling rates**				
	0%	**25%**	**50%**	**75%**	**100%**
1.0 PE to 1 Paper Sack Ratio					
Polyethylene	6822.70	6400.67	5908.31	5415.95	4923.59
Paper	17197.41	15298.31	13399.21	11500.11	9601.01
1.5 PE to 1 Paper Sack Ratio					
Polyethylene	10234.04	9601.01	8862.47	8123.93	7385.39
Paper	17197.41	15298.31	13399.21	11500.11	9601.01
2 PE to 1 Paper Sack Ratio					
Polyethylene	13715.73	12766.18	11711.12	10761.57	9812.02
Paper	17197.41	15298.31	13399.21	11500.11	9601.01

The energy requirements for the plastic polyethylene sacks were found to be 20 to 40% less than for paper sacks at zero percent recycling for both sacks. As recycling increases, the energy requirements became equivalent at approximately a 90% recycling rate (for a 2:1 ratio)

Energy requirements for Grocery Sacks



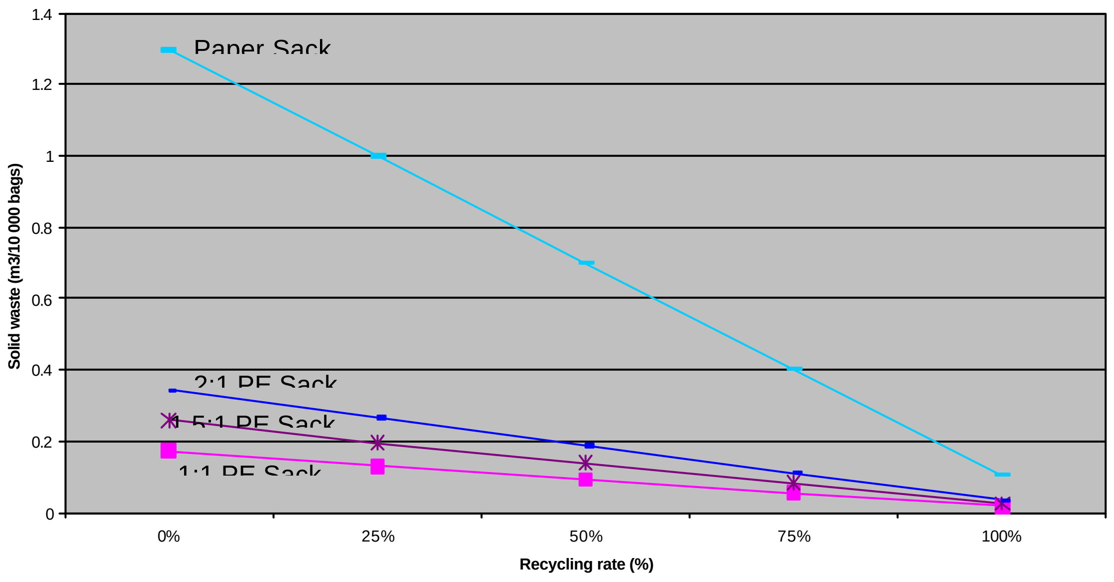
Environmental

Solid waste emissions

Solid waste emissions (m^3/ 10 000 bags)					
Sack Type	**Recycling rates**				
	0%	**25%**	**50%**	**75%**	**100%**
1 PE to 1 Paper Sack Ratio					
Polyethylene	0.17	0.13	0.09	0.05	0.02
Paper	1.30	1.00	0.70	0.40	0.10
1.5 PE to 1 Paper					
Polyethylene	0.26	0.19	0.14	0.082	0.025
Paper	1.30	1.00	0.70	0.40	0.10
2.0 PE to 1 Paper					
Polyethylene	0.34	0.27	0.19	0.11	0.03
Paper	1.30	1.00	0.70	0.40	0.10

For the purposes of this study solid wastes comprised ash from energy generation and incineration and post consumer solid wastes. Polyethylene sacks were found to contribute 74 to 80 percent less solid waste than paper sacks at zero percent recycling. Polyethylene sacks continued to contribute less solid waste than paper sacks at all recycling rates.

Total solid wastes for grocery sacks



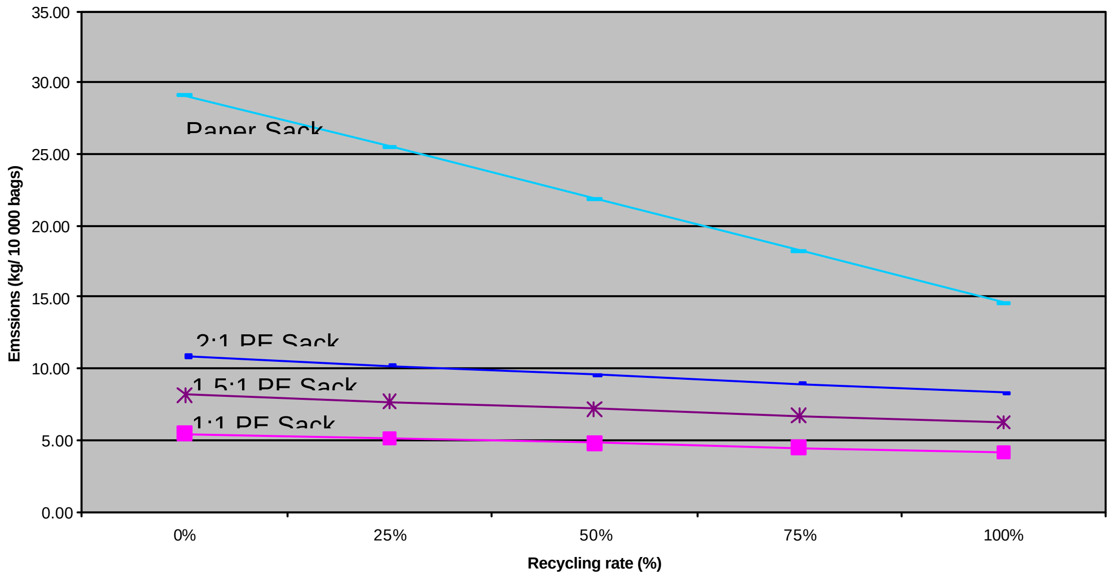
Atmospheric emissions

Atmospheric emissions (kg/ 10 000 bags)					
Sack Type	**Recycling rates**				
	0%	**25%**	**50%**	**75%**	**100%**
1 PE to 1 Paper Sack Ratio					
Polyethylene	5.41	5.11	4.78	4.48	4.14
Paper	29.12	25.49	21.86	18.23	14.61
1.5 PE to 1 Paper					
Polyethylene	8.12	7.67	7.17	6.71	6.21
Paper	29.12	25.49	21.86	18.23	14.61
2.0 PE to 1 Paper					
Polyethylene	10.84	10.21	9.57	8.94	8.30
Paper	29.12	25.49	21.86	18.23	14.61

Six components were analysed in combination in this category, namely particulates, nitrogen oxides (NO_x), Hydrocarbons, sulphur oxides (SO_x), carbon monoxide and odorous sulphur.

Atmospheric emissions for the polyethylene sack were found to range from 63 to 73 percent less than for paper sack at zero percent recycling. These lower impacts for polyethylene sack continued throughout all recycling rates.

Atmospheric emissions of grocery sacks



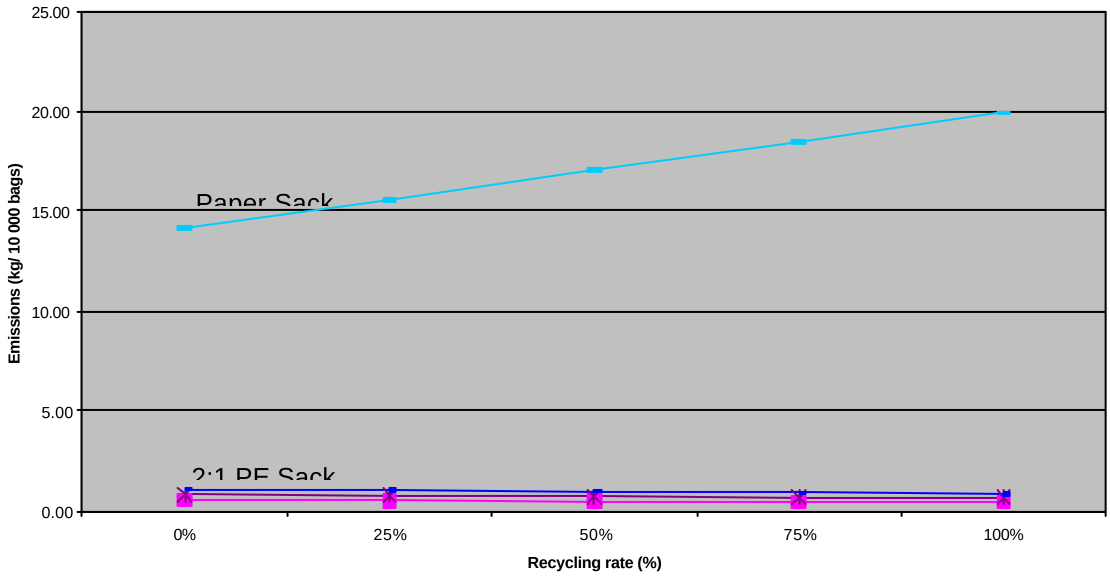
Waterborne wastes

Waterborne emissions (kg/ 10 000 bags)					
Sack Type	**Recycling rates**				
	0%	**25%**	**50%**	**75%**	**100%**
1 PE to 1 Paper Sack Ratio					
Polyethylene	0.54	0.51	0.48	0.45	0.45
Paper	14.15	15.56	17.06	18.46	19.91
1.5 PE to 1 Paper					
Polyethylene	0.82	0.77	0.73	0.68	0.68
Paper	14.15	15.56	17.06	18.46	19.91
2.0 PE to 1 Paper					
Polyethylene	1.09	1.04	1.00	0.91	0.86
Paper	14.15	15.56	17.06	18.46	19.91

Four components were analysed in combination in this category, namely dissolved solids, biological oxygen demand (BOD), suspended solids and acids.

At zero percent recycling rate the polyethylene sack contributed over 90 percent less waterborne wastes than the paper sack. As the rates of recycling increased the difference was found to increase as the recycling of paper contributes more to waterborne wastes than paper made from virgin material.

Waterborne wastes for grocery sacks



Recyclability

Both polyethylene and paper sacks were found to be recyclable. Manufacturing and scrap trim from the fabrication of the sacks were typically recycled. Post consumer recycling for both sacks was not found to be significant. In the case of paper sacks, recycling efforts relied on the collection of old newspapers as a support. For Polyethylene sacks, efforts were found to focus on industrial film scrap.

Combustion

Polyethylene releases 2.75 times more energy upon incineration than unbleached paper. However on an unequal basis, paper grocery sacks weigh 4 to 5 times more than plastic grocery sacks. Therefore the paper sack was noted as having the greater potential for energy release from incineration than the polyethylene sack.

Landfill impacts

The landfill volume occupied by the polyethylene sack is 70 to 80 percent less than the volume occupied by paper sacks given equivalent uses. It was noted that little data exists regarding the rate of degradation for both polyethylene and paper. It was therefore argued that the rate of decomposition could not be estimated and so no estimates regarding the potential impact on landfill leachate or methane gas production were included.

Discussion

The products under consideration are clearly are directly relevant to the South African study. In terms of comparison to a South African situation the factors discussed earlier may alter the results significantly. Unfortunately the only access to the study was in the form of the final report. It was not possible to get better access to the study results.

Study 2: Title: **"Distribution in Paper Sacks,"** CIT Ekologik, Chalmers Industriteknik, 2000.

The study was undertaken by CIT Ekologik, an independent Swedish environmental consultancy, on behalf of Eurosac and CEPI Eurokraft.

Goal

To compare the environmental performance of distribution in 25kg paper sacks with alternative distribution systems. The alternatives include bulk distribution, 25kg Plastic sacks and 1000kg 'big bags'. It is noted that the products analysed in this study are fundamentally different products to check out carrier bags – they are bigger bags.

Objectives

The primary objective of the study was to compare the environmental impacts of distribution in paper sacks with those of distribution in other systems for filling goods in Europe.

Scope

All of the systems studied include extraction of natural resources, production of raw materials, production of sacks/big bags/silos, after use treatment and all associated transport.

On the comparison of the distribution systems, it became clear that the distribution system transport itself gave the highest impact of the studied systems. This was due to the assumed distribution of 1000kg of filling goods over a distance of 300km. It was also noted that the environmental effects were of the same size regardless of the packaging system and were therefore removed from the presentation of the study results.

The paper and plastics sacks are described as follows:

Bag type	Micron/ g/m^2	Dimensions (cm)
LDPE	140	37 x 72 x 13
Paper	2 x 110	50 x 70 x 13

The lifecycle phases covered in this report are explained in the table below

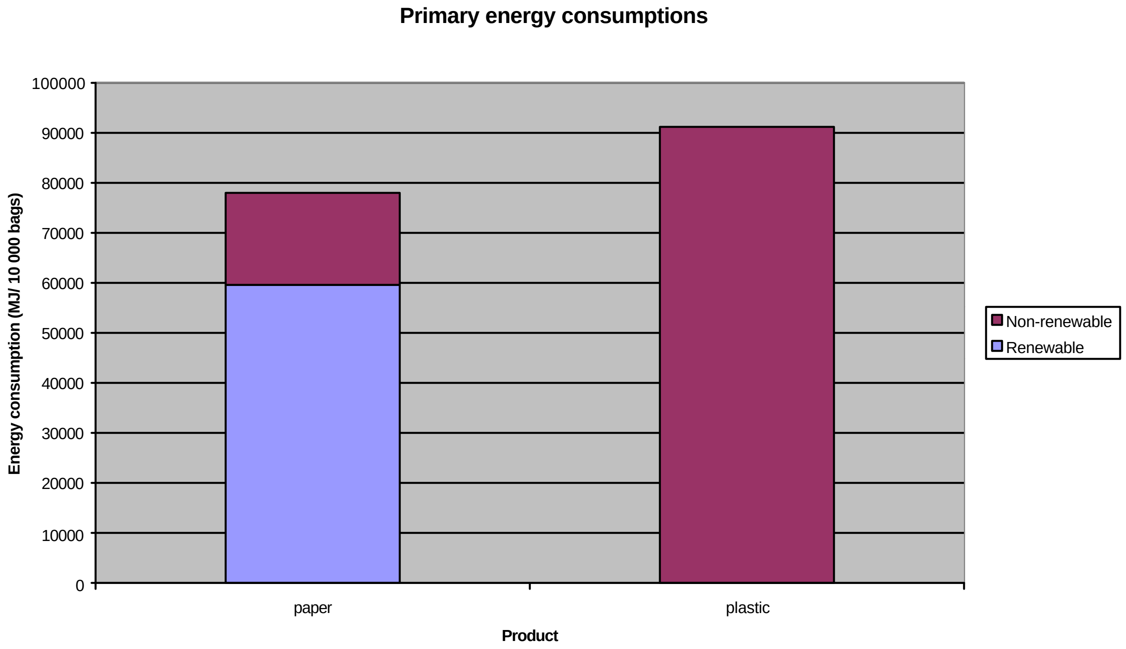
Life cycle stage	Explanation
Raw material production	Production of paper and LDPE from original source
Conversion	The conversion of paper and resin into Sacks
Waste management	Waste management, incineration, land filling or composting were considered as separate scenarios. The recycling scenario has assumed 100% recycling for both paper and plastic. Note for ease of comparison only reflected the recycling waste management scenarios have been reflected, however where relevant reference is made to other scenarios.
System expansion	The systems are expanded to include parts of other life cycles that are affected by the compared systems. The purpose of this system expansion is to avoid allocation problems that arise at waste incineration or at open loop recycling of material from one life cycle to another. The systems are expanded to include parts of other systems that are affected by the recycling of major materials after use in the distribution system.

This life cycle analysis considered environmental impacts under the following headings:

Impact category	Unit
Primary energy consumption	MJ/ 10 000 bags
Abiotic resource depletion	Kg/ year/ 10 000 bags
Global warming	Kg CO_2 equivalents/ 10 000 bags
Acidification	Kg SO_2 equivalents/ 10 000 bags
Nutrient enrichment	Kg NO_x equivalents / 10 000 bags
Photochemical ozone formation	Kg C_2H_2 equivalents/ 10 000 bags
Aquatic ecotoxicity (water emissions)	M^3 polluted water
Air emissions	Kg contaminated body weight
Water emissions	Kg contaminated bodyweight

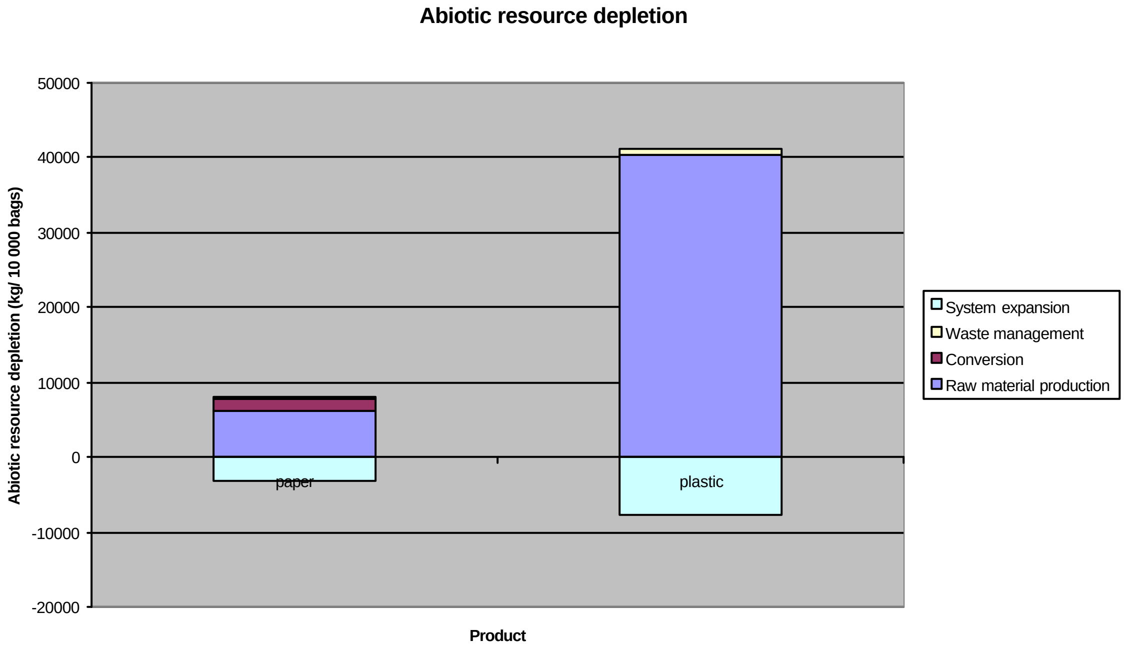
The findings of the analysis are presented in the following sections.

Primary energy consumption



Primary energy consumption was calculated including energy utilization in the production of the raw material (i.e. crude oil and wood). The LDPE sacks were found to give a higher contribution to the depletion of non-renewable resources than paper. This is due to the use of fossil raw material and energy in the production of LDPE.

Abiotic resource depletion

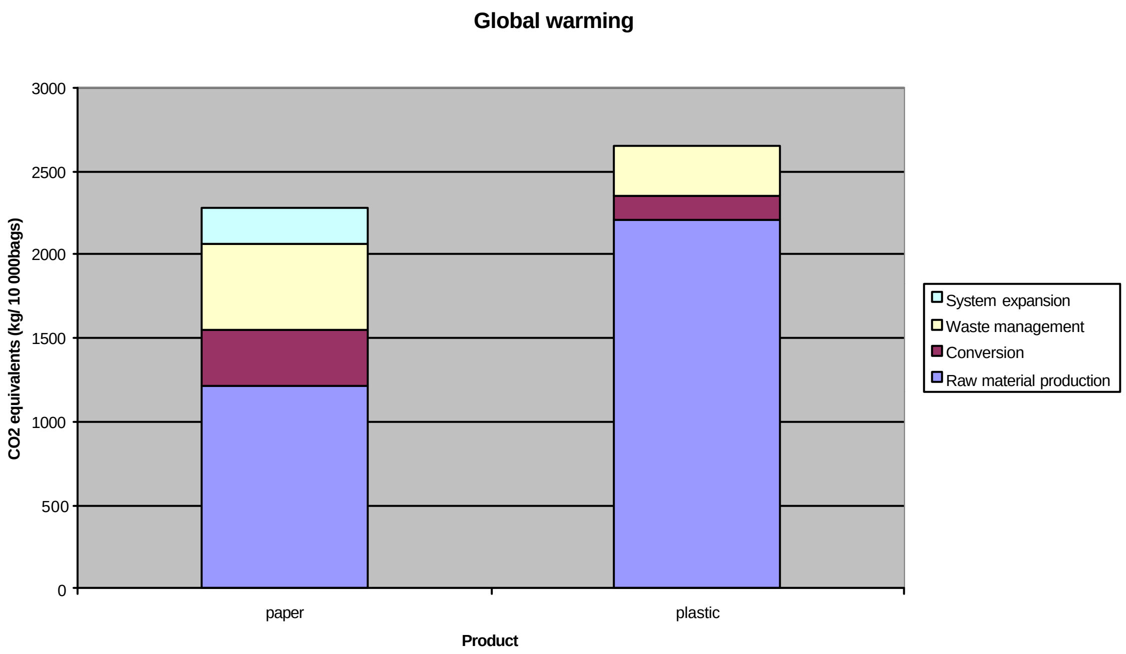


The depletion of abiotic resources such as metal ores and fossil fuels is problematic since it results in a situation where future generations will be required to resort to use other resources. It is important to note in this respect that, in Europe, forests grow faster than they are depleted and this was therefore not included as resource depletion.

The LDPE sack was found to give the highest contribution to abiotic resource depletion. This was dependant on the fact that, in the study geography, LDPE is made from crude oil and natural gas. The characterization factor associated to extraction of natural gas and oil is large due to the assumption that annual extraction is large when compared to reserves.

In addition the recycling scenarios gave higher contributions than the corresponding incineration scenarios since the energy produced on incineration was assumed to replace heat and electricity from other sources. Heat energy has been assumed to be a mix of 60% light fuel oil and 40% natural gas, and electrical energy was based on European averages.

Global warming



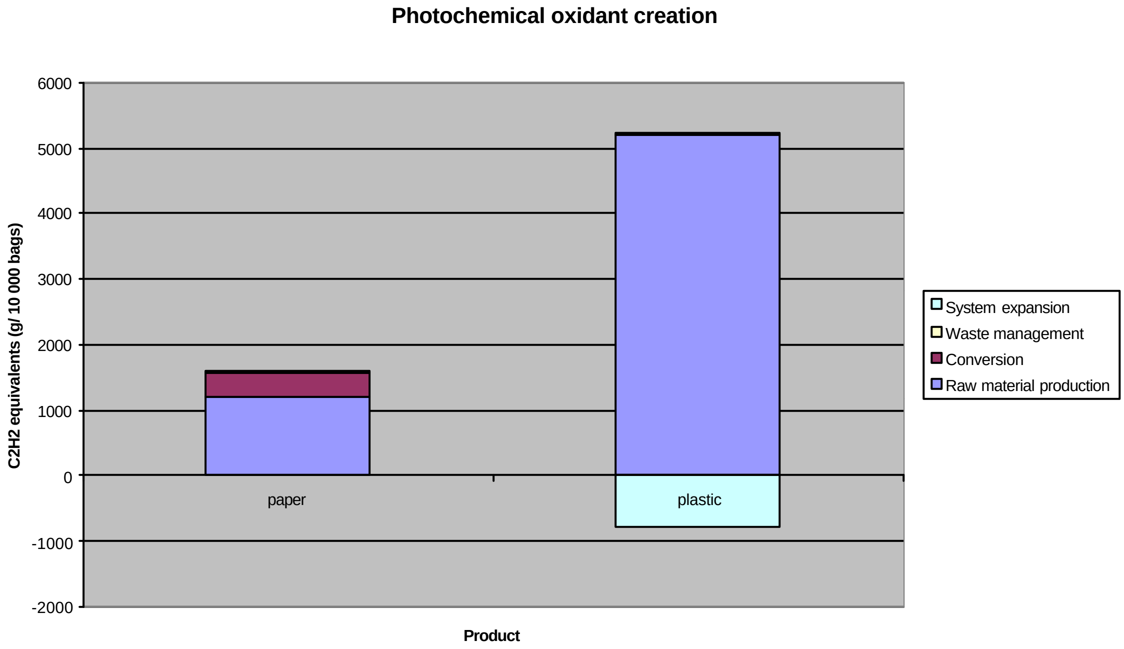
Global warming is caused by increases in the atmospheric concentration of chemical substances that absorb infrared radiation. Global warming is measured in CO_2 equivalents.

It was found that the LDPE sacks gave the highest potential contribution to global warming. It was also found that the contribution to global warming from paper sacks on incineration was low because the carbon dioxide at incineration of paper was deemed to be biological thereby eliminating a net contribution to global warming. In addition the heat generated during incineration has been assumed to replace heat produced from a mix of 60% light fuel oil and 40% natural gas.

The contribution from the LDPE sack, incineration scenario was found to be higher than the incineration scenarios for the paper sacks. This was due to the characterization of carbon dioxide emissions from incineration of LDPE as fossil, as opposed to biological. LDPE was found to have a higher 'heat value' than paper thereby allowing greater recovery of energy.

The contribution to global warming from the paper sacks, recycling scenario was found to be high. This was as a result of system expansion as the recycled sacks were assumed to replace virgin paper from other products that were assumed to end up in landfills thereby causing methane gas emissions.

Photo chemical oxidant creation



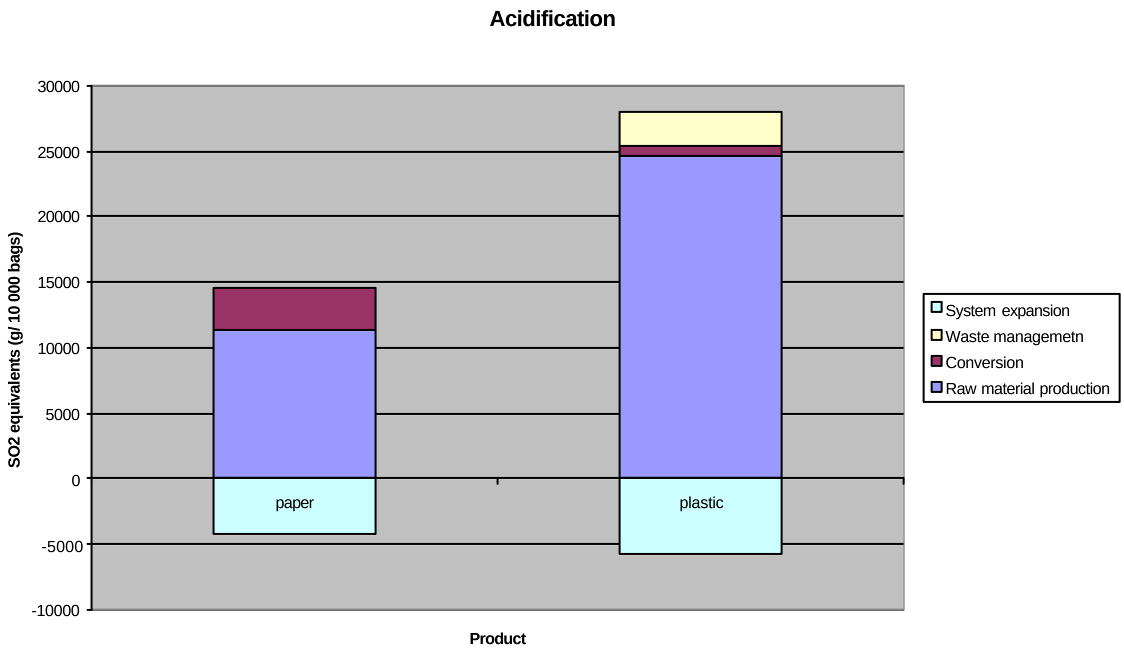
This impact category reflects the creation of oxidizing compounds through photochemical reactions in the air. The most important oxidant, in this context, is ozone.

The LDPE sack gave the highest contribution to photochemical oxidant creation. This was as a result of the emission of hydrocarbons from the production of LDPE.

The landfill scenarios for the paper sacks gave the higher contributions than the other scenarios for the paper sacks due to the formation of methane during decomposition.

An additional difference between photo oxidant creation was found to be a gap in data provided by STFI (i.e. lack of detail).

Acidification



Acidification is the reduction of the pH value in terrestrial and water systems. This is problematic since it causes substances, including nutrients, in the soil to dissolve and be carried away by water systems.

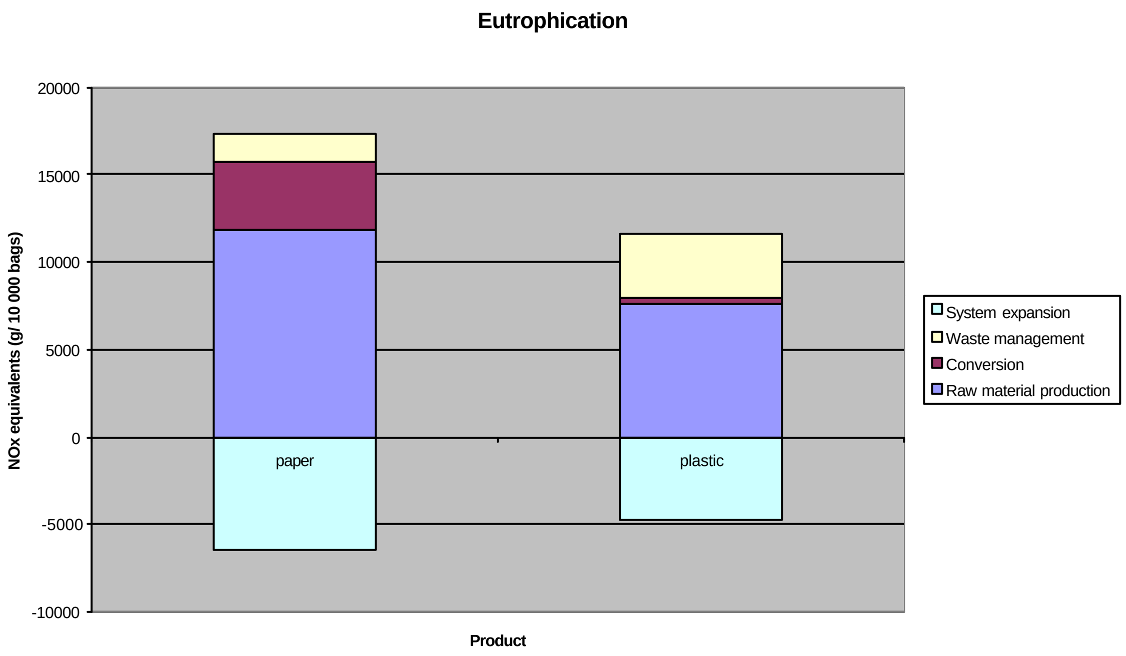
The LDPE sack gave the highest contribution to acidification due to emissions of NO_x and SO_2 associated with the use of fossil fuels.

During the incineration of LDPE, NO_x, is created, contributing to acidification.

The positive contribution to acidification from the recycling of LDPE comes from creation of NO_x and SO_2 at electricity generation. The negative contribution from the system expansion at the recycling of LDPE is mainly from the avoided LDPE production, the avoided LDPE recycling and from the alternative energy production.

The difference between the LDPE sack and the paper sack is however rather high, which primarily depends on the fact that at recycling, the LDPE has been assumed to replace only 17% virgin material while the paper replaces 44% virgin material.

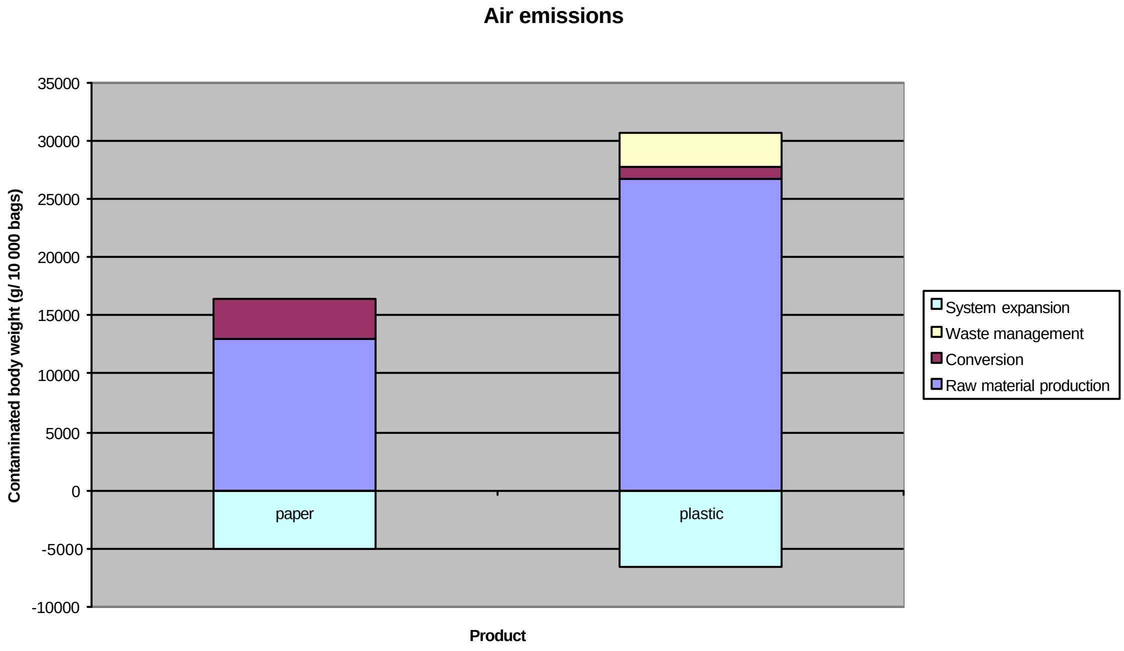
Eutrophication



Eutrophication is the disturbance of the nutritional balance in the soil. In aquatic systems this leads to increased production of biomass, which may lead to oxygen deficiency on decomposition.

The paper sack gave the highest contribution to eutrophication due to the high levels of COD from sack paper production.

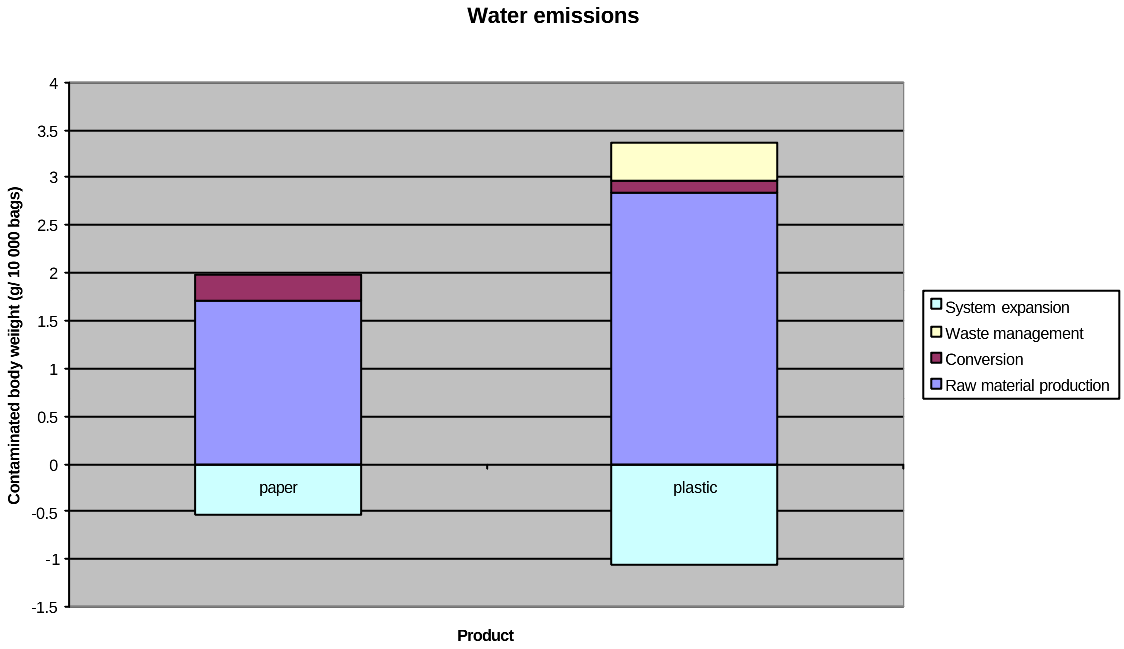
Air emissions



For human toxicity caused by air emission, it is the LDPE sack that gives the highest contribution. The emissions of NO_x and SO_2 associated with the use of fossil fuels at the production of LDPE were found to dominate thereby giving the LDPE sack a greater contribution to air emissions.

The positive contribution from the recycling of LDPE arises due to the creation of NO_x and SO_2 at electricity generation. The negative contribution from the system expansion at the recycling of LDPE is mainly from the avoided LDPE production, the avoided LDPE recycling and from the alternative energy production.

Water emissions

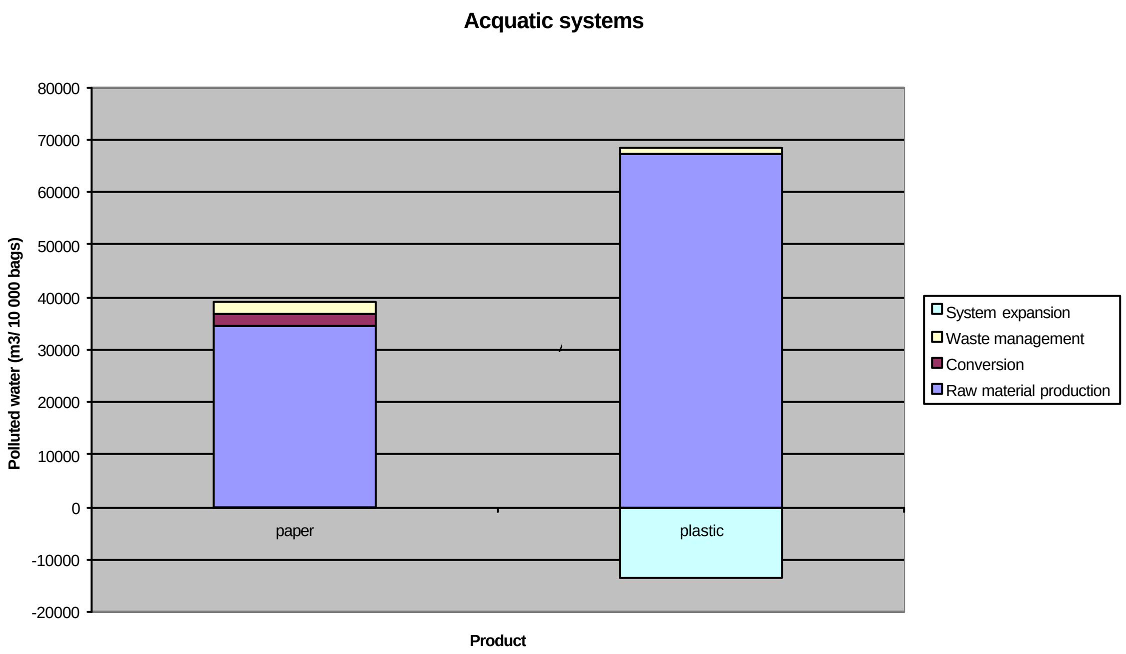


For human toxicity caused by water emissions, it is the bleached paper sack, landfill scenario that gives the highest contribution.

The negative contributions from the system expansions for recycling were found to be higher for the LDPE sacks than for the paper sacks. The recycling of LDPE was assumed to replace 83% recycled material from other products and 17% virgin material. The recycling of paper was assumed to replace 56% recycled material from other products and 44% virgin material.

The slight negative contribution from the recycling of paper is due to the production of electricity. This is a negative contribution due to the lack of emissions of iron (Fe) to water from European average electricity production.

Pollution of aquatic systems



The contribution to the pollution of aquatic systems from the production of LDPE was found to be higher than the contribution from paper production.

The negative contributions from system expansions for recycling are higher for the LDPE sacks than for the paper sacks.

3.10.1 Conclusion

The objective of this section was to prepare a comparison of the environmental life cycle effects of both plastic and paper checkout carrier bags. It was found however that due to the sensitivity of the results of LCA to factors such as scope, objective, geography, climate, energy sources including others that LCA's are limited in their comparison, firstly, between studies and, secondly, between environments (e.g. Europe and South Africa).

Life cycle studies analysing relevant products were found, the findings of which are listed for each of the impact categories in the table below:

Impact category	**Study 1** **1/6 barrel grocery sacks**	**Study 2** **25 kg (capacity) distribution sacks**
	Paper versus Plastic	**Paper versus Plastic**
Primary energy	Plastic life cycle uses 23.08% less	Paper life cycle uses 80.00% less
Solid waste	Plastic life cycle produces 75.68% less	Category not considered
Abiotic resource depletion	Category not considered	Paper life cycle depletes 85.00% less
Global warming	Category not considered	Paper life cycle contributes 95.69% less
Acidification	Category not considered	Paper lifecycle contributes 53.79% less
Nutrient enrichment	Category not considered	Plastic life cycle 55.36% less
Photochemical ozone formation	Category not considered	Paper life cycle contributes 64.04% less
Aquatic ecotoxicity	Category not considered	Paper life cycle contributes 37.04% less
Air emissions	Plastic life cycle contributes 57.45% less	Paper life cycle contributes 52.23% less
Water emissions	Plastic life cycle has 96.58% fewer	Paper life cycle contributes 28.79% less

Clearly the results presented in the table above are contradictory. This serves as an illustration as to the possible effect of project scope, system limitations, objectives and assumptions and possible geographic factors on the LCA results. Furthermore, close examination of the exact by-products examined as emissions in each LCA may reveal differences which identify why the results are contradictory (the consultants are not privy to these details). Greater access to studies may have shed light on sources of differences unfortunately however access was limited to the final reports of the projects. This however would shed no light on the possible geographic and environmental differences between study locations and South Africa. Furthermore, any LCA can be constructed to carry a specific message by carefully selecting the appropriate impacts to examine.

It is therefore concluded that in order to formulate an accurate assessment of which life cycle is the more environmentally friendly in the South African context a streamlined LCA should be commissioned.