The Litterability of Plastic Bags: Key Design Criteria

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ABSTRACT

Single use plastic bags are used by the billion in supermarkets, fast food outlets and retail stores because of their excellent fitness for use, resource efficiency and cheap price. They come in many varied shapes, sizes and materials. Because of their light-weight nature they are only a tiny fraction of the tonnage of plastic used in the packaging industry, yet they make a major contribution to litter, thanks to their large surface area and lack of biodegradability. In 2006 the Australian Government Department of Environment and Heritage initiated and funded, courtesy of the Natural Heritage Trust, a study to investigate the effect of bag design on litterability. This paper draws on report materials from the study that are the intellectual property of the Commonwealth. The paper presents a review of previous studies on plastic bags, a review of international plastic bag regulations, as well as the results of an assessment of the environmental impact of bag design using a streamlined life cycle assessment and the litterability of bag design using equipment including wind tunnels. The paper concludes with recommendations for bag design to maintain resource efficiency while reducing litterability.

Keywords: plastic bags, litterability, plastic bag design, life cycle assessment.

1. INTRODUCTION

Australian retailers provide their customers with two main types of single use plastic bags – light-weight high density polyethylene (HDPE) bags in supermarkets and fast food outlets and heavier gauge linear low density polyethylene (LLDPE) bags in department stores. The bags have various designs, for instance with or without a gusset, and with and without handle reinforcement. HDPE bags are frequently reused by householders as rubbish bags. The number of plastic bags was estimated in 2002 to be around 6.9 billion per annum (6 billion made from HDPE and 0.9 billion made from LLDPE [1]. A more recent estimate is 4.2 billion per annum (3.92 billion from HDPE and 0.3 billion from LLDPE), of which it is estimated for the HPDE bags that 51% are handed out at supermarkets, 11% through general merchandise, electrical and apparel stores, 18% through other food and liquor outlets, 9% through other retail and 7% through fast food and convenience stores [2]. An estimated 80 million find their way into air and waterways each year [3].

The exceptional properties of plastic make the bags extremely durable, so littered bags may survive in tact for many years. The bags if not disposed of correctly can become unsightly litter as well as a hazard for fauna.

The Australian Federal and State governments are considering their options for government regulation of plastic bags and around the world a variety of policies have been introduced with varying degrees of success. These range from voluntary codes of practice to levies through to bans. Environmental groups across the globe also want drastic action.

The Australian Retailers Association (ARA) Code of Practice was introduced in 2003, committing large supermarkets to a 25% reduction by end of 2004 in plastic bags issued, and a 50% reduction by end of 2005 [4]. The code expired in 2005. Some retailers have introduced a charge for bags and experienced an 80% reduction. Some small communities have also banned all retail plastic check-out bags, and experienced close to a 100% reduction. The Environment Protection and Heritage Council (EPHC), the council of State and Federal environment ministers, agreed in July 2005 to phase-out the use of HDPE bags by the end of 2008 [5]. On 17th July 2006 in a media release the Victorian Minister for the Environment announced that free plastic bags will be banned in Victoria from 2009. Retailers who give out plastic bags will have to charge a minimum of 10 cents per bag.

To date no reports have been published on whether the design of the bag or the composition of the bag influences the bag's "litterability" which is defined as the potential to exacerbate litter, in the air, sea or on land.

This paper presents the results of a review of previous studies on plastic bags, a review of international plastic bag regulations, and a further study on the design of plastic bags, conducted between January and June 2006 [6]. The purpose of the study was to further develop the scientific understanding behind various aspects of plastic bag litter impacts and assist in the design of future policies. Life cycle assessment (LCA) on different plastic bag designs are described, as well as test results for mechanical properties and dispersion by wind for bags of varying design. Section 2 presents a summary of previous studies undertaken in Australia on plastic bags to provide background on the development of policies around plastic bags.

2. PREVIOUS AUSTRALIAN STUDIES ON PLASTIC BAGS

In 2002 a report commissioned by Environment Australia, the Department of the Environment and Heritage, Australian Government, explored the likely impacts of levies and taxes on plastic bags and the potential impacts of alternatives by considering both the environmental and economic impacts [1]. The report found that different approaches have been taken throughout the world to plastic bags. At the time, Ireland was the only country that had introduced a plastic shopping bag levy that was paid directly by consumers. Denmark and Italy had indirect taxes paid by producers and Bangladesh, Taiwan, South Africa and parts of India were in the process of introducing bans on the manufacture and distribution of plastic bags.

The LCA[1] that was completed in the 2002 study found that environmental gains could be delivered if there was a shift from single use bags to more durable reusable bags. There was little or negative gains if shifts were made from single use plastic bags to other single use bags made from biodegradable materials or from paper. There may have been litter gains but these were offset by negative resource use, energy and greenhouse outcomes [1].

A number of options were investigated and it was found that voluntary and legislated levy options or expanding the Code of Practice for Shopping bags were the most viable options. The economic and environmental profile of five different potential measures based upon potential options for Australia was modelled in the 2002 study: a 15cents

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[1] The bags studied were singlet HDPE; 50% recycled singlet HDPE; boutique LLDPE; calico; woven HDPE swag bag; polypropylene fibre 'green bag'; Kraft paper handled; solid PP smart box; reusable LLDPE; biodegradable – starch based bag; and biodegradable – polyethylene with pro-degradant additives.

legislated levy with expanded Code of Practice; a 25cents legislated levy with expanded Code of Practice; a voluntary levy as part of the expanded Code of Practice; an expanded Code of Practice and a current Code of Practice (draft III) [1].

In 2002 a study into Biodegradable Plastics – Developments and Environmental Impacts was completed for Environment Australia (now the Australian Government Department of Environment and Heritage, DEH) [7]. The study found that there were nine different types of biodegradable plastics available with potential applications ranging from films, flushable sanitary products, bottles, food service components and loose fill foam. At the time the market penetration was low in Australia whilst in Europe several biodegradable plastics were being used for different applications. The study highlighted that there were several international standards and test methods for biodegradable plastics but there was currently none in Australia. A range of environmental impacts and benefits of biodegradable plastics were discussed and a number of key recommendations were made for successfully introducing degradable plastics into Australia.

DEH commissioned a further study on plastic bags in 2003 which was concerned with investigating the impacts of introducing degradable plastic bags into the Australian market with particular focus upon the effects on national recycling efforts, local manufacturing and landfills [8]. This was at a time when many different types of degradable plastics were being introduced into the Australia market and this was resulting in confusion about their impacts and benefits. The five types of degradation of degradable plastics were: biodegradable, compostable, oxo-degradable, photodegradable and water-soluble. There were also three different compositional structures of degradable plastics: thermoplastic starch-based polymers, polyesters and starch-polyester blends. It was reported that there is "*insufficient data to say with any certainty, how long many degradable polymers take to fully biodegrade, and the impacts of any end products in the environment*" [8, p 5]. Other findings were that [8, p 5-8]:

- *"The advantages of degradable polymers in landfill was questionable;*
- *The LCA*[2] *concluded that reusable bags have lower environmental impacts than all of the single-use bags including both conventional HDPE bags and degradable bags;*
- *Degradable polymers could potentially reduce the visual impacts of plastic bags in the litter stream;*
- *Degradable plastics have the potential to interfere with the processing of recovered polymers and to destabilise and compromise the properties of recycled polymers if they enter the plastics recycling stream;*
- *The choice for retailers and bag manufactures appears to be either to pursue a recycling strategy* *<u>or</u>* *a composting strategy for the bags – not both;*
- *The need for an Australian standard for degradable plastics".*

3. PLASTIC BAG REGULATIONS INTERNATIONALLY

A review of plastic bag legislation around the world, in 2006, covered 17 countries and found different approaches to the issues [6]. Some countries have introduced bans on all polyethylene bags (e.g., Bangladesh) and all non-biodegradable grocery plastic bags (e.g., France), while others have bans on bags with particular wall thicknesses (e.g., India and Nepal with wall thickness less than 0.02mm; Kenya 0.03mm; Taiwan 0.06mm; Rwanda 0.1mm; and South Africa 0.025mm). Taxes are applied to bags with particular wall thickness (e.g., Denmark, Ireland, Kenya) or on particular types of bags (e.g., Malta). The literature did not indicate why particular thicknesses were selected in the different regions.

4. BAG DESIGNS

The 2006 study evaluated whether bag design had an influence on the litterability of bags [6]. In March 2006 a wide range of single use light-weight carry bags (29) were collected from retail outlets in Melbourne. The outlets included supermarkets, food markets, takeaway shops, department stores, clothing chain stores, chemists, video stores, and bookshops. All the bags had some common features. Each bag was made from blown film (a continuous tube) with secondary welding and cutting operations to form the bag. The designs varied in a few details, such as the handles

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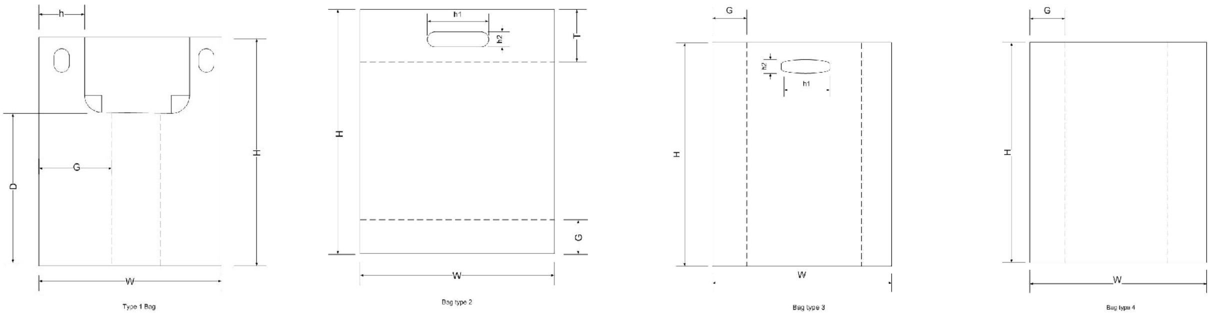
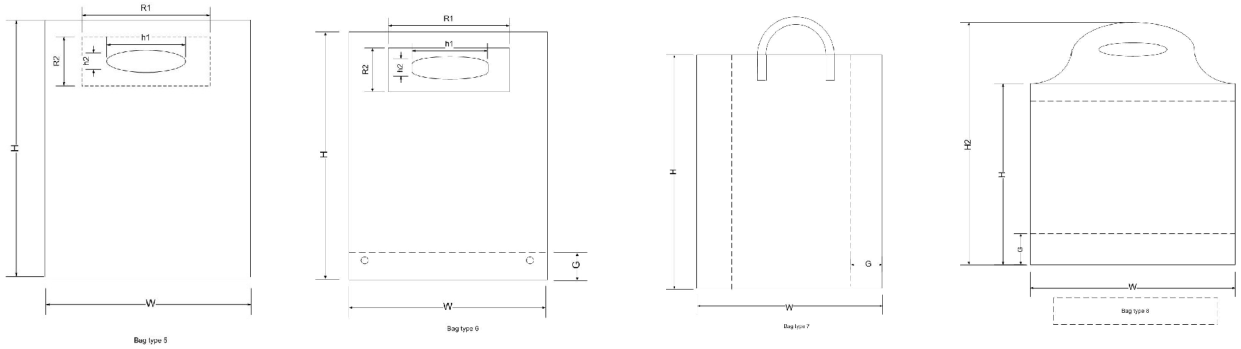
[2] Bag materials covered in the LCA were: degradable polymers consisting of (a) starch polybutylene succinate/adipate; (b) starch with polybutylene adipate terephthalate; (c) starch-polyester blend; (d) starch-polyethylene blend; (e) polyethylene + prodegradant; and (f) polylactic acid. The alternative bags were: singlet HDPE; Kraft paper handled; PP fibre "green bag"; woven HDPE "swag bag"; calico and LLDPE "bag for life" [9].

might be reinforced, cut out, or integral and the bag might have a gusset. Some bags were also coloured. The eight basic bag designs are shown in Table 1.

Table 1 The eight different designs from the samples collected



Design 1 **Design 2** **Design 3** **Design 4**



Design 5 **Design 6** **Design 7** **Design 8**

Source: [6].

Characteristic dimensions of each bag type were measured. This included the carrying volume, bag lay-flat height and width, size of handles, film thickness and bag mass. These are summarised in Table 2 below.

- These characteristics varied enormously.
- The carrying volume is a measure of how much shopping can be carried in the bag. This varied from 3.5 to 29.5 litres.
- The height and width is a measure of the litter area of the bag: the bigger the area, the more the visual impact when the bag is littered. The height varied from 300 to 570 mm. The width varied from 205 to 440 mm.
- The lay-flat area varied from 0.1 to 0.2 m^2.
- The thickness of the bag and its mass are indicators of its resource efficiency: the thinner and lighter the bag, the fewer resources used to produce it. The thickness varied from 7 to 97 microns.
- The bag mass varied from 2.5 to 39 grams.
- Volume to weight ratio is another measure of the resource efficiency. This varied from 0.3 to 3.7 litres/gram.

Supermarket bags had the best resource efficiency, with 3 or more litres/gram. Bags from boutique retail shop had the worst resource efficiency, at less than 1 litre/gram.

In summary, the collected bags varied markedly in carrying capacity (volume) and weight of the bag (mass) and had some minor variations in handle and gusset design.

Table 2 Bag characteristics

Design	Retailer (sample of bags collected)	Composition	Vol. (l)	Height (mm)	Width (mm)	Lay-flat area (m2)	Thickness (microns)	Mass (g)	Resource efficiency (l/g)
1	Supermarket 3	HDPE#	21.0	535	300	0.161	17	7.6	2.8
2	Video shop 1	HDPE	16.5	475	360	0.171	25	10.5	1.6
3	Bakery 1	HDPE	3.5	480	240	0.115	40	6.2	0.6
4	Butchers 1	HDPE	22.0	570	305	0.174	15	5.9	3.7
5	Fashion store 1	LLDPE	5.0	375	250	0.094	97	18.2	0.3
6	Department store 2	LLDPE	27.5	475	365	0.173	44	16.8	1.6
7	Fashion store 5	HDPE	29.5	485	405	0.196	72	38.8	0.8
8	Department store 3	HDPE	15.5	360	390	0.140	20	5.8	2.7

Recycled

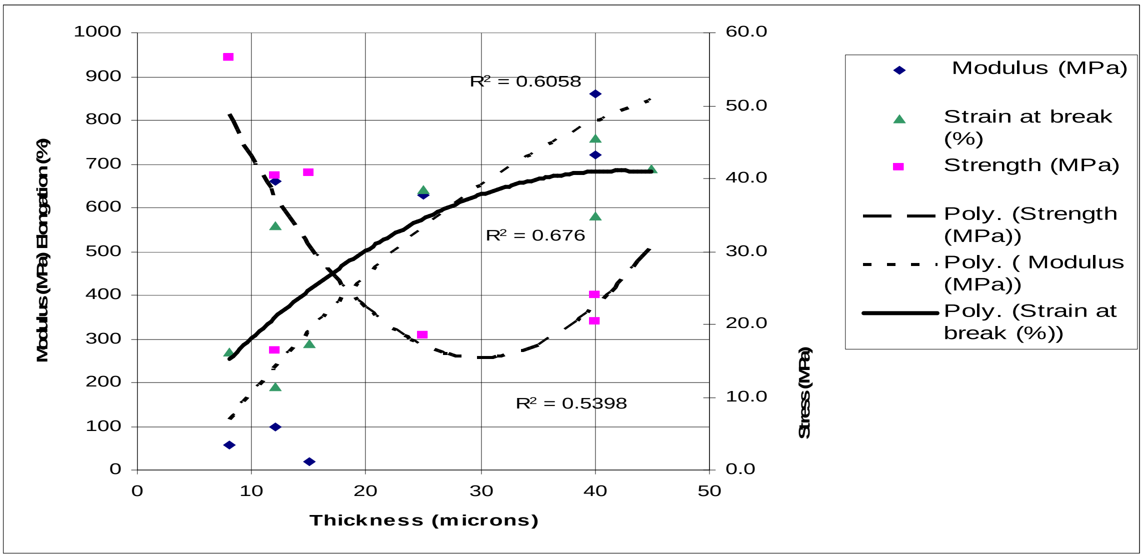
5. COMPOSITION AND MECHANICAL PROPERTIES OF BAGS

The mechanical properties were investigated to determine whether there was a relationship between litterability and the composition and mechanical properties of bags.

The composition of the bags was determined using differential scanning calorimetry (DSC). The bags were made of high density polyethylene (HDPE) or linear low density polyethylene (LLDPE). Some were labelled as degradable (this was not tested).

Good properties are needed to ensure the shopping (contents placed inside the bags) gets home safely. The bags were tested to failure in a number of different types of test, to assess the influence of bag characteristics, such as thickness, on bag performance. Stiffness is needed so that bags don't stretch excessively under a heavy load. Strength is needed to ensure the bag can hold a heavy load without failing. Some stretching is needed when the shopping has sharp corners, to prevent puncture or tearing. The test methods used for modulus, strength and strain at break were ASTM D882, for puncture ASTM D5748, and for tear ASTM D1938. Thinner bags were found to be stronger, but thicker bags were stiffer (Figure 1), stretched more and could resist tearing and puncturing better [6].

Figure 1 Tensile properties of bags as a function of thickness



The averaged results for HDPE and LLDPE bags are given in Table 3. The HDPE bags were stiffer while the LLDPE bags could stretch more. The bag size and mass had no significant influence on properties.

Table 3 Results for Mechanical Properties – averages for HDPE and LLDPE bags

	Modulus (MPa)	Strength (MPa)	Strain at break (%)	Puncture Max load (N)	Tear Resistance (N)
HDPE	508	20.1	630	37.8	6.6
LLDPE	147	19.2	690	40.9	7.8

In summary, bags are made of two materials, either HDPE or LLDPE. The material has a marked effect on mechanical properties. HDPE bags are stronger while LLDPE bags are tougher.

Bag design must suit the application and bags must have an appropriate specification, otherwise the packaged goods will be damaged by bag failure. The wide variation in bag dimensions as well as mechanical properties is surprising, considering the similarity of the application for these bags. This clearly shows that many current bags are "over-designed". The bags could fulfil their application requirements (of volume and kilos of goods to be carried) with lower bag mass by reducing wall thickness.

6. LITTERING OF BAGS CARRIED BY WIND

The eight bag designs were evaluated for their tendency to be dispersed by the wind. This tendency was evaluated in terms of the likelihood to inflate and fly off in the wind, the likelihood to disperse in the wind, and the likelihood to be snagged.

The likelihood to inflate and fly off in the wind was evaluated by placing closed bags in a wind tunnel, and measuring the air speed at "lift off". A summary of data is given in Table 4. The airspeed at lift-off varied from 0.8 to 3.1 m/s (equivalent to a wind speed of 3 to 11 km/hr). There was no significant difference between HDPE and LLDPE bags. Surprisingly, for LLDPE bags there was no difference between placing the bags facing upwind or downwind. For the HDPE bags, the bags were slightly harder to inflate if they faced downwind, as expected. This difference between HDPE and LLDPE bag behaviour was attributed to the HDPE bags being lighter on average.

A search for correlation between lift off speed and bag design characteristics revealed none at all: there was no significant correlation between lift-off speed and bag mass, volume, height, width, cross-section area or composition. In summary, all bags are likely to lift-off and fly in the wind at relatively low wind speeds; there is no design that is less likely to lift off.

How far a littered bag will disperse was evaluated by tethering bags in a wind tunnel and measuring the drag at various wind speeds. Drag is proportional to terminal velocity, and it is assumed that terminal velocity determines how long the bag will stay in the air before returning to earth. It is assumed that a bag will continue to "fly" in the wind until it snags on something on the earth's surface. The quicker a bag returns to earth, the sooner it may get snagged, ending its dispersal in the wind. A summary of results is given in Table 4. The drag coefficient correlated with bag volume (R^2=0.89), as expected, and bag cross section area (R^2=0.80). There was no significant correlation with other bag characteristics, including mass (R^2=0.50), height, width, and composition. The terminal velocity occurs when the force due to gravity is balanced by the force due to drag, so it is proportional to the bag's mass and inversely proportional to its drag coefficient. The calculations for the average for all HPDE bags compared to the average for LLDPE bags showed the terminal velocity was significantly lower for HDPE than LLDPE bags (Table 4). This suggests that littered LLDPE bags will return to earth quicker than HDPE, which may result in shorter dispersal distances *if the bag snags*. This was attributed to the combination of slightly lower drag coefficient and higher mass of LLDPE bags. Whether the bag snags will be discussed below. In summary, all littered bags are expected to disperse in the wind; bags with bigger volumes experience more drag and have lower terminal velocities. This may lead to longer dispersal distances.

Table 4 Results for littering of bags carried by the wind

	Bag mass (g)	**Down-stream Air speed (m/s)**	**Up-stream Air speed (m/s)**	**Drag Co-efficient**	**Terminal Velocity (m/s)**	**Probability of snagging**
HDPE	11.8±11	1.8±0.6	1.2±0.2	2.9±0.6	1.2±0.3	0.62±0.41
LLDPE	18.8±2.4	2.0±0.6	2.0±0.7	2.6±1.0	2.2±0.7	0.25±0.25

How likely a bag is to snag was evaluated by repeatedly releasing a bag in a wind tunnel upstream of a snag. Snagging may be a good or bad thing. It is unsightly on the banks of a river or at the beach, but can be useful in the vicinity of a landfill. It is assumed that dispersal of a wind (or water) borne bag will be terminated by snagging. Probability of snagging was found to vary significantly with bag type. That is, some bags snagged every launch, and some never snagged. Lighter bags snagged more frequently than heavier bags – snagging also showed a weak correlation with bag thickness and mass. The light bags are generally HDPE bags, so HDPE bags are more likely to snag than LLDPE bags (Table 4). It was observed that HDPE bags tended to fold around the snag, empty of air, and remain snagged, while LLDPE bags tended to fold, remain inflated and slip off the snag. In summary, low mass thin HDPE bags are more likely to snag than high mass thick LLDPE bags.

The wind-borne dispersal distance depends on both factors, how quickly the bag returns to earth as well as how likely it is to snag. Light bags have a lower terminal velocity, so are slower to return to earth, hence they would tend to disperse large distances. However, they are more likely to snag when they land back on the earth's surface, ending their dispersal. Heavier bags return to earth more quickly but are less likely to snag. Heavier bags would tend to disperse small distances, not snag, and disperse further on the next windy day, effectively dispersing for large distances until snagged. This suggests that both light and heavy bags (so, both HDPE and LLDPE bags) are likely to disperse long distances in moderate to high winds. Field trials would be needed to ascertain if there is any significant difference in dispersal distances between HDPE and LLDPE bags. However, owing to the difficulty in controlling launched plastic bags in real wind conditions, such field trials are undesirable.

In summary, all bags are likely to inflate, and hence disperse in the wind, even at low wind speeds. Bags with bigger volumes (and hence cross-sectional areas) have higher drag coefficients. Bags with higher mass have higher terminal velocities. Bags with low mass were more likely to snag (typically, HDPE bags have lower mass). Hence both low mass (HDPE) bags and high mass (LLDPE) bags are likely to disperse considerable distances, until they snag.

7. LIFE CYCLE ASSESSMENT RESULTS

Using life cycle assessment modelling and only accounting for the production of the polymer, the 14 selected bags were modelled under two scenarios per:

- Bag mass (gram); and
- Bag volume (litres).

Three environmental indicators were calculated: greenhouse gas emissions, cumulative energy demand and minerals and fuels depletion. Greenhouse gas emissions cause climate change due to the emission of carbon dioxide (CO2), methane or other global warming gases into the atmosphere – this indicator is represented in CO2 equivalents. Cumulative energy demand includes fossil, renewable, electrical energy and feedstock (energy incorporated into materials such as plastic). Minerals and fuels depletion includes the additional energy required to extract resources (both mineral and fossil) due to depletion of reserves, leaving lower quality reserves behind.

Figure 2 presents the greenhouse gas emissions per bag (on a mass basis). As would be expected the heavier and bigger the bag the higher its environmental impact will be. This is illustrated by the LLDPE material used in bags such as Fashion store 1, Fashion store 2, Fashion store 3, Department store 2 and Fashion store 4. This type of bag is typical of fashion and department stores where LLDPE material is used as it is perceived to represent a higher quality bag carrying a more expensive product. The HDPE bags on the other hand have a lower impact because they are more lightweight than the LLDPE bags and in some cases also have a smaller dimension than the LLDPE bags. Based upon the sampled bags, the Supermarket 1 and Fast food take away 3 bags have the lowest greenhouse emissions values.

Figure 2 Greenhouse gas emissions per gram of bag

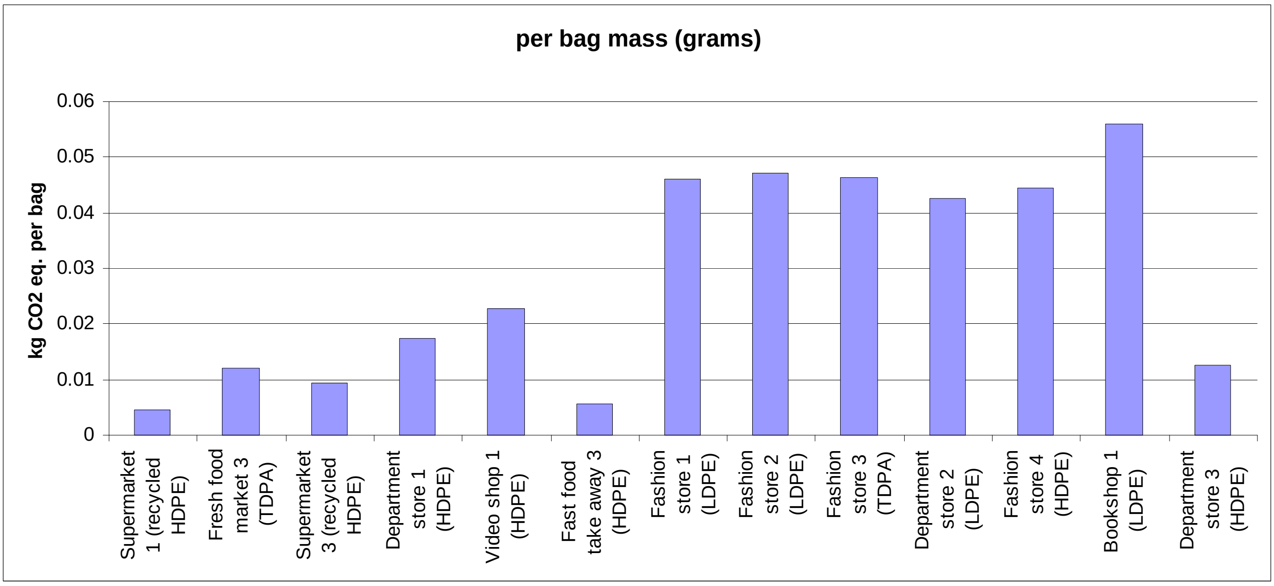


Table 5 presents the characterisation results of plastic bags per gram of bag for three environmental impacts – global warming, cumulative energy demand and resource depletion.

Table 5 Summary of Characterisation Results per gram of bag

Plastic bag	Global Warming (kg CO_2 eq.)	Cumulative energy demand (MJ LHV)	Resource Depletion (MJ surplus)
Supermarket 1 (recycled HDPE)	0.004	0.06	0.004
Fast food take away 3 (HDPE)	0.005	0.19	0.016
Supermarket 2 (Recycled HDPE)	0.009	0.12	0.008
Fresh food market 3 (bio/rec HDPE)	0.012	0.41	0.027
Department store 3 (HDPE)	0.013	0.44	0.037
Department store 1 (HDPE)	0.017	0.61	0.051
Video shop 1 (HDPE)	0.023	0.79	0.067
Fashion store 2 (HDPE)	0.044	1.54	0.129
Fashion store 3 (compostable HDPE)	0.046	1.58	0.103
Department store 2 (LLDPE)	0.043	1.37	0.114
Fashion store 1 (LLDPE)	0.046	1.48	0.124
Fashion store 2 (LLDPE)	0.047	1.51	0.127
Bookshop 1 (LLDPE)	0.056	1.80	0.151

The greenhouse gas emissions per bag volume are presented in Figure 3. In general a bag with a low emissions value had a low ratio of mass to volume (i.e., good bag efficiency). Most bags have a good mass to volume ratio except the Fashion store 1, Fashion store 2 and Bookshop 1 bags. The supermarket bags (e.g., Supermarket 1 and Supermarket 3) have very good mass to volume ratios.

Figure 3 Greenhouse gas emissions per volume of bag

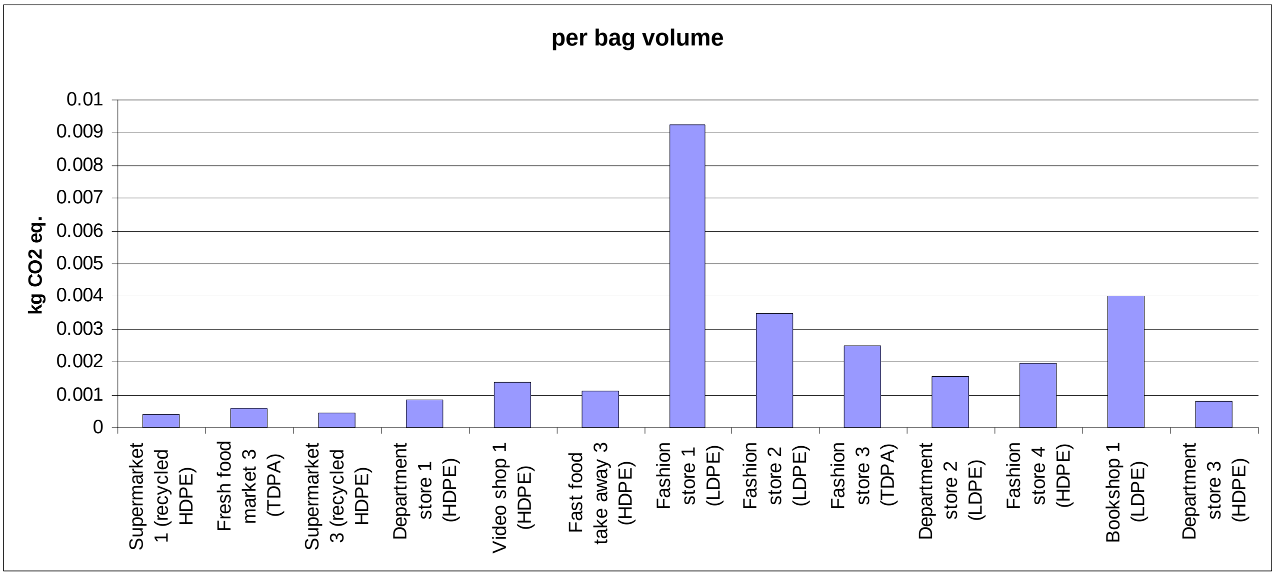


Table 6 presents the characterisation results of plastic bags by volume of the bag for three environmental impacts – global warming, cumulative energy demand and resource depletion.

Table 6 Summary of Characterisation Results per bag (on a volume basis)

Impact category	Global Warming (kg CO_2 eq.)	Cumulative energy demand (MJ LHV)	Resource Depletion (MJ surplus)
Supermarket 1 (recycled HDPE)	0.000388	0.00477	0.000344
Fresh food market 3 (bio/rec HDPE)	0.000598	0.0203	0.00133
Supermarket 2 (Recycled HDPE)	0.000444	0.00546	0.000393
Department store 1 (HDPE)	0.000868	0.0301	0.00253
Video shop 1 (HDPE)	0.00139	0.0481	0.00403
Fast food take away 3 (HDPE)	0.00111	0.0387	0.00324
Fashion store 1 (LLDPE)	0.00922	0.297	0.0248
Fashion store 2 (LLDPE)	0.00349	0.112	0.00938
Fashion store 3 (compostable HDPE)	0.00251	0.0851	0.00555
Department store 2 (LLDPE)	0.00155	0.0498	0.00416
Fashion store 2 (HDPE)	0.00197	0.0686	0.00575
Bookshop 1 (LLDPE)	0.004	0.129	0.0108
Department store 3 (HDPE)	0.000811	0.0281	0.00236

8. DISCUSSION AND CONCLUSIONS

Single use plastic bags have similar shapes and functions. Twenty nine different bags collected from retailers in Melbourne were characterised in terms of design, composition, mechanical properties and litterability. There are large variations in carrying capacity (volume) and weight of the bag (mass) and some variation in handle and gusset design. Bags are either high or linear low density polyethylene (HDPE or LLDPE respectively). Composition has a significant effect on mechanical properties – HDPE bags tend to be stiffer, while LLDPE bags tend to be tougher.

All bags were found to be likely to inflate and hence disperse in the wind. Lightweight bags had slightly higher drag coefficients and lower terminal velocities and were more likely to snag than heavier bags. This means they would tend to disperse large distances, until snagged. Heavier bags would tend to disperse small distances, not snag, and disperse further on the next windy day, effectively dispersing for large distances until snagged. Typically, lightweight bags are made of HDPE and heavier bags from LLDPE. So overall, it was found that bag design has little effect on bag litterability or tendency to litter. There is no current bag design that would yield significantly less littering.

Life cycle assessment showed that HDPE bags have lower greenhouse effects and embodied energy than LLDPE bags as they are thinner and lighter.

Bag design must suit the application and bags must have an appropriate specification, otherwise the packaged goods will be damaged by bag failure. It is clear from the wide variation in bag mechanical properties that many current bags are "over-designed" and could fulfil their application requirements with lower mass by reducing wall thickness. This would reduce the environmental impact in terms of green house gases and embodied energy.

It was found that a limited number of bag design parameters correlate with litterability. Small bags have lower visibility than large bags and thin light (HDPE) bags snag more easily than heavier (LLDPE) bags. However, bag size has to be appropriate to the application, and so "small bags" is not an option when a large bag is needed. Choosing thick heavy bags because they snag less easily is counter-productive, because they have lower resource efficiency and worse LCA impacts, as well as allowing wide dispersal because they don't snag. The characteristic that thin light HDPE bags snag easily could be used to as a means to minimise littering, consistent with the Environment Protection and Heritage Council (EPHC) Best Practice Guidelines for management of plastic bag litter at landfill sites [10].

9. ACKNOWLEDGEMENTS

The authors acknowledge the support of the Australian Government Department of Environment and Heritage in initiating and funding the study. This paper draws on report materials that are the intellectual property of the Commonwealth.

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