2014

Life Cycle Assessment of Grocery Bags in Common Use in the United States

Robert M. Kimmel, Sc.D.

Life Cycle Assessment of Grocery Bags in Common Use in the United States

Robert M. Kimmel, Sc.D.

Associate Professor of Packaging Science

Director, Clemson University Center for Flexible Packaging

Clemson University, Clemson, SC

Kay D. Cooksey, Ph.D.

Cryovac Chair in Packaging Science

Clemson University, Clemson, SC

Allison Littman

Principal

Sustainable Ally, Lebanon, TN

Contents

Executive Summary

Background

In recent years, municipalities throughout the United States have considered and some have instituted regulations and restrictions on retail grocery and carrier bags in order to promote sustainability and reduce perceived litter problems. At the time of writing of this report, about 6% of the U.S. population was covered by legislation or regulation affecting the selection and use of grocery bags. Such legislation is designed to encourage use of selected carrier bag types and discourage use of other types. Much controversy exists, however, as to whether the various alternatives encouraged by the regulations are environmentally superior solutions.

In light of this trend, the intended application of this study is to provide an objective, data-driven platform upon which decisions about grocery bag use can be made. This study aims to fulfill that goal by making a comparative assertion among the six types of grocery carrier bags studied based on their respective potential environmental impacts, using data appropriate to the United States. Since widespread misconceptions exist among consumers regarding the potential environmental impact of the various bag types, the authors also hope to equip the general public with the information they need to make informed decisions about their own individual bag use. The authors intend to use the results of this study in a comparative assertion to be disclosed to the public, especially legislators and consumers.

The method chosen to execute this study was a Life Cycle Assessment (LCA), in which the grocery carrier bags are analyzed on a cumulative basis to make a comparative assertion among the bags studied. This study followed the procedure detailed in the International Organization for Standardization (ISO) standards to ensure quality results and to maintain consistency with other similar carrier bag LCAs. In accordance with the ISO standards, the study was independently peer-reviewed. This study is considered a cradle-to-grave life cycle assessment, as it includes raw material extraction, manufacturing, transportation, and end-of-life consumer disposal of each carrier bag.

The grocery carrier bags studied were selected as representative of the bags in most common use in the United States. They fall in two general categories, as follows:

- Paper bags and Plastic Retail Bags (PRBs)—bags intended to be used one time for groceries and then reused for other applications (often referred to as "single-use" bags)
    - HDPE lightweight PRBs with 0% recycled content (PRB 0% RC)
    - HDPE lightweight PRBs with 30% recycled content (PRB 30% RC)
    - Paper bags with 40% recycled content (Paper 40% RC)
    - Paper bags with 100% recycled content (Paper 100% RC)

• "Multiple Use" bags—bags intended to be used multiple times for groceries (often referred to as "reusable bags")

  • Reusable LDPE bags (LDPE) (sometimes referred to as "plastic carry bags")
  • Reusable NWPP bags with an LDPE stability insert (NWPP)

The general bag types and their key characteristics are shown in Figure X.1 below.

Figure X.1 Types of Bags Studied

Twelve environmental impact categories were studied using SimaPro modeling software, as shown in Figure X.2.

Global Warming Potential *Greenhouse Gases*	Water Depletion *Water lost*	Cumulative Energy Demand *Energy needed from all sources*
Terrestrial Acidification *Soil Pollutants*	Freshwater Eutrophication *Nutrients that increase biomass*	Marine Eutrophication *Nutrients that increase biomass*
Human Toxicity *Harmful organic compounds*	Terrestrial Ecotoxicity *Harmful organic compounds*	Freshwater Ecotoxicity *Harmful organic compounds*
Marine Ecotoxicity *Harmful organic compounds*	Fossil Fuel Depletion *Amount of fossil fuel used up*	Photochemical Oxidant Formation *Compounds that react under UV to form ozone*

Figure X.2 Environmental Impact Categories

The twelve environmental impact categories were studied in two cases and in three scenarios for each case, as shown in Table X.1.

Secondary uses of PRBs and Paper bags	Not included	Included
Scenario 1	One trip	
Scenario 2	3.1, 14.6 and 44 trips	
Scenario 3	Number of trips for equivalence of environmental impacts for reusable bags with environmental impacts of either PRBs (30% RC) or Paper (40% RC) bags	

Table X.1 Cases and scenarios studied

PRBs and Paper bags that have been used once for grocery shopping are frequently reused for secondary purposes, the most common of these being trash can liners. These secondary uses were modeled in the present study using an avoided burden approach; that is, it was assumed that reusing PRBs or paper bags for secondary uses avoided the purchase of new, similar bags for the secondary uses. Based on data available for secondary uses of PRBs in the U.S. and the U.K., 40% secondary uses were used for Case 2. In the absence of quantitative data on Paper bag reuse, a secondary reuse rate of 22.1% was calculated for Paper bags based on the assuming the ratio of reused to not-recycled bags was the same for Paper bags as for PRBs.

Functional units

Four functional units were selected for the present study. Selection was based on the national survey of reusable bag use published in May, 2014 by Edelman Berland. The functional units and the rationale for their selection are shown in Table X.2.

Functional Unit	Selection Rationale
No. of bags used for one grocery shopping trip	Comparison of bags intended for one grocery bag use
No. of bags used for 3.1 grocery shopping trips	Comparison with the average National rate of reuses of LDPE bags
No. of bags used for 14.6 grocery shopping trips	Comparison with the average National rate of reuses of NWPP bags
No. of bags used for 44 grocery shopping trips	Nationally, 20% of people reuse their NWPP bags more than 44 times

Table X.2 Selection of Functional Units

Reference flow

In order to determine the specific number of bags needed to carry out the demands of the four functional units defined for this study, an original bagging study was carried out on the campus of Clemson University to provide quantitative information on the number of bags used by a typical American family for a trip to the grocery store. The resulting data are shown in Table X.3.

	One Trip		3.1 Trips		14.6 Trips		44 Trips	
	No. Bags	Wt. of Bags (g)	No. Bags	Wt. of Bags (g)	No. Bags	Wt. of Bags (g)	No. Bags	Wt. of Bags (g)
PRBs	9.8	61.0	30.5	189.1	143.7	890.7	433.0	2684
LDPE	8.3	295.6	8.3	295.6	8.3	295.6	8.3	295.6
NWPP	6.7	621.9	6.7	621.9	6.7	621.9	6.7	621.9
Paper	8.4	457.2	26.1	1417	122.7	6675	369.8	20116

Table X.3 Average no. and weight of bags used per functional unit

A statistical analysis of the bagging data from 60 baggers showed that the average numbers of bags/type are statistically accurate to a 95% level of confidence. A sensitivity analysis was conducted to determine the effects on the comparisons among the environmental impact category data for different types of bags resulting from the statistical variability in the number of bags per functional unit. This analysis showed that the qualitative key findings of the study were not affected by the statistical variability in number of bags.

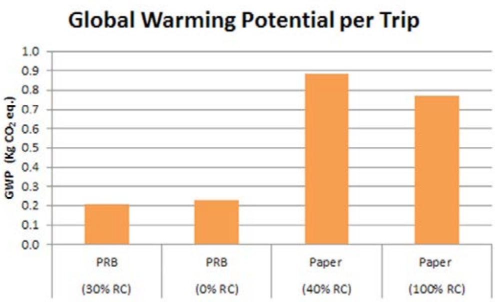
Methodology

Detailed flow charts for the life cycles of each of the studied bags were compiled, from which the processes used and the materials and energy needed and generated in each life cycle stage could be identified and modeled.

Most of the values for environmental impact categories were generated using World ReCiPe Midpoint H/A V1.07, which is the hierarchist, or consensus model within World ReCiPe. The ReCiPe method generates a broad scope of impact categories that offers much opportunity for comparison among bag types. Values for Global Warming Potential were generated using IPCC 2007 100-year V1.02. Values for Cumulative Energy Demand were generated using Cumulative Energy Demand V1.08. Input data for the modeling came from the US-EI 2.2 Database, supplemented by data from bag manufacturers. U.S. data was used wherever possible, except for NWPP manufacture in China. The most up-to-date data sources available were used. The earliest date for some of the data was 2003.

Environmental impact categories data

Using Global Warming Potential as an example, the following figures (X.3–X.8) illustrate the types of data obtained for each of the environmental impact categories.



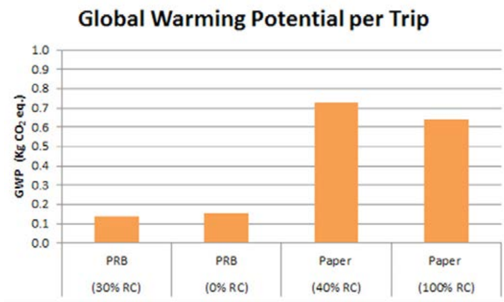
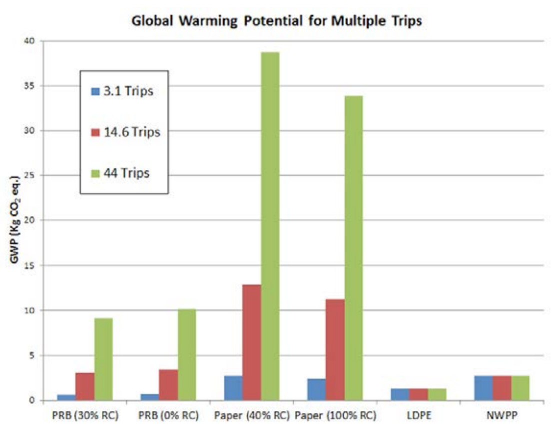
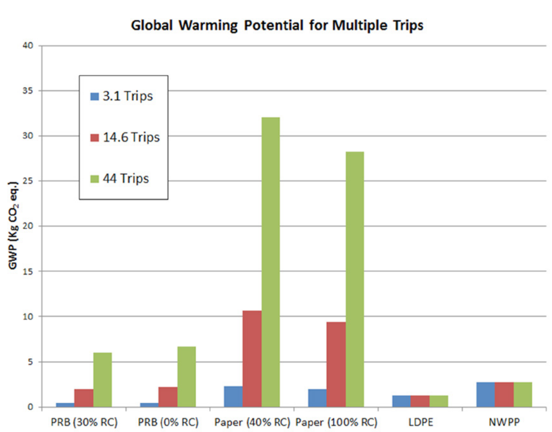


Figure X.3 (Secondary uses not included) and Figure X.4 Scenario 1 (Secondary uses included) Global Warming Potential of PRBs and Paper bags, per trip to supermarket



Case 1—Secondary Uses Not Included

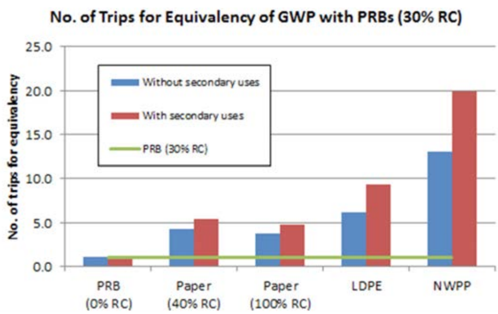


Case 2—Secondary Uses Included

The above figures show that the Global Warming Potential of Paper bags is 3.3 to 5.4 times that of PRBs, depending on recycle content and whether or not secondary uses are included.

Figures X.5 and X.6 show that at 3.1 trips, LDPE bags have about 2 to 3 times the GWP of PRBs and about half the GWP of Paper bags. NWPP bags have about 4 to 6 times the GWP of PRBs and about equal GWP to Paper bags. At 14.6 trips, LDPE bags have about half the GWP of PRBs, while NWPP bags have about the same GWP as PRBs. Both reusable bags have much lower GWP than Paper bags. At 44 trips, both LDPE and NWPP bags have much lower GWPs than either Paper bags or PRBs.

Figure X.5 and Figure X.6 Scenario 2—Global Warming Potential for all studied bags, for multiple numbers of trips



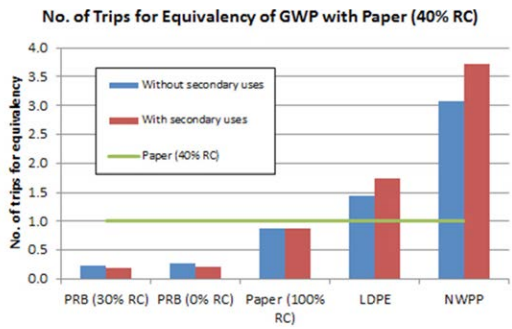


Figure X.7 and Figure X.8 Scenario 3—Number of trips for each type of bag to have GWP equivalency with PRB (30% RC) or Paper (40% RC)

Scenario 3 utilized a methodology of comparing environmental impacts of bags to each other by calculating the number of trips required for bag types designed to be reused as grocery carrier bags to have an equivalent environmental impact to a bag type intended to be used one time for grocery shopping. Figure X.7 shows the results of these calculations comparing GWP of each type of bag with GWP for PRB (30% RC). Figure X.8 shows the same calculation using Paper (40% RC) bags as the bag for comparison with the other types. In both figures the impacts of secondary uses are shown.

The Scenario 3 equivalency charts shown in Figures X.7 and X.8 are derived from the same data shown in the Scenario 1 and 2 charts, but make it easier to visualize the environmental impact category relationships among the different types of bags. These figures also show that the differences in GWP from changing the recycle content of PRBs from 0% to 30% and of Paper bags from 40% to 100% are much smaller than the differences among the various types of bags.

Figure X.9 shows the results of comparing each of the twelve environmental impact categories with the PRB (30% RC) used as the selected bag for comparison. In the body of the report, data were also calculated using the Paper (40% RC) bag for comparison and with secondary uses included. The high numbers for Water Depletion and Terrestrial Ecotoxicity for NWPP bags result from cotton thread used to sew the bags.

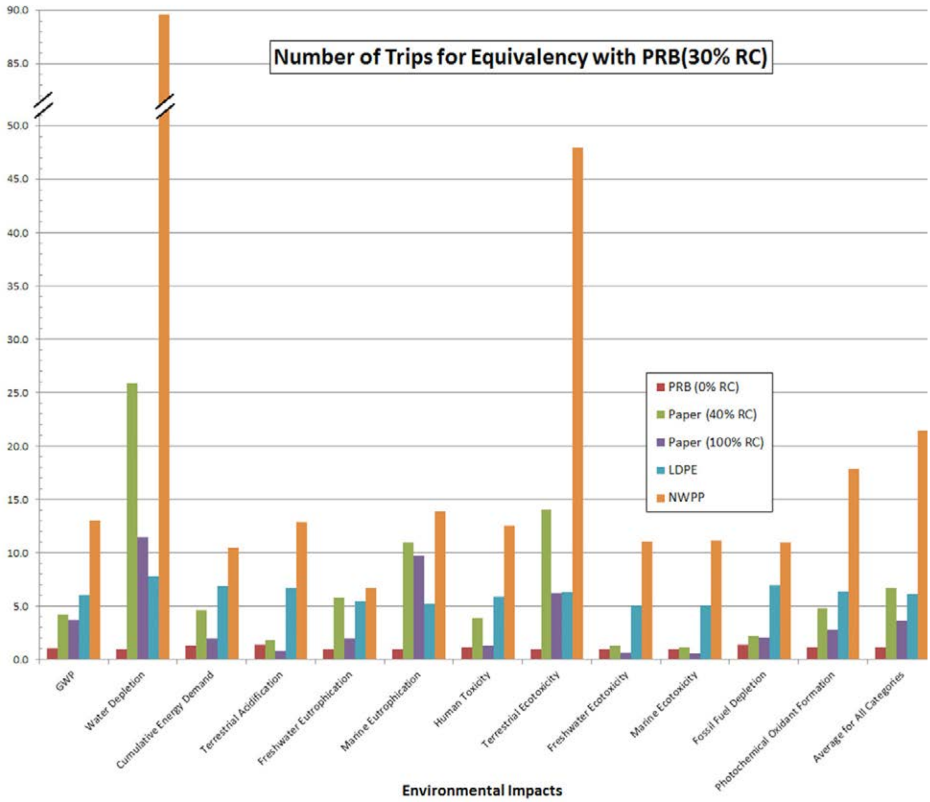


Figure X.9 Number of trips required for equivalency with PRB (30% RC), secondary uses not included

Note that since "number of trips" is dimensionless, an average number of trips for all twelve environmental impact categories can be calculated. The results for each type of bag and each impact category are discussed in detail in the body of this report.

Table X.4 shows the number of trips required for equivalency of each of the environmental impact categories with PRBs (30% RC); Table X.5 shows the number

		No. of Trips for Equivalency to PRB (30% RC)									
Impact category	**Unit**	**PRB (0% RC)**		**Paper (40% RC)**		**Paper (100% RC)**		**LDPE**		**NWPP**	
Secondary uses included?		No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
GWP	Kg CO2 eq	1.1	1.1	4.2	5.4	3.7	4.7	6.1	9.3	13.0	19.9
Water Depletion	gal	1.0	1.0	25.9	33.2	11.5	14.8	7.8	12.7	89.6	146.4
Cumulative Energy Demand	MJ eq.	1.3	1.5	4.7	6.1	2.0	2.7	6.9	11.6	10.5	17.6
Terrestrial Acidification	g SO2 eq	1.4	1.5	1.8	2.2	0.8	1.0	6.8	10.7	12.9	20.4
Freshwater Eutrophication	g P eq	1.0	1.0	5.8	8.0	2.0	2.7	5.5	9.6	6.7	11.9
Marine Eutrophication	g N eq	1.0	1.0	11.0	11.8	9.7	10.7	5.2	6.1	13.9	16.2
Human Toxicity	g 1,4-DB eq	1.2	1.2	3.9	4.9	1.3	1.8	5.9	9.3	12.6	19.8
Terrestrial Ecotoxicity	g 1,4-DB eq	1.0	1.0	14.1	18.4	6.2	8.2	6.3	10.5	47.9	80.0
Freshwater Ecotoxicity	g 1,4-DB eq	1.0	1.0	1.3	1.2	0.7	0.6	5.1	5.7	11.0	12.4
Marine Ecotoxicity	g 1,4-DB eq	1.0	1.0	1.1	1.0	0.6	0.5	5.1	5.7	11.1	12.4
Fossil Fuel Depletion	g oil eq	1.4	1.5	2.3	3.0	2.0	2.7	7.0	11.8	11.0	18.6
Photochemical Oxidant Formation	g NMVOC	1.1	1.2	4.8	6.7	2.8	3.9	6.4	11.1	17.9	31.2
Average for All Categories		**1.1**	**1.2**	**6.7**	**8.5**	**3.6**	**4.5**	**6.2**	**9.5**	**21.5**	**33.9**

Table X.4 Number of trips required for equivalency with PRB (30% RC), with and without secondary uses included

of trips required for equivalency of each of the environmental impact categories with Paper (40% RC) bags.

Table X.4 shows that the inclusion of secondary uses for PRBs and Paper bags in the models for calculating the environmental impact categories results in an increase in the average for all environmental impact categories of about 3% for PRB (0% RC), about 25% for Paper bags and about 55% for the reusable bags LDPE and NWPP.

		No. of Trips for Equivalency to Paper (40% RC)									
Impact category	**Unit**	**PRB (30% RC)**		**PRB (0% RC)**		**Paper (100% RC)**		**LDPE**		**NWPP**	
	Secondary uses included?	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
GWP	Kg CO2 eq	0.2	0.2	0.3	0.2	0.9	0.9	1.4	1.7	3.1	3.7
Water Depletion	gal	0.0	0.0	0.0	0.0	0.4	0.4	0.3	0.4	3.5	4.4
Cumulative Energy Demand	MJ eq.	0.2	0.2	0.3	0.2	0.4	0.4	1.5	1.9	2.2	2.9
Terrestrial Acidification	g SO2 eq	0.6	0.4	0.8	0.7	0.4	0.4	3.7	4.8	7.1	9.1
Freshwater Eutrophication	g P eq	0.2	0.1	0.2	0.1	0.3	0.3	0.9	1.2	1.2	1.5
Marine Eutrophication	g N eq	0.1	0.1	0.1	0.1	0.9	0.9	0.5	0.5	1.3	1.4
Human Toxicity	g 1,4-DB eq	0.3	0.2	0.3	0.2	0.3	0.4	1.5	1.9	3.2	4.0
Terrestrial Ecotoxicity	g 1,4-DB eq	0.1	0.1	0.1	0.1	0.4	0.4	0.4	0.6	3.4	4.3
Freshwater Ecotoxicity	g 1,4-DB eq	0.8	0.8	0.7	0.8	0.5	0.5	3.9	4.8	8.4	10.4
Marine Ecotoxicity	g 1,4-DB eq	0.9	1.0	0.9	0.9	0.5	0.5	4.5	5.6	9.8	12.1
Fossil Fuel Depletion	g oil eq	0.4	0.3	0.6	0.5	0.9	0.9	3.1	4.0	4.9	6.2
Photochemical Oxidant Formation	g NMVOC	0.2	0.1	0.2	0.2	0.6	0.6	1.3	1.7	3.7	4.7
Average for All Categories		**0.3**	**0.3**	**0.4**	**0.3**	**0.6**	**0.6**	**1.9**	**2.4**	**4.3**	**5.4**

Table X.5 Number of trips required for equivalency with Paper (40% RC), with and without secondary uses included

Table X.5 shows that the inclusion of secondary uses for PRBs and Paper bags in the models for calculating the environmental impact categories results in a decrease in the average for all environmental impact categories of about 8% for PRBs, an increase of about 1% for Paper (100% RC) and an increase of about 25% for the reusable bags LDPE and NWPP.

Relationships to consumer behavior

Consumer behavior in the use of reusable bags was derived from a survey by Edelman Berland (May, 2014). The key findings of this National survey, conducted from February 28—March 7, 2014, as related to the LCA study are reproduced below.

- 28% of 3,568 individuals surveyed had acquired a reusable bag in the past year, leading to a sample size for the detailed survey of 1,002 individuals. 87% of these people had used reusable bags for grocery shopping. The survey had a margin of error of ±3.1%.
- Consumers forget to bring their reusable bags to the store 40% of the time and opt for a PRB or Paper bag instead.
- 61% of people prefer NWPP bags, but 41% typically use PRBs
- About 1/3 of the 1,002 people survey sample acquired an LDPE bag in the past year, but only 6% prefer to use them
- 10% of people prefer to use paper bags and about 8% typically use them.

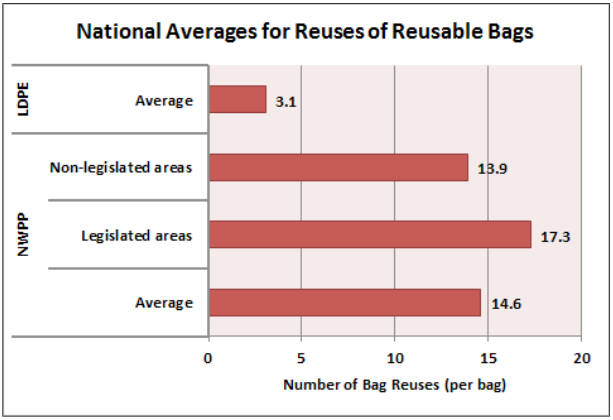


Figure X.10 Key findings for reuses of reusable LDPE and NWPP Bags from the Edelman Berland Study

Figure X.11 which shows the cumulative % of people vs. the number of times they reuse their NWPP bags was derived from data provided by Edelman Berland.

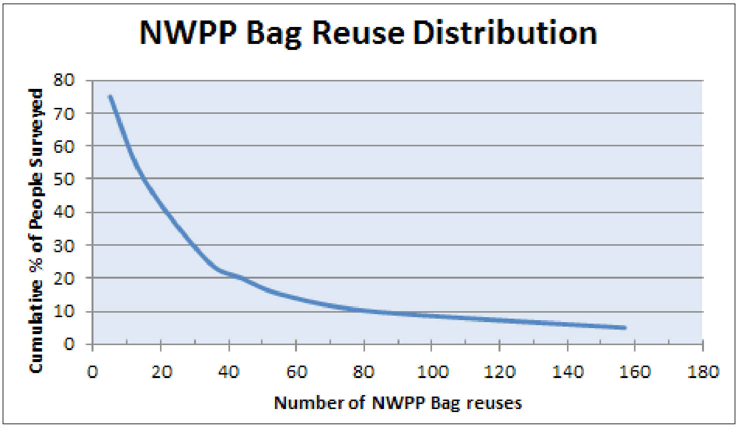


Figure X.11 Cumulative % of people vs. number of NWPP bag reuses (Edelman Berland data)

Combining the averages from Tables X.4 and X.5 with the consumer behavior data discussed above leads to the charts shown below that illustrate some of the key findings of the present study.

Even though both Los Angeles and San Francisco mandate that LDPE reusable bags last for 125 grocery shopping trips, consumers across the country are reusing them only an average of 3.1 times. As shown in Figure X.12, this is only one-third to one-half the number of uses that would result in the average of all 12 environmental impact categories for LDPE bags being equivalent to that of PRBs. It is however enough reuses to make the average environmental impacts of LDPE bags superior to those of Paper bags.

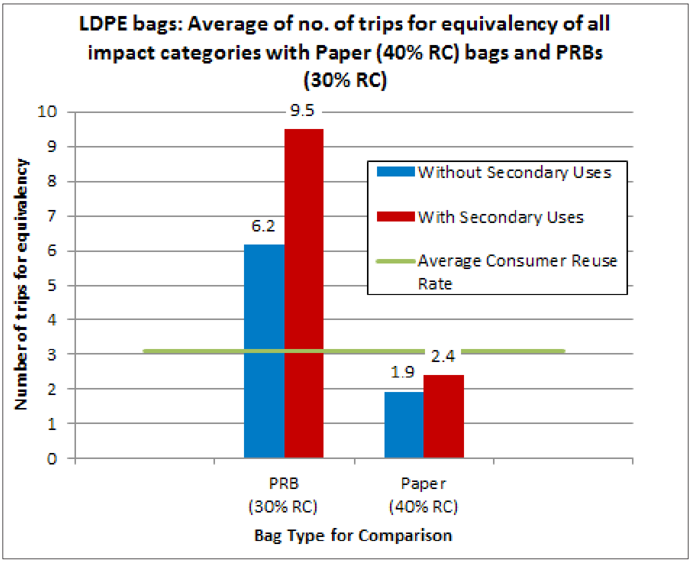


Figure X.12 Average Consumer Reuse Rate of LDPE bags compared with average of Number of Trips for Equivalency of Environmental Impacts of LDPE Bags with Environmental Impacts of Paper (40% RC) bags and PRBs (30% RC)

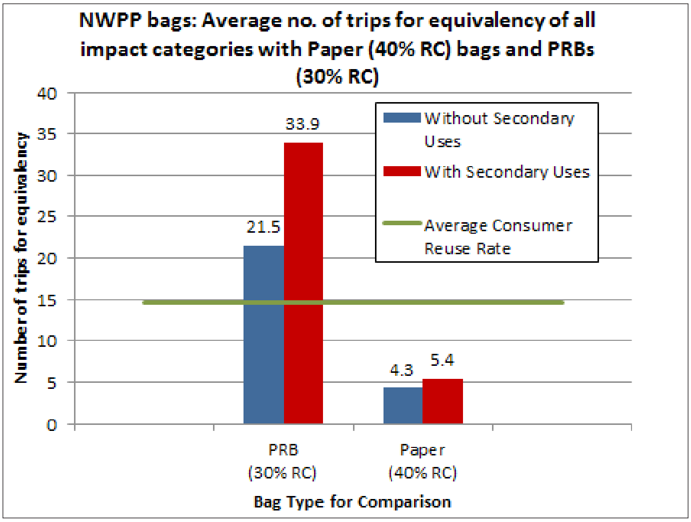


Figure X.13 Average Consumer Reuse Rate of NWPP bags compared with average of Number of Trips for Equivalency of Environmental Impacts of NWPP Bags with Environmental impacts of Paper (40%RC) bags and PRBs (30%RC)

Los Angeles and San Francisco also mandate that NWPP reusable bags last for 125 shopping trips. However, as shown in Figure X.11, less than 10% of people nationally are reusing their NWPP this many times. By combining the data in Figures X.11 and X.13, we can see that about 75% of people are reusing their NWPP bags enough times to result in their average environmental impact being equivalent or superior to Paper bags. On the other hand, only 25% or 41% of people (depending on whether secondary uses of PRBs are included in the calculations or not) reuse their NWPP bags enough times so that the average of the environmental impact categories for NWPP bags is less than the average of the environmental impact categories for the number of PRBs (30% RC) required to make the same number of grocery trips.

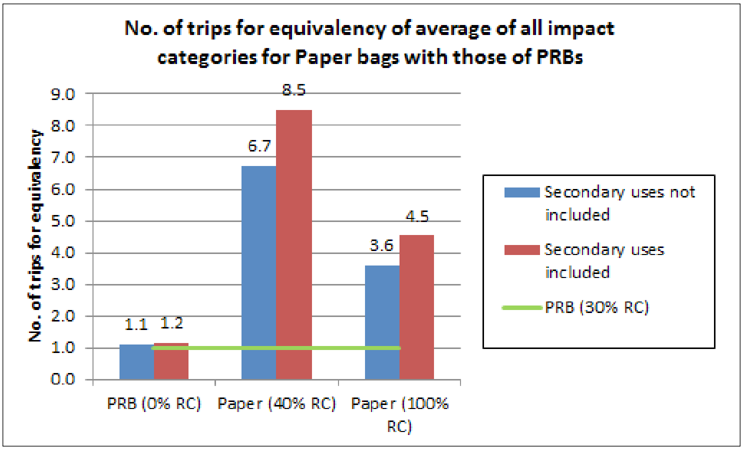


Figure X.14 Average number of Trips for Equivalency of Environmental Impacts of Paper Bags with Environmental Impacts of PRBs, with and without secondary uses included

Figure X.14 shows that Paper bags, even with 100% recycle content, have about four times the average environmental impact vs. PRBs. At 40% recycle content, this increases to more than seven times.

Key findings

From an environmental impact point of view, for the types of bags studied:

- Reusable LDPE and NWPP bags have lower average impact on the environment than PRBs if reused a "sufficient" number of times
- The majority of reusable bag users DO NOT use their LDPE or NWPP bags a "sufficient" number of times
- Reusing NWPP bags about the national average number of reuses has about the same environmental impacts as using PRBs
- LDPE reusable bags should be preferred over NWPP bags, but only 6% of consumers state they prefer LDPE reusable bags and only 3% use them regularly.
- Other bag types (PRB, NWPP, LDPE) have lower environmental impacts than paper bags and are preferred 9 to 1 vs. paper bags.
- For either PRBs or Paper bags, higher recycle content results, on average, in lower environmental impacts, but these differences are much smaller than the differences among the various types of bags.

Other environmental impact data included in this report include:

- Breakdown for some of the environmental impact categories into life cycle processes—raw material extraction/production; production processes; transportation and waste processing/disposal
- Alternate values for secondary uses of PRBs and Paper bags
- Effects of de-inking Paper bags during recycling
- Effects of washing NWPP bags
- Thicker LDPE bags to assess the effect of the 4 mil (rather than 2.25 mil) thick bags required by some municipalities

Supplemental findings

During the development and compilation of information for this study, we had the opportunity to collect and evaluate data in several areas directly relevant to consumer and legislative perceptions about grocery carrier bags.

Polyethylene Raw Materials used for PRBs

98% of the ethane used to make the high density polyethylene and LLDPE from which PRBs are manufactured in the U.S. comes from a by-product of domestic natural gas production. Natural gas is in plentiful supply today in the U.S. Making and using PRBs therefore does not affect imports of either oil or natural gas, nor does it take away oil, gasoline or natural gas from uses such as heating or transportation.

Grocery bags and recycling

As documented in various sections of this report, the main sources of recycled materials used in the manufacture of Paper bags, PRBs and NWPP bag inserts are not recycled bags, but other sources of paper and ethylene polymers. Paper bags can be recycled through municipal curbside collection and get mixed with other sources of recycled Kraft paper, especially corrugated boxes. PRBs, like other plastic films, cannot be recycled in most curbside collection systems because they interfere with the processing machinery at the Materials Recycling Facilities. PRB manufacturers would, however, very much like to source material for recycling from used PRBs. PRB manufacturers and manufacturers of other films have cooperated to establish recycling points at retail establishments. Such recycling facilities are now available to about 95% of the U.S. population. The Sustainable Packaging Coalition has recently initiated a program called “how2recycle” to provide consumers information on how and where to recycle grocery bags, plastic and multi-material packages.[1]

Litter

A compilation of all of the statistically-based, scientific studies of litter in the U.S. and Canada over an 18 year period shows consistently that “plastic bags” (which includes trash bags, grocery bags, retail bags and dry cleaning bags) make up a very small portion of litter, usually less than 1%. Neither plastic bags nor Kraft bags are a significant component of roadway litter. Plastic bags are a very small component of litter found in storm drains and around retail areas.

Safe Use of Reusable bags

Many municipal, state and federal government web sites, as well as those of other "advice to consumer" type websites, strongly recommend that consumers should frequently clean their reusable bags by washing NWPP types in a washing machine and by wiping (with hot water or perhaps disinfecting wipes) their LDPE types. Cleaning is recommended to avoid the transfer and growth of viral and bacterial contamination from food and supermarket sources to the consumer's home and person. Direct evidence of the types of contamination that can occur is documented in an annex to this report. The Edelman Berland survey reports that only 15% of consumers wash their NWPP bags frequently and 23% never wash them.

Summary and recommendations

The authors are satisfied that they have achieved their goal to provide a comparative assertion among the six types of grocery carrier bags included in the report based on their respective potential environmental impacts. The carrier bags selected were those in most common use in the United States and the underlying data were, as far as is possible, based on United States data.

Our results are based on a study of twelve environmental impact categories. Our results show that reusable LDPE and NWPP bags will have lower average impacts on the environment compared to PRBs if the reusable bags are reused for a *sufficient* number of grocery shopping trips. However, according to a recent national survey, a majority of consumers do not reuse their reusable bags for this *sufficient* number of trips, especially for LDPE bags. Moreover, 40% of people forget to bring their reusable bags with them to the store and half the people who prefer NWPP bags used PRBs at their most recent shopping trip. In addition, only 15% of people follow the recommended cleaning procedures to ensure safe use of reusable bags.

Our results also show that Paper bags, even with 100% recycle content, have significantly higher average impacts on the environment than either of the reusable bags or PRBs.

Many of the regulations now in place or being considered in the United States encourage consumers to use reusable bags through banning PRBs and imposing a fee on the use of Paper bags. A number of grocery chains in non-legislated areas provide Paper bags and sell various reusable bags. Our results in this study show that these regulations and policies may result in negative impact on the environment rather than positive. Even though Paper bags come from a renewable resource and are easily recycled, it is likely that they are not the best environmental choice. Reusable bags should only be preferred if consumers are educated to use them safely and consistently, and reuse them enough times to lower their relative environmental impacts compared to PRB alternatives.

Our recommendation, based on our work in this study, is that consumers should be given a choice between reusable bags and PRBs and that any of these should be preferred over Paper bags. Most important is that much more attention should be focused on educating consumers to make an informed choice of which bags to use by providing them facts—facts about reusable bag use, facts about proper recycling or disposal of PRBs, facts about the potential environmental impacts of their choices—based on sound scientific evidence.

Note

1. http://www.how2recycle.info/
   http://www.plasticfilmrecycling.org/s00/index.html

Glossary

$CaCO_3$	Calcium Carbonate
EPA	Environmental Protection Agency
GWP	Global Warming Potential
HDPE	High Density Polyethylene
ISO	International Organization for Standardization
LCA	Life Cycle Assessment (Analysis)
LDPE	Low Density Polyethylene
LLDPE	Linear Low Density Polyethylene
MSW	Municipal Solid Waste
NWPP	Non-Woven Polypropylene
PCR	Post-Consumer Recycled
PP	Polypropylene
PRB	Plastic Retail Bag: a light-weight HDPE plastic bag with cut-out handles; sometimes known as a "T-shirt bag"
RC	Recycled Content: the portion of a product's or package's weight that is composed of materials that have been recovered from waste; this may include post-industrial or post-consumer materials. (U. S. Environmental Protection Agency, 2013)
Recycle	Materials that have served their intended purpose and have been diverted or recovered from waste intended for disposal In-plant recycle (called "regrind" in the plastics industry and "broke" in the paper industry)—materials generated in manufacturing and converting processes, such as scrap, trimmings, or start-up materials Post-industrial recycle (also called pre-consumer recycle)—finished (film or fully dried paper) materials recovered from manufacturing or converting operations that have not been used for their intended business or

consumer purposes. This category includes handle cut-outs, rejected or returned finished rolls and the like.

Post-consumer recycle—used materials that have served their intended purpose; this includes both materials that have been used by consumers and materials that have been used by businesses. Commercial materials are usually recovered outside of curbside or drop off collection programs and include items such as pallet wrap, corrugated cartons and other commercial packaging. The EPA defines post-consumer recycle as a material or finished product that has served its intended use and has been diverted or recovered from the waste destined for disposal, having completed its life as a consumer item.

TiO_2 Titanium dioxide

1. Introduction

1.1 Background

As environmental awareness continues to grow among consumers, government, and industry, disposal of grocery carrier bags has garnered significant attention. In recent years, municipalities have considered and some have instituted regulations and restrictions on retail grocery and carrier bags in efforts to promote sustainability and reduce perceived litter problems (Californians Against Waste, 2013) (Florida Department of Environmental Protection, 2013)[1]. Such legislation is designed to encourage use of selected carrier bag types and discourage use of other types. Legislators may believe that these laws will reduce the nation's use of fossil fuels, curtail litter in communities, and improve the overall environmental impact of transporting groceries. Clearly, legislation to be enacted or recommendations to be made should be informed by objective information based on accepted scientific methods. Data comparing the potential environmental impacts of alternative bag materials and types in the United States would be especially useful.

Several studies have examined the potential environmental impacts of different carrier bags in various parts of the world (Franklin Associates, Ltd, 1990) (Fry, 2011) (Greene, Life Cycle Assessment of Reusable and Single-Use Plastic Bags in California, 2011) (Yaros, 2007).[2] No study thus far, however, has taken into consideration the geographic area of the United States with its specific sourcing, manufacturing, transport, reuse and disposal scenarios, nor compared the particular bag types that are the subjects of the present study, nor considered data only recently collected on the actual consumer use patterns of reusable bags (Edelman Berland, 2014).

1.2 Life Cycle Assessment methodology

The method chosen to execute this study was a Life Cycle Assessment (LCA). This method seeks to eliminate biases and subjectivity related to public perception, activist group opinions, and other nonscientific influences. The LCA method makes objective measurements based on a quantifiable inventory of all inputs and outputs associated with the entire life cycle of a product or service. This includes extraction of raw materials, manufacturing of the product, distribution of the product, and ultimate product disposal. However, LCA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

The results of an LCA study can be evaluated on an individual level (e.g. single material input, particular processing step) in order to highlight high-impact steps or on a cumulative basis (e.g. whole product life cycle) for benchmarking or comparative purposes. This study primarily analyzes the grocery carrier bags on a cumulative basis to make a comparative assertion among the bags studied.

This study followed the procedure detailed in the International Organization for Standardization (ISO) standards to ensure quality results and to maintain consistency with other similar carrier bag LCAs. The particular ISO standards utilized are:

- ISO 14040: 2006—Environmental Management—Life cycle assessment—Principles and framework
- ISO 14044: 2006—Environmental Management—Life cycle assessment—Requirements and guidelines.

The four steps included in the study are: Goal and Scope, Life Cycle Inventory, Life Cycle Impact Assessment, and Interpretation.

This study is considered a cradle-to-grave life cycle assessment, as it includes raw material extraction, manufacturing, transportation, and end-of-life consumer disposal of each carrier bag.

Notes

1. The referenced websites maintain an updated list of ordinances affecting the use of grocery bags throughout the United States.
2. Additional LCA studies, both older and for other countries, are referenced in the studies cited.

2. Goal

In light of a recent trend in which municipalities are considering various types of grocery bag legislation, the intended application of this study is to provide an objective, data-driven platform upon which such decisions can be made. This study aims to fulfill that goal by making a comparative assertion among the four types (two categories with two variants each) of grocery carrier bags included in the report based on their respective potential environmental impacts. Since widespread misconceptions exist among consumers regarding the potential environmental impact of the various bag types, the authors also hope to equip the general public with the information they need to make informed decisions about their own individual bag use. The authors intend to use the results of this study in a comparative assertion to be disclosed to the public, especially legislators and consumers. Thus, the intended audience for this study consists of interested organizations (supermarkets, environmental and public service groups, materials suppliers, carrier bag manufacturers), the general public, and public legislative and regulatory individuals and groups. The carrier bags studied were chosen to be representative of the bags in most common use in the United States in 2012 and to include bag types specifically mentioned in the Los Angeles and San Francisco ordinances (County of Los Angeles Department of Public Works, Environmental Programs Division, 2012) (San Francisco Department of the Environment, 2013). An additional goal is to append to the LCA study available scientific data regarding litter and bag safety.

3. Scope

3.1 Carrier bags studied

The grocery carrier bags studied fall in two general categories, as follows:

- Paper bags and Plastic Retail Bags (PRBs)—bags intended to be used one time for groceries and then reused for other applications (often referred to as "single-use" bags)
  - HDPE lightweight PRBs with 0% recycled content (PRB 0% RC)
  - HDPE lightweight PRBs with 30% recycled content (PRB 30% RC)
  - Paper bags with 40% recycled content (Paper 40% RC)
  - Paper bags with 100% recycled content (Paper 100% RC)
- "Multiple Use" bags—bags intended to be used multiple times for groceries (often referred to as "reusable bags")
  - Reusable LDPE bags (LDPE) (sometimes referred to as "plastic carry bags")
  - Reusable NWPP bags with an LDPE stability insert (NWPP)

Descriptions of bags considered in this study:

PRBs are the conventional, lightweight plastic bags typically provided at no cost in many supermarkets in the United States. The bags have very thin walls (15 microns or 0.6 mils) and are water resistant. The average weight of the bags in this study was 6.2 g. The top of each bag is cut to form an integral handle and a simple wire holder is used to hold a stack of bags for dispensing.

Large PRB manufacturers incorporate approximately 30% total recycled content in their bags. The RC content includes such materials as the film scrap from cutting-out the handles, post-industrial scrap from other HDPE producers and post-consumer scrap from both retail store recycle collection points and industrial collection operations. The post-consumer scrap from both consumer and industrial sources routinely contains films from ethylene polymers other than HDPE. Post-consumer scrap is typically contaminated with foreign materials and requires separation and washing processes to make it suitable for recycling into PRBs. Large PRB manufacturers have installed the special facilities needed to handle, clean and reprocess this wide variety of recycled material sources. They routinely supply PRBs containing 30% RC to their customers[1] and are trying to achieve routine supply of 40% RC bags (Staff, 2012). Smaller manufacturers are limited to lower RC content or even 0% RC content. PRBs with 0% and 30% were therefore included in this study, but 30% RC was selected for comparison with other types of bags because of its prevalence in the marketplace.

PRB manufacturers include some LLDPE in their recipes to provide extensibility and improved tear resistance to their bags. Some of the LLDPE is purchased as virgin resin, while additional LLDPE comes from post-industrial and post-consumer recycle.

The total consumption of new, unused PRBs in the U.S. is about 100 billion bags per year, some of which are imported. (U. S. International Trade Commission, 2009) At 6.2 g per bag, this amounts to about 1.4 billion pounds of bags distributed yearly. Although PRBs are often reused as trash-can liners or for other applications, they are not typically considered reusable for the application of carrying groceries. Secondary uses of PRBs are excluded from the base case of the present study, but are discussed in an alternative case. (See Section 5.4)

Paper Bags represented in this study are one of the two most common sizes provided to consumers in grocery stores. They measure 12 x 7 x 14 inches and have a nominal volume of 1/7th of a barrel (which is how they are sold). They are made from unbleached Kraft paper and the bags used in the present study weighed 54.4 g (International Paper, 2013) (Duro Bag Co., 2011).

Other paper bags distributed in grocery stores include the 1/6th barrel size (12 x 7 x 17 inches) and a variety of bags with handles. The paper bag chosen for inclusion in the present study was the smaller and most often used of the two sizes most commonly sold by the industry to retailers for groceries (Duro Bag Mfg., 2005).

Grocery and retail bags use about 43% of all the Kraft paper produced and typically contain at least 40% recycled wastepaper content ((Twede & Selke, 2005), p. 333) This wastepaper content is predominantly OCC (Old Corrugated Containers). (UW Extension, 2012) Since corrugated boxes, grocery bags and other uses of unbleached Kraft paper are usually printed with water-based inks at low ink coverage, most of the recycle used in grocery bags does not have to go through an extensive deinking process. Several types of glue can be used for the side and bottom seams of paper bags, including hot melts, starch or dextrin-based adhesives or polyvinyl acetate adhesives (Avebe, 2013) (G. Gierenz, 2008, p. 54), (Fry, 2011) (Adhesives Products, Inc., 2011). 100% recycle content paper bags are available from the major manufacturers, although as little as 5 to 10% of this content may have been actually recycled by a consumer (Natural Grocers, 2013). Paper bags with both 40% and 100% recycle content have been included in this study. Paper bags are designed as a single use container for groceries, but are often reused by consumers for a variety of applications. These secondary uses are not included in the base case of the present study, but are discussed as an alternative case. (See Section 5.4)

Low-density Polyethylene (LDPE) Reusable Bags are relatively thick polyethylene bags available in a wide variety of shapes, sizes, and handles. These bags are designed to be durable enough to be reusable and are often customized for specific retail outlets. They are sometimes referred to as "Plastic Carry-Out" bags. Consumers are accustomed to seeing these types of bags in clothing and specialty stores.

In November 2010, the County of Los Angeles Board of Supervisors adopted an ordinance that encourages the use of a reusable Plastic Carry-out bag in certain stores selling groceries (County of Los Angeles Department of Public Works, Environmental Programs Division, 2012). The authors have therefore included in this study an example of one of these bags—the "Wave Top" LDPE Bag manufactured by Roplast Industries.[2]

These bags measure 17 x 17 x 6 inches and have an average thickness of 2.25 mils (Roplast Industries, 2013). The bags used in the present study weighed 35.6 g.

According to Roplast's web site and information received from an industry source,[3] the Roplast LDPE bag contains no RC content. (Roplast) LDPE bags could be recycled at the same retail collection points as other polyethylene products. These collection points accept, for example, PRBs, wraps, stretch films, and trash bags.

NWPP Reusable Bags are offered by many supermarkets and other stores selling groceries and can often be purchased for as low as $1.00 per bag. Many are given away as promotions. They are fabricated from a non-woven polypropylene fabric, and include a long handle and a hard plastic rectangular insert to stabilize the bottom. Bags intended for the grocery market are available in several different sizes and fabric weights. For example, the following NWPP bags are listed on the Los Angeles County web site (County of Los Angeles Department of Public Works, Environmental Programs Division, 2012)

Typical NWPP Bags (various suppliers)	
Dimensions (inches)	Fabric Weight (g/square meter)
15"x13"x10"	120
13" x 15" x 10"	90
12.5" x 13" x 8.5"	N/A
12.5" x 17" x 8"	110
14" x 12" x 8"	90

Table 3.1 Typical dimensions and weight of NWPP bags from various supplies

The typical NWPP bag used in the present study weighed 60.8 g and the insert adds an additional 32 g.

The vast majority of these bags are made in China and distributed in the U.S. by a number of importers. The bags are provided in many colors and can be customized with logos or other printing.

NWPP bags cannot be recycled easily. Fabrics present difficulties in recycling facilities similar to those presented by films, in that they foul up the sorting machines. The bag handles are also difficult for the machines to process. In addition, the intense and varied colors of NWPPs limit recycling opportunities. Therefore, this study assumes 0% recycling of NWPP bags with 100% going to MSW at the end of their life.

According to a report by Moore Recycling Associates based on data collected in 2008-2010, some polypropylene (PP) is recycled in China, from both domestic and imported mixed resin sources (Moore, 2011?). Some of this recycled PP is used for woven PP bags. NWPP bags are not mentioned. Since the Moore Report, China has implemented its “Green Fence” policy, severely restricting imports of recycled materials (Guilford, 2013). Since there is no evidence that NWPP bags contain recycled PP, the present study assumed 0% RC content in NWPP bags. A new study by Muthu and Li of the environmental impact of grocery bags in China, Hong Kong and Thailand made this same assumption. These authors had local knowledge of Chinese practices. (Muthu, 2014, p. 23) Based on input from a bag importer, the present study assumes that the material used for the insert is made from 100% recycled content.[4]

NWPP bags are assembled and the handles are attached by sewing. The authors collected NWPP bags from several sources in different parts of the United States and found that all were sewn with cotton thread.

Bag types not included: Cotton bags were included in the UK Environment Agency Carrier Bag Study and were found to have many times the potential environmental impacts of the other bag types studied (Fry, 2011). Compostable bags (such as those made from PLA-polylactic acid) and HDPE bags containing additives to promote degradation or physical breakdown are in very limited distribution in the United States and were therefore not included in the scope of the present study.

Table 3.2 shows the weight and percent RC content of the bags studied. Weights of representative bags were measured by the authors.

Bag Type	Weight (g)	% RC	Example
PRB (0% RC)	6.2	0	
PRB (30% RC)	6.2	30	
Paper (40% RC)	54.4	40	
Paper (100% RC)	54.4	100	
LDPE	35.6	0	
NWPP	Bag: 60.8 Insert: 32.0	0 100	

Table 3.2 Measured weight and percent RC (post-consumer and post-industrial recycle content) of bags studied

3.2 Function and functional unit

The product system being studied includes bags typically used in grocery store settings. The functions of this product system include bagging, carrying out, and transporting groceries from retail stores to homes.

Because the selected carrier bags for comparison vary in weight, carrier volume, and durability, four functional units were defined to facilitate an impartial comparison of environmental impacts.[5] The functional units used to compare impacts have been specified as:

(1) Bags used by U.S. consumers to transport the shopping items for one trip (52 items) from the grocery store to the consumer's home in 2012.
(2) Bags used by U.S. consumers to transport the shopping items for 3.1 trips (161.2 items) from the grocery store to the consumer's home in 2012.
(3) Bags used by U.S. consumers to transport the shopping items for 14.6 trips (759.2 items) from the grocery store to the consumer's home in 2012.
(4) Bags used by U.S. consumers to transport the shopping items for 44 trips (2288 items) from the grocery store to the consumer's home in 2012.

The assumptions and calculations for the number of items per trip are shown in Section 3.3 below.

3.3 Reference flow

The reference flow is the specific number of bags needed to carry out the demands of the functional unit. The number of bags needed is dependent upon bag volume and consumers' or supermarket attendants' behavior when loading products into the bags.

As described in previous studies (Franklin Associates, Ltd, 1990), carrier bags with identical capacity are not necessarily filled with the same volume of contents. This tendency may be a result of perceived bag strength rather than actual bag performance characteristics. Nevertheless, this tendency must be taken into account when making carrier bag comparisons.

Thus, results from a study conducted by Clemson University were used to establish expected item capacity for each carrier bag. The details of this study are shown below.

3.3.1 Methods for reference flow study

The bags used in this study have different capacities for the typical items for which consumers shop in grocery stores. In order to be able to compare the various bags, the authors decided to determine the average number of each type of bag that would be required for a typical shopping trip for a family of four in the U.S.

Highlights:
- Statistically-based study with 60 participants, or "baggers"
- Typical grocery trip for a family of four

- Average of 1.85 trips per week to stores that typically use bags for carrying groceries
- Purchases of about $300/week for food for home preparation, household products, personal care products

The Food Marketing Institute (FMI, 2013) reported that in 2012 consumers made an average of 2.2 grocery trips per week of which 1.4 trips were to supermarkets and the remainder to other types of stores, such as supercenters, warehouse clubs, discount stores, dollar stores and others. At all the types of stores listed in the study, except warehouse club stores, consumers typically carry their purchases in the bags that are the subject of this study. At warehouse club stores, consumers typically either use corrugated cartons and trays provided by the store or place their purchases directly in their vehicles, although some consumers may bring reusable bags. Based on the data reported by FMI,[6] the authors estimated that consumers would use bags for an average of 1.85 trips per week. (Food Marketing Institute, 2012)

The latest data from the U.S. Department of Commerce report that in 2010 a typical family of four, including two adults and two elementary school-age children, spent $221 per week for food for home preparation under a "moderate cost plan." (United States Census Bureau, 2012) The authors estimated that this typical family would spend about $80 for personal care and household items in addition to food, giving a total spending per week of about $301/family. This would include items purchased in warehouse club stores that would usually not be bagged. The authors developed a list of 52 items that would represent one trip of the 2.2 shopping trips/week for the typical family. These 52 items cost $147.50 to purchase in a Clemson, SC supermarket. The items are listed in detail in Annex A to this report. The authors' total cost to purchase the 52 items/trip for 2.2 trips was $324.50. This total would be expected to exceed the Census Bureau projection of $301 for several reasons: cost inflation from 2012 to 2013; all items purchased in a regional chain supermarket rather than some in a warehouse club or other "discount" outlet; regional pricing vs. national average pricing.

For comparison, the UK Environment Carrier Bag Study found that one month's shopping consisted of 483 items (Fry, 2011, p. 17), while the present study, as documented above, utilized 416 items (8 times 52 items) for one month's shopping.

Using four identical sets of the 52 items, four "bagging lines" were set up in a room on the Clemson campus. Each bagging line used one of the four types of bags in this study—PRBs, LDPE, NWPP and Paper—with the appropriate dispensing system. Sixty individuals were given general instructions on bagging by several people who had grocery store bagging experience. They were given the option to not use a bag for any items they felt did not need a bag.

3.3.2 Results of reference flow study

Each participant bagged the 52 items in each type of bag. The order of bags for each participant was random. Tables 3.3 and 3.4 show the collected and analyzed data.

Bagging Study - 60 Participants - 52 Items							
Bag Type		Bags/Trip	Bag Weight g/trip	Total Weight g /Bag	Total Items Bagged	Unbagged Items	Items/Bag
PRB	**Average**	**9.8**	**61.0**	**3285**	**47.5**	**4.6**	**5.2**
	Std. Dev.	2.6		845	3.7	3.7	1.3
	Median	9.5					
LDPE	**Average**	**8.3**	**295.6**	**4038**	**49.0**	**3.1**	**6.1**
	Std. Dev.	1.8		880	2.6	2.6	1.3
	Median	8.0					
NWPP	**Average**	**6.7**	**621.9***	**4875**	**48.6**	**3.4**	**7.6**
	Std. Dev.	1.7		1018	2.9	2.9	1.7
	Median	6.0					
Paper	**Average**	**8.4**	**457.2**	**3891**	**47.3**	**4.8**	**6.5**
	Std. Dev.	1.7		743	2.2	2.2	1.1
	Median	8.0					
*NWPP Bag			407.3				
NWPP Insert			214.6				

Table 3.3 Number of bags and corresponding weight material for 52 items

	One Trip		3.1 Trips		14.6 Trips		44 Trips	
	No. Bags	Wt. of Bags (g)	No. Bags	Wt. of Bags (g)	No. Bags	Wt. of Bags (g)	No. Bags	Wt. of Bags (g)
PRBs	9.8	61.0	30.5	189.1	143.7	890.7	433.0	2684
LDPE	8.3	295.6	8.3	295.6	8.3	295.6	8.3	295.6
NWPP	6.7	621.9	6.7	621.9	6.7	621.9	6.7	621.9
Paper	8.4	457.2	26.1	1417	122.7	6675	369.8	20116

Table 3.4 Average number and weight of bags used per functional unit

On average, about four items were left unbagged for each bag type. These were items such as a gallon of milk, a bag of pet food, a 2-roll pack of paper towels or a pack of toilet paper rolls. These unbagged items could be considered representative of the items that would be purchased in a warehouse club store. The NWPP bag averaged the most items per bag and the PRB averaged the least number of items per bag. The average total bag weight per trip and per multiple trips and the average number of bags per trip and per multiple trips were used to calculate the environmental impact category data in this report.

The U.K. Environment Agency Study reported that the weight capacity of carrier bags is 18 to 19 kg (Fry, 2011, p. 17). Note that the total weight of the filled bags in the present study, as shown in Table 3.3 is about 3.2 to about 4.9 kg. Bag capacity is therefore limited by bag volume, not by bag weight capacity.

To ensure the statistical significance of the above results, an ANOVA (**AN**alysis **O**f **VA**riance) analysis was conducted. The ANOVA results are shown in Table 3.5

ANOVA Results					
Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F	p
Between Bag Types	279.5	3	93.18	24.21	<0.0001
Within One Bag Type	908.4	236	3.849		
Total	1188	239			

Table 3.5 Statistical analysis by ANOVA of the bagging study results

The analysis shows that, with an F value of 24.21 vs. an $F_{critical}$ value of 2.64 (from standard statistical tables for the degrees of freedom in this study at 95% confidence level) and a very low value of p, there is high confidence that, where differences exist in the average number of bags used by type, these are representative differences.

Figure 3.1 shows the average bags/trip for each bag type plotted with their 95% confidence intervals.

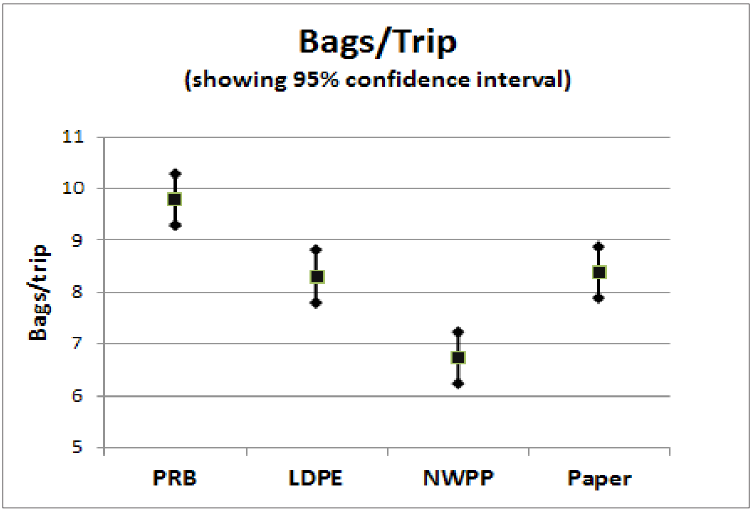


Figure 3.1 Average bags/trip for each bag type showing 95% confidence interavls.

We conclude therefore that we are justified to use the average bags/type found in the bagging study as the bases for our potential impact study and for comparison of the potential impacts among the bag types. The sensitivities of the environmental impact data to the statistical variability in bags/trip are shown in Section 6.5 of this report.

For comparison, Table 3.6 shows the reference flow assumptions used in other LCA-type studies of grocery bags compared with the results of our reference flow study. However, it should be noted that it is highly unlikely that the various studies used identical size bags.

Ratio of Bags Used per Trip			
Study	PRB/Paper	PRB/NWPP	PRB/LDPE
Franklin Associates[7]	1.5:1–2:1		
Boustead[8]	1:1–1.5:1		
UK Environment Agency[9]	1.26:1	1.24:1	
Chico[10]	1.5:1	1.5:1	1.5:1
Clemson	1.17:1	1.46:1	1:18:1

Table 3.6 Comparison of Reference Flow Data with other LCA Studies

To illustrate the types of differences that might exist among various studies, Table 3.7 compares the bag weights and items/bag used in the UK Environment Agency study (Fry, 2011, p. 18) with the present study.

Bag Type	Weight per Bag (g)		Items per Bag	
	Clemson	UK	Clemson	UK
PRB	6.2	8.12	5.2	5.88
Paper	54.4	55.20	6.5	7.43
LDPE	35.6	34.94	6.1	7.96
NWPP	92.8	115.83	7.6	7.3

Table 3.7 Comparison of Bag Weights and Bag Capacities with UK Study

3.4 System boundaries

Environmental impacts of each carrier bag were investigated using a 'cradle to grave' life cycle assessment approach. Thus, the included processes are: raw material extraction or harvesting, transportation of all materials, materials and operations for bag production and converting, packaging used in transportation and distribution, and final disposal.

The following processes are included in the Base Case life cycle assessment of each type of carrier bag:

0% RC PRB, 30% RC PRB, LDPE, and NWPP

The following processes were included in the life cycle analysis of these carrier bags: extraction of fuel and other feedstocks as raw materials; transportation of raw materials to polymer manufacturer; materials and operations for production of polymer;

transportation from polymer manufacturer to bag manufacturer; materials and operations for production of bags; transportation from bag manufacturer to supermarket; distribution packaging used during transportation; final disposal. For the PRB incorporating recycled content, the system boundaries were expanded to include avoided products. Since recycling eliminates the need for virgin production of materials, the burden typically associated with the material being avoided can be subtracted from the overall inventory of the process. Processes included in the reprocessing of post-consumer recycle included: transport, sorting, washing, pellet extrusion, combining with post-industrial recycle, re-extrusion of pellets.

40% RC Paper, 100% RC Paper

The following processes were included in the life cycle assessment of these carrier bags: tree growth and harvesting; transportation of raw materials to pulp and paper mill; materials and operations involved in production of paper bags; transportation from bag manufacturer to supermarket; distribution packaging used in transportation; final disposal. It was assumed that none of the RC required a specific deinking process before being incorporated into new carrier bags. Since recycled inputs displace virgin materials, the burden associated with virgin paper was not included in those portions of product with recycled content. For recycled content components, only the recovery and other steps involved in preparing the recovered content for reuse in new bags were included.

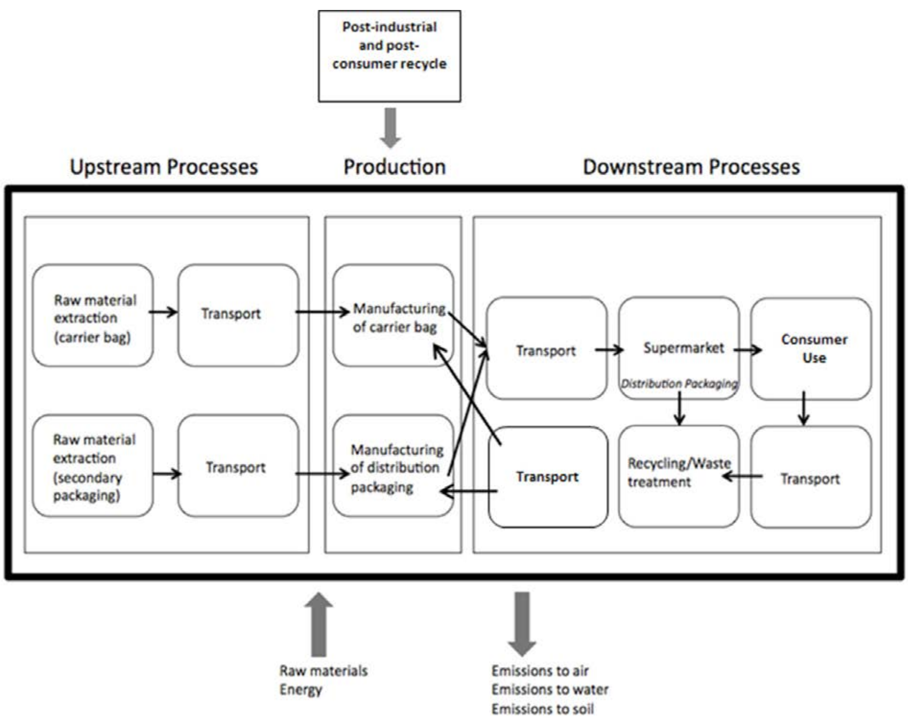


Figure 3.2 System boundary diagram for all studied bag types

An overview of the processes accounted for in the study is shown in Figure 3.2. Detailed flow diagrams for each general type of carrier bag are shown in Section 4.2. Detailed mass balance diagrams are shown in Annex B.

3.5 Allocation procedures

In accordance with ISO 14044, recycling in our processes was modeled using the cut-off method, detailed below:

- A *credit* was given (i.e. the avoided energy use, GHG emissions, water use, and waste generation of virgin materials and all of the other potential environmental impacts) in instances where recycled material replaced virgin material in bag production.
- Although the impacts associated with virgin material production are avoided when recycled material is used, a *burden* must be assigned (i.e. the amount of energy and GHG emissions produced by "refurbishing" of the recycled material) to account for conversion of material into a usable form, such as pellets or pulp. This step includes collection of recycled materials, transport to a material processor, transport to the bag manufacturer, and all inputs associated with processing the recycled material into a usable form for bag production (e.g. cleaning, sorting, pelletizing).

For the Alternative Scenario-Secondary Uses, system expansion was employed to demonstrate PRB and Paper bag reuse, described below:

- The avoided manufacture of trash-can liners when PRBs or Paper bags are used for secondary uses such as to contain garbage (e.g. wastebasket liner, trash disposal, and animal refuse) was accounted for as a *credit* to the PRB bags and Paper bags.

3.6 Impact assessment methodology

A summary of the methods used to calculate various impacts is shown in Table 3.8 and a description of these environmental impact categories can be found in Annex C.

Most of the values for environmental impact categories were generated using World ReCiPe Midpoint H/A, which is the hierarchist, or consensus model within World ReCiPe. The ReCiPe method generates a broad scope of impact categories that offers much opportunity for comparison among bag types.

Methods used to calculate impact categories		
Impact category	Unit	Method Used
Global warming potential	kg CO_2 eq	IPCC 2007 100-year V1.02
Terrestrial acidification	g SO_2 eq	World ReCiPe Midpoint H/A V1.07
Freshwater eutrophication	g P eq	
Marine eutrophication	g N eq	
Human toxicity	g 1,4-DB eq	
Terrestrial ecotoxicity	g 1,4-DB eq	
Freshwater ecotoxicity	g 1,4-DB eq	
Marine ecotoxicity	g 1,4-DB eq	
Fossil depletion	g oil eq	
Photochemical oxidant formation	g NMVOC	
Water depletion	gal	
Cumulative energy demand	MJ-equiv	Cumulative Energy Demand V1.08

Table 3.8 Summary of methods used to calculate environmental impacts on bags

3.7 Modeling

3.7.1 Software

SimaPro software system, developed by PRé Consultants, was used as the primary modeling software for this study.

3.7.2 Limitations

As with other LCA studies, certain limitations that may have influenced the results of this study should be noted. For example, it was imperative to make generalized assumptions about bag properties, consumer behavior, etc. that may not accurately reflect reality. These have been noted throughout the study and sensitivity analyses have been carried out in order to determine the effects of some of these decisions. Since the nature of the data collection related to the SimaPro database is so intensive, many processes in the model reflect technology that existed two, five, and even ten years ago. Thus, some of these processes may be outdated and yield different values than their current respective environmental impacts.

3.8 Data quality

3.8.1 Sources of the data

The US-EI 2.2 Database developed by Sylvatica is a product of Ecoinvent Center and is derived from the Ecoinvent 2.2 database. The US-EI 2.2 database applies U.S.

electricity data to all applicable Ecoinvent datasets and was utilized for the following cradle-to-gate material life cycle inventories: HDPE, LDPE, LLDPE, PP, limestone, titanium dioxide, cotton thread, corrugated board, acrylonitrile-butadiene-styrene copolymer resin (ABS), phenolic resin, and paraffin[11] (Swiss Centre for Lifecycle Inventories, 2007). US-EI 2.2 Database was also used to model HDPE, LDPE, and PP film extrusion. Energy requirements for conversion of each substrate into bags are estimated based on representative manufacturing equipment specifications and values are disclosed in Table 4.2. All U.S. material and packaging transport was assumed to be carried out by trucks weighing 16-32 tons and was modeled using US-EI 2.2. In the case of NWPP bags, transoceanic freight ships were used to represent travel from China, also provided by US-EI 2.2. The US-EI 2.2 database was developed as a modification that links all applicable data sets to US electricity data. Table 3.9 shows the specific processes from SimaPro that were used in generating the LCA data for this study. A summary of other assumptions and sensitivities is provided in ANNEX D.

Product/Process	Title in SimaPro	Library	Notes/Additions
Raw Materials			
HDPE	High density polyethylene resin, at plant NREL/RNA	US-EI 2.2	
LDPE	Low density polyethylene resin, at plant NREL/RNA	US-EI 2.2	
PP	Polypropylene resin, at plant NREL/RNA	US-EI 2.2	Changed to China grid electricity
Paper	Kraft paper, unbleached, at plant/RER WITH US ELECTRICITY	US-EI 2.2	
LLDPE	Linear low density polyethylene resin, at plant NREL/RNA	US-EI 2.2	
Calcium carbonate	Limestone, milled, packed, at plant/CH WITH US ELECTRICITY	US-EI 2.2	
Titanium dioxide	Titanium dioxide, production mix, at plant/RER WITH US ELECTRICITY	US-EI 2.2	
Cotton	Yarn, cotton, at plant/GLO WITH US ELECTRICITY	US-EI 2.2	
Corrugated case	Corrugated board, recycling fiber, single wall, at plant/RER WITH US ELECTRICITY	US-EI 2.2	
Glue	Acrylonitrile-butadiene-styrene copolymer resin, at plant NREL; Phenolic resin, at plant/RER WITH US ELECTRICITY; Paraffin, at plant/RER WITH US ELECTRICITY	US-EI 2.2	

Processes			
Extrusion	Extrusion, plastic film/RER WITH US ELECTRICITY	US-EI 2.2	
US land transportation	Transport, lorry 16-32t, EURO5/ RER WITH US ELECTRICITY	US-EI 2.2	
Ocean transportation	Transport, transoceanic freight ship/ tkm/OCE	US-EI 2.2	
Paper recycling	Paper, recycling, without deinking, at plant/RER WITH US ELECTRICITY	US-EI 2.2	
Plastic recycling	HDPE, recycling, modified to reflect actual industry data[12]	US-EI 2.2 (modified)	
Energy			
Electricity (U.S.)	Electricity, medium voltage, at grid/ US U WITH US ELECTRICITY	Ecoinvent unit processes	
Electricity (China)	Electricity, medium voltage, at grid/ CN	Ecoinvent unit processes	
End-of-Life			
Sanitary Landfill	Sanitary landfill waste, polyethylene, paper/corrugated (polyethylene data used for PP)	US-EI 2.2	
Incineration	Waste incineration, polyethylene, paper/corrugated (polyethylene data used for PP)	US-EI 2.2	

Table 3.9 SimaPro processes used in study

3.8.2 Time-related coverage

The data used to model HDPE, LDPE, LLDPE, PP, and ABS polymers represent data from 2008. Paper production, limestone, titanium dioxide, phenolic resin, and paraffin data is reflective of technology from 2003. Corrugated board and cotton thread information represents data from 2007. The plastic film extrusion processes are modeled from 2005 data. PE recycling data were updated to 2012. Manufacturing equipment used to estimate bag conversion energy use is representative of machinery commonly used in 2012. Truck transport data from 2007 and transoceanic shipping data from 2003 were utilized. It is important to note that because data is derived from processes occurring from 2003 to 2012, it may not properly reflect current technology. Although all of the materials and production processes utilized in this study are well-established, it is possible that certain processes have improved in the last several years and, thus, would realistically result in a decreased environmental impact. Data for recycling, landfill disposal, and incineration are from 2011 information provided by the U.S. Environmental Protection Agency.

3.8.3 Geographical coverage

Data used for modeling raw material production of HDPE, LDPE, and LLDPE polymers is representative of processes utilized in North America. Because China-specific manufacturing data for NWPP was not available, North American production technology with China's grid electricity values was substituted. Paper production information is from an average of two European producers with integrated mills, and a U.S. paper manufacturer confirmed that values used were similar to U.S. processes. Limestone data were collected from a Swiss company, with a substitution for U.S. electricity, and include milling and packing. Titanium dioxide production is modeled after a cross-section of plants in Europe and 50% is assumed to be produced by the sulfate process and 50% by the chloride process. Cotton thread was modeled with the assumption that 40% was produced in the U.S. and 60% was produced in China. Corrugated board data was provided from European industry averages by FEFCO, an association of corrugated board manufacturers, and U.S. electricity data was substituted for European values. ABS reflects North American production from a single, confidential source. Phenolic resin production is not representative of a particular geography; instead, literature sources informed stoichiometric calculations for process data and energy demand was estimated from a large chemical plant using U.S. grid electricity. Paraffin data is based on average European production with energy profiles substituted with U.S. grid electricity. To model all transportation scenarios and distances, the authors chose U.S. locations in which each process is likely to occur. Since one of the largest PRB manufacturers is located in the greater Cincinnati area, Indiana was chosen as a representative location for PRB bag production. One of the leading U.S.-based LDPE bag producers is based out of Oroville, CA; thus, all LDPE bag manufacturing was modeled in California. Since a large proportion of NWPP bag production is carried out in China, the manufacturing model for NWPP bags in this study reflects this. Although paper bag production is quite varied in the U.S., Ohio was used to model paper bag production in this study, as a large percentage are produced in and around Ohio. Because the largest polymer processors and distributors exist near the Gulf Coast of Texas, both virgin and recycled polymer content was modeled to have originated there. Although distribution models of NWPP bags vary depending on each particular manufacturer, a Florida-based distributor was used in this study since, geographically, it represents an intuitive location for imports from China and many NWPP bag importers are known to have distribution facilities in that area. Based on a search of predominant limestone producers in the U.S., Vermont and Alabama represented the largest areas of distribution. Thus, an average distance from Vermont and Alabama to limestone's destination was used in modeling its use. Since titanium dioxide is produced in many states throughout the U.S., a Tennessee-based production model was used in the PRB scenarios and a California-based production model was used in the LDPE scenario to reflect the most likely origin of titanium dioxide for each process. A large glue manufacturer is located in Indiana and was used to model glue supply to Ohio for paper bag production. For all bag types, the distance from the bag manufacturer to the supermarket was set at 450 miles.

3.8.4 Technology coverage

The weight measurements collected for this study utilize bags representative of current bag manufacturing technology. Equipment and processes used in polymer production, film extrusion, and bag conversion steps are modeled using average technology from the time period referenced for each in 3.8.2. Although some state-of-the-art, high efficiency equipment does exist and is currently employed by some manufacturers, it was not taken into account for this study. Equipment and processes for incorporation of recycle into PRBs was based on 2012 manufacturing technology. Although paper production represents averages from two European producers, it is assumed that European technology is representative of equipment also used in the United States.

3.9 Critical Review

As mandated by the ISO 14040 guidelines to support comparative assertions, a critical review was conducted by the following panel:

Vee Subramanian (chairman), PRé North America.
Katherine O'Dea (member), GreenBlue
Dr. Susan E. M. Selke (member), Michigan State University

The panel's Final Statement is reproduced in Annex H. The authors' responses to panel feedback are also documented in Annex H.

3.10 Reporting

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

Notes

1. Confidential communication from industry source to R. Kimmel (August, 2012).
2. Other municipalities have specified a thicker, 4 mil, LDPE bag. Details and the effects on the environmental impact categories of this thicker, heavier bag are discussed in Section 6.4.
3. Confidential communication from industry source to R. Kimmel (August, 2012).
4. Private communication from Hilex Poly to R. Kimmel (August, 2012).
5. The rationale for choosing the functional units is discussed in detail in Section 4.5 below.
6. The FMI reported that of the consumers surveyed, 26% visited a warehouse club store "almost every time" (24%) or "fairly often" (76%). Assuming "almost every time" means every trip and "fairly often" means on ½ of trips, about 15% of the 2.2 trips per week are to warehouse club stores (where bags or sacks would not be used). Consumers would therefore use bags or sacks for an average of 1.85 trips per week.
7. Franklin Associates, Ltd., 1990.
8. Yaros, 2007.
9. Fry, 2011.
10. Greene, Life Cycle Assessment of Reusable and Single-Use Plastic Bags in California, 2011.
11. ABS, phenolic resin, and paraffin are the components estimated to make up glue used in paper bag production as 32%, 48%, and 20%, respectively.
12. Confidential communication of actual industry data to A. Littman (August, 2013).

4. Inventory Analysis

This section identifies the data used in modeling life cycle scenarios for each carrier bag and details of the assumptions used for each.

Bagging Study Capacity Results (52 items/trip)										
			One Trip		3.1 Trips		14.6 Trips		44 Trips	
Bag type	**g/ bag**	**Items /bag**	**No. Bags**	**Wt. of Bags (g)**	**No. Bags**	**Wt. of Bags (g)**	**No. Bags**	**Wt. of Bags (g)**	**No. Bags**	**Wt. of Bags (g)**
PRB (0% RC)	6.24	5.2	9.8	61.3	30.5	189.1	143.7	890.7	433.0	2684
PRB (30% RC)	6.24	5.2	9.8	61.3	30.5	189.1	143.7	890.7	433.0	2684
Paper (40% RC)	54.4	6.5	8.4	457.2	26.1	1417	122.7	6675	369.8	20116
Paper (100% RC)	54.4	6.5	8.4	457.2	26.1	1417	122.7	6675	369.8	20116
LDPE	35.6	6.1	8.3	295.6	8.3	295.6	8.3	295.6	8.3	295.6
NWPP	92.8*	7.6	6.7	621.9**	6.7	621.9**	6.7	621.9**	6.7	621.9**

*Bag: 60.8 g Insert: 32.0 g **Bag: 407.3 g Insert: 214.6 g

Table 4.1 Assumed weight, capacity, and required bags for functional units

4.1 Raw materials

The raw materials and exact compositions for the PRB bags were provided by Hilex Poly Co. LLC.[1] Data for the LDPE bags were estimated from HDPE data and the authors' experience. Estimates were made about the materials used in NWPP bags, as information from manufacturers was not available.

PRBs

HDPE and LLDPE, the plastics from which PRBs are produced, are manufactured by the polymerization of ethylene, a gas. Ethylene is obtained from the steam cracking of the gas ethane. Ethane is a by-product of both oil refining and natural gas processing. Because of today's plentiful supply of natural gas in the United States, almost all ethane comes from natural gas processing. (U. S. Energy Information Administration, 2012). Therefore, in this study all of the polyolefins for PRBs are assumed to derive from processing of natural gas.

Paper bags

The raw material for paper bags is cellulosic fibers. Although paper can be made from many kinds of fibers, in most parts of the world wood is the most available and economical source of supply.

LDPE bags

LDPE, the plastic from which LDPE bags are produced, is manufactured from the same ethane/ethylene raw material discussed in the PRB section.

NWPP bags

NWPP bags are produced from propane/propylene raw materials, which are obtained from oil refining and gas processing. In this study, polypropylene is assumed to be produced in China from 23% oil refining and 77% natural gas processing. The LDPE sheets are assumed to be produced from 100% recycle, some of which may have been collected in the U.S. or Europe and shipped to China.

4.2 Bag manufacturing processes

PRBs are manufactured in a continuous film-to-bag process from HDPE, with some LLDPE added. HDPE has a very linear structure with only a few short side branches, leading to a higher density range and a relatively crystalline structure, higher strength and higher stiffness, compared to other types of polyethylene. LLDPE also has a very linear structure, but with many short side branches. These branches inhibit crystallization and provide a tougher, more extensible film (Carter, 2009).

The process for manufacturing PRBs from their raw materials is shown schematically in Figure 4.1. For completeness, this chart includes PRB reuse for secondary applications, which is excluded from the Base Case of this study, but included as an alternative scenario.

The following components were included in the modeling of each PRB; however, the percent composition data are confidential to the manufacturer who provided them for this study: HDPE, LLDPE, calcium carbonate ($CaCO_3$), and titanium dioxide. Ink was not included in the model. Milled limestone was used to model $CaCO_3$, as it was the most similar process available. In-plant recycle in the film manufacturing process is currently 2.4%.[2]

Paper bags are made in the multi-step operation shown in Figure 4.2. The manufacturing process frees the cellulosic fibers from logs by breaking down the wood into a wet, fibrous mass, or pulp. First the bark, which is highly colored and contains few fibers, must be removed. The logs can then be mechanically broken into chips to feed the pulp making process. The pulp is then further processed to obtain long, refined fibers suitable for making paper.

Chemical pulping produces higher quality, stronger paper and is therefore the primary source of paper for packaging. Chemical pulping employs a sulfate process, also known as the Kraft process (Kraft comes from the German word for strong). Kraft

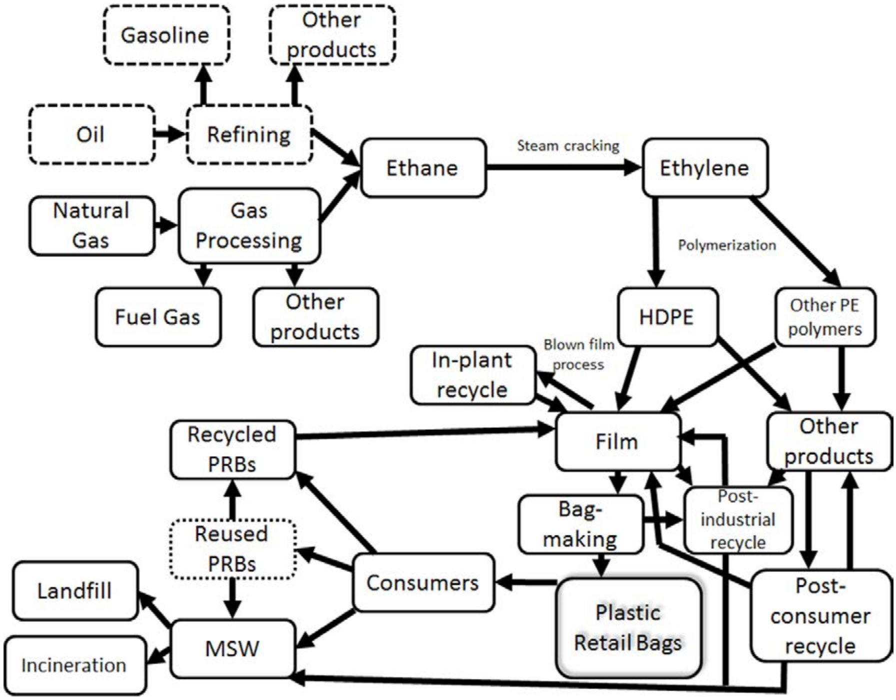


Figure 4.1 Schematic of PRB manufacture and use

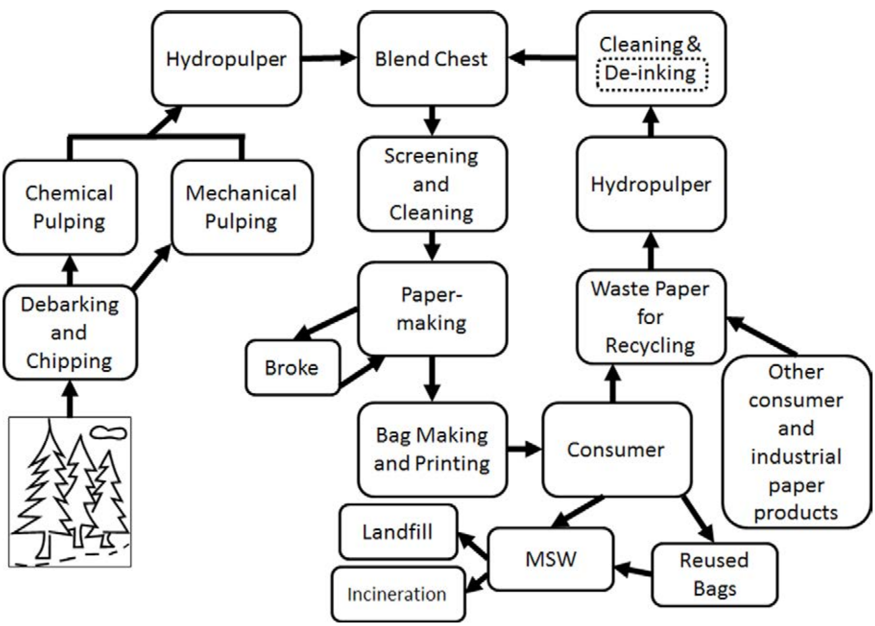


Figure 4.2 Schematic of Kraft paper bag manufacture and use

pulping uses a solution of two chemicals, sodium hydroxide and sodium sulfide. The organic sulfide gases that are released by the Kraft process are responsible for the undesirable odor generated by Kraft pulping facilities. The process removes about 80% of the lignin from the raw pulp as well as other undesirable components. The pulp must then go through a variety of cleaning and refining operations; hydropulpers are used to create a slurry, a thick liquid with the consistency of oatmeal that feeds the papermaking process (Twede & Selke, 2005, pp. 173-189). The in-plant recycle used in a paper mill is called "broke." Industry sources estimated the typical % broke at 10%.[3]

Recycled wastepaper must be repulped to break it back into fibers and then cleaned and decontaminated. As shown in Figure 4.2, virgin and recycled pulp are blended together, cleaned and refined, and then made into paper. The figure includes de-inking, which is not included in the Base Case of this study, but is examined as sensitivity (Section 6.2). It also included secondary uses that are also not included in the Base Case, but are analyzed in an alternative scenario (Section 5.4). Rolls of paper are shipped to converters who fabricate and print paper grocery bags.

An adhesive must be used to form both the lineal seam that makes a flat sheet of paper into a tube and the square bottom (Twede & Selke, 2005, pp. 333-336). As noted above in Section 3.1, hot-melt, starch/dextrin and polyvinyl acetate adhesives are all offered for gluing the side-seams and bottoms of paper grocery bags (Adhesives Products, Inc., 2011). In the absence of any other available quantitative data either for the glue composition or for the life cycle components, the hot-melt adhesive used in the U.K. Environment Study was also used in the present study. This was described in the U.K. study as 32% ABS, 48% phenolic resin and 20% paraffin, with 1.44 g of glue per 52.99 g of Kraft paper (Fry, 2011), p. 89. This ratio results in 27.2 g of glue for every 1000 g of Kraft paper.

LDPE bags are manufactured from LDPE from the same raw material in PRBs, using a process similar to that shown in Figure 4.1. The differences are in the polymerization process and in the molecular structure of the resulting polymer or plastic. LDPE is not as stiff or as strong as HDPE, but is more extensible. According to Roplast's web site, the handle area of the bag's Wave Top is designed to be about twice as thick as the body of the bag to enhance durability. This is accomplished in the set-up and control of the filmmaking process (Roplast Industries, 2013).

The following components were included in the modeling of every 1 kg of LDPE bags: 400 g LDPE, 330 g LLDPE, 100 g calcium carbonate, and 70 g titanium dioxide.[4] Similar to the PRBs, limestone was used to model $CaCO_3$, as it was the closest material available. Based on the data shown on Roplast's web site (see Section 3.1), zero content of post-industrial and post-consumer recycle was assumed.

NWPP bags contain the plastic polypropylene (PP), which is created using a process very similar to that used to make HDPE, shown schematically in Figure 4.3. However, instead of being made into a continuous film, a non-woven fabric is created by extruding fibers, entangling and separating them using mechanical and pneumatic means, and then flattening them and heat-bonding them at the points where fibers cross, creating a fabric (Silva, 2010). A major difference between PP and HDPE processing is that PP melts at about 166°C (331°F) while HDPE melts at about 130°C (266°F), thus requiring more energy input for melt processing to make fibers or films. In a separate process, LDPE sheets made from 100% recycled material that are about 0.6 mm (23 mils) thick and made in a film-casting rather than a blown-film process are cut into rectangles and inserted into the bottoms of the NWPP bags for stability.

Due to the complexity of the non-woven process, 10% in-plant recycle has been assumed for the non-woven PP fabric. Due to the differences between the film-making processes used for the insert vs. PRB and LDPE bags, and the problems associated with running 100% recycled material, 10% in-plant recycle was assumed for the insert as well. As discussed in Section 3.1, the PP non-woven fabric has been assumed to contain 0% recycled material.

As noted in Section 3.1, NWPP bags imported into the United States are assembled by sewing the side panels, bottoms and handles together with cotton thread. The UK Environment Study determined that 0.9 g of cotton thread is used per NWPP bag. This amount is in good agreement with our estimate of 0.88 gm of cotton thread.[5] Using these same data, the following components were included in the modeling of every 1 kg of NWPP bags: 645 g PP (for bag), 345 g LDPE (for insert), and 9.7

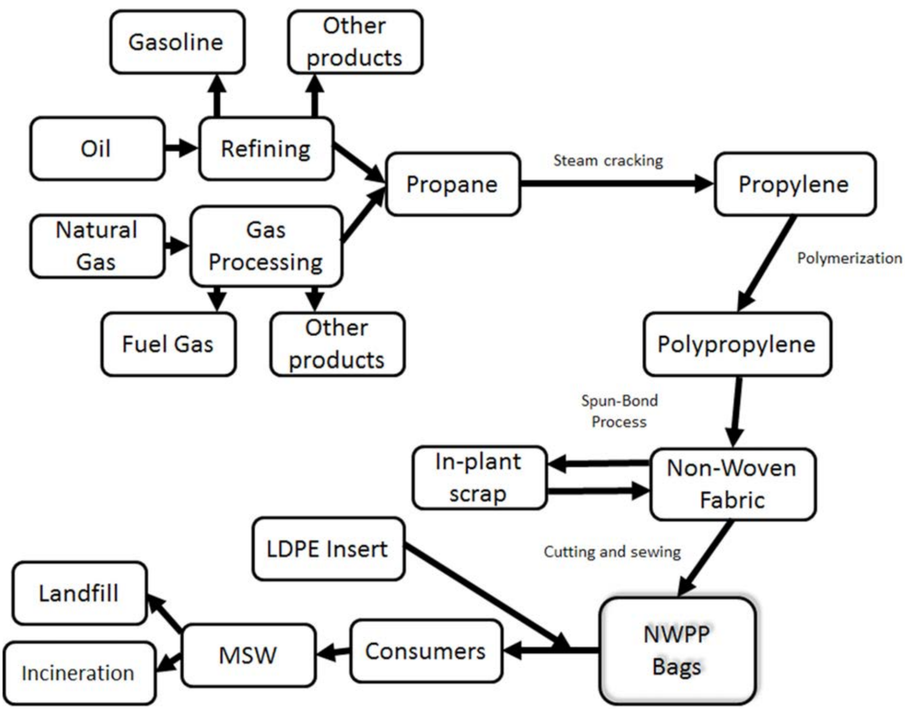


Figure 4.3 Schematic of NWPP bag manufacture and use

g cotton thread.[6] Muthu studied NWPP bags produced both by sewing and heat-bonding. Even though the heat-bonded bag was 25% lighter in weight than the sewn bag, Muthu found that "it was clear that sewing technology was better in terms of environmental damage and carbon footprint than thermal technology…due to its lower energy requirements, low level of water creation and other related factors in terms of comparative unit weight." (Muthu, 2014, p. 33)

Table 4.2 provides the values that were used to model the conversion of each substrate (i.e. plastic or paper) into the usable bag form. These estimates were made based on manufacturer specifications of representative bag conversion machinery.

Bag type	Electricity (kWh/kg)	Based on
PRB (0% RC)[7]	0.4899	90 bags/min @ 12 kW power
PRB (30% RC)[7]	0.4899	90 bags/min @ 12 kW power
LDPE bag	0.4899	Estimated approx. same as HDPE
NWPP bag	0.6120	Estimated approx. same as HDPE +25% to include spun-bond process
Paper bag (40% RC)[8]	0.0421	80 bags/min @ 10 kW power
Paper bag (100% RC)[8]	0.0421	80 bags/min @ 10 kW power

Table 4.2 Energy Requirements for conversion into bags

4.3 Transport and distribution packaging

The transportation profiles of each of the carrier bags are detailed in Table 4.3. The distances represent transportation of raw materials to production locations and production locations to supermarkets based on estimations from industry contacts. An average of 450 miles for transport of bags from the bag manufacturer or distributor to the supermarket was assumed for all bag types.

Bag type	From	To	Mode of transport	Approx. distance (miles)
PRB (0% RC)	Polymer resin producer in Texas	Bag manufacturer in Indiana	Truck	833
	Limestone producer in Vermont or Alabama (avg.)	Bag manufacturer in Indiana	Truck	716
	Titanium dioxide producer in Tennessee	Bag manufacturer in Indiana	Truck	188
	Bag manufacturer in Indiana	Supermarket	Truck	450

Bag type	From	To	Mode of transport	Approx. distance (miles)
PRB (30% RC)	Polymer resin producer in Texas	Bag manufacturer in Indiana	Truck	833
	Limestone producer in Vermont or Alabama (avg.)	Bag manufacturer in Indiana	Truck	716
	Titanium dioxide producer in Tennessee	Bag manufacturer in Indiana	Truck	188
	Post-consumer and post-industrial HDPE recycler in Texas	Bag manufacturer in Indiana	Truck	833
	Bag manufacturer in Indiana	Supermarket	Truck	450
LDPE bag	Polymer resin producer in Texas	Bag manufacturer in California	Truck	1997
	Limestone producer in California	Bag manufacturer in California	Truck	509
	Titanium dioxide producer in California	Bag manufacturer in California	Truck	458
	Bag manufacturer in Indiana	Supermarket	Truck	450
NWPP bag	Polymer resin producer in China	Bag manufacturer in China	Truck	500
	Bag manufacturer in China	Bag distributor in Florida	Sea freight	10000
	Bag distributor in Florida	Supermarket	Truck	450
Paper bag (40% RC)	Timberland producer or recycler in West Virginia	Bag manufacturer in Ohio	Truck	200
	Glue manufacturer in Indiana	Bag manufacturer in Ohio	Truck	200
	Bag manufacturer in Ohio	Supermarket	Truck	450
Paper bag (100% RC)	Recycler in West Virginia	Bag manufacturer in Ohio	Truck	200
	Glue manufacturer in Indiana	Bag manufacturer in Ohio	Truck	200
	Bag manufacturer in Ohio	Supermarket	Truck	450

Table 4.3 Assumed transport scenarios for each bag type

Based on information from an industry source, all bag types are shipped in the United States (or from China to the U.S. in the case of NWPP) in corrugated boxes.

Only the corrugated boxes themselves have been included in the calculation of distribution packaging. Although some suppliers may include a flexible, polymer liner bag within the corrugated container, this is not consistent in all instances and, thus, is not included. Pallets, strapping tape and stretch film have not been included. Use and amounts of strapping or stretch film are highly variable. Pallets, if used, are almost always reused many times. Table 4.4 shows the distribution packaging used to model transport of bags from manufacturer to supermarket.

Bag type	Box capacity (bags/case)	Corrugated weight (g)
0% RC PRB	2000	382
30% RC PRB	2000	382
40% RC Paper	500	900
100% RC Paper	500	900
LDPE	250	270
NWPP	100	1000

Table 4.4 Assumed distribution packaging for each bag type[9]

4.4 Recycling and end-of-life

4.4.1 Recycling of PRBs

The EPA reported that 8.6% of PRBs was recycled in 2011 (U. S. Environmental Protection Agency, 2013), Table 7,[10] although an industry source has stated that this number is as high as 15% (Staff, 2012). The 8.6% rate was used for this study.

4.4.2 Use of recycled materials in PRB manufacture

HDPE is widely used for bottles for milk, food products, household cleaning products and personal care products. The Association of Post-Consumer Plastic Recyclers reported that 984 million pounds of bottle PCR was available in 2011, about 30% of the total HDPE resin used. The major uses for HDPE bottle PCR are pipe, plastic lumber, decking, railroad ties, and non-food application bottles (Association of Post-Consumer Plastic Recyclers, 2012). Historically, a substantial amount of HDPE bottle PCR has been exported to China, but this has changed with the advent of the so-called "green fence" (Guilford, 2013).

PRB manufacturers have therefore turned to other sources of post-consumer and post-industrial recycle for reprocessing into PRBs. These include:

- post-industrial recycle (primarily handle cut-outs) recovered both from in-house operations and from other PRB manufacturers who lack the capability to reprocess this material;
- post-consumer recycle consisting of mixed bales of shrink and stretch films from various industries, mostly LDPE and LLDPE;

• post-consumer recycle from retailer bag recycling programs that collect not only PRBs made of HDPE, but also bags, wraps and films made from related polyethylene polymers.

PRB manufacturers who incorporate PCR into their bags have therefore adapted their processes to manage and control the presence of these other related, but different plastics (Canadian Plastics Industry Association, 1999).

The processes used in the present study for processing of post-consumer recycle for use in PRBs were based on the model in SimaPro for HDPE recycling. Modifications were made to the SimaPro model and recipe and selected data (e.g. energy use) were based on confidential information from an industry source.[11] The basic process steps are shown in Figure 4.4.

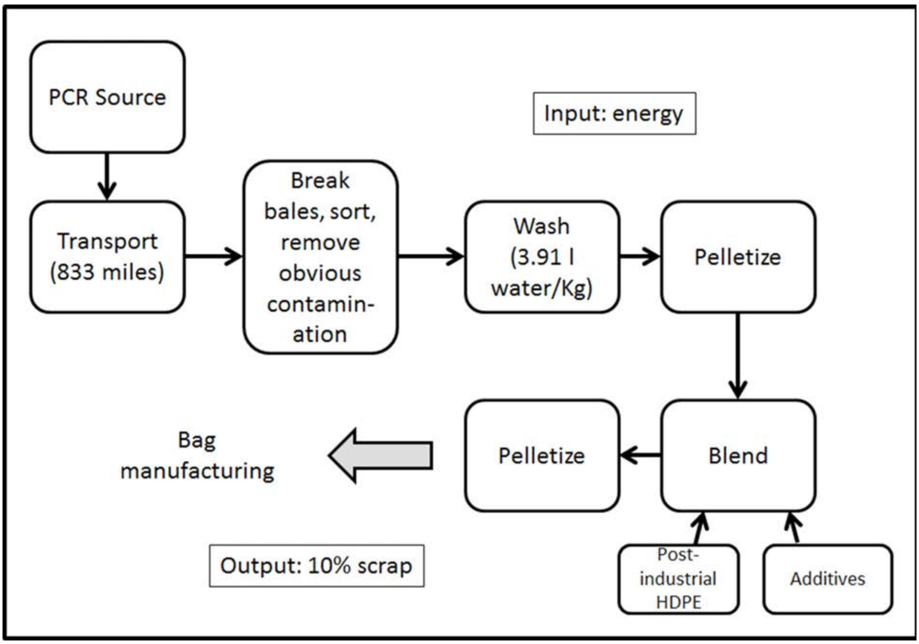


Figure 4.4 Processing Steps for PCR used in PRBs

There are always losses from the bales of PCR that are received for reprocessing. Industry sources report that this loss averages about 10% of material received.[12] The unusable materials are sent to MSW.

4.4.3 Recycling of Paper Bags

According to the EPA, 139.2 billion pounds of waste paper and paperboard were generated in 2011, of which 65.6% (91.8 billion pounds) was recovered and recycled. Of this total, 76.0 billion pounds of containers and packaging (including corrugated boxes) were generated, with 75.4% (57.3 billion pounds) recovered and recycled. Of the total containers and packaging generated, about 1.5 billion pounds were bags and sacks, of which 49.5% were recovered and recycled in 2009 (the last year for which the EPA breaks out this category) (U. S. Environmental Protection Agency, 2013), Tables 4, 19, 20, 21. For the present study, the 49.5% recycle rate reported by the EPA was used for bags and sacks and the 75.4% recycle rate was used for all paperboard containers and packaging, under the assumption that supermarkets do not in general separate corrugated boxes from other paper and paperboard recyclables.[13]

4.4.4. Use of recycled materials in paper bag manufacture

As described in Section 3.1, most of the recycle used in the manufacture of paper bags comes from OCC (Old Corrugated Containers). SimaPro models using the Ecoinvent US-EI 2.2 database were used to model paper recycling processes. Based on published industry data, an estimated 20% loss in reprocessing of recycled paper and paperboard materials was assumed (TAPPI, 2001)

4.4.5 LDPE bags

Since the EPA consolidates LDPE bag and sack waste generation and recovery with wraps (shrink and stretch wrap used for pallet loads included), no specific data on LDPE bag waste generation and recovery have been located. LDPE bags can be recycled at the same collection locations discussed above for PRBs. In the absence of quantitative data, a 0% recycle rate was used for the present study. As discussed above in Section 3.1, based on industry data, this study assumed that 0% post-industrial and post-consumer recycle is used in the manufacture of reusable LDPE bags.

4.4.6 NWPP Bags

According to the EPA, no PP bags, sacks or wraps were recycled in 2010 and only 0.5% or 80 million pounds of the total 15 billion pounds of PP discarded were recovered (U. S. Environmental Protection Agency, 2011), Table 4. Moore Recycling Associates reported that 35.4 million pounds of PP bottles were recycled in 2010, increasing to 43.8 million pounds in 2011. (Association of Post-Consumer Plastic Recyclers, 2012), p. 4. Moore Recycling Associates has also reported that 72.5% of the U.S. population has access to PP bottle recycling and 61.1% has access to PP non-bottle rigid recycling (Mouw, 2013). A 0% recycle rate for NWPPs was used for the present study. Some of the difficulties encountered in attempting to recycle NWPP bags were discussed in Section 3.1 above.

Although some NWPP suppliers claim that their bags contain PCR, this is unlikely to be the case (Foster, 2010). The study by Moore Recycling Associates discussed in Section 3.1 provides no evidence that the PP non-woven fabric used in China to manufacture NWPP bags contains recycle (Moore, 2011?). This is confirmed by Muthu in his study. (Muthu, 2014, pp. 23, 34)An industry source informed the authors that the rigid insert used in NWPP bags is cast from 100% LDPE recycle.[14] The SimaPro model for polyethylene recycling was used to model the recycling process for this product.

4.4.7 End-of-Life Assumptions

The latest data from the EPA show that 17.8% of MSW (Municipal Solid Waste) was incinerated and 82.2% was landfilled in 2011 (U. S. Environmental Protection Agency, 2013). These percentages were used for disposal of all bag types. Table 4.5 summarizes the percentages used in modeling each of the bag types.

Bag type	% Recycled	End-of-life	
		% Incinerated	% Landfilled
PRB	8.6	16.3	75.1
Paper	49.5	9.0	41.5
LDPE	0	17.8	82.2
NWPP	0	17.8	82.2
Corrugate	75.4	4.4	20.2

Table 4.5 Diversion and disposal of bag types and secondary packaging

Table 4.6 summarizes the data from the Ecoinvent US-EI 2.2 database that were used in the SimaPro model for landfill waste. Landfill includes base seal, leachate collection system and treatment of leachate in a municipal wastewater treatment plant.

Material	Water Content (%)	Degradability after 100 yrs. (%)
PRB, LDPE, NWPP	0.4	1
Paper, Corrugate	13.7	27

Table 4.6 Landfill Waste Data

Table 4.7 summarizes the data from the Ecoinvent US-EI 2.2 database that were used in the SimaPro model for incinerated waste.

Material	Water Content (%)	Waste Energy Produced (MJ/kg)		Landfilled Residues (kg)	
		Electric	Thermal	Slag	Residues
PRB, LDPE, NWPP	0.4	5	10.02	0.01917	0.0005762
Paper, Corrugate	27	1.32	2.77	0.08005	0.01256

Table 4.7 Incinerated Waste Data

As noted in the Introduction section of this report (see Section 1.1), one of the driving forces for grocery bag legislation is perceived litter issues with PRBs. This perception raises the question whether or not litter should be considered one of the end-of-life outcomes for PRBs in the Life Cycle Analysis. Keep America Beautiful in its latest national litter survey (MSW Consultants, 2009) states that roadway litter in the U.S. exceeds 51 billion pieces and that non-roadway litter adds an additional undetermined amount to this total. Stein (Stein, ER Planning Report Brief: Plastic Retail Bags in Litter, 2013) analyzed 20 years of scientifically-designed, statistically-based litter surveys in the U.S. and Canada and concluded that total plastic bag litter was less than 1% (by number of pieces). Combining these data with the estimated annual production of PRBs of 100 billion bags (U. S. International Trade Commission, 2009), and assuming that all of the plastic bag litter resulted from only one year's production and use of PRBs, leads to the conclusion that less than 0.5% of PRBs end their life as litter. This LCA study therefore assumes that litter should not be considered a significant end-of-life outcome for PRBs. Details of these litter data are included as Annex F to this report.

4.5 Usable Life of LDPE and NWPP Reusable Bags

4.5.1 Ordinance requirements

Some of the ordinances that have been put in place to regulate the use of grocery bags specify a minimum number of trips for which reusable bags should be reusable. The minimum numbers vary widely. For example, both Los Angeles and San Francisco counties require that reusable bags be reusable for a minimum of 125 store trips (County of Los Angeles Department of Public Works, Environmental Programs Division, 2012) (Department of the Environment, City and County of San Francisco, 2012). In these regulations, required tests that bags must meet are specified. Seattle's regulations state "20 repeat uses would seem a reasonable minimum." (Seattle Public Utilities, 2013) Boulder, Colorado's ordinance requires a minimum of 75 reuses (City Council of the City of Boulder, Colorado, 2012). Again, tests are specified.

4.5.2 The CSU Chico Study

The Institute for Sustainable Development of California State University, Chico reported in 2010 a survey of reusable and single-use grocery bags in Northern California (Greene, Survey of Reusable and Single-use Grocery Bags in Northern California, 2010). At the time of the survey, the ban in San Francisco of plastic bags at large grocery stores had been in effect for three years, but other areas surveyed did not have plastic bag regulations in place. 50 stores were surveyed including large grocery stores, specialty and discount grocery stores and pharmacies. Table 4.8 is a summary of the survey results, calculated by the authors from the detailed data reported in the CSU Chico survey.

These data show that even three years after the San Francisco ordinance regulating plastic bags had been in place, a relatively small number of consumers preferred to replace PRBs with reusable bags rather than paper bags.

	% Single-use Plastic Bags (PRBs)	% Single-use Paper Bags	% Reusable Bags (NWPPs)
Total of all stores	66.2	23.6	10.2
Total-excluding pharmacies	65.3	24.0	10.3
San Francisco only	6	80	14
Other areas	69	21	10

Table 4.8 Summary of CSU Chico Survey of Grocery Bag Use in Northern California[15]

4.5.3 Model based on import and population data

The U.S. International Trade Commission imports database can be accessed to determine the total number of reusable bag imports by searching using code 4902.92.3031[16]—"Travel, sports and similar bags, except backpacks, of man-made fiber."[17] The resulting data are shown as Table 4.9. The table shows that imports were approximately stable from 1998–2001. This average number of 119.8 million can be considered an estimate of the base number of non-grocery bag imports. Table 4.9 also includes the additional assumption (made for the purposes of this study) that the number of non-grocery bags imported increased at a growth rate of 3%/year starting from this 1998–2001 base. Total imports jumped dramatically to over 500 million in 2008, the year following the first San Francisco plastic bag ordinance. By subtracting the estimate of non-grocery bag imports from total imports, an estimate for the average NWPP grocery bag imports for 2008–2012 can be calculated.

Year	Total Imports	Estimated Imports of Non-Grocery Bags*	Estimated Imports of Grocery Bags
	(millions of bags/yr.)		
1998	100.1	100.1	0
1999	131.5	131.5	0
2000	127.3	127.3	0
2001	120.1	120.1	0
2002	152.7	123.3	29.4
2003	200.6	127.0	73.6
2004	264.9	130.9	134.0
2005	301.1	134.8	166.3
2006	318.5	138.8	179.7
2007	361.8	143.0	218.8
2008	503.8	147.3	356.5

Year	Total Imports	Estimated Imports of Non-Grocery Bags*	Estimated Imports of Grocery Bags
	(millions of bags/yr.)		
2009	415.7	151.7	264.0
2010	532.8	156.2	376.6
2011	570.5	160.9	409.6
2012	590.0	165.8	424.2
Avg., 1998–2001		119.8	
Avg., 2008–2012	522.6		366.2

* 3%/yr. compounded growth off 1998-2001 average base

Table 4.9 ITC Data for Reusable Bag Imports

The ITC data can be combined with the census data for the number of U.S. households in 2010 (Daphne Lofquist, 2012) and with the CSU Chico Survey data to estimate the average usage of NWPP bags prior to disposal with and without regulation. These calculations are shown in Table 4.10. In the absence of any other data on reusable bag use, Table 4.10 assumes that the CSU Chico findings for reusable bag use before and after regulation in Northern California are representative of consumer behavior across the U.S.

Row		Source	Without regulation	With regulation
1	% Reusable Bags	Table 4.8	10	14
2	U.S. Households (2010)	U.S. Census Bureau Data	117,000,000	117,000,000
3	Households using reusable bags	Row 1 x Row 2	11,700,000	16,380,000
4	Average reusable bags needed for one trip	Table 3.4	6.7	6.7
5	Average bags needed for one trip for all households using reusable bags (2010)	Row 3 x Row 4	78,390,000	109,746,000
6	Average imports/yr. of NWPP (2008-2012)	Table 4.9	366,177,000	366,177,000
7	Bags imported/bags needed	Row 6/Row 5	4.67	3.34
8	Trips/household/yr.	(1.85 trips/wk.) X (365 days/7 days/wk.)	96.5	96.5
9	Average no. of reuses if all imported bags are used	Row 8/Row 7	20.7	28.9

Table 4.10 Estimate from Census and Import Data of Average Reuse of NWPP Bags

4.5.4 The Edelman Berland Study

Edelman Berland, the research arm of Edelman Public Relations, published in May 2014 the results of a comprehensive, nationwide study to document the actual reuse rate of reusable bags. (Edelman Berland, 2014)

The key findings of this new study that relate to the present LCA analysis are as follows:

- 28% of 3,568 individuals surveyed had not acquired a reusable bag in the past year, leading to a sample size for the study of 1,002 individuals. 87% of these people had used reusable bags for grocery shopping. The survey had a margin of error of ±3.1%.
- Consumers forget to bring their reusable bags to the store 40% of the time and opt for a PRB or paper bag instead.
- 61% of people prefer NWPP bags, but 41% typically use PRBs
- The average reuse rate for NWPP bags is 14.6 times (17.3 times in markets where legislation is in place; 13.9 times in non-legislated markets)[18]
- About 1/3 of the study sample acquired an LDPE bag in the past year, but only 6% prefer to use them.
- The average reuse rate of LDPE bags is 3.1 times.
- 10% of people prefer to use paper bags and about 8% typically use them.

Edelman Berland graciously provided us the histogram for NWPP bags that shows, for the entire sample of 1,002 people, the per cent of people vs. the number of times they reuse their bags. From these data we created the chart shown in Figure 4.5.

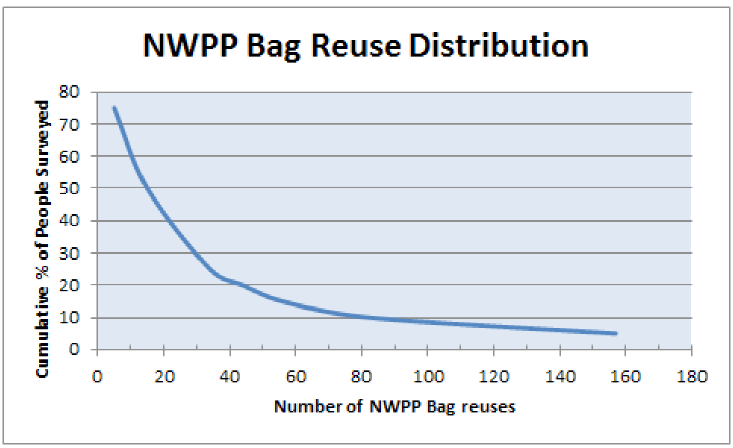


Figure 4.5 Cumulative % of people vs. number of NWPP bag reuses (Edelman Berland data)

Figure 4.5 shows that 50% of people reuse their bags more than14.6 times (the National average), while 20% of people reuse their bags more than 44 times.

4.5.5 Selection of functional units

Based on these data and the above discussion, the authors chose the following functional units as a basis of comparison of the types of grocery bags in the current study.

Functional Unit (No. of Trips)	Scenario
1	Comparison of bags intended for one grocery bag use
3.1	Comparison with the average national rate of reuses of LDPE bags
14.6	Comparison with the average national rate of reuses of NWPP bags
44	Comparison with the number of reuses of NWPP bags that 20% of people nationally exceed.

Table 4.11 Functional Units Representing Various Use Scenarios

4.6 Materials and processes not included in Life Cycle Analysis

Capital equipment

The construction and demolition of buildings, machines, and equipment associated with bag production are traditionally depreciated over their predicted period of use. These annual impacts are negligible when compared to the burden of current operations. Therefore, the construction, maintenance and demolition of buildings and the manufacture of vehicles, equipment and other machines are not included in the primary data used in the present study.

Corrugated transport to bag manufacturer

It has been assumed that corrugated is supplied locally to the bag manufacturers. This transport step has not been included in the study.

Carrier bag storage at supermarket and at distributors' warehouses

Since each supermarket/distributor employs different methods for storing carrier bags within their facility, any environmental impacts resulting from such storage have not been able to be quantized and are not included in the study.

Consumer transportation from supermarket

Since the particular bag type used by consumers when grocery shopping is expected to have no measurable effect on vehicle weight, fuel efficiency or emissions, consumer transportation has not been included in the study.

Transport of recyclables to recycling centers

It has been assumed that transportation of bags and corrugated for recycling occurs locally. These transport steps have not been included in the study.

Ink on bags and Ink on distribution packaging

As ink used to print bags and distribution packaging makes up only a small portion of the total finished product and is inherently difficult to measure, ink has not been included in the study.

Pallets

Because transportation practices for each bag type depend so heavily on specific supplier practices and pallets are inherently difficult to keep track of in the distribution process, pallets were not included in the study. In addition, pallets are almost always reused multiple times, spreading their potential impacts over many bags and greatly reducing the impact of this factor.

Notes

1. Confidential communication from Hilex Poly LLC to A. Littman (August, 2012).
2. Confidential communication from industry source to R. Kimmel (August, 2012).
3. International Paper, personal communication to R. Kimmel (October, 2012).
4. Confidential communication from industry source to A. Littman (August, 2012).
5. Based on a measured weight of thread of 0.8 gm in a typical NWPP bag used in this study plus 10% process scrap (estimate based on input from Clemson Apparel Research, private communication).
6. Based on the measured weight of the NWPP bags used in this study and assuming 0.9 g of cotton thread per bag (Fry, 2011), p. 86.
7. Values based on data provided by leading PRB manufacturer for in-house equipment.
8. Values based on Ruian Amanda Import and Export Trade Co. specifications for Model Number A-400 Paper Bag Making Machine.
9. Data provided by Hilex Poly LLC to A. Littman (August, 2012).
10. The HDPE portion of the category “bags, sacks and wraps.”
11. Confidential communication from Hilex Poly to A. Littman (August, 2012).
12. Confidential communication from Hilex Poly to A. Littman (August, 2012).
13. For corrugated boxes only, the EPA reports a 91% recycle rate. However, the authors believe that since supermarkets in general mix corrugated with other paper and paperboard recyclables, that the 75.4% rate is the appropriate value for the present analysis.
14. Private communication from Hilex Poly to R. Kimmel (August, 2012).
15. Greene, Survey of Reusable and Single-Use Grocery Bags in Northern California (2010).
16. Code provided by an industry source.
17. http://dataweb.usitc.gov/
18. Note that these data are 40% and 33% less respectively than the estimates developed in Section 4.5.3.

5. Impact Assessment

The following assessment of the environment impacts of the six bag types studied in this report is divided into four main scenarios:

Base Case (Case 1)—Secondary uses of PRBs and Paper Bags not included

Scenario 1—PRBs and Paper Bags used one time for groceries and reusable bags discarded after one trip

Scenario 2—Multiple trips

Scenario 3—Number of trips for equivalency

Case 2—Secondary uses of PRBs and Paper Bags included

Scenario 1—PRBs and Paper Bags used one time for groceries and reusable bags discarded after one trip

Scenario 2—Multiple trips

Scenario 3—Number of trips for equivalency

5.1 Base Case—Case 1

5.1.1 Scenario 1—PRBs and Paper Bags used one time for groceries and reusable bags discarded after one trip

The bags included in the Base Case of this study that are intended for one use as grocery bags are PRBs with 0 and 30% RC and Paper bags with 40 and 100% RC. Since they are intended to be used for one trip to the supermarket, they are most appropriately compared on that basis. The reusable bags included in the Base Case of this study are intended to be used for multiple trips to the supermarket. Notwithstanding, it is possible that they may be used only one time for their intended use. The following charts show potential environmental impacts for each of the bag types studied for one trip to the supermarket. The number of bags required per trip is based on the reference flow study discussed in Section 3.3 and summarized in Table 3.4. These impacts were found using the following methods: IPCC 2007 100-year V1.02, Cumulative Energy Demand V1.08, and World ReCiPe Midpoint H/A V1.07. Detailed tables of the results can be found in Annex E.

Global Warming Potential (GWP): GWP is a relative measure of how much heat a greenhouse gas (e.g., nitrous oxide, methane) traps in the atmosphere compared to the amount of heat trapped by a similar amount of carbon dioxide calculated over a specific time interval (100 years in the present study). It is expressed in kilograms of carbon dioxide (CO_2) equivalents.

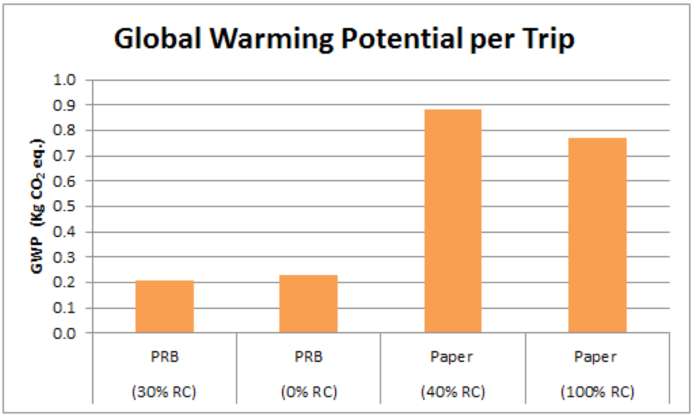


Figure 5.1 Global warming potential of PRBs and Paper bags, per trip to supermarket

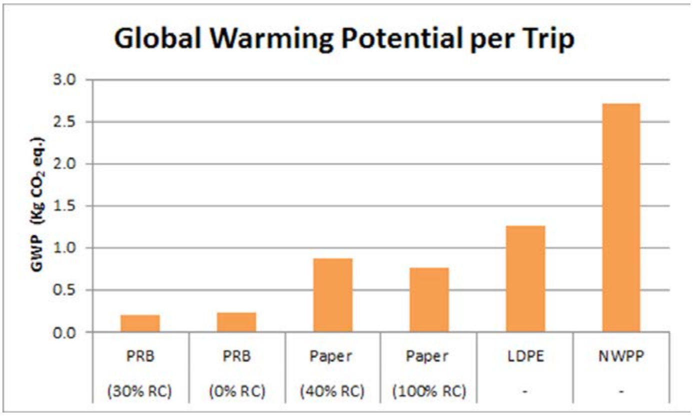


Figure 5.2 Global warming potential of PRBs and Paper bags, per trip to supermarket, compared to GWP of reusable bags discarded after one trip

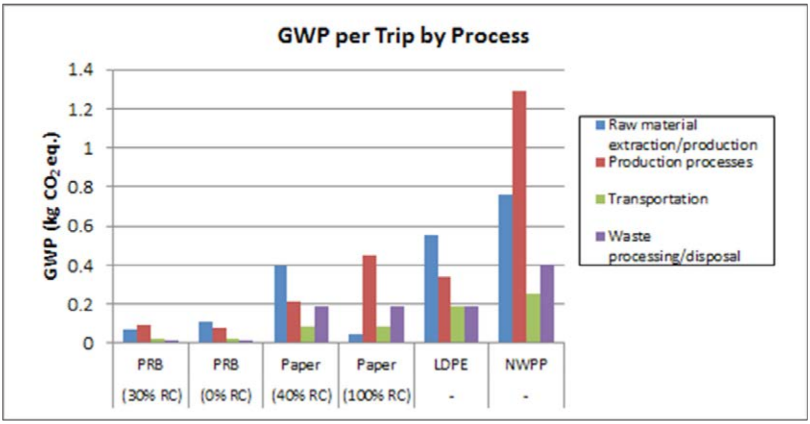


Figure 5.3 Breakdown by life cycle processes of GWP per trip

Figure 5.1 shows that the GWP per trip for Paper bags is several times the GWP for PRBs. The Figure also shows that increasing the recycle content of either bag type decreases the GWP per Trip. Figure 5.2 shows that the GWP per Trip for the reusable bags is greater than that of PRBs and Paper bags. This is primarily because of the weight of material in each set of bags. If reusable bags are reused for multiple trips in a sufficient number, the purpose for which they are designed, the GWP of a set of reusable bags will be equal to or less than that of PRBs and Paper bags (See Section 5.2).

Figure 5.3 shows how each group of processes contributes to the GWP of each of the bag types. Reprocessing of recycle materials for reuse is included in "production processes," while the avoided burden of making virgin material is subtracted from "raw material extraction/production." Therefore, bag types containing more RC content show a higher contribution of Production processes to GWP than Raw material extraction/production. NWPP bags show this trend because the LDPE insert is 100% recycle material. In general, "transportation" and "waste processing/disposal" contribute less to GWP for each bag type than either "raw material extraction/production" or "production processes" (except for Paper (100% RC)) for which "raw material extraction/production" is a very small GWP contributor.

Water Depletion: Water depletion, measured in gallons, is the total water lost during the life cycle.

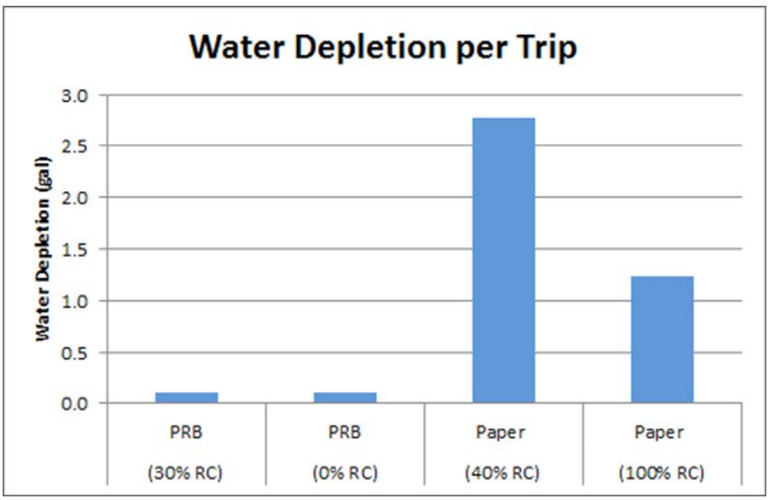


Figure 5.4 Water Depletion of PRBs and Paper bags, per trip to supermarket

Figure 5.4 shows that Paper bags use much more water than PRBs. Figure 5.6 shows that Water Depletion for the Paper (40% RC) bag is generated primarily from Raw material extraction/production, while for the Paper (100% RC) bag, Production processes that include recycling are the main contributor. Figure 5.5 shows that on a per trip basis, the polymer bags (PRBs, LDPE) deplete less water than the Paper bags. Figure 5.6 shows that NWPP bags do not follow this same pattern due to large water

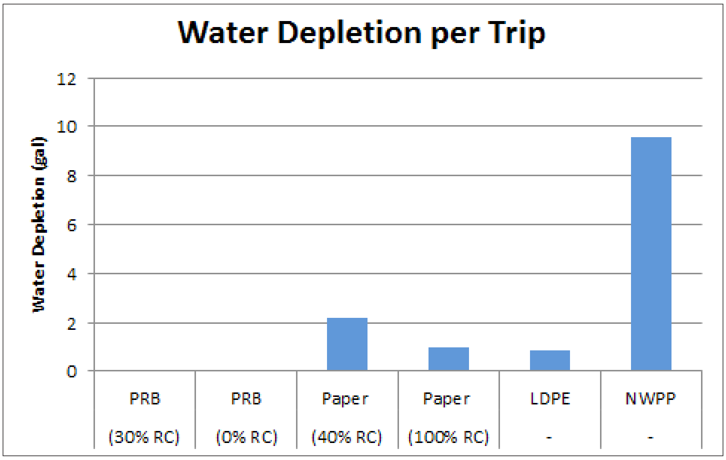


Figure 5.5 Water Depletion of PRBs and Paper bags, per trip to supermarket, compared to Water Depletion of reusable bags discarded after one trip

depletion in their Raw material/extraction processes. This contribution comes from the growing and processing of cotton for the thread used to sew the NWPP bags. Again, if reusable bags are reused for multiple trips in a sufficient number, the purpose for which they are designed, the relationships among the Water Depletion of the various bags will change (See Section 5.2).

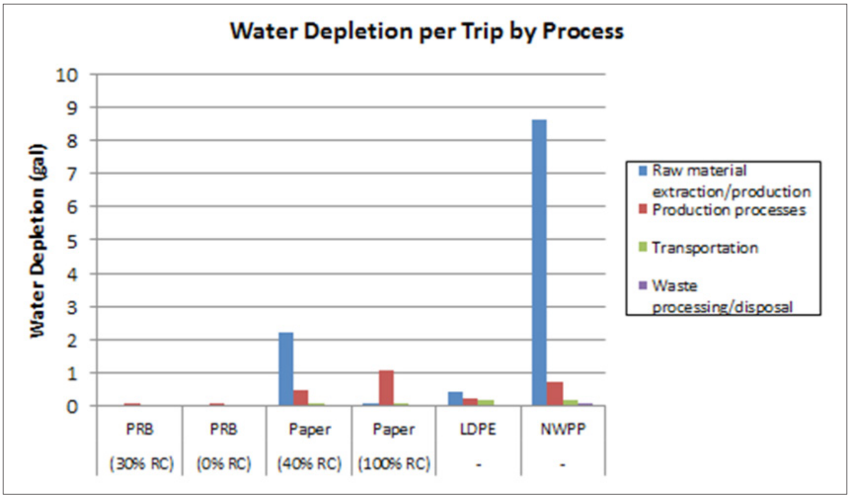


Figure 5.6 Breakdown by life cycle process of Water Depletion per trip

Cumulative Energy Demand: Cumulative Energy Demand is the total amount of energy from all sources required for manufacture, transport, reprocessing and disposal. It is measured in MegaJoule (MJ) equivalents. The fossil fuel used is a separate category discussed below.

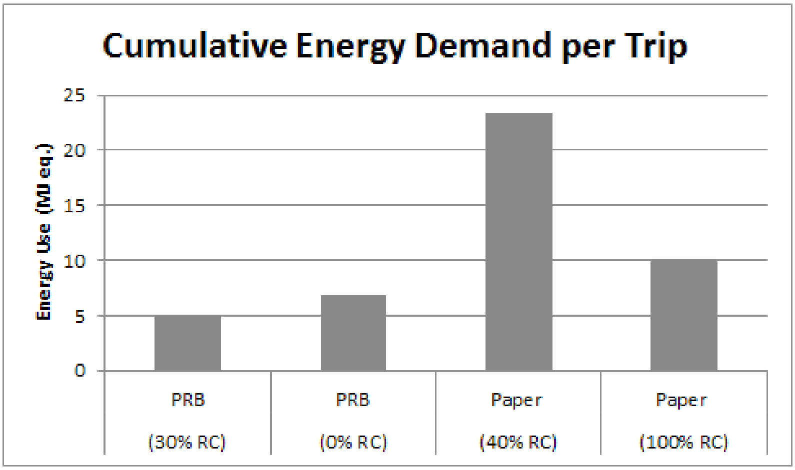


Figure 5.7 Cumulative Energy Demand of PRBs and Paper bags, per trip to supermarket

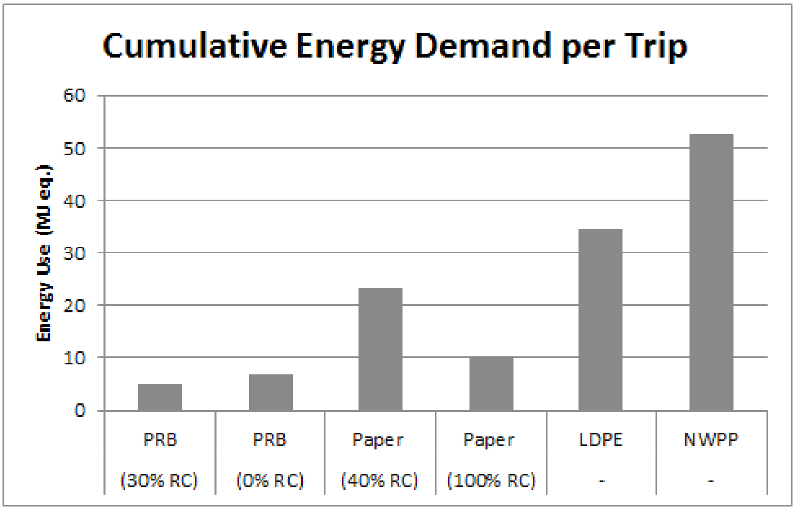


Figure 5.8 Cumulative Energy Demand of PRBs and Paper bags, per trip to supermarket, compared to Cumulative Energy Demand of reusable bags discarded after one trip

Figure 5.7 shows that Paper bags use two to almost five times the Cumulative Energy as PRBs. Total weight and process complexity negatively impact the cumulative energy used by paper bags during their life cycle. Figure 5.8 shows that the Cumulative Energy Demand per Trip for the reusable bags is greater than that of PRBs and Paper bags. This is primarily because of the weight of material in each set of bags. If reusable bags are reused for multiple trips in a sufficient number, the purpose for which they are designed, the Cumulative Energy Demand of a set of reusable bags will be equal to or less than that of the PRBs and Paper bags (See Section 5.2).

Terrestrial Acidification: Acidification of soil results when pollutants such as sulfur dioxide (SO_2), nitrates, nitrites, phosphates, hydrochloric acid and ammonia deposited in the soil make the soil more acidic, decrease its mineral content and increase concentrations of potentially toxic elements. Acidification is measured as g SO_2 equivalents.

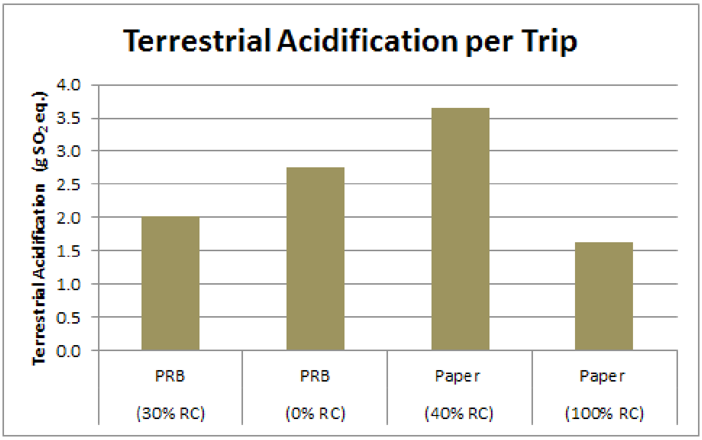


Figure 5.9 Terrestrial acidification from PRBs and Paper bags, per trip to supermarket

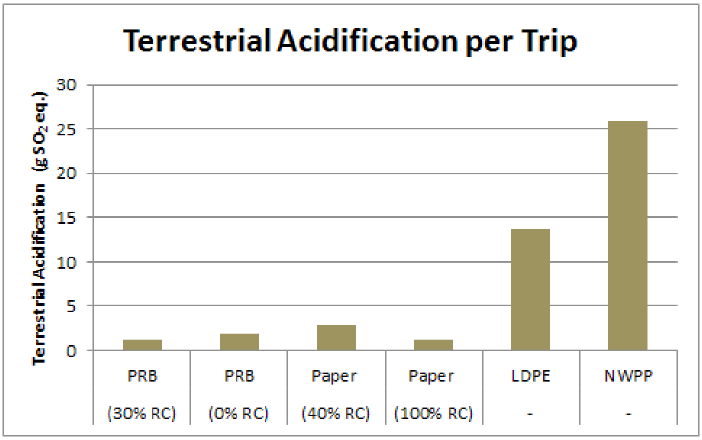


Figure 5.10 Terrestrial acidification from PRBs and Paper bags, per trip to supermarket, compared to Terrestrial acidification from reusable bags discarded after one trip

Figure 5.9 shows that the contributions to Terrestrial Acidification for PRBs are more similar to those of the Paper bags than the previous two impact categories discussed. Nevertheless, Terrestrial Acidification from Paper (40% RC) bags is almost twice that from PRBs (30% RC). Increasing Paper bag recycle content to 100% drops its Terrestrial Acidification contribution to less than the PRBs. Figure 5.10 shows that on a one-time use basis, NWPP bags and LDPE bags are both relatively high contributors to acid pollution of the soil compared to PRBs and Paper bags. These contributions are primarily due to the higher bag weights, but the cotton thread of the

NWPP bags also adds to the impact. If reusable bags are reused for multiple trips in a sufficient number, the purpose for which they are designed, the Terrestrial Acidification from a set of reusable bags will be equal to or less than that of the PRBs and Paper bags (See Section 5.2).

Eutrophication: Nutrients such as phosphorous (P) and nitrogen (N) promote an increase in biomass, damaging other life forms. Freshwater eutrophication is measured in phosphorous equivalents, while marine eutrophication is measured in nitrogen equivalents.

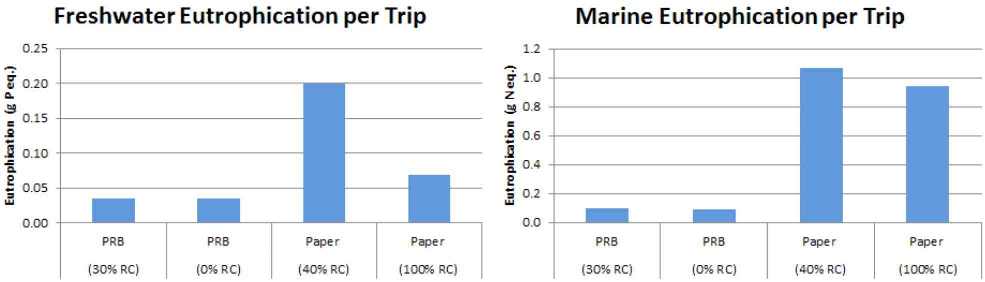


Figure 5.11 Freshwater and marine eutrophication from PRBs and Paper bags, per trip to supermarket

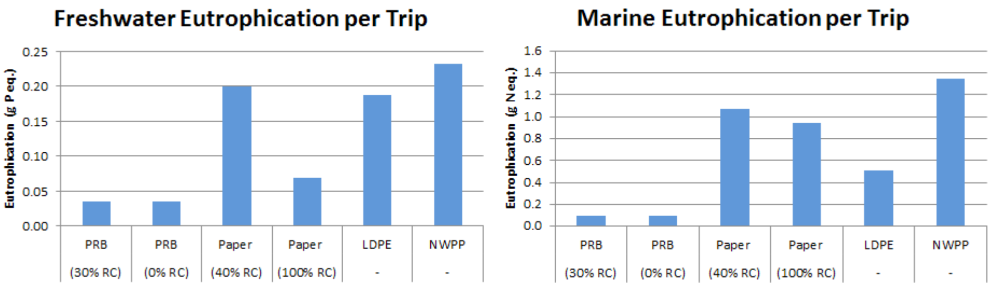


Figure 5.12 Freshwater and marine eutrophication from PRBs and Paper bags, per trip to supermarket, compared to Freshwater and marine eutrophication from reusable bags discarded after one trip

Figure 5.11 shows that Paper bag production and recycling have greater effects on eutrophication than PRBs. Higher recycle content for Paper bags compared to bags with lower recycle content reduces freshwater eutrophication to a much larger extent than it reduces marine eutrophication. Figure 5.12 shows that, if discarded after only one trip, the reusable bags' contributions to freshwater eutrophication are comparable to those of Paper (40% RC) bags. This can also be seen in the figure for marine eutrophication for NWPP bags. If reusable bags are reused for multiple trips in a sufficient number, the purpose for which they are designed, the Eutrophication from a set of reusable bags will be equal to or less than that of PRBs and Paper bags (See Section 5.2).

Toxicity: Toxicity is the degree to which humans and organisms in the soil, freshwater and marine environments can be damaged by exposure to organic compounds. Toxicity is measured in terms of dichlorobenzene (1,4-DB) equivalents.

Organic compounds that can cause illnesses both for humans and terrestrial organisms are more serious problems for paper bags than for PRBs, as shown in Figure 5.13, although human toxicity for Paper (100% RC) and PRB (30% RC) are comparable. Freshwater and marine ecotoxicity are about the same for both Paper bags and PRBs. Again, Paper bags with 100% recycle content are slightly better than the other PRBs and Paper bags with 40% recycle content for these categories. For reusable bags discarded after one use (Figure 5.14), the higher weight of the LDPE and NWPP bags

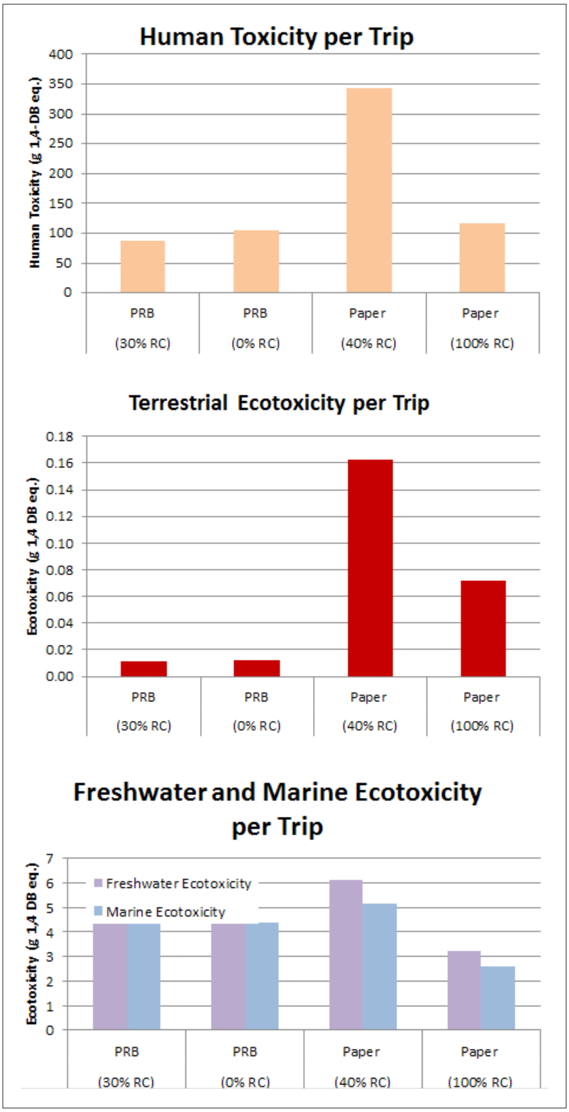


Figure 5.13 Human toxicity and terrestrial, freshwater and marine ecotoxicity from PRBs and Paper bags, per trip to supermarket

leads to higher contributions to Human toxicity and marine and freshwater ecotoxicity. LDPE bags have low Terrestrial Ecotoxicity, but NWPP terrestrial ecotoxicity is increased by contributions from the raising and processing of cotton for the sewing thread. In line with the other environmental impact categories examined, if reusable bags are reused for multiple trips in a sufficient number, the purpose for which they are designed, the toxicity and ecotoxicities from a set of reusable bags will be equal to or less than that of the PRBs and Paper bags (See Section 5.2).

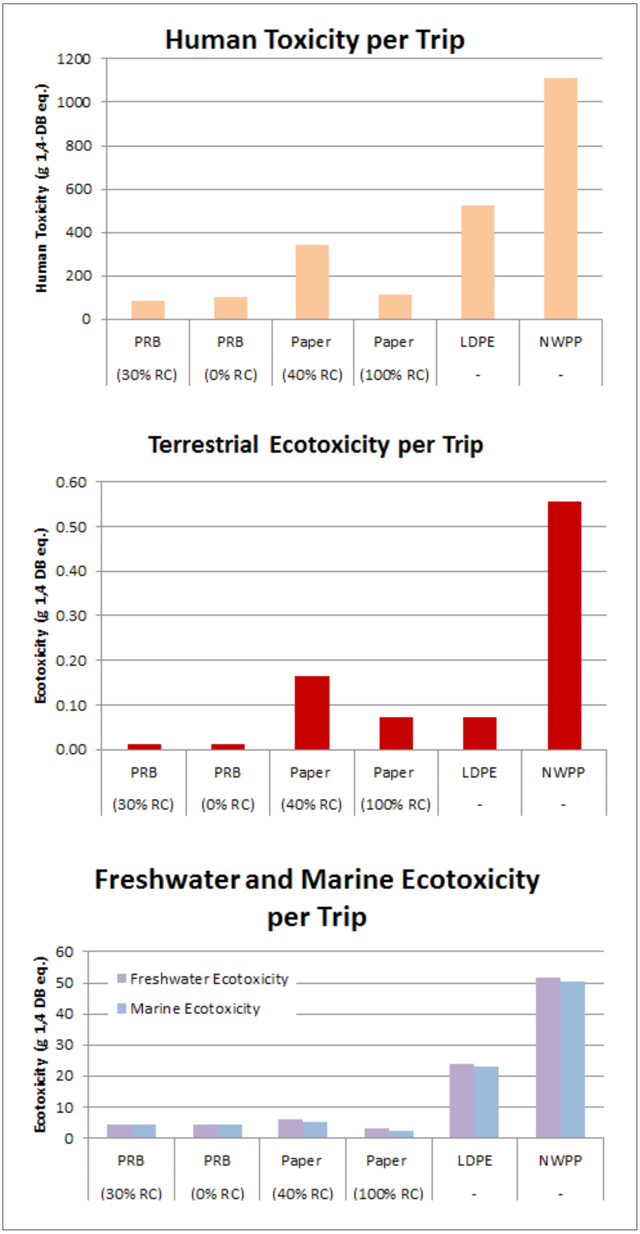


Figure 5.14 Human toxicity and terrestrial, freshwater and marine ecotoxicity from PRBs and Paper bags, per trip to supermarket, compared to Human toxicity and terrestrial, freshwater and marine ecotoxicity from reusable bags discarded after one trip

Fossil Fuel Depletion: Fossil fuel depletion is the amount of fossil fuel (natural gas or oil) that is used up during the life cycle.

Fossil Fuel Depletion includes raw material sourcing as well as energy used in processing and transport. Figure 5.15 shows that Paper bags deplete somewhat more fossil fuel than PRBs. Since biomass is often used to generate power for manufacturing virgin paper and conventional fossil fuels are commonly used to reprocess recycled wood fiber into usable form, paper bags with higher recycle content are only slightly more

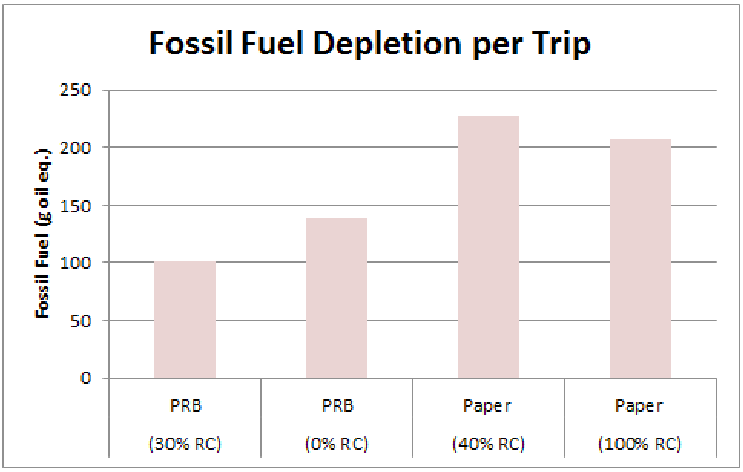


Figure 5.15 Fossil fuel depletion from PRBs and Paper bags, per trip to supermarket

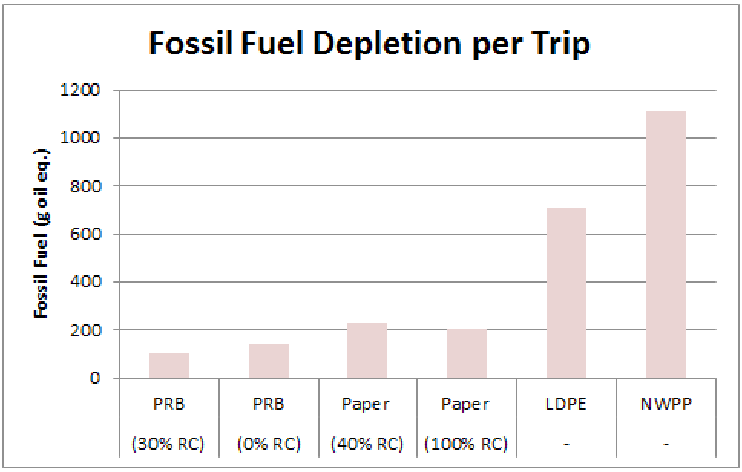


Figure 5.16 Fossil fuel depletion from PRBs and Paper bags, per trip to supermarket, compared to Fossil fuel depletion from reusable bags discarded after one trip

favorable than those with lower content in this category. The shift of fossil fuel depletion for paper with higher recycle content from raw material extraction to production (which included recycling) can be seen in Figure 5.17. Additionally, extra process steps can negatively impact paper bags with high recycled content. Incorporating increased amounts of recycled content reduces fossil fuel depletion for PRBs.

Figure 5.16 shows that discarding reusable bags after one trip depletes more fossil fuel than PRBs and Paper bags. Again, if reusable bags are reused for multiple trips in a sufficient number, the purpose for which they are designed, the fossil fuel depletion from a set of reusable bags will be equal to or less than that of the PRBs and Paper bags (See Section 5.1.2).

This study assumes that raw materials for PRBs and LDPE bags are sourced in the U.S. As pointed out in Section 4.1, the ethylene from which the polymers for these bags are manufactured is derived from a by-product of domestically-produced natural gas. Therefore, although the model used for the present study assumes that fossil fuel is depleted to provide the raw materials for the polymers, the amount of fuel gas available is in fact not reduced.

The polymer for NWPPs is assumed to be produced in China from a combination of oil and natural gas sources.

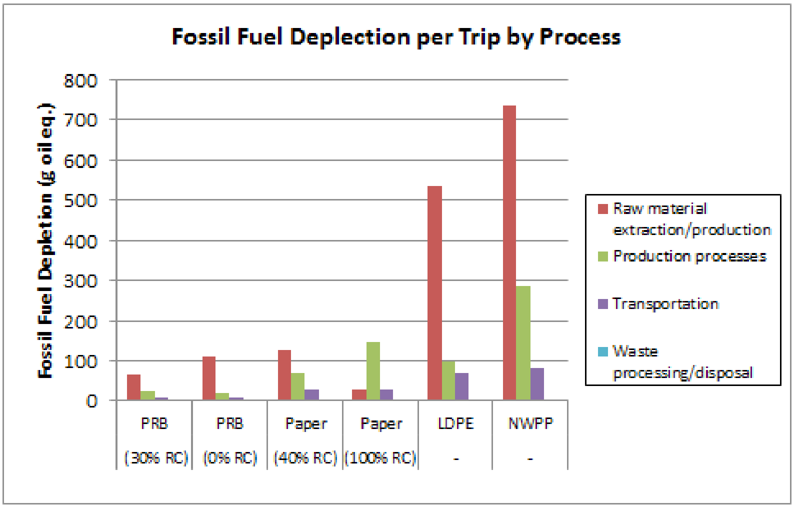


Figure 5.17 Breakdown by life cycle process of Fossil Fuel Depletion per trip

Photochemical oxidant formation: Photochemical oxidant formation (POF) is the amount of nitrogen oxides and volatile organic compounds that form in smog and react under the action of sunlight to form ozone. It is measured as the weight of non-methane volatile organic compounds (g NMVOC).

Figure 5.18 shows that Photochemical oxidant formation for Paper bags is several times that of PRBs, even for Paper (100% RC) bags. Figure 5.19 shows that Photochemical oxidant formation for the reusable bags discarded after one trip is greater than that of PRBS and Paper bags, primarily because of the increased material weight of the reusable bags. If reusable bags are reused for multiple trips in a sufficient number, the purpose for which they are designed, the Photochemcial oxidant formation from a set of reusable bags will be equal to or less than that of PRBs and Paper bags (See Section 5.1.2).

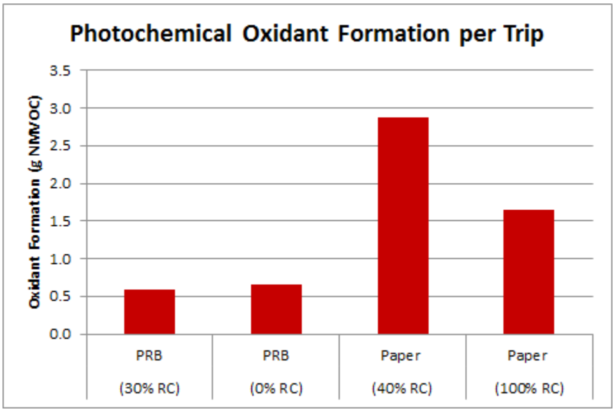


Figure 5.18 Photochemical oxidant formation from PRBs and Paper bags, per trip to supermarket

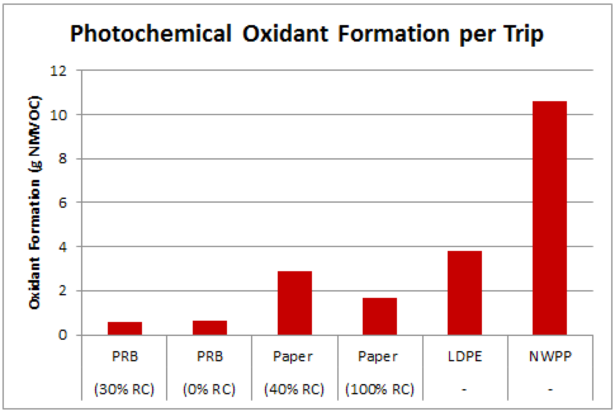


Figure 5.19 Photochemical oxidant formation from PRBs and Paper bags, per trip to supermarket, compared to Photochemical oxidant formation from reusable bags discarded after one trip.

5.1.2 Scenario 2—Multiple Trips

LDPE and NWPP bags are intended to be used for multiple trips to the supermarket. Therefore, in order to compare reusable bags with PRBs or Paper bags, a new set of PRBs or paper bags has to be used for each trip. As discussed above in Section 4.5, the usable life (i.e. the maximum number of possible trips) has not been determined in a scientifically designed study. Only recently has anyone collected and published data on actual consumer practices. (Edelman Berland, 2014) Based on the available data (see Section 4.5), we have selected 3.1 trips, 14.6 trips and 44 trips as functional units for comparing the environmental impacts of the two types of reusable bags with each other and with the Paper and PRB bags. The following figures show the environmental impacts of the six variants of bags used in the present study for 3.1, 14.6 and 44 trips.

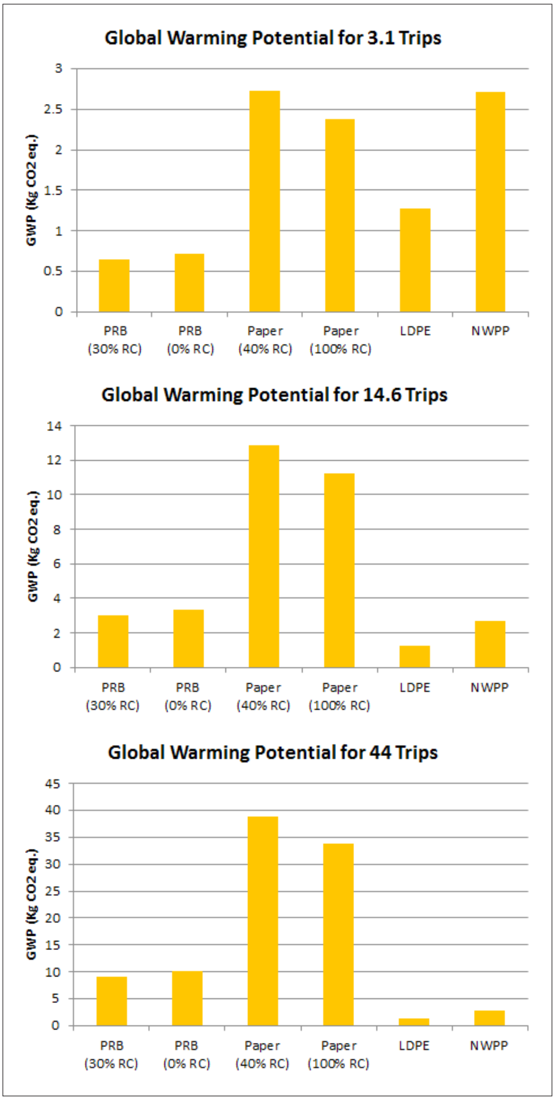
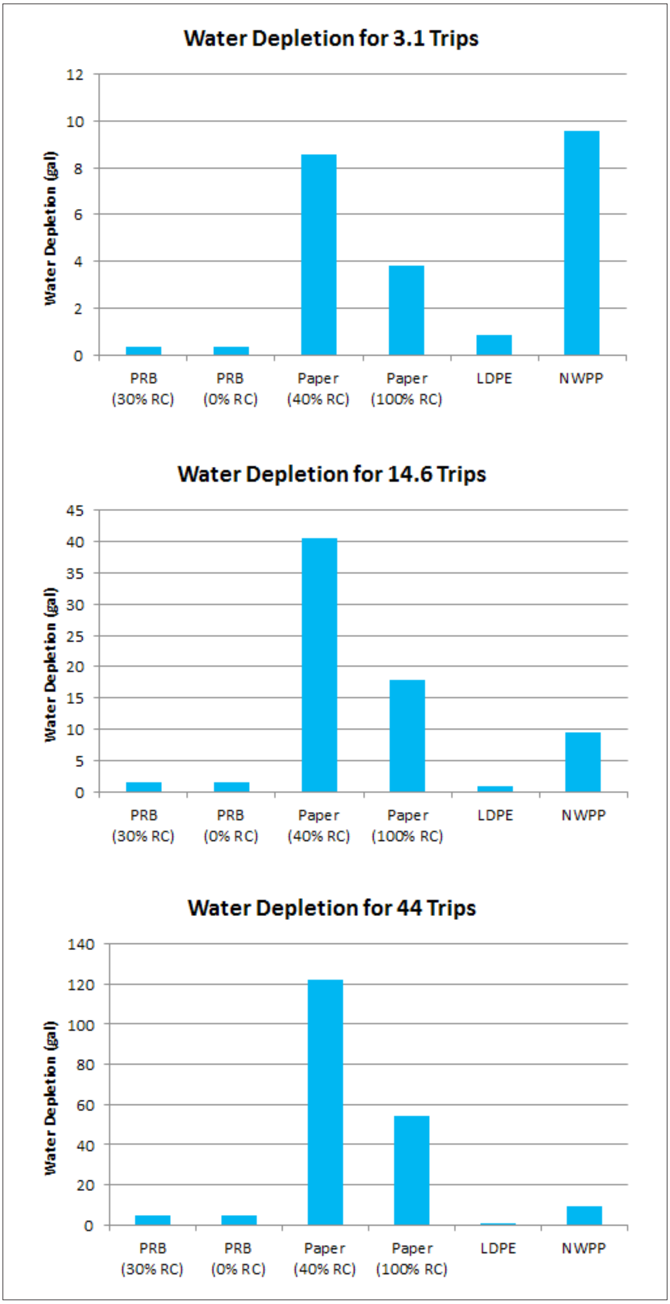


Figure 5.20 Global Warming Potential for PRBs, Paper bags and reusable bags for multiple numbers of trips



5.21 Water Depletion for PRBs, Paper bags and reusable bags for multiple numbers of trips

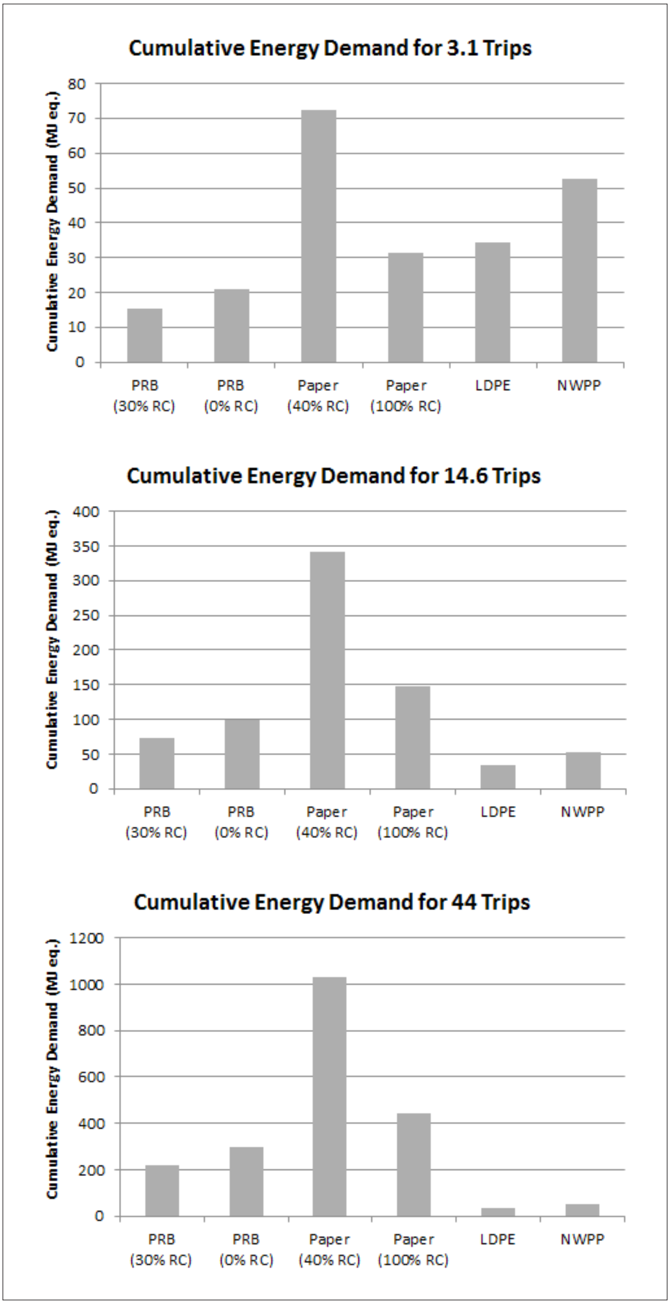


Figure 5.22 Cumulative Energy Demand for PRBs, Paper bags and reusable bags for multiple numbers of trips

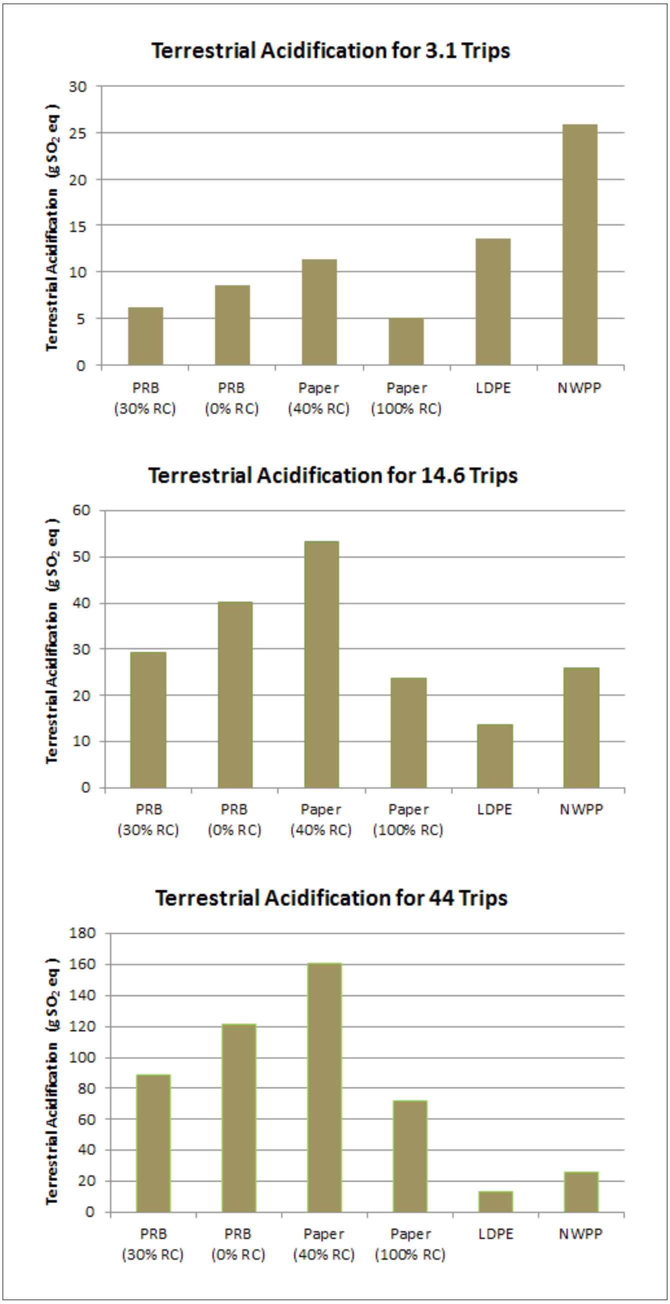


Figure 5.23 Terrestrial Acidification for PRBs, Paper bags and reusable bags for multiple numbers of trips

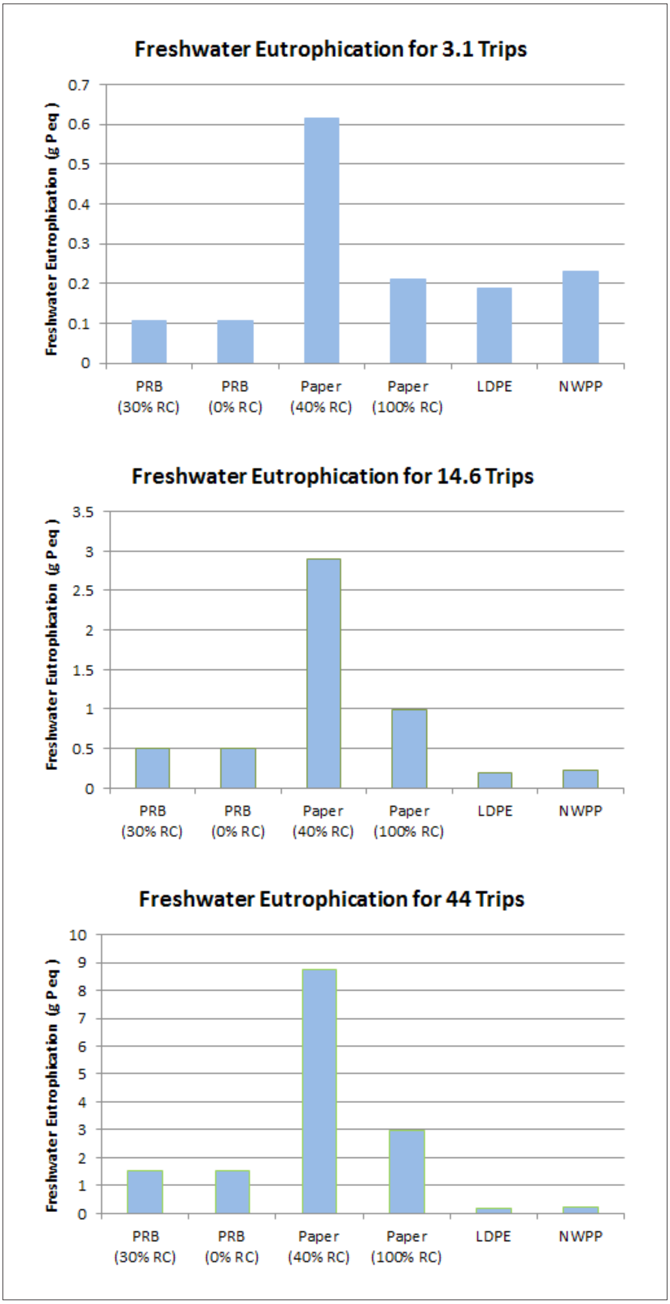


Figure 5.24 Freshwater Eutrophication for PRBs, Paper bags and reusable bags for multiple numbers of trips

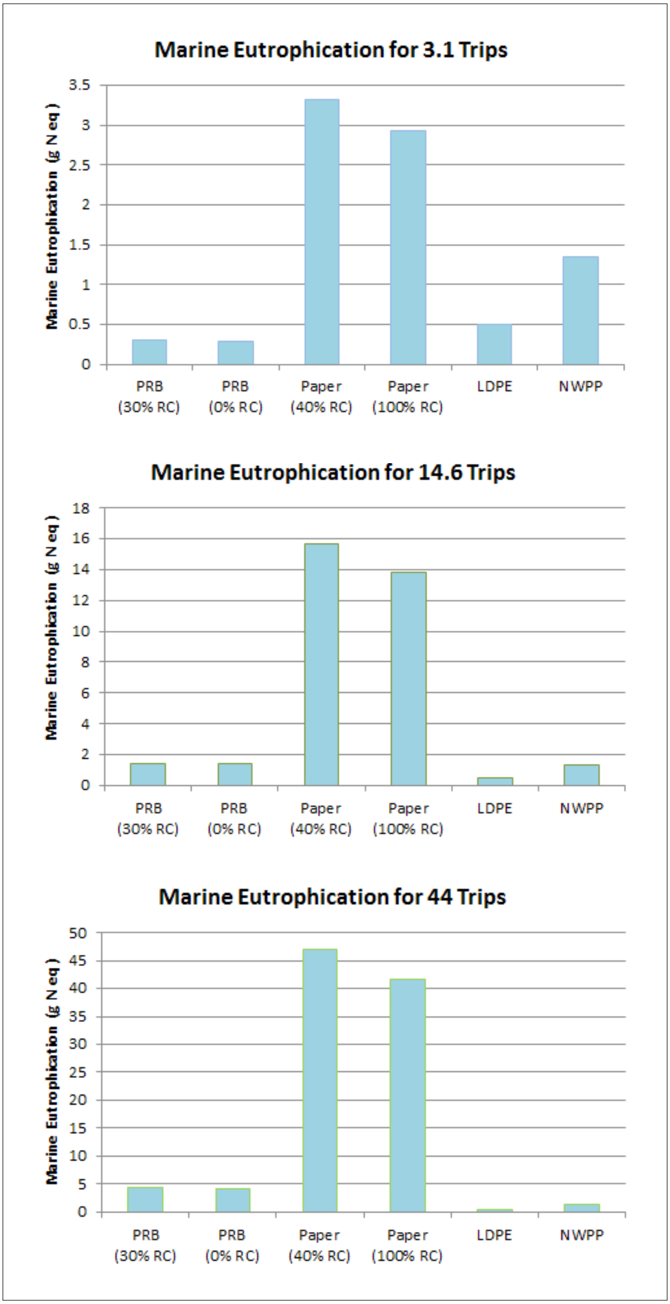


Figure 5.25 Marine Eutrophication for PRBs, Paper and reusable bags for multiple numbers of trips

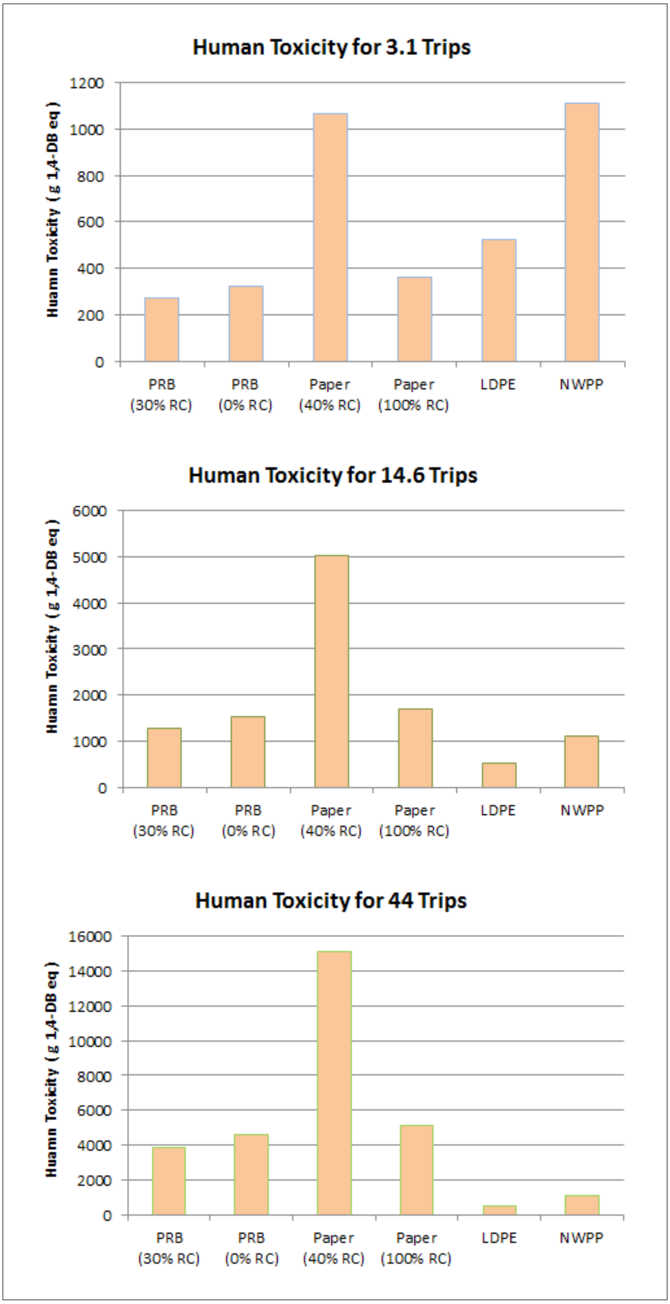


Figure 5.26 Human Toxicity for PRBs, Paper bag and reusable bags for multiple numbers of trips

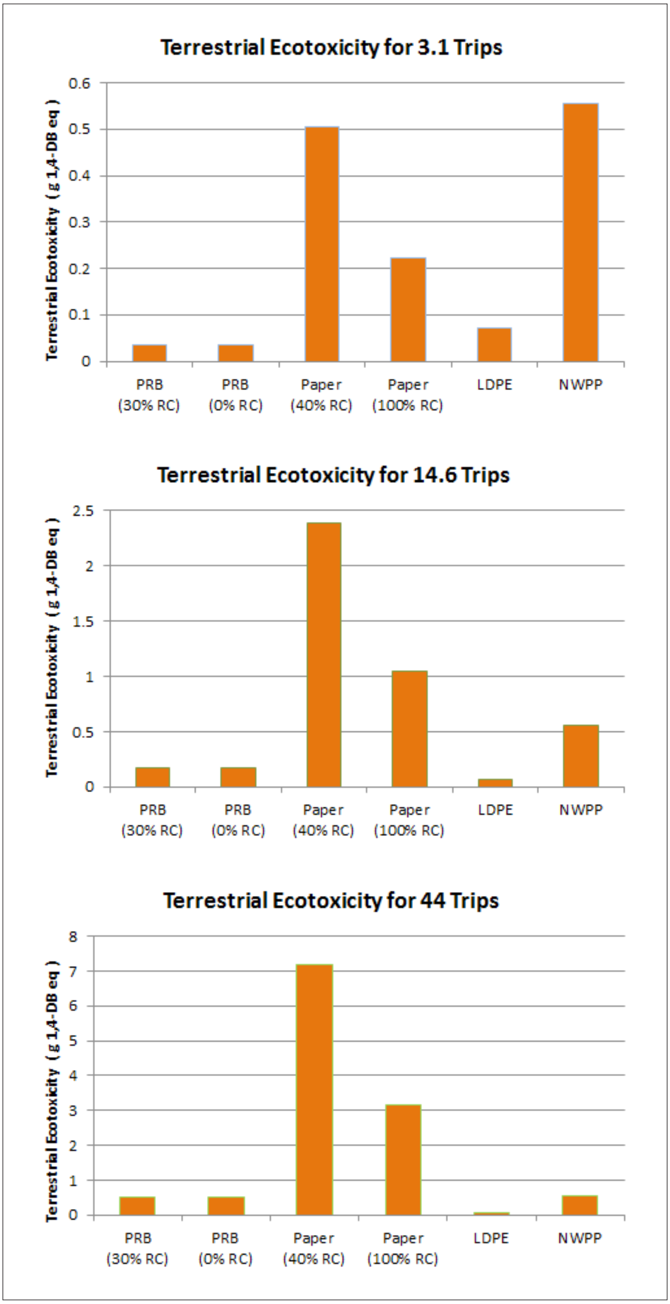


Figure 5.27 Terrestial Ecotoxicity for PRBs, Paper and reusable bags for multiple numbers of trips

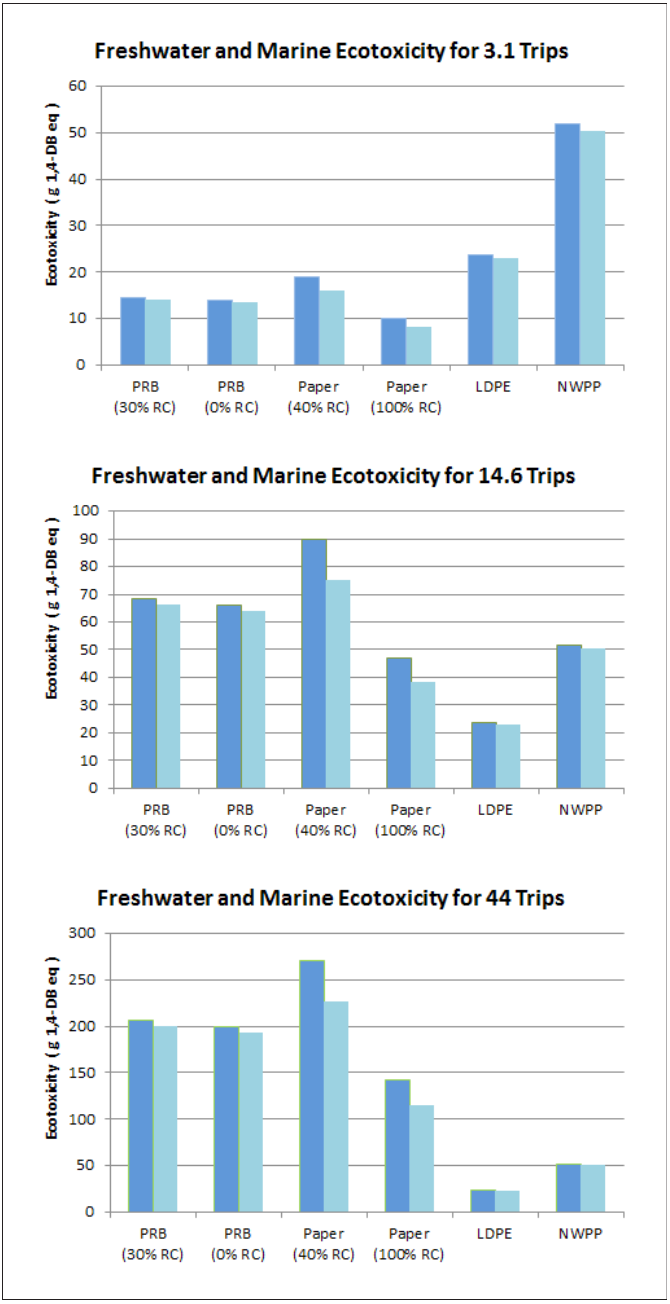


Figure 5.28 Freshwater and Marine Ecotoxicity for PRBs, Paper bags and reusable bags for multiple numbers of trips

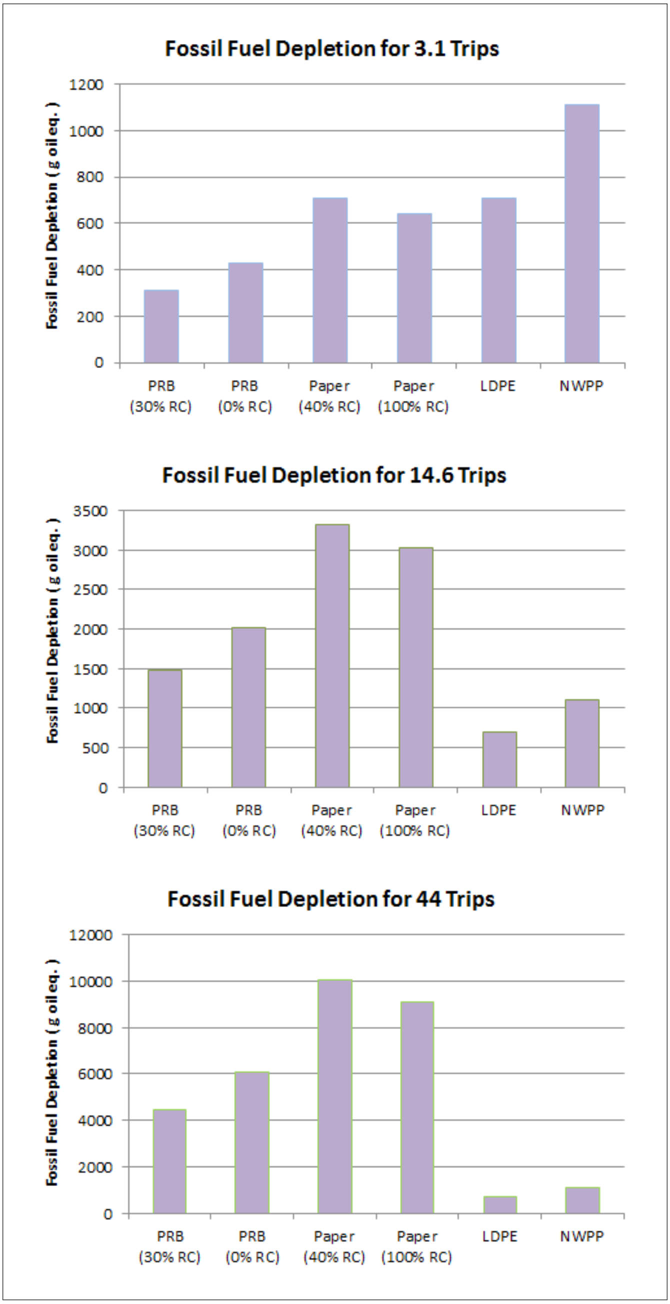


Figure 5.29 Fossil Fuel Depletion for PRBs, Paper bags and reusable bags for multiple numbers of trips

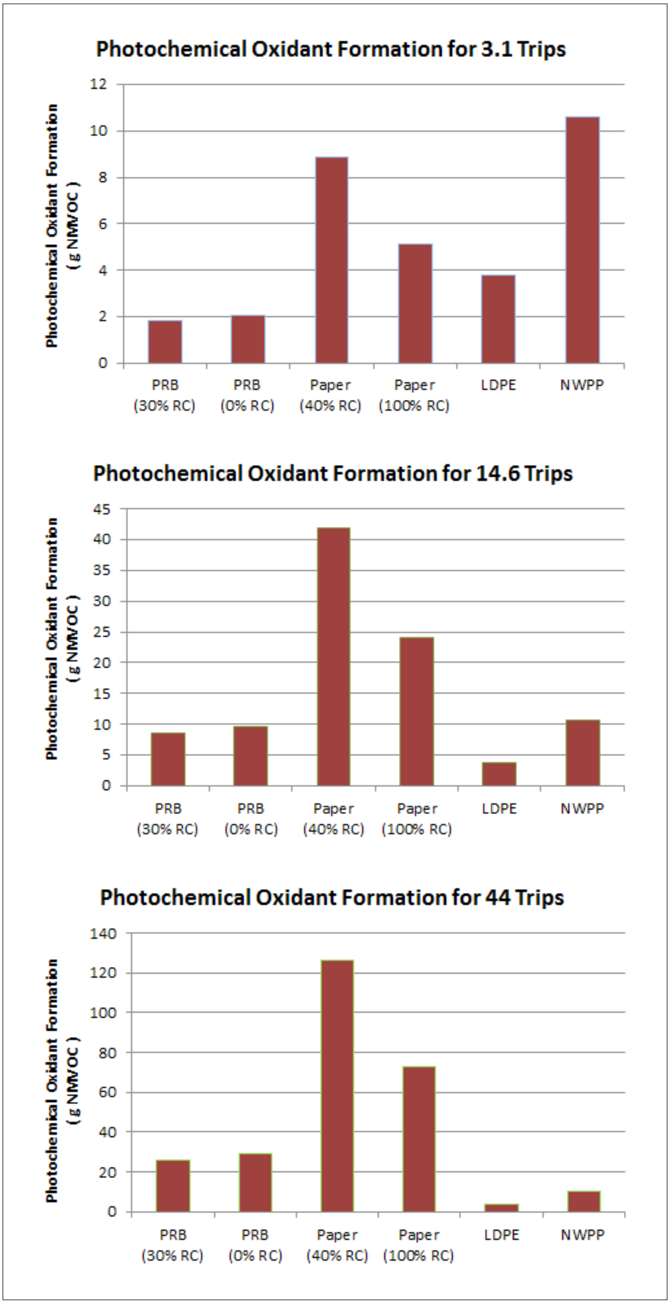


Figure 5.30 Photochemical Oxidant Formation for PRBs, Paper bags and reusable bags for multiple numbers of trips

The following observations can be made from Figures 5.20 through 5.30 above:

For 3.1 trips—

- Paper (40% RC) Bags have higher environmental impacts for all categories than PRBs with either recycle content.
- Paper (100% RC) Bags have higher environmental impacts than PRBs with either recycle content for all categories except Terrestrial Acidification and Freshwater and Marine Ecotoxicity.
- LDPE bags have higher environmental impacts for all categories than PRBs with either recycle content.
- NWPP Bags have higher environmental impacts for all categories than PRBs with either recycle content.

For 14.6 trips—

- Paper (40% RC) Bags have higher environmental impacts for all categories than PRBs with either recycle content.
- Paper (100% RC) Bags have higher environmental impacts than PRBs with either recycle content for all categories except Terrestrial Acidification and Freshwater and Marine Ecotoxicity.
- LDPE bags have lower environmental impacts for all categories than PRBs with either recycle content or Paper bags with either recycle content
- NWPP bags have lower environmental impacts than PRBs with either recycle content for all categories except Water Depletion, Terrestrial Ecotoxicity and Photochemical Oxidant Formation.
- NWPP bags have lower environmental impacts for all categories than Paper (40% RC) bags.
- NWPP bags have lower environmental impacts than Paper (100% RC) bags for all categories except Terrestrial Acidification and Freshwater and Marine Ecotoxicity.

For 44 trips—

- Paper (40% RC) Bags have higher environmental impacts than PRBs with either recycle content for all categories.
- Paper (100% RC) Bags have higher environmental impacts than PRBs with either recycle content for all categories except Terrestrial Acidification, and Freshwater and Marine Ecotoxicity.
- LDPE bags have lower environmental impacts for all categories than PRBs with either recycle content or Paper bags with either recycle content
- NWPP Bags have lower environmental impacts than PRBs with either recycle content for all categories except Water Depletion and Terrestrial Ecotoxicity.
- NWPP Bags have lower environmental impacts for all categories than Paper bags with either recycle content.

5.1.3 Scenario 3 – Number of trips for equivalence

Two previous LCA studies of grocery carrier bags used a methodology of comparing the environmental impacts of bags to each other by calculating the number of trips required for a reusable bag to have an equivalent environmental impact to a bag intended for one-time use (Fry, 2011) (Greene, Life Cycle Assessment of Reusable and Single-Use Plastic Bags in California, 2011). Both studies compared reusable bags to PRBs using this methodology.

Paper bags were also compared to PRBs using this methodology, even though they are not primarily intended to be reused for grocery carrier bags.

To apply this methodology to the present study, we chose the PRB (30% RC) and the Paper (40% RC) bag for comparison with the other bags studied. We used these bags for comparison because they are the bags found in most of the large U.S. retail markets.

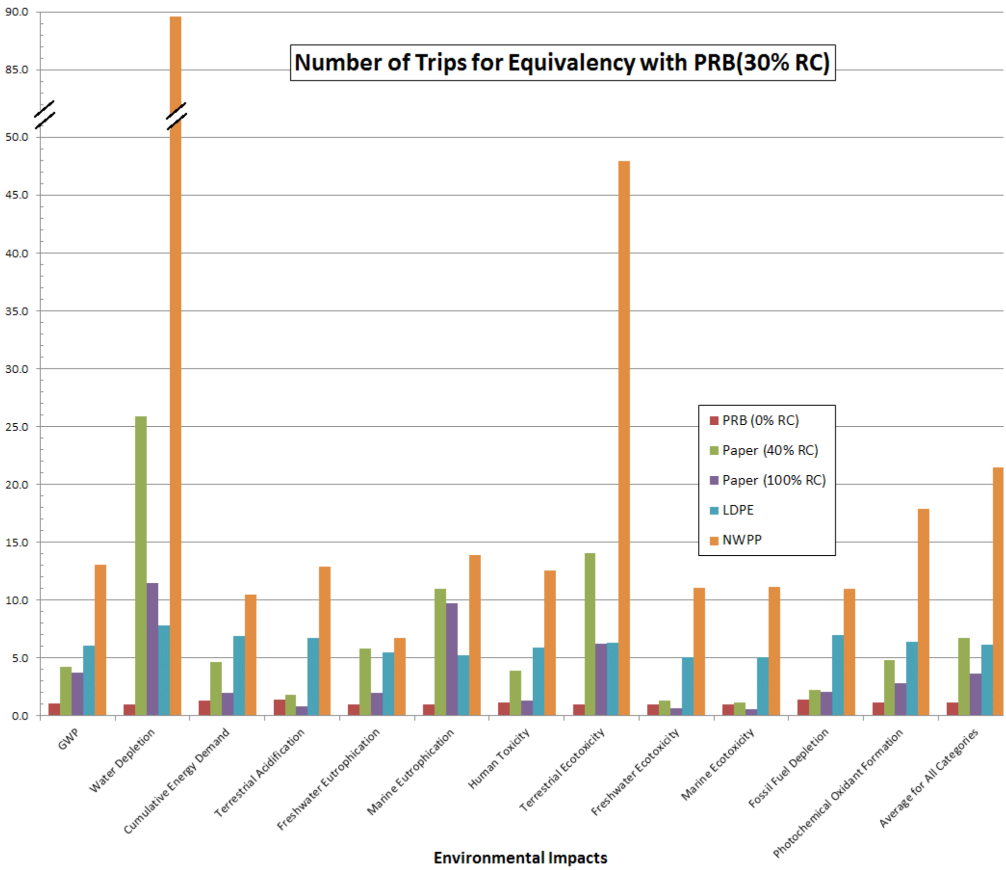


Figure 5.31 Number of trips required for equivalency with PRB (30% RC)

Figure 5.31 shows the number of trips required for equivalency with PRB (30% RC) for each of the environmental impact categories for each type of bag studied. Also shown in the figure is the average for all of the environmental impact categories of the number of trips for equivalency.

Figure 5.32 shows just the average for the all of the environmental impact categories of the number of trips required for equivalency with PRB (30% RC).

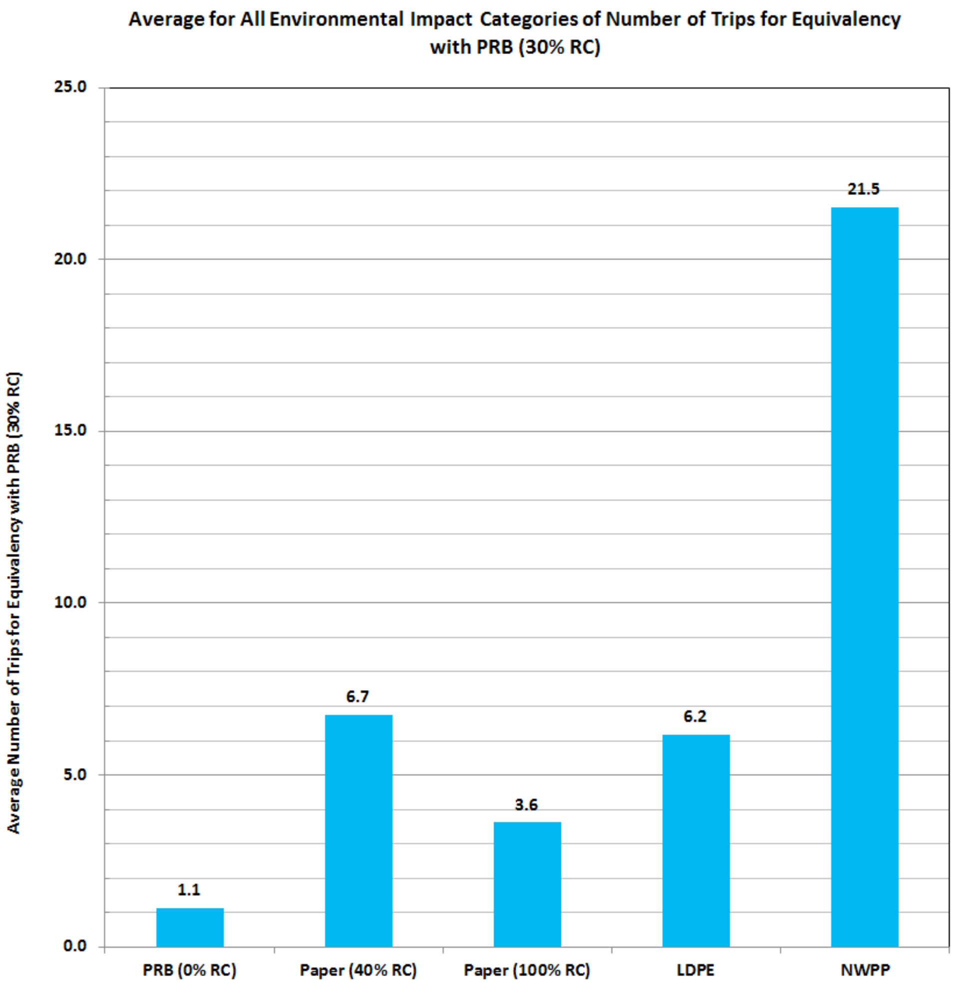


Figure 5.32 Average for all environmental impact categories of the number of trips required for equivalency with PRB (30% RC)

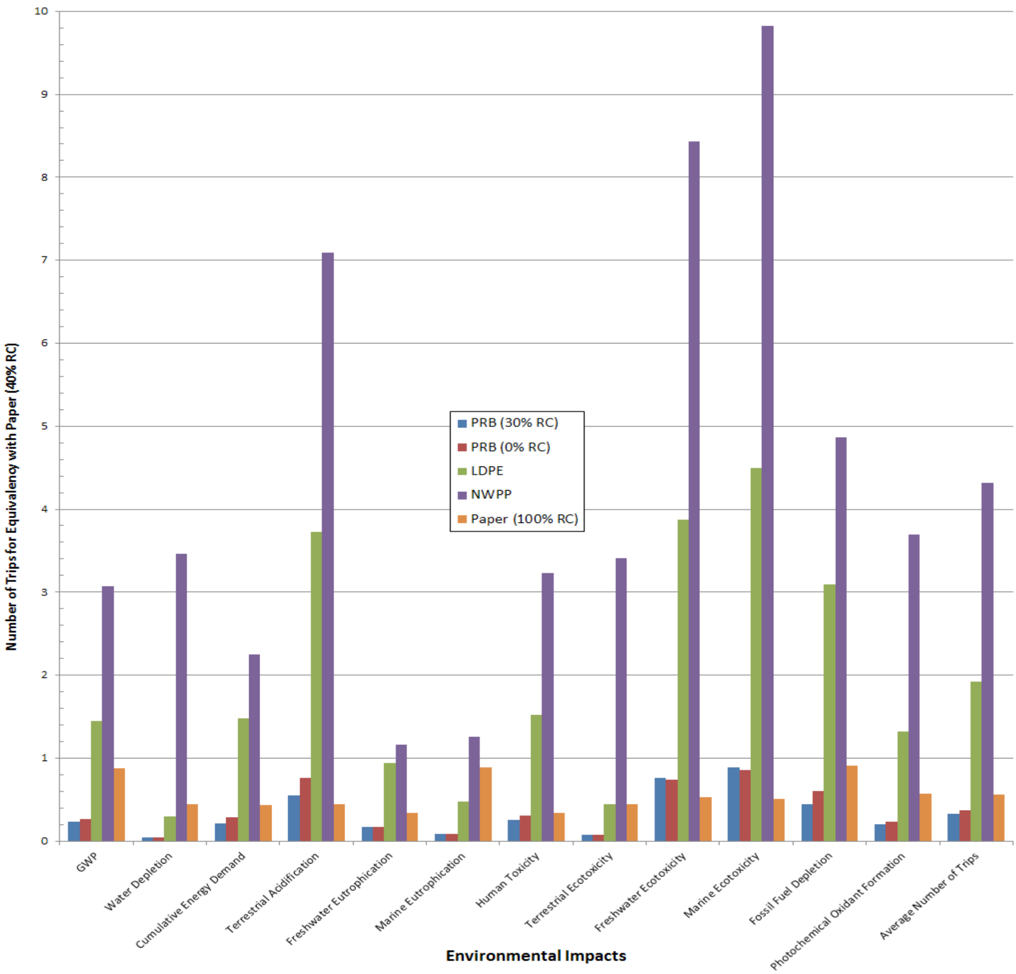


Figure 5.33 Number of trips required for equivalency with Paper (40% RC)

Figure 5.33 shows the number of trips required for equivalency with Paper (40% RC) for each of the environmental impact categories for each type of bag studied. Also shown in the figure is the average for all of the environmental impact categories of the number of trips for equivalency.

Figure 5.34 shows just the average for the all of the environmental impact categories of the number of trips required for equivalency with Paper (40% RC).

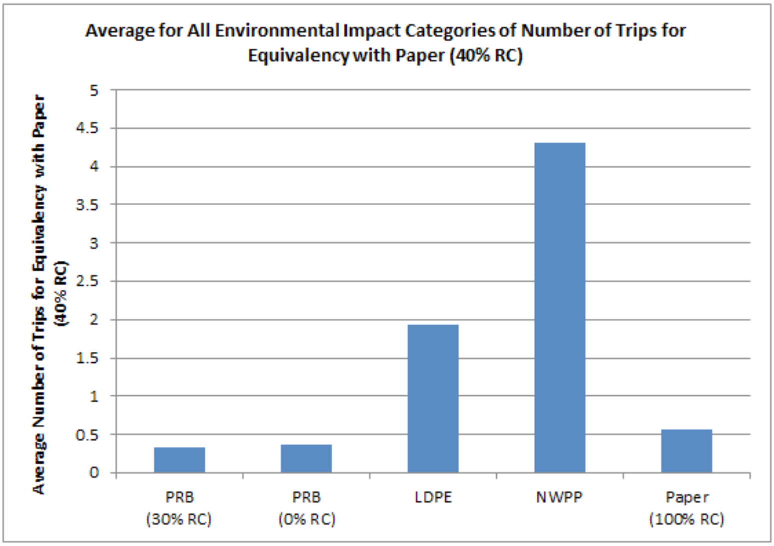


Figure 5.34 Average for all environmental impact categories of the number of trips required for equivalency with paper (40% RC)

Table 5.1 shows a similar comparison of each of the reusable bag types studied with each of the single use bag types studied.

Bag Type	Average for All Environmental Impact Categories of the Number of Trips Required For Equivalency	
	LDPE	NWPP
Paper (40% RC)	0.9	3.2
Paper (100% RC)	1.7	6.0
PRB (30% RC)	6.2	21.5
PRB (0% RC)	5.5	19.2

Table 5.1 Comparision of Reusable Bag Types with PRBs and Paper bags based on average for all environmental impact categories of the number of trips required for equivalency

Figures 5.31 and 5.32 show the results depicted in the figures of Section 5.1.2 in a different way and more clearly illustrate the conclusions. NWPP bags have significantly higher Water Depletion and Terrestrial Ecotoxicity than PRBs. All of the other environmental impact categories for NWPP bags are more than ten times those of PRBs, except for Freshwater Eutrophication. All of the environmental impact categories for LDPE bags are five times or more than those of PRBs. NWPP bags have significantly higher Terrestrial Acidification, and Freshwater and Marine Ecotoxicity than Paper (40% RC) bags. All of the other environmental impact categories for NWPP bags are more than three times those of Paper (40% RC) bags, except for Cumulative Energy Demand and Eutrophication.

Increasing the recycle of content of Paper bags to 100% reduces all of the environmental impact categories, some significantly.

Paper bags with either 40% or 100% RC content have higher environmental impacts for all of the categories than PRBs with 30% RC content. For three of the impact categories, Terrestrial acidification, Freshwater ecotoxity and marine ecotoxicty, Paper bags with 100% RC content have lower enviromental impact than PRBs with 0% RC content, but for the other 9 categories, PRBs (0% RC) are superior. As shown in Figures 5.33 and 5.34, looking at the average of the number of trips required for equivalency of all 12 environmental impact categories shows that, from an environmental impact perspective, PRBs with either recycle content should be preferred for bags intended for one use as grocery carrier bags over Paper bags of the size and RC contents studied.

Table 5.1 compares each of the two reusable bag types with the two PRBs and two Paper bag types studied, using the average for all 12 environmental impact categories of the number of trips required for equivalency of the reusable bag with the selected PRB or Paper bag. The Table shows that, on this basis, LDPE bags could be discarded after one or two trips and still have equivalent environmental impacts to either of the Paper bag types. LDPE bags would have to be used for about 6 trips to have equivalent environmental impacts to the PRBs required for 6 trips. NWPP bags would have to be used for 3–6 trips for equivalency with Paper bags and for about 20 trips for equivalency with PRBs.

5.2. Case 2—Secondary uses of PRBs and Paper bags included

5.2.1 Background for the discussion of secondary uses

The Base Case discussed above does not include the potential impacts on the environmental impact categories of secondary uses for PRBs and Paper bags. As an alternative scenario, secondary uses of these bags were modeled using an avoided burden approach. The avoided burden was calculated by assuming that reusing PRBs or Paper bags for secondary purposes (that is, purposes other than grocery shopping) avoided the purchase of other bags for these secondary purposes. For each type of bag studied, it was assumed that bags that did not have to be purchased could be represented by the same type of bag being reused (i.e., a PRB (0% RC) bag avoided for a 0% RC bag reused, a Paper (40% RC) bag for a 40% RC bag, etc.).

We should note that reusable bags can also be diverted to secondary uses. However, another reusable bag would have to be provided to replace the diverted bag in the set required for a shopping trip. This circumstance therefore differs from PRBs and Paper bags, where a new set of bags is assumed to be provided for each shopping trip in any case.

The per cent reuse for PRBs was derived from two published consumer studies, one in the U.S. and one in the UK. A consumer study conducted by an independent consultant in the U.S. in 2007 revealed that 92% of the consumers surveyed reused plastic shopping bags, with about 59% of respondents using them to contain trash

(APCO Insight, 2007). A similar study was carried out in the U.K. about one year earlier, using twice the number of respondents, which found that 93% of the consumers surveyed reused their PRBs, that 73% reused their bags for trash and that 59% always reused all the PRBs they acquired when shopping for groceries (Andrew Irving Associates, 2005). The U.K. Environment Agency Study analyzed the Irving data in more depth and estimated that 76% of PRBs were reused (Fry, 2011, p. 30). U.S. PRB manufacturers believe about 60% of PRBs are reused.[1] A summary of the two studies is shown in Table 5.2.

Main Use	% of Respondents	
	APCO (U.S.)	Irving (U.K.)
Wastebasket (bin) liner	30	47
Trash disposal	20	21
Animal refuse	9	5
Reuse groceries	3	6
Carry bag/non-grocery shopping	17	4
Storage	2	2
Lunch bag	6	2
Other	1	2
Recycle	4	4
Discard	8	7
Number of respondents	502	1048

Table 5.2 Surveys of consumer PRB reuse

Evidence that consumers will purchase plastic trash bags if PRBs are not available is provided in a study prepared in 2008 for the Connecticut General Assembly entitled “Effect of Plastic Bag Taxes and Bans on Garbage Bag Sales.” (Frisman, 2008) Frisman stated that, after Ireland imposed a tax on plastic shopping bag sales in 2002, it was reported that sales of plastic trash can liners increased 77%. Both Australia and Scotland relied on these data in formulating their plastic bag regulations.

Thus, to model the secondary use of PRBs using an avoided burden approach, a reuse rate of 40% of bags was selected based on the data cited above. This is the same percentage used in the UK Environment Study. This figure is less than the larger reuse rates reported for the UK (76%) and for the U.S. (60%), based on the reasoning that if PRBs were not available, consumers would find other alternatives for some of their needs and therefore not purchase new bags for all of the secondary uses.

No data could be located for reuse of Paper grocery bags comparable to those cited above for PRBs. However, the Internet abounds with recommendations for how to reuse Paper grocery bags. A typical such Internet site is reproduced as Figure 5.35.

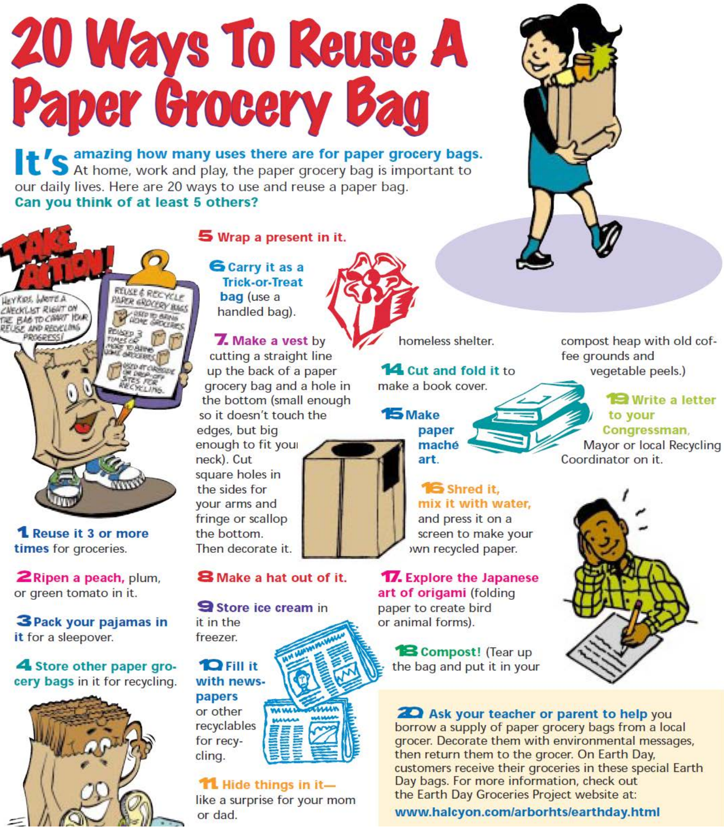


Figure 5.35 Example of a web site detailing reuses of paper grocery bags[2]

In the absence of any data to provide a basis for a quantitative estimate of paper bag secondary use, the authors decided to assume that the Paper bags were reused in the same ratio as PRBs, based on the ratio of % of reused bags to % not recycled bags. This was calculated as shown in Table 5.3.

	PRBs	Paper Bags
% recycled	8.6	49.5
% not recycled	91.4	50.5
% reused	40	22.1
% to end-of-life	51.4	18.6
%reused/% not recycled	43.8	43.8

Table 5.3 Calculation of % Reuse for Paper Bags

The charts below show the environmental impact categories for each type of bag studied, including 40% secondary uses for PRBs and 22.1% uses for Paper bags, for the same scenarios shown above in Sections 5.1, 5.2 and 5.3.

5.2.2 Scenario 1—PRBs, Paper Bags and Reusable Bags discarded after one trip—Secondary uses included

Global Warming Potential (GWP):

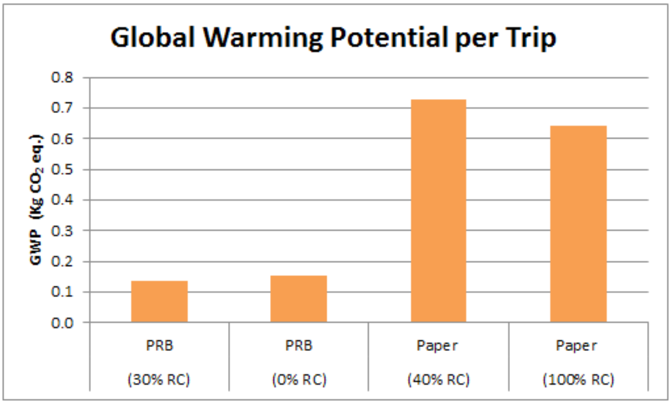


Figure 5.36 Global warming potential of PRBs and Paper bags, per trip to supermarket, secondary uses included

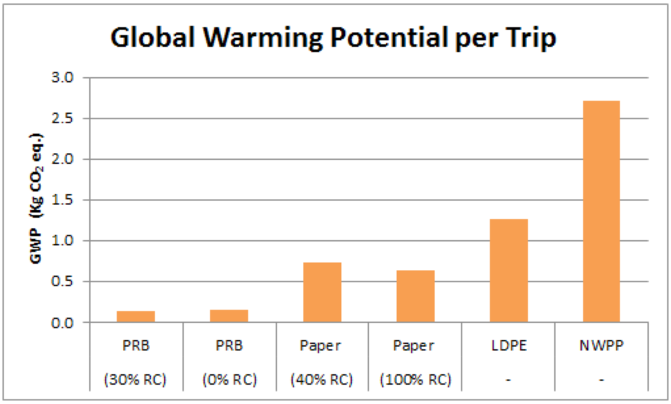


Figure 5.37 Global warming potential of PRB and Paper bags, per trip to supermarket, compared to GWP of reusable bags discarded after one trip, secondary uses included

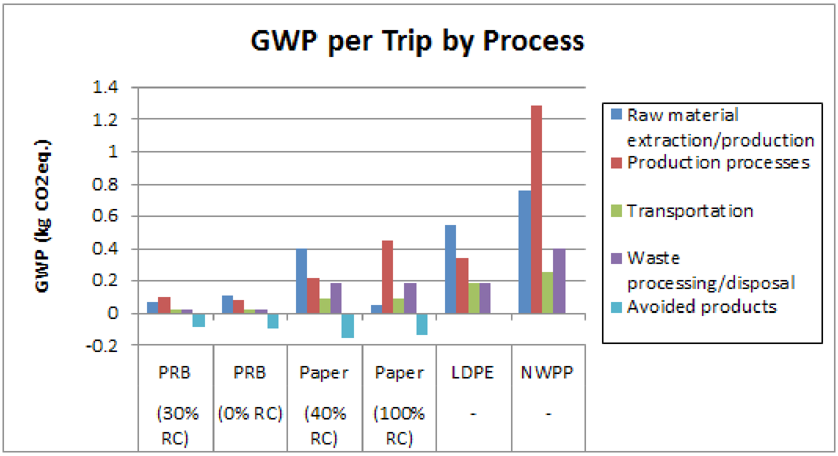


Figure 5.38 Breakdown by life cycle process of GWP per trip, secondary uses included

Figure 5.38 shows the effect on GWP of the PRB and Paper bags of the secondary uses at the levels assumed for this scenario. The effects of subtracting the net GWP burden of the avoided products are to reduce the GWP impacts for PRBs and Paper bags. There are no changes from the Base Case for the reusable bags. The GWP impacts with and without secondary uses can be seen by comparing Figure 5.35 with Figure 5.1.

Similar effects are seen for all of the environmental impact categories as shown in Figures 5.39 through 5.66

Water Depletion:

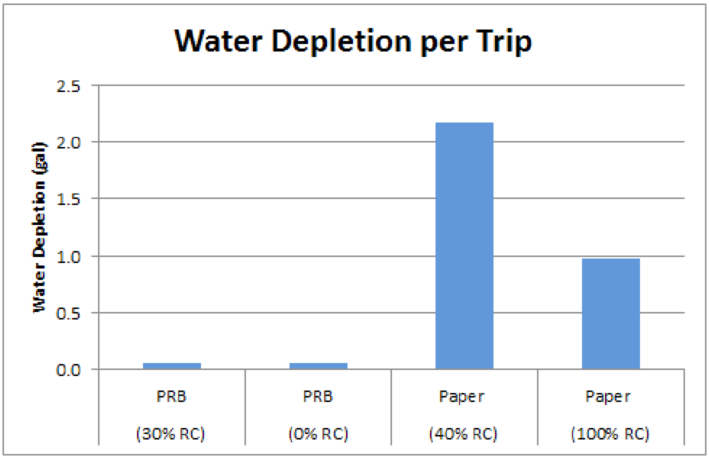


Figure 5.39 Water Depletion of PRBs and Paper bags, per trip to supermarket, secondary uses included

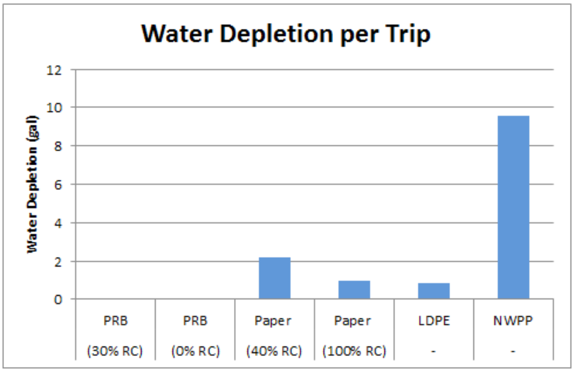


Figure 5.40 Water Depletion of PRBs and Paper bags, per trip to supermarket, compared to Water Depletion of reusable bags discarded after one trip, secondary uses included

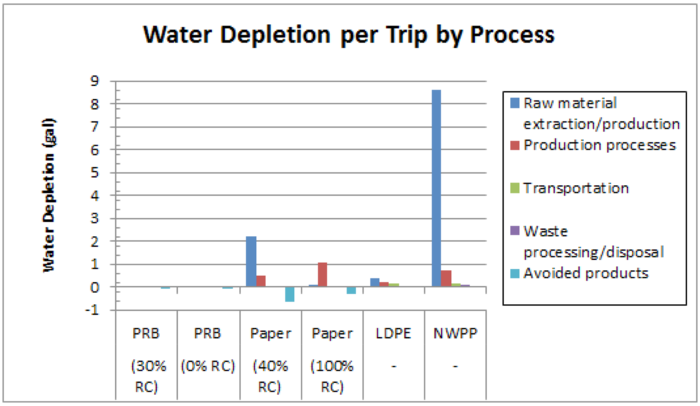


Figure 5.41 Breakdown by life cycle process of Water Depletion per trip, secondary uses included

<u>Cumulative Energy Demand</u>:

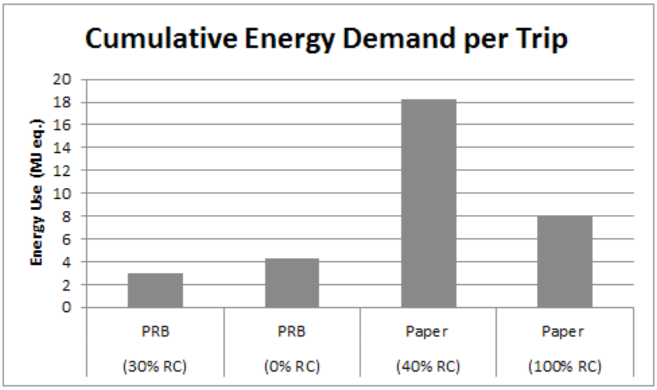


Figure 5.42 Cumulative Energy Demand of PRBs and Paper bags, per trip to supermarket, secondary uses included

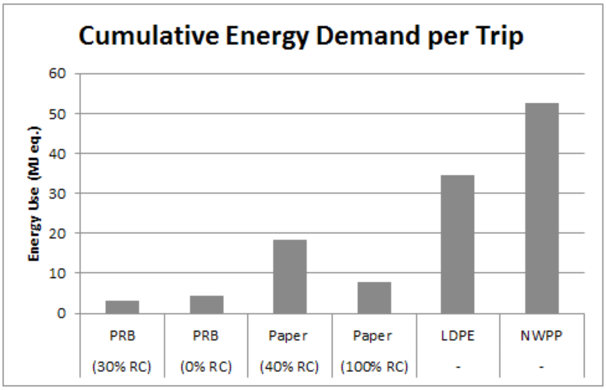


Figure 5.43 Cumulative Energy Demand of PRBs and Paper bags, per trip to supermarket, compared to Cumulative Energy Demand of reusable bags discarded after one trip, secondary uses included

Terrestrial Acidification:

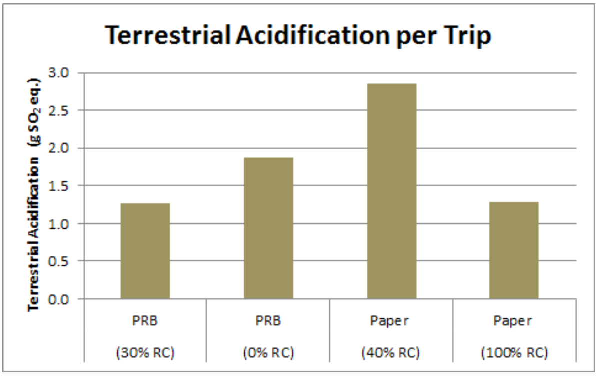


Figure 5.44 Terrestrial acidification from PRBs and Paper bags, per trip to supermarket, secondary uses included

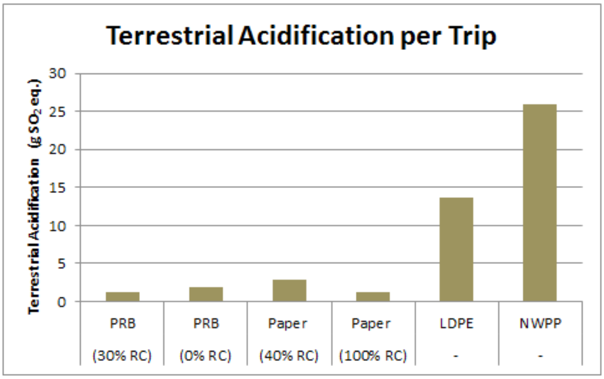


Figure 5.45 Terrestrial acidification from PRBs and Paper bags, per trip to supermarket, compared to Terrestrial acidification from reusable bags discarded after one trip

Eutrophication:

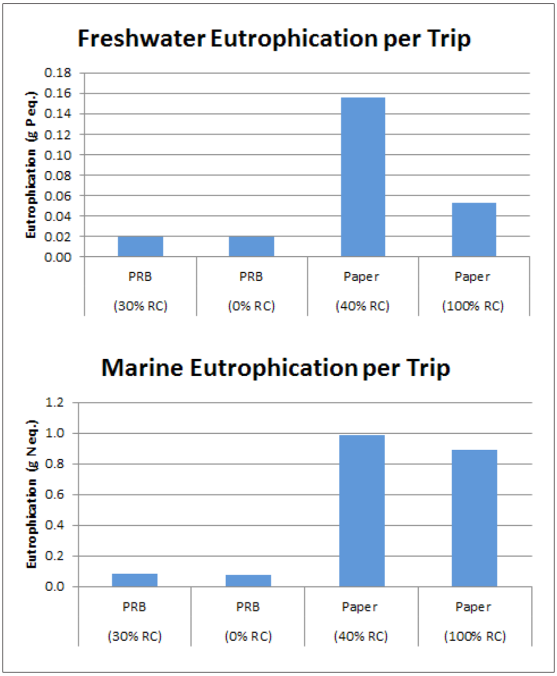


Figure 5.46 Freshwater and marine eutrophication from PRBs and Paper bags, per trip to supermarket, secondary uses included

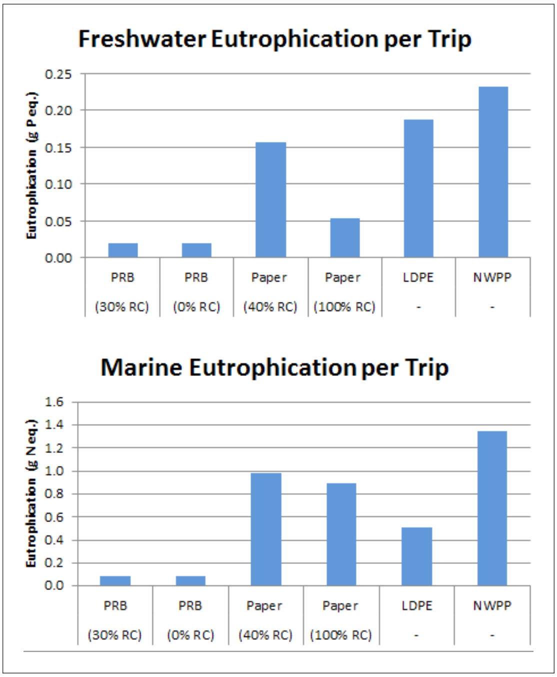


Figure 5.47 Freshwater and marine eutrophication from PRBs and Paper bags, per trip to the supermarket, compared to Freshwater and marine eutrophication from reusable bags discarded after one trip, secondary uses included

Toxicity:

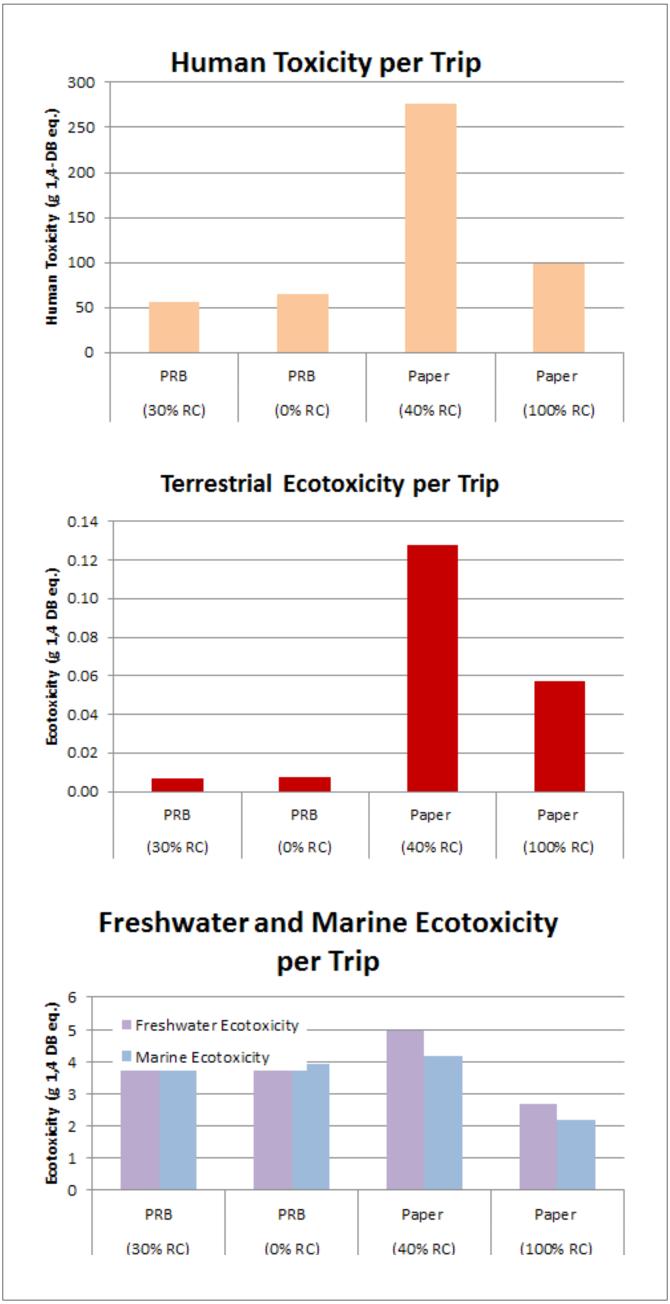


Figure 5.48 Human toxicity and terrestrial, freshwater and marine ecotoxicity from PRBs and Paper bags, per trip to supermarket, secondary uses included

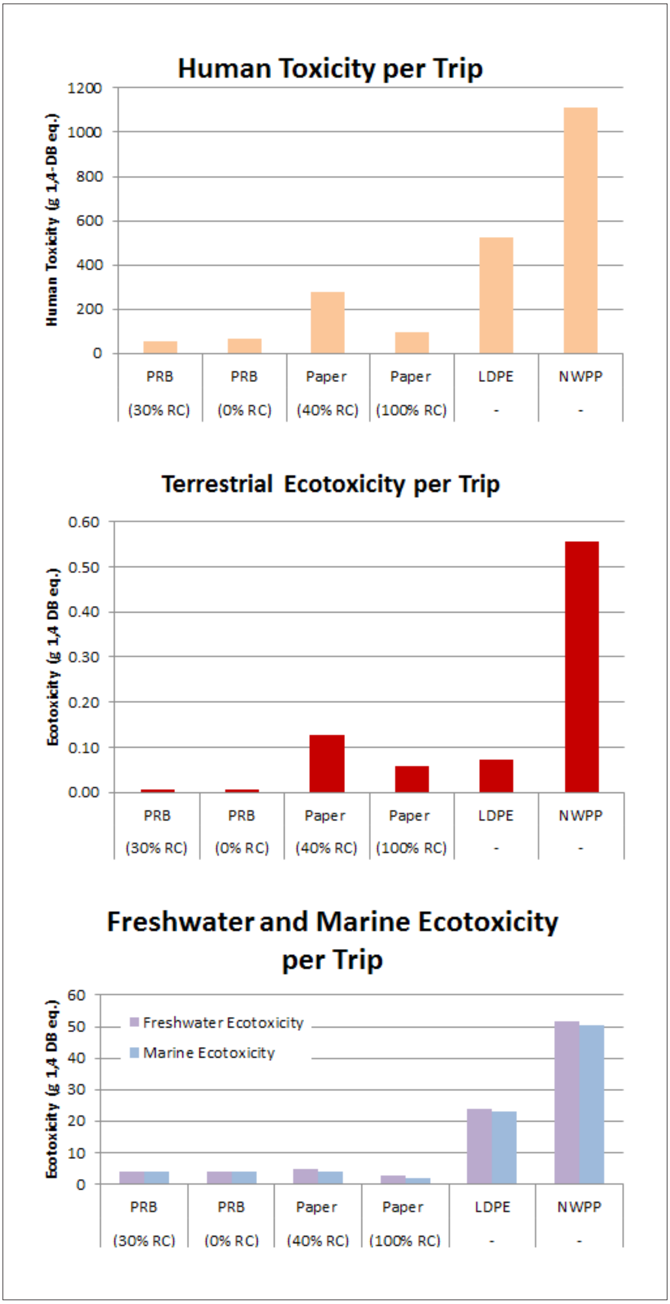


Figure 5.49 Human toxicity and terrestrial, freshwater and marine ecotoxicity from PRBs and Paper bags, per trip to supermarket, compared to Human toxicity and terrestrial, freshwater and marine ecotoxicity from reusuable bags discarded after one trip, secondary uses included

Fossil Fuel Depletion:

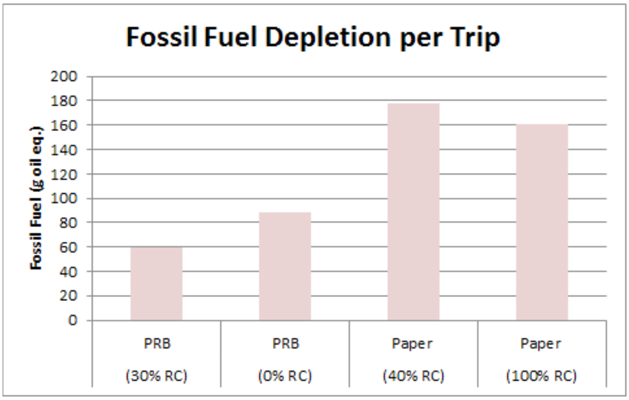


Figure 5.50 Fossil fuel depletion from PRBs and Paper bags, per trip to supermarket, secondary uses included

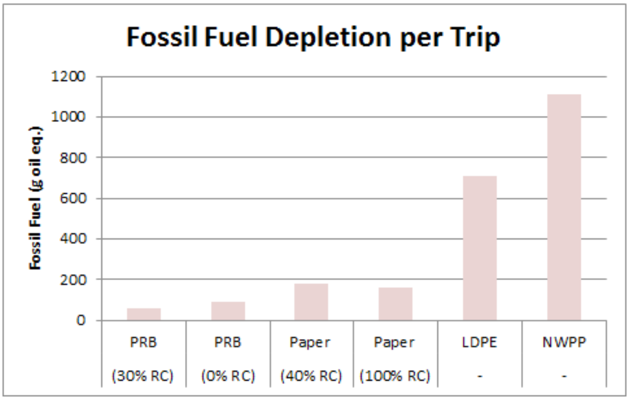


Figure 5.51 Fossil fuel depletion from PRBs and Paper bags, per trip to supermarket, compared to Fossil fuel Depletion from reusable bags discarded after one trip, secondary uses included

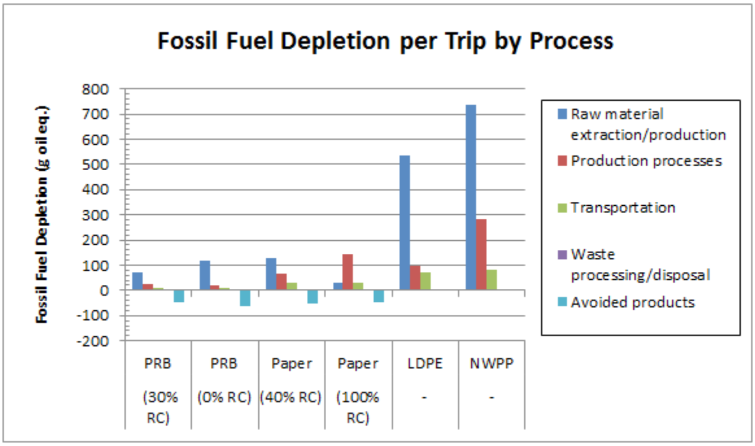


Figure 5.52 Breakdown by life cycle process of Fossil Fuel Depletion per trip, secondary uses included

Photochemical oxidant formation:

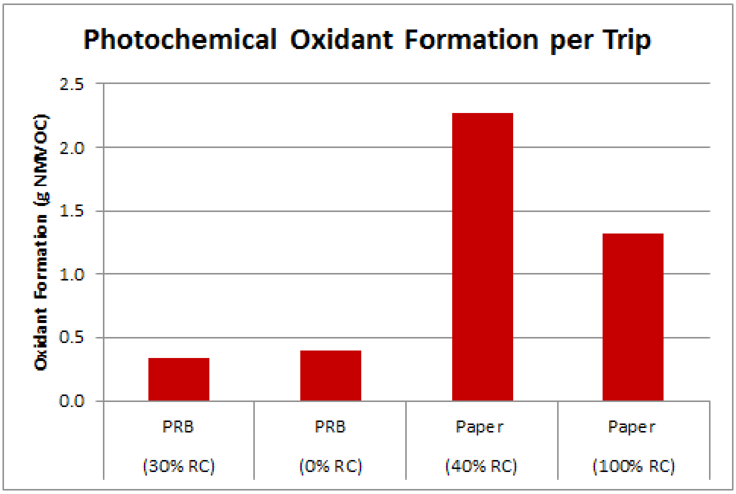


Figure 5.53 Photochemical oxidant formation from PRBs and Paper bags, per trip to supermarket, secondary uses included

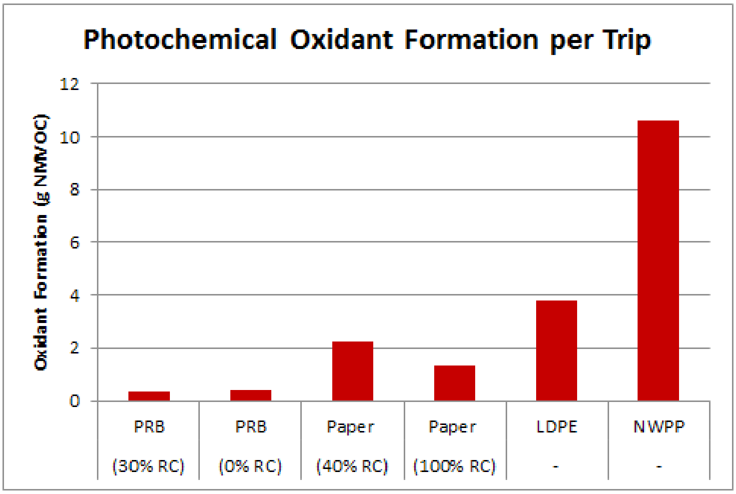


Figure 5.54 Photochemical oxidant formation from PRBs and Paper bags, per trip to the supermarket, compared to Photochemical oxidant formation from reusable bags discarded after one trip, secondary uses included

5.2.3 Scenario 2—Multiple Trips—secondary uses included

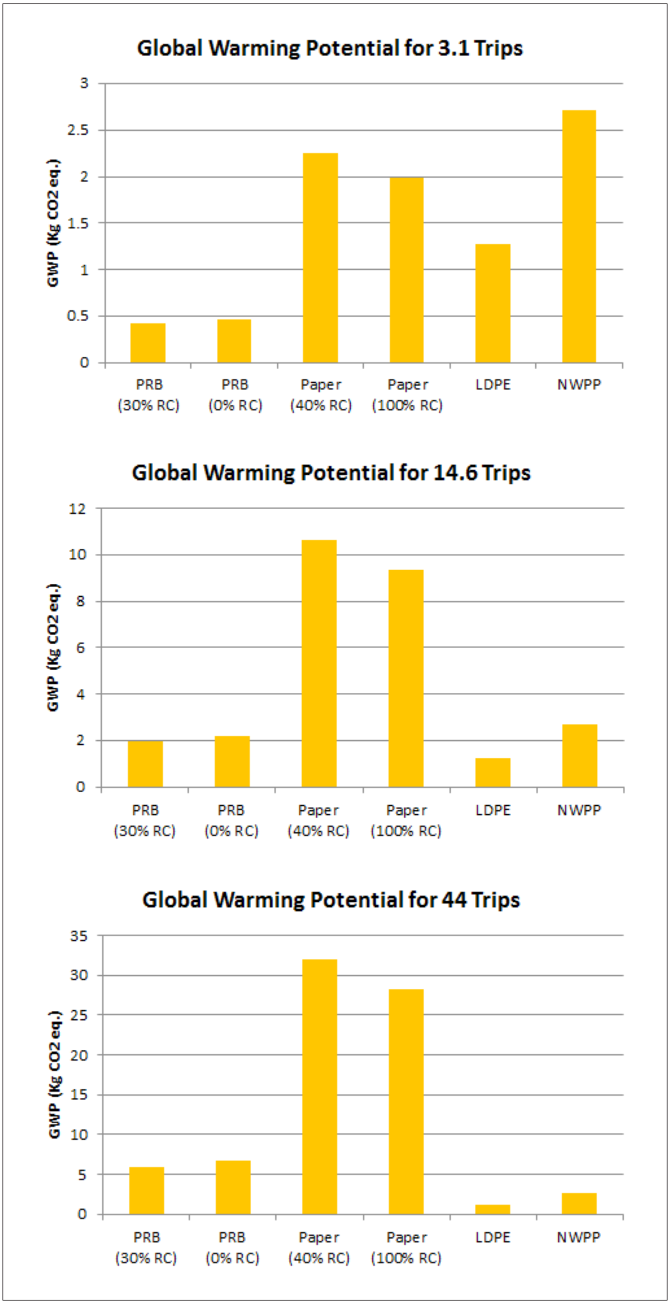


Figure 5.55 Global Warming Potential for PRBs, Paper bags and reusable bags for multiple numbers of trips, secondary uses included

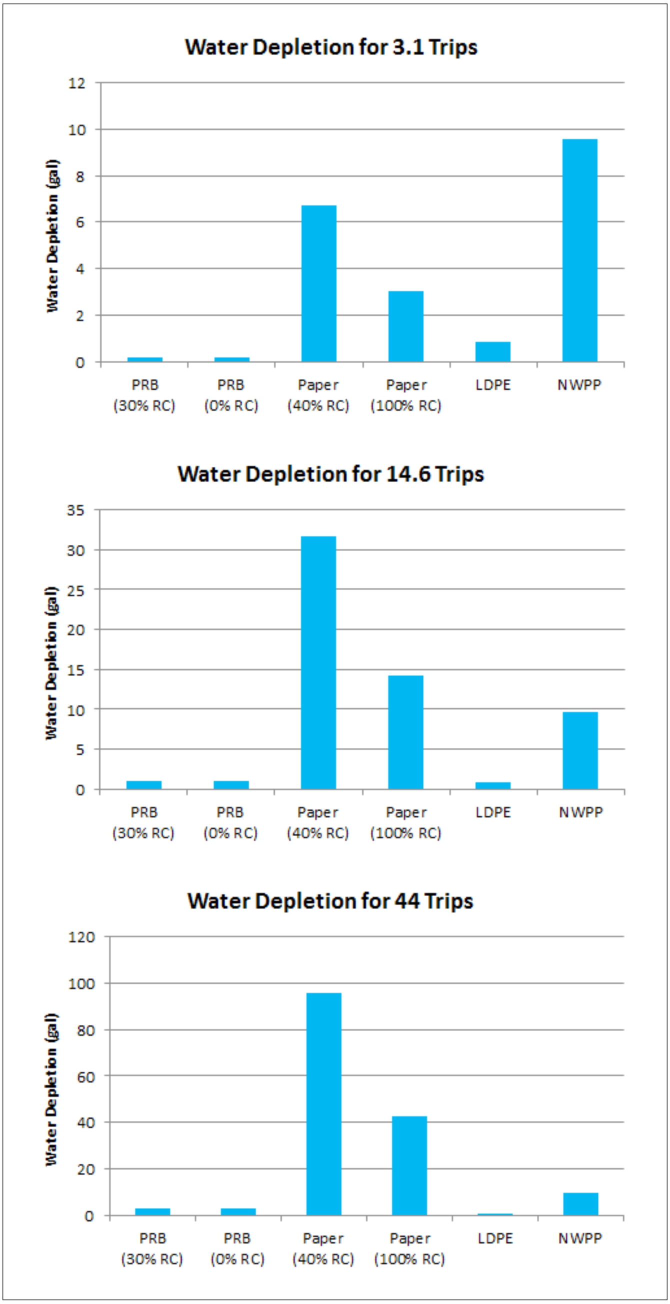


Figure 5.56 Water Depletion for PRBs, Paper bags and reusable bags for multiple numbers of trips, secondary uses included

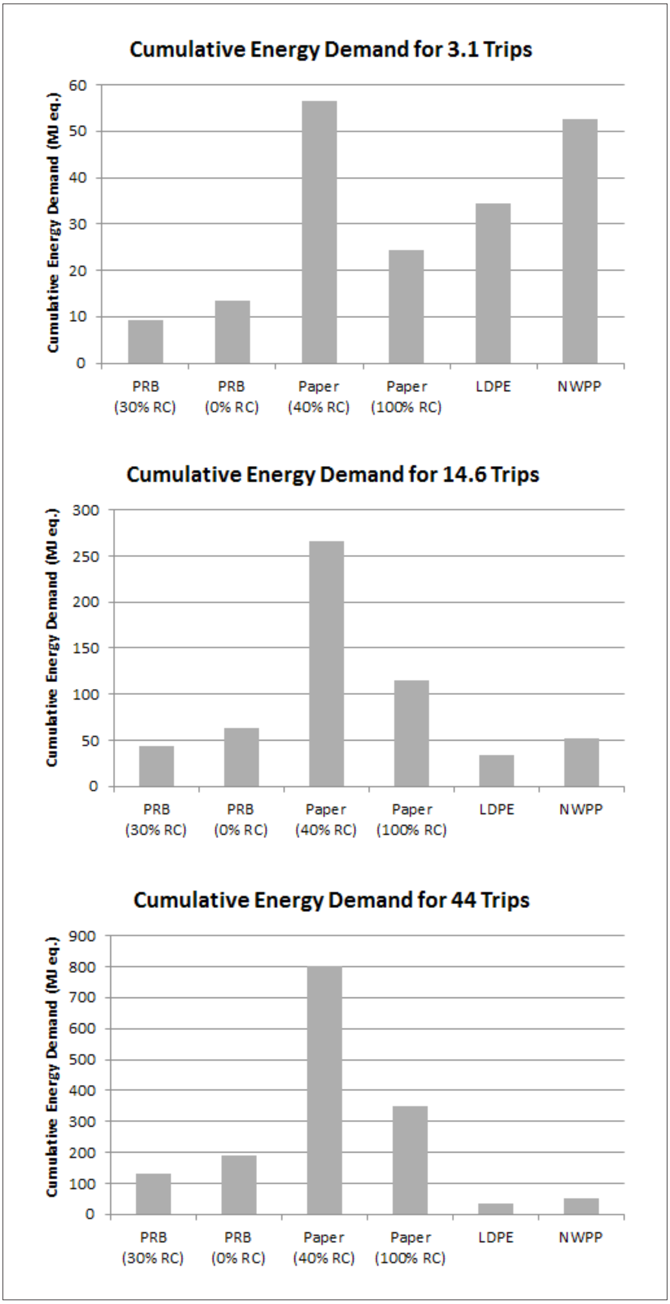


Figure 5.57 Cumulative Energy for PRBs, Paper bags and reusable bags for multiple numbers of trips, secondary uses included

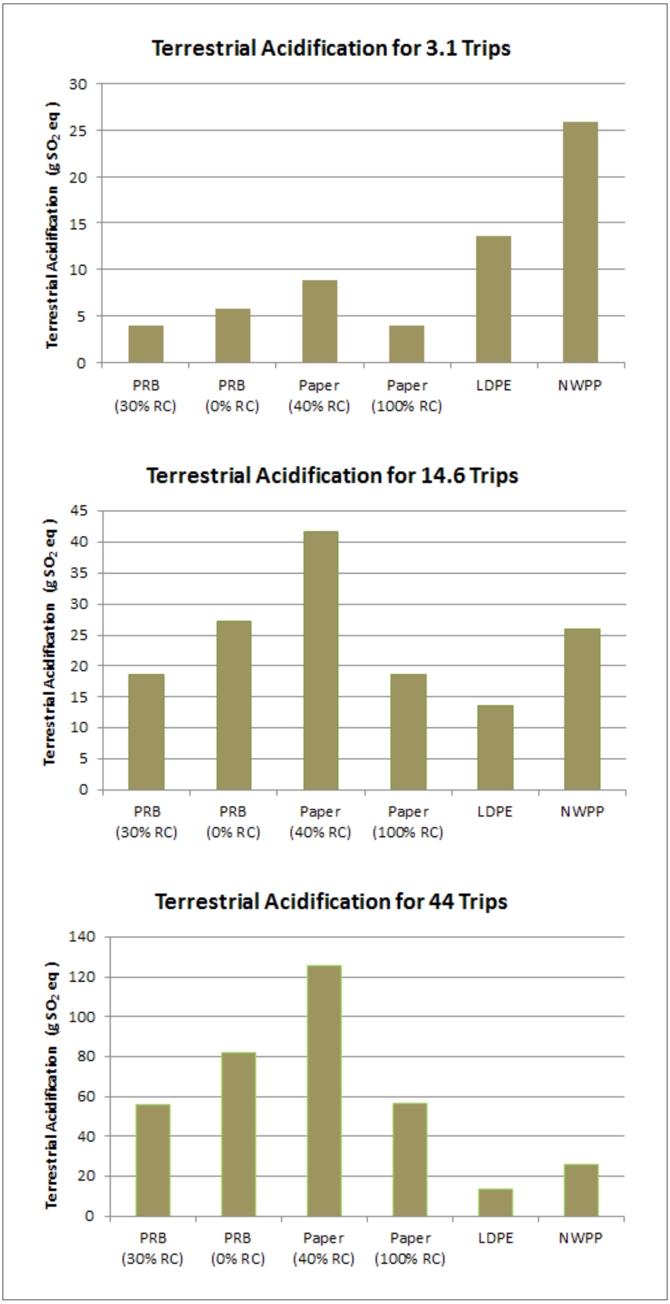


Figure 5.58 Terrestrial Acidification for PRBs, Paper bags and reusable bags for multiple numbers of trips, secondary uses included

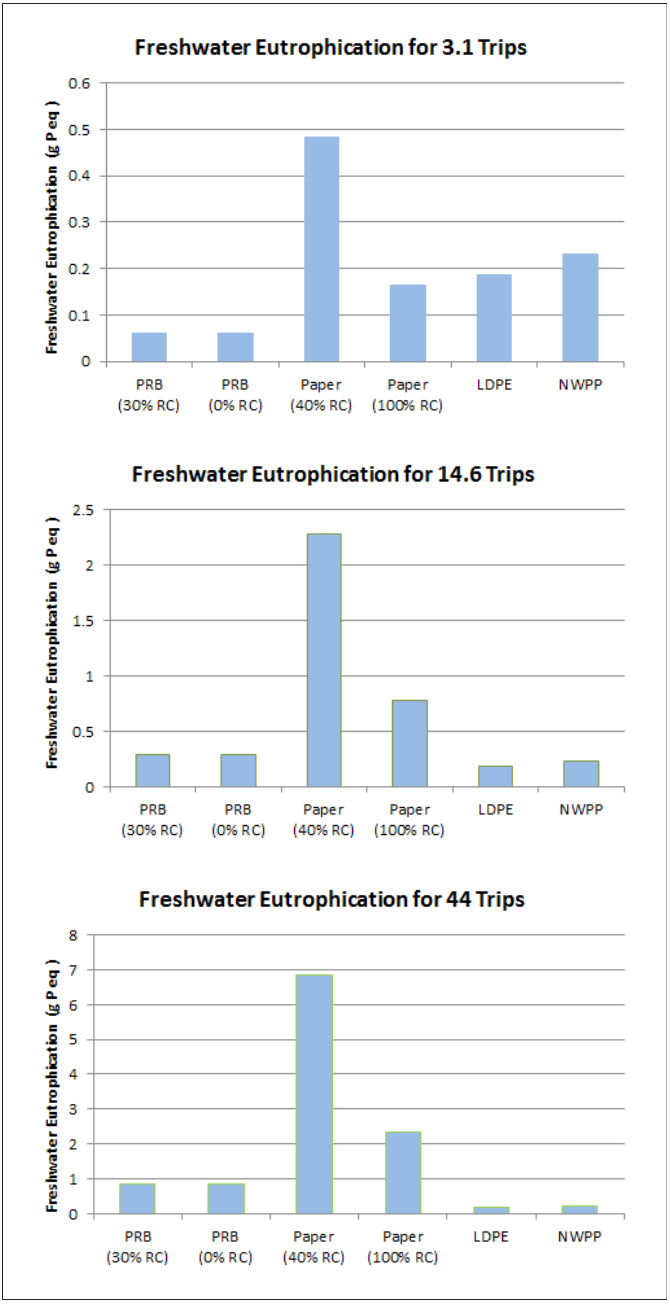


Figure 5.59 Freshwater Eutrophication for PRBs, Paper bags and reusable bags for multiple numbers of trips, secondary uses included

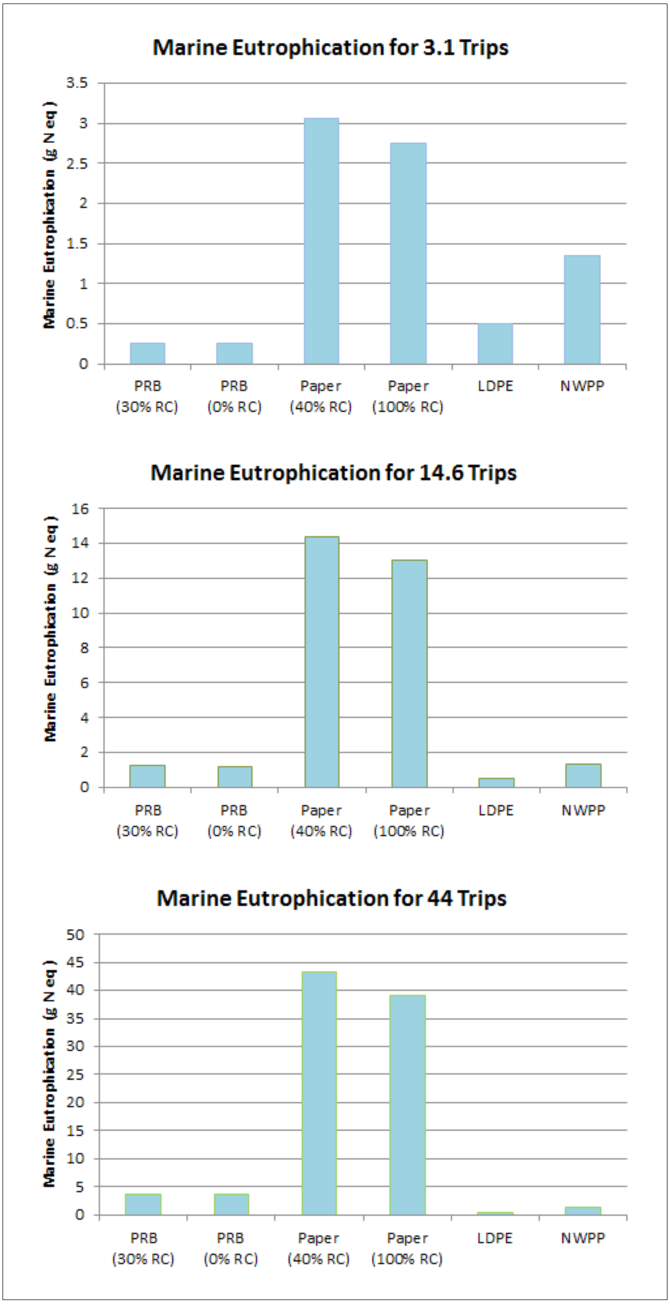


Figure 5.60 Marine Eutrophication for PRBs, Paper and reusable bags for multiple numbers of trips, secondary uses included

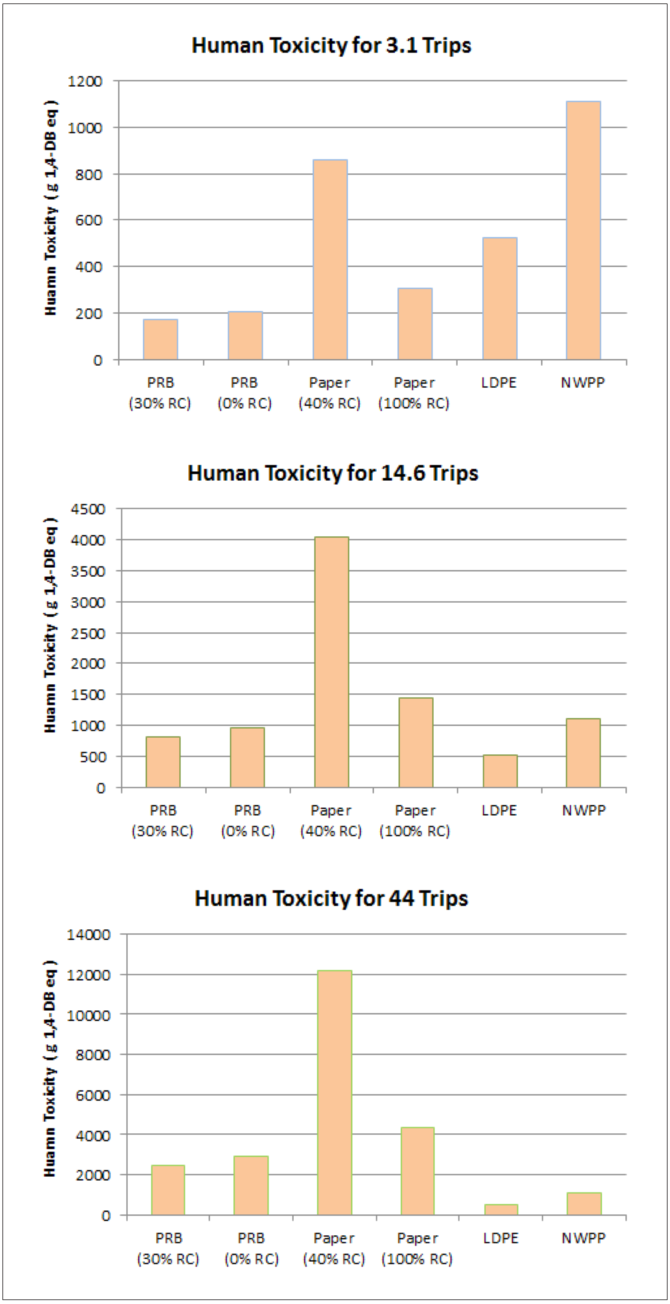


Figure 5.61 Human Toxicity for PRBs, Paper bags and reusable bags for multiple numbers of trips, secondary uses included

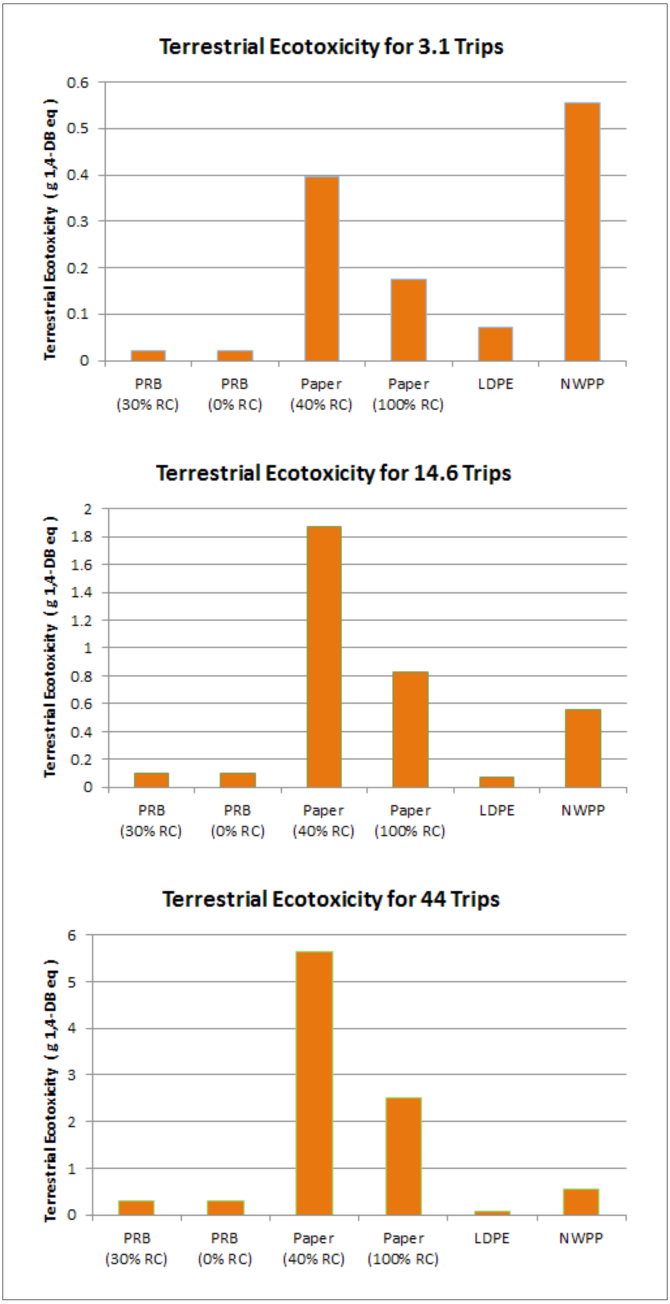


Figure 5.62 Terrestrial Ecotoxicity for PRBs, Paper and reusable bags for multiple numbers of trips, secondary uses included

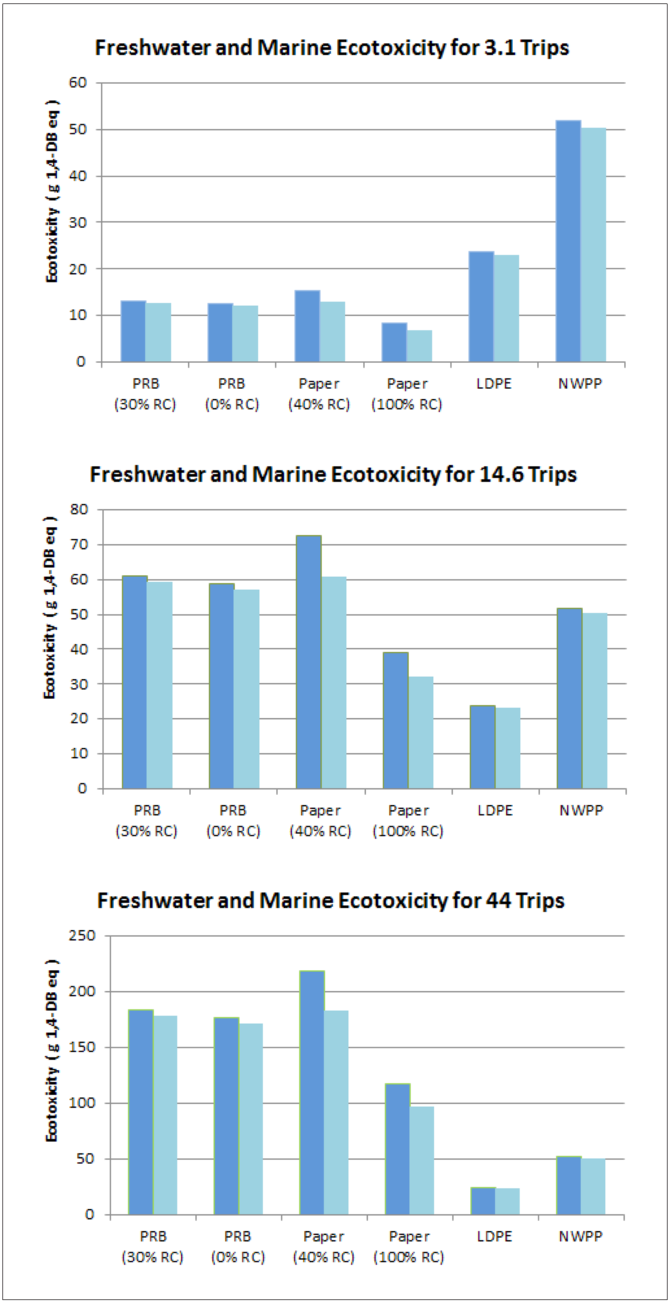


Figure 5.63 Freshwater and Marine Ecotoxicity for PRBs, Paper bags and reusable bags for multiple numbers of trips, secondary uses included

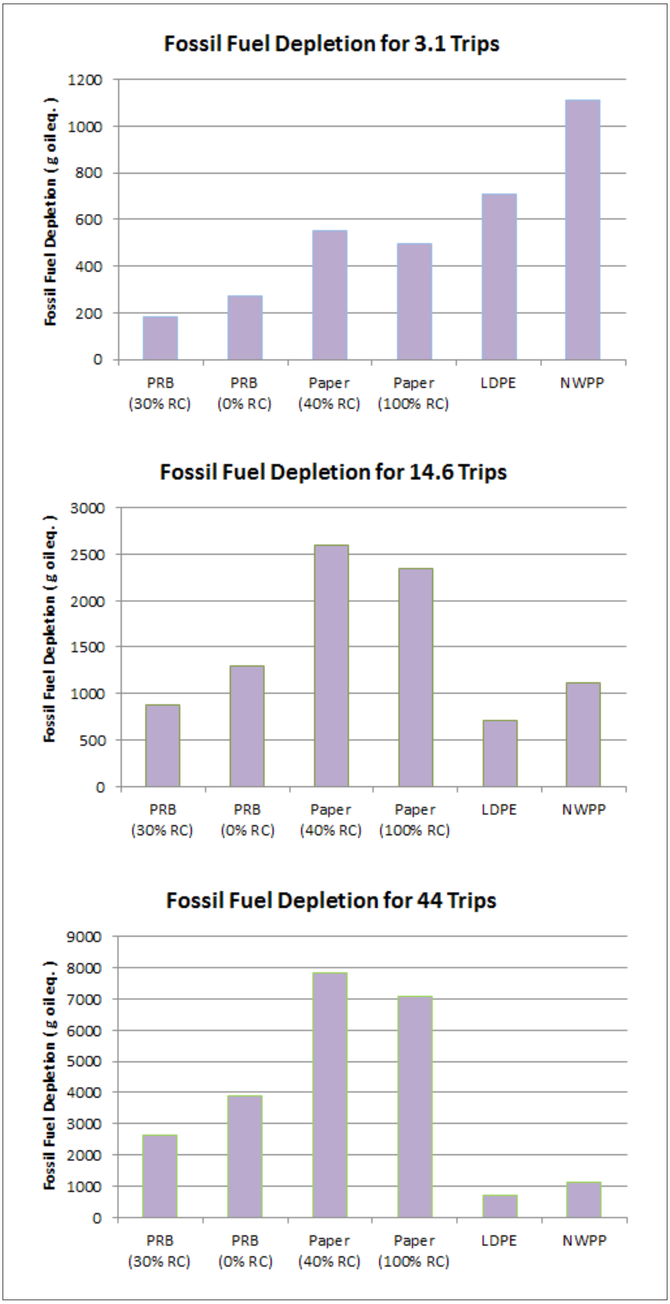


Figure 5.64 Fossil Fuel Depletion for PRBs, Paper bags and reusable bags for multiple numbers of trips, secondary uses included

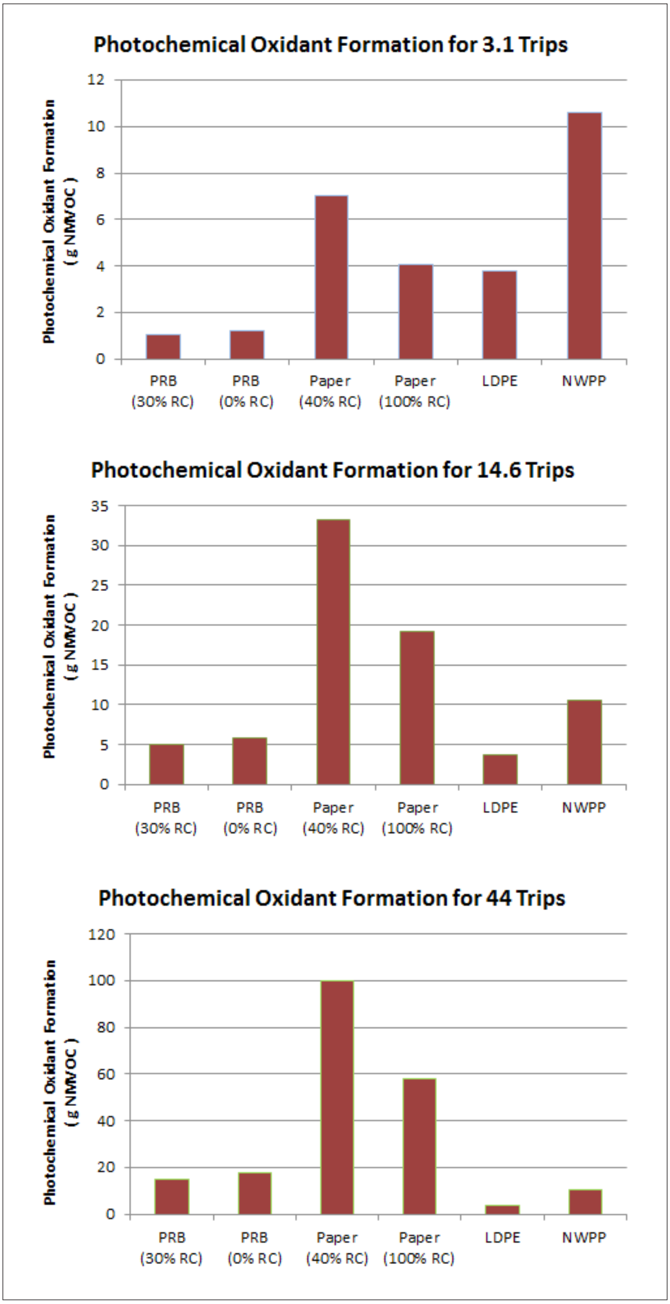


Figure 5.65 Photochemical Oxidant Formation for PRBs, Paper bags and reusable bags for multiple numbers of trips, secondary uses included

The following observations can be made from Figures 5.55 through 5.65 above:

For 3.1 trips—

- Paper (40% RC) Bags have higher environmental impacts than PRBs with either recycle content for all categories except Terrestrial Acidification.
- Paper (100% RC) Bags have higher environmental impacts than PRBs with either recycle content for all categories except Terrestrial Acidification and Freshwater and Marine Ecotoxicity.
- LDPE bags have higher environmental impacts for all categories than PRBs with either recycle content.
- NWPP Bags have higher environmental impacts for all categories than PRBs with either recycle content.

For 14.6 trips—

- Paper (40% RC) Bags have higher environmental impacts than PRBs with either recycle content for all categories.
- Paper (100% RC) Bags have higher environmental impacts than PRBs (30% RC) for all categories except Freshwater and Marine Ecotoxicity.
- Paper (100% RC) Bags have higher environmental impacts than PRBs (0% RC) for all categories except Terrestrial Acidification and Freshwater and Marine Ecotoxicity.
- LDPE bags have lower environmental impacts for all categories than PRBs with either recycle content or Paper bags with either recycle content
- NWPP bags have higher environmental impacts than PRB (30% RC) for all categories except Freshwater Eutrophication and Freshwater and Marine Ecotoxicity.
- NWPP bags have higher environmental impacts than PRB (0% RC) for six of the twelve categories studied.
- NWPP bags have lower environmental impacts for all categories than Paper (40% RC) bags.
- Paper (100% RC) Bags have higher environmental impacts than NWPP bags for all categories except Terrestrial Acidification and Freshwater and Marine Ecotoxicity.

For 44 trips—

- Paper (40% RC) Bags have higher environmental impacts than PRBs with either recycle content for all categories.
- Paper (100% RC) Bags have higher environmental impacts than PRBs (30% RC) for all categories except Freshwater and Marine Ecotoxicity.
- Paper (100% RC) Bags have higher environmental impacts than PRBs (0% RC) for all categories except Terrestrial Acidification and Freshwater and Marine Ecotoxicity.

- LDPE bags have lower environmental impacts for all categories than PRBs with either recycle content or Paper bags with either recycle content
- NWPP Bags have lower environmental impacts than PRBs with either recycle content for all categories except Water Depletion.
- NWPP Bags have lower environmental impacts for all categories than Paper bags with either recycle content.

5.2.4 Scenario 3 Number of trips for equivalence—secondary uses included

Figures 5.66 and 5.67 show the number of trips required for equivalency with PRB (30% RC) and with Paper (40% RC) for each of the environmental impact categories for each type of bag studied with secondary uses for PRBs and Paper bags included. Also shown in the figure is the average for the all of the environmental impact categories of the number of trips for equivalency. Tables 5.4 and 5.5 show the number of trips required for equivalency with PRB (30% RC) and with Paper (40% RC) for each of the environmental impact categories for each type of bag studied both with and without (Base Case) secondary uses included.

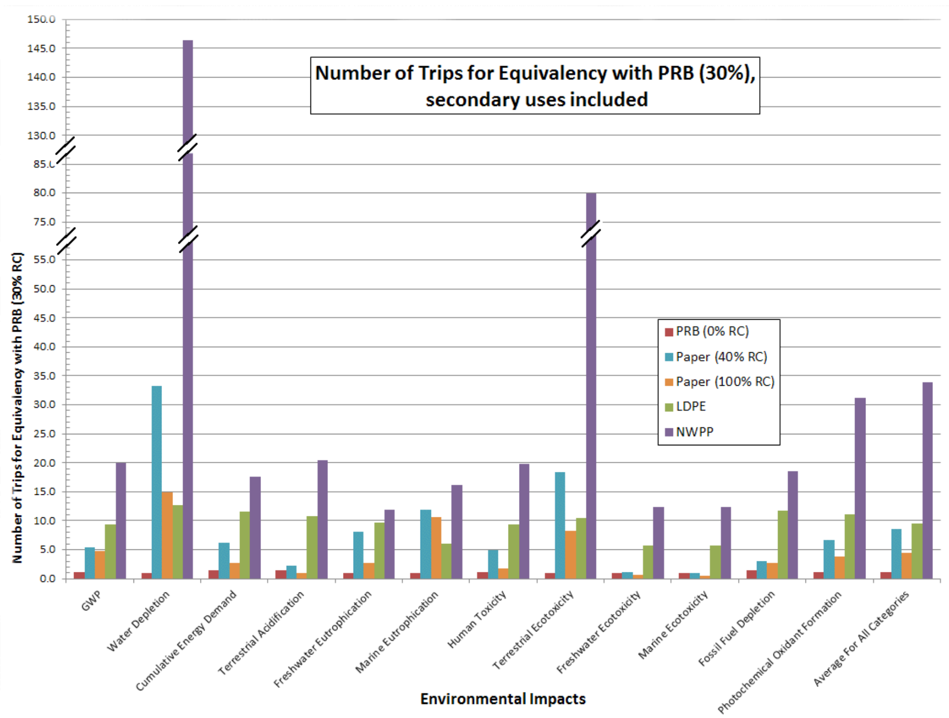


Figure 5.66 Number of trips required for equivalency with PRB (30%RC), secondary uses included

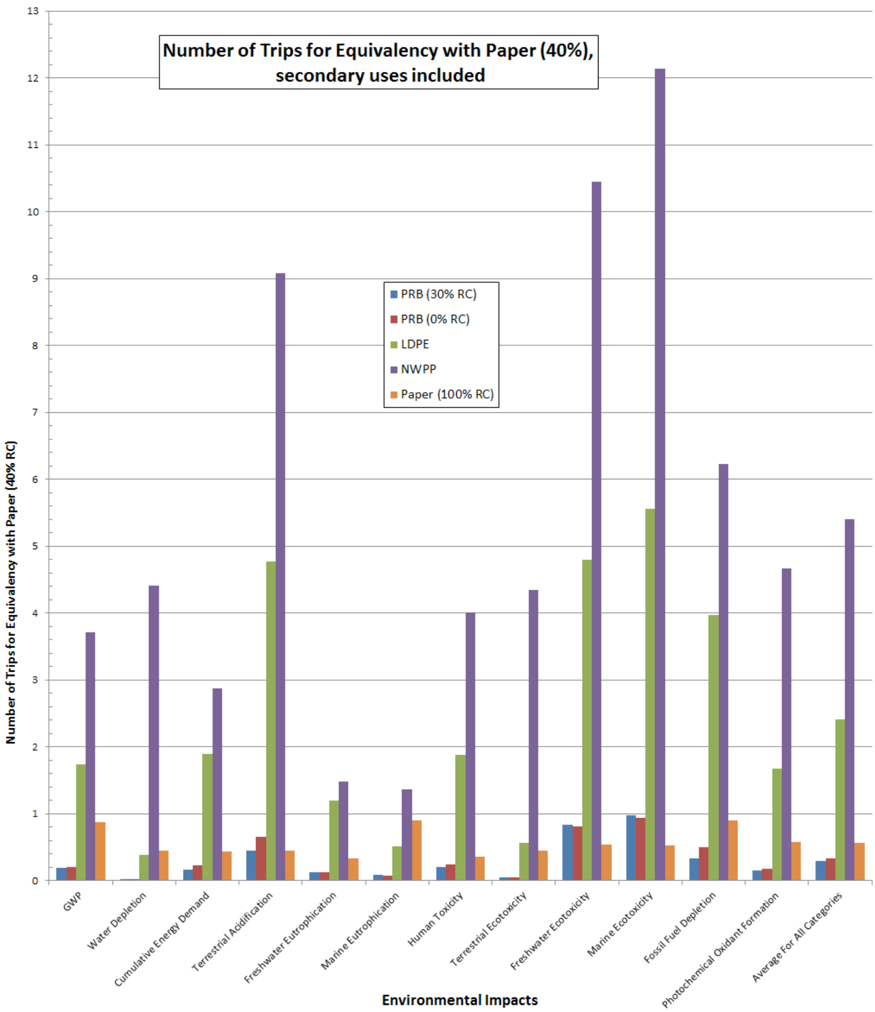


Figure 5.67 Number of trips required for equivalency with Paper (40% RC), secondary uses included

		No. of Trips for Equivalency to PRB (30% RC)									
Impact category	**Unit**	**PRB (0% RC)**		**Paper (40% RC)**		**Paper (100% RC)**		**LDPE**		**NWPP**	
Secondary uses included?		No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
GWP	Kg CO2 eq	1.1	1.1	4.2	5.4	3.7	4.7	6.1	9.3	13.0	19.9
Water Depletion	gal	1.0	1.0	25.9	33.2	11.5	14.8	7.8	12.7	89.6	146.4
Cumulative Energy Demand	MJ eq.	1.3	1.5	4.7	6.1	2.0	2.7	6.9	11.6	10.5	17.6
Terrestrial Acidification	g SO2 eq	1.4	1.5	1.8	2.2	0.8	1.0	6.8	10.7	12.9	20.4
Freshwater Eutrophication	g P eq	1.0	1.0	5.8	8.0	2.0	2.7	5.5	9.6	6.7	11.9
Marine Eutrophication	g N eq	1.0	1.0	11.0	11.8	9.7	10.7	5.2	6.1	13.9	16.2
Human Toxicity	g 1,4-DB eq	1.2	1.2	3.9	4.9	1.3	1.8	5.9	9.3	12.6	19.8
Terrestrial Ecotoxicity	g 1,4-DB eq	1.0	1.0	14.1	18.4	6.2	8.2	6.3	10.5	47.9	80.0
Freshwater Ecotoxicity	g 1,4-DB eq	1.0	1.0	1.3	1.2	0.7	0.6	5.1	5.7	11.0	12.4
Marine Ecotoxicity	g 1,4-DB eq	1.0	1.0	1.1	1.0	0.6	0.5	5.1	5.7	11.1	12.4
Fossil Fuel Depletion	g oil eq	1.4	1.5	2.3	3.0	2.0	2.7	7.0	11.8	11.0	18.6
Photochemical Oxidant Formation	g NMVOC	1.1	1.2	4.8	6.7	2.8	3.9	6.4	11.1	17.9	31.2
Average for All Categories		**1.1**	**1.2**	**6.7**	**8.5**	**3.6**	**4.5**	**6.2**	**9.5**	**21.5**	**33.9**
Average, excl. Water Depletion		1.1	1.2	5.0	6.3	2.9	3.6	6.0	9.2	15.3	23.7

Table 5.4 Number of trips required for equivalency with PRB (30% RC), with and without secondary uses included

		No. of Trips for Equivalency to Paper (40% RC)									
Impact category	**Unit**	**PRB (30% RC)**		**PRB (0% RC)**		**Paper (100% RC)**		**LDPE**		**NWPP**	
Secondary uses included?		No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
GWP	Kg CO2 eq	0.2	0.2	0.3	0.2	0.9	0.9	1.4	1.7	3.1	3.7
Water Depletion	gal	0.0	0.0	0.0	0.0	0.4	0.4	0.3	0.4	3.5	4.4
Cumulative Energy Demand	MJ eq.	0.2	0.2	0.3	0.2	0.4	0.4	1.5	1.9	2.2	2.9
Terrestrial Acidification	g SO2 eq	0.6	0.4	0.8	0.7	0.4	0.4	3.7	4.8	7.1	9.1
Freshwater Eutrophication	g P eq	0.2	0.1	0.2	0.1	0.3	0.3	0.9	1.2	1.2	1.5
Marine Eutrophication	g N eq	0.1	0.1	0.1	0.1	0.9	0.9	0.5	0.5	1.3	1.4
Human Toxicity	g 1,4-DB eq	0.3	0.2	0.3	0.2	0.3	0.4	1.5	1.9	3.2	4.0
Terrestrial Ecotoxicity	g 1,4-DB eq	0.1	0.1	0.1	0.1	0.4	0.4	0.4	0.6	3.4	4.3
Freshwater Ecotoxicity	g 1,4-DB eq	0.8	0.8	0.7	0.8	0.5	0.5	3.9	4.8	8.4	10.4
Marine Ecotoxicity	g 1,4-DB eq	0.9	1.0	0.9	0.9	0.5	0.5	4.5	5.6	9.8	12.1
Fossil Fuel Depletion	g oil eq	0.4	0.3	0.6	0.5	0.9	0.9	3.1	4.0	4.9	6.2
Photochemical Oxidant Formation	g NMVOC	0.2	0.1	0.2	0.2	0.6	0.6	1.3	1.7	3.7	4.7
Average for All Categories		**0.3**	**0.3**	**0.4**	**0.3**	**0.6**	**0.6**	**1.9**	**2.4**	**4.3**	**5.4**
Average, excl. Water Depletion		0.4	0.3	0.4	0.4	0.6	0.6	2.1	2.6	4.4	5.5

Table 5.5 Number of trips required for equivalency with Paper (40% RC), with and without secondary uses included

Examining Figure 5.66 reveals that for NWPP bags especially, the average of all of the impact categories is weighted substantially by the large relative values of the Water Depletion and Terrestrial Ecotoxicity categories in comparison with PRBs (30% RC). LCA modeling of the Water Depletion category is especially challenging because water resources availability is geographically variable and water resources availability varies significantly with time (Brent, 2013). We have therefore included in Tables 5.4 and 5.5 the averages of all of the impact categories, with Water Depletion excluded. These data can be seen graphically in Section 7 below.

Table 5.4 shows that the inclusion of secondary uses for PRBs and Paper bags in the models for calculating the environmental impact categories results in an increase in the average for all environmental impact categories of about 3% for PRB (0% RC), about 25% for Paper bags and about 55% for the reusable bags LDPE and NWPP. These changes can be seen also in Figure 5.68, which shows just the averages for the all of the environmental impact categories of the number of trips required for equivalency with PRB (30% RC) with and without secondary uses included. The sensitivities of the calculations to the % of secondary uses assumed is discussed in Section 6.1. Excluding the Water Depletion category from the average of all of the impact categories results in a 20–30% decrease in the averages for NWPP and Paper bags compared to PRBs (30% RC).

Table 5.5 shows that the inclusion of secondary uses for PRBs and Paper bags in the models for calculating the environmental impact categories results in a decrease in the average for all environmental impact categories of about 8% for PRBs, an increase of about 1% for Paper (100% RC) and an increase of about 25% for the reusable bags LDPE and NWPP. Excluding the Water Depletion category from the average of all of the impact categories results in an increase of about 8% in the averages for PRBs and LDPE bags compared to Paper (40% RC) bags.

Figure 5.69 shows just the averages for the all of the environmental impact categories of the number of trips required for equivalency with Paper (40% RC) with and without secondary uses included.

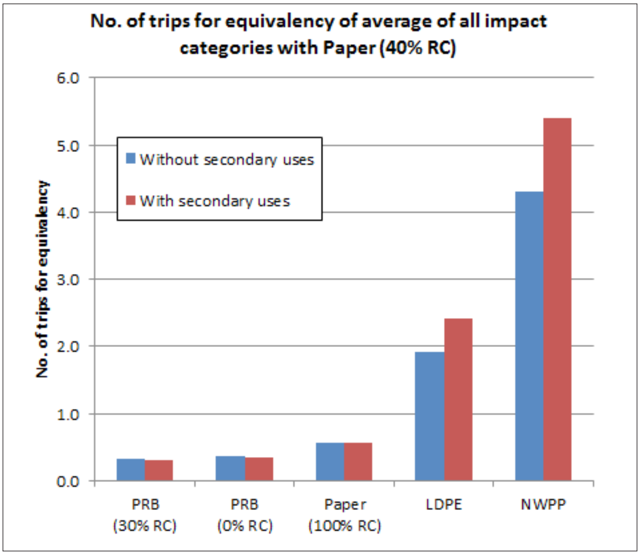


Figure 5.68 Average for all environmental impact categories of the number of trips required for equivalency with PRB (30% RC), with and without secondary uses

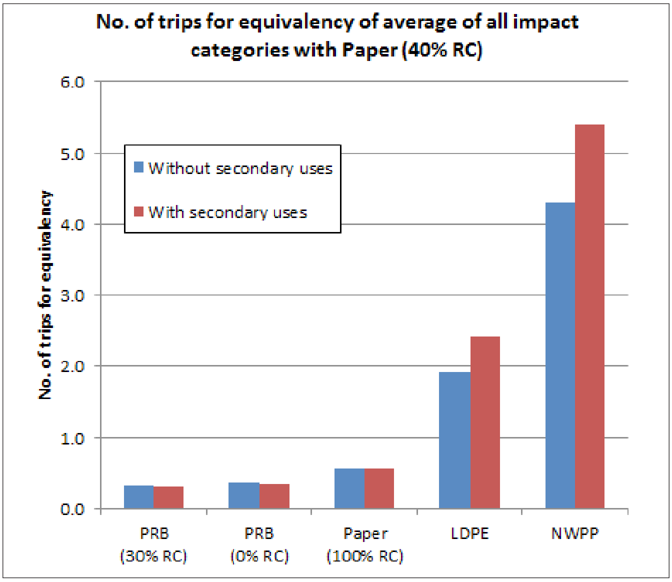


Figure 5.69 Average for all environmental impact categories of the number of trips required for equivalency with Paper (40% RC), with and without secondary uses

Table 5.6 shows a similar comparison of each of the reusable bag types studied with each of the PRB and Paper bag types studied, with and without the inclusion of secondary uses for the PRBs and Paper bags.

	Average for All Environmental Impact Categories of the Number of Trips Required For Equivalency			
Bag Type	**LDPE**		**NWPP**	
	Without secondary uses	**With secondary uses**	**Without secondary uses**	**With secondary uses**
Paper (40% RC)	0.9	1.1	3.2	4.0
Paper (100% RC)	1.7	2.1	6.0	7.5
PRB (30% RC)	6.2	9.5	21.5	33.9
PRB (0% RC)	5.5	8.3	19.2	29.4

Table 5.6 Comparison of Reusable Bag Types with PRBs and Paper bags based on average for all environmental impact categories of the number of trips required for equivalency

Comparing the results presented in Section 5.4 for LCA models including secondary uses of both Paper bags and PRBs with those detailed at the end of Section 5.3 for models without secondary uses (Base Case), one can see that the qualitative conclusions from the data remain the same:

From an environmental impact point of view,

- LDPE reusable bags should be preferred over NWPP bags.
- Either type of reusable bag should be preferred over any of the PRBs or Paper bags studied, if the reusable bags are used for a sufficient number of trips. Quantitatively, what "sufficient" is will be determined by which environmental impact categories are important to the decision-maker.
- PRBs with either recycle content should be preferred for bags intended for one-time use as grocery carrier bags over Paper bags of the types studied.

Quantitatively, inclusion in the LCA models of secondary uses for PRBs and Paper bags will increase the number of trips required for equivalency of any of the environmental impacts for reusable bags with those bags.

Note

1. Confidential communication from industry source to R. Kimmel (September, 2012).
2. City of Fort Collins Environmental Services Department (2004).

6. Sensitivity Analysis

Sensitivity analyses were conducted to determine the significance of certain decisions and assumptions on final report results. The factors considered and shown below are:

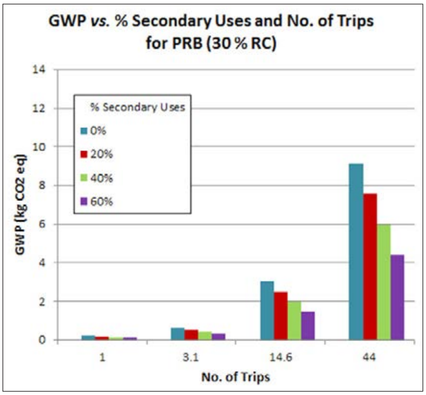
- Secondary use of PRBs and Paper bags
- Effects of de-inking assumptions for Paper bags
- Background and assumptions regarding washing and/or disinfection of LDPE and NWPP bags
- Thickness of LDPE bags
- Statistical variability in the number of bags required per trip
- Alternative assessment methods

For most of the sensitivities, effects of changing assumptions on only GWP and Fossil Fuel Depletion are shown. These categories were chosen because they seem to be those most cited in other reports. Indeed, many of the previous LCA studies on Grocery Carrier Bags focus only on GWP. The trends shown as a result of changing assumptions are expected to be similar for the potential environmental impact categories not shown. Detailed data for the various charts can be found in Annex E.

6.1 Secondary use of PRBs and Paper bags

Case 2 presented in Section 5.2 assumes that 40% of PRBs and 22.1% of Paper bags are reused by consumers for secondary uses. The effects on Global Warming Potential of varying PRB reuse rates between 0% and 60% are shown in Figures 6.1 and 6.2.

The changes in % secondary reuse of PRBs on the number of trips for Equivalency in GWP between PRB (30 %RC) and reusable bags are shown in Figure 6.2.



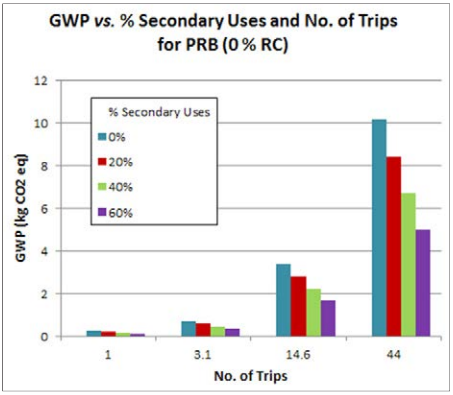


Figure 6.1 Effects of adjusting secondary use rate for PRBs

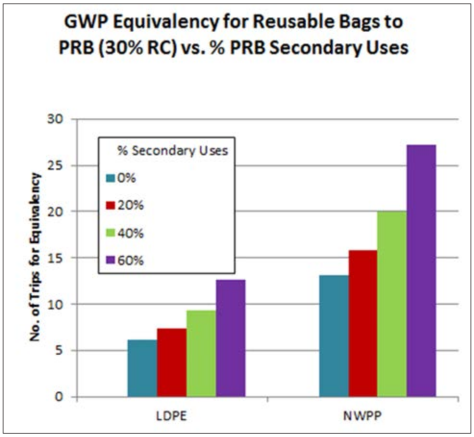


Figure 6.2 Effect of adjusting secondary use rate for PRB (30% RC) on Number of Trips Required for GWP Equivalency of Reusable Bags with PRBs

With increasing levels of secondary use, the potential environmental impacts of the PRB bags decrease, due to the decreasing burden of avoided virgin material and bag production. This results in an increase in the number of trips for equivalency required of the reusable bags.

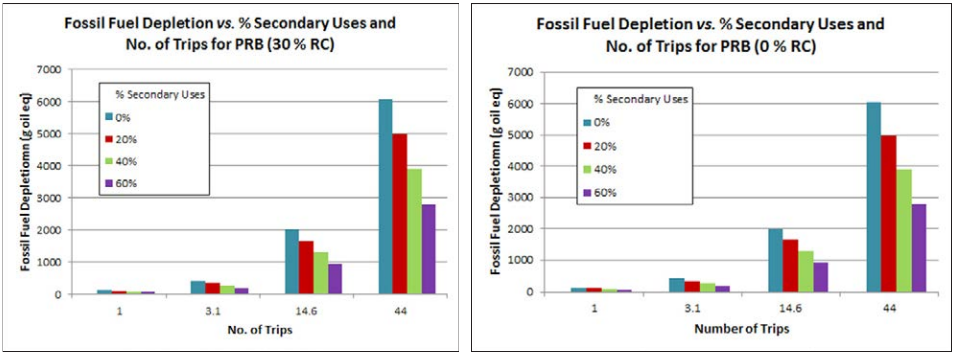


Figure 6.3 Effects of adjusting secondary use rate for PRBs

Analogous charts for Fossil Fuel Depletion are shown in Figures 6.3 and 6.4

Based on the discussion in Section 5.4 above, 22.1% secondary uses for Paper bags were assumed in the Alternative Scenario, even though no quantitative data can be located to back up this assumption. The effects of adjusting the secondary use rate to 0% and11.05% for both the 40% RC Paper bags and the 100% RC paper bags are shown in Figures 6.5 and 6.6.

As seen for PRBs, with increasing levels of secondary use, the potential environmental impacts of the paper bags decrease, due to the decreasing burden of avoided virgin material and bag production.

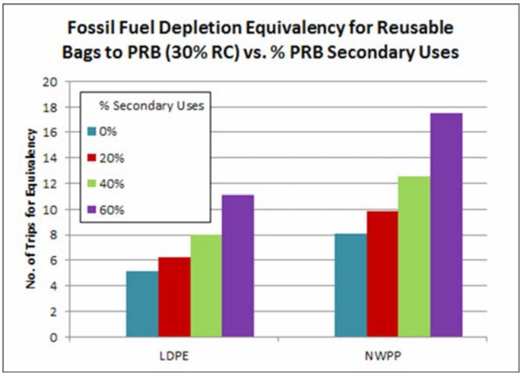


Figure 6.4 Effect of adjusting secondary use rate for PRB (30% RC) on Number of Trips Required for Fossil Fuel Depletion Equivalency of Reusable Bags with PRBs.

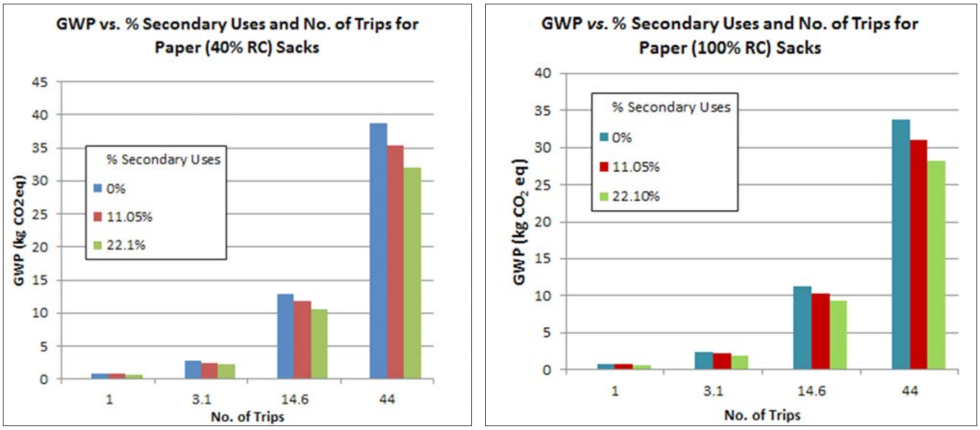


Figure 6.5 Effect on GWP of adjusting secondary use rate for paper bags

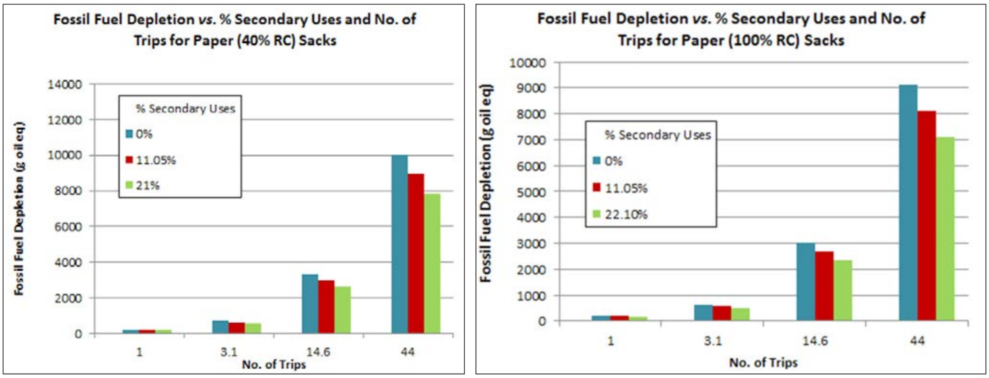


Figure 6.6 Effect on Fossil Fuel Depletion of adjusting secondary use rate for paper bags

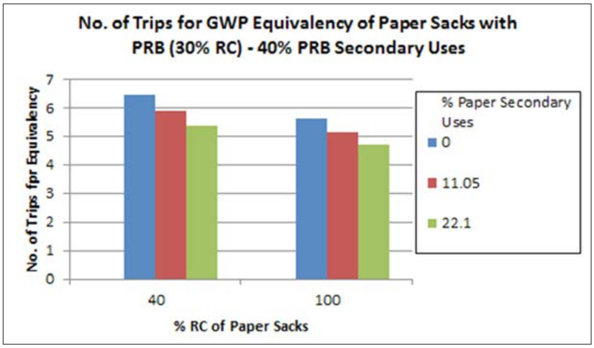


Figure 6.7 No. of Trips for GWP Equivalency of Paper Bags with PRBs (30% RC)-40% Secondary PRB Uses depending on % Secondary Uses of Paper Bags

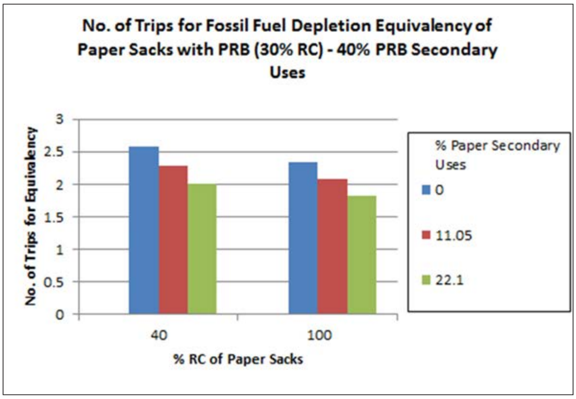


Figure 6.8 No. of Trips for Fossil Fuel Depletion Equivalency of Paper Bags with PRBs (30% RC)-40% Secondary PRB Uses depending on % Secondary Uses of Paper Bags

Figures 6.7 and 6.8 show the change in the GWP impact of paper bags (for both % RC contents) relative to the GWP impact of PRBs (30% RC), assuming varying % of secondary uses for each of the bag types.

As expected, the relative GWP impact of Paper bags vs. PRBs increases with increasing secondary uses of PRBs and decreases with increasing secondary uses of paper bags. However, even with 0% secondary uses of PRBs and 22.1% secondary uses of paper bags, the GWP impact of paper bags relative to PRBs is 3.1 to 3.5 times depending on the %RC of the paper bags.

6.2 Effects of de-inking assumptions on key environmental impacts of paper bags

The Base Case used in this study assumed that none of the post-industrial or post-consumer waste paper being recycled into paper grocery bags required a separate de-inking process. However, contacts with the industry indicate that some fraction of the waste paper may be de-inked. The effects of the de-inking assumption on key environmental impacts of paper bags compared with PRBs (30% RC) are shown in Tables 6.1 and 6.2 below. All data are from the Base Case (no secondary uses of PRBs or Paper bags).

Impact category	Units	One Trip			No. of Trips for Equivalency with PRB (30% RC)		
De-inking		0%	25%	50%	0%	25%	50%
GWP	kg CO_2 eq	0.881	0.924	0.967	4.2	4.4	4.6
Fossil fuel depletion	g oil eq	228	239	250	2.3	2.4	2.5

Table 6.1 Effect of de-inking assumption on Paper (40% RC)

Impact category	Units	One Trip			No. of Trips for Equivalency with PRB (30% RC)		
De-inking		0%	25%	50%	0%	25%	50%
GWP	kg CO_2 eq	0.739	0.846	0.953	3.6	4.1	4.6
Fossil fuel depletion	g oil eq	207	235	263	2	2.3	2.6

Table 6.2 Effect of de-inking assumption on Paper (100% RC)

Note that at 50% de-inking, the Fossil Fuel depletion of 100% RC Paper bags is greater than that of 40% RC Paper bags. In other words, there is a balance in environmental costs between incorporating more RC into paper and the de-inking of that RC material, if de-inking were required.

6.3 Disinfection/washing of reusable bags

6.3.1 Background

The USDA cautions consumers as follows:

- "Place raw seafood, meat, and poultry in plastic bags. Separate them from other foods in your grocery cart and bags.
- "Clean reusable grocery bags regularly. Wash canvas and cloth bags in the washing machine and wash plastic reusable bags with hot, soapy water." (U. S. Department of Agriculture, 2010)

Many municipal and state web sites echo these same guidelines.

Eugene, OR in its "FAQ's for Shoppers" states:

How can shoppers keep their reusable shopping bags clean and safe?

A 2010 study showed that 97% of shoppers have never washed their reusable bags. There are a few simple steps shoppers can follow to keep reusable bags clean and to keep themselves and their families safe from germs. Wash reusable grocery bags at least once per month:

> • Cloth reusable bags should be washed in a washing machine using laundry detergent and dried in the dryer or air-dried.
> • Plastic-lined reusable bags should be wiped using hot water and soap and air-dried.
> • Check that both cloth and plastic-lined reusable bags are completely dry before storing them.
>
> Always put raw meats into a disposable plastic bag before putting them in a reusable bag. When using reusable bags, keep meats, fresh produce, and ready-to-eat foods separated from other food products. Additionally, consumers should clean any reusable bags used for carrying food before using for other purposes such as carrying books or gym clothes. (City of Eugene, OR, 2013)

Los Angeles County counsels consumers:

> • Remember to clean/wash your reusable bags frequently.
> • Follow the care instructions on the tag of the bag. Most cloth and fabric bags can be machine washed, while durable plastic bags should be wiped clean.
> • Allow bags to dry before folding and storing.
> • Set aside specific reusable bags for packing groceries and use separate bags for raw meat products, being careful with where they are stored. (Department of Public Works, Environmental Programs Division, 2013)

Austin, TX counsels consumers to wash bags regularly and to bag meat, poultry and fish in lightweight plastic bags (City of Austin, 2013)

From the above recommendations, as well as those of other "advice to consumer" type websites, it is clear that consumers should regularly clean their reusable bags by washing NWPP types in a washing machine and by wiping (with hot water or perhaps disinfecting wipes) their LDPE types. Direct evidence of the types of contamination that can occur is documented in Annex G to this report.

6.3.2 Effects of washing assumptions on potential water depletion of NWPP bags

Because of the wide variability in methods for disinfecting LDPE bags and the lack of any consumer data documenting consumer practices, we have not attempted in the present study to estimate the potential environmental impacts of these practices.

We have attempted to estimate the water depletion effects resulting from periodic washing of NWPP bags. The discussion below is based on the assumption that consumers would NOT want to wash possibly contaminated grocery bags with their other laundry. Obviously, consumers who would add used NWPP bags to a load of regular household washing, without increasing the water level setting to accommodate the NWPP bags, would cause no additional water depletion. Any additional detergent required to wash NWPP bags has not been included in the estimates below.

A review of the 52 grocery items purchased by the typical family of four (Annex A) shows that one or two NWPPs would be used each trip for raw meats, fish, and poultry and for fruit, vegetable and dairy products that may be wet or moist. One bag would be 15% of the 6.7 NWPP bags/trip and 2 bags would be 30%. A reasonable assumption would therefore be that a consumer who followed the food safety guidelines cited in Section 6.3.1 would wash about 20% of NWPP bags after each trip.

An ENERGY STAR washing machine uses ~15 gallons of water per load (U. S. Environmental Protection Agency, 2013). Front-loading machines use 20-25 gallons/load and top-loading machines use about 40 gallons/load (California Energy Commission, 2013). All three types of machines provide a means of adjusting water use to the size of the load being washed. The U.S. Energy Administration reported that 81.5% of household washing machines are top loading and 18.5% are front-loading (U. S. Energy Information Administration, 2013). Assuming 20 gals/load for the front-loading machines and 40 gals/load for the top-loading machines, the average water use for a full load would therefore be about 36 gals. We estimated a full load containing only NWPP bags would be 18 bags, so that typical water use for one bag would be 2 gals water/bag/wash). Based on available data for electricity use, we assumed 0.014 kWh/bag, based on the same 18 bag full load.

Table 6.3 shows the impact on Water Depletion of various assumptions. In terms of water depletion, washing fewer bags per wash is equivalent to washing more bags less often. As discussed above in Section 5.1, the Water Depletion for no washing comes from the manufacture of the NWPP bags, primarily the growing and processing of cotton for the sewing thread used to assemble the bags.

	100% of bags washed after every trip using 2 gals/ water/bag	20% of bags washed after every trip using 2 gals/ water/bag	20% of bags washed after every second trip or 10% of bags washed after every trip using 2 gals/ water/bag	5% of bags OR ¼ of trips OR ½ gal water/bag	2.5% of bags OR 1/8 of trips OR ¼ gal water/ bag	No washing
Water Depletion (gal) per one trip	22.8	12.2	10.9	10.3	9.9	9.6

Table 6.3 Effects of changing assumptions about washing of NWPP bags on potential water depletion

6.4 Effects of thickness of reusable LDPE bags on environmental impact categories

Los Angeles and San Francisco plastic bag ordinances and others specify a minimum thickness of 2.25 mils (0.00225 in) for reusable LDPE bags (Department of the Environment, City and County of San Francisco, 2012) (County of Los Angeles Department of Public Works, Environmental Programs Division, 2012). However, the ordinances of other municipalities set a minimum thickness of 4 mils (0.004 in) for reusable LDPE bags (City of Eugene, OR, 2013) (City of Austin, 2013). Assuming that the 4 mil bags are substantially similar in size and construction to the 2.25 mil bags of the base case of this study, the potential environmental impact categories for the thicker bags will be approximately proportional to the weights of the respective bags. The resulting estimated potential environmental impact categories relative to PRBs (30% RC) assuming no secondary PRB uses (Base Case) are shown in Figure 6.9. The average value of the 12 impact categories is 11.0 for the 4 mil bags vs. 6.2 for the 2.25 mil bags.

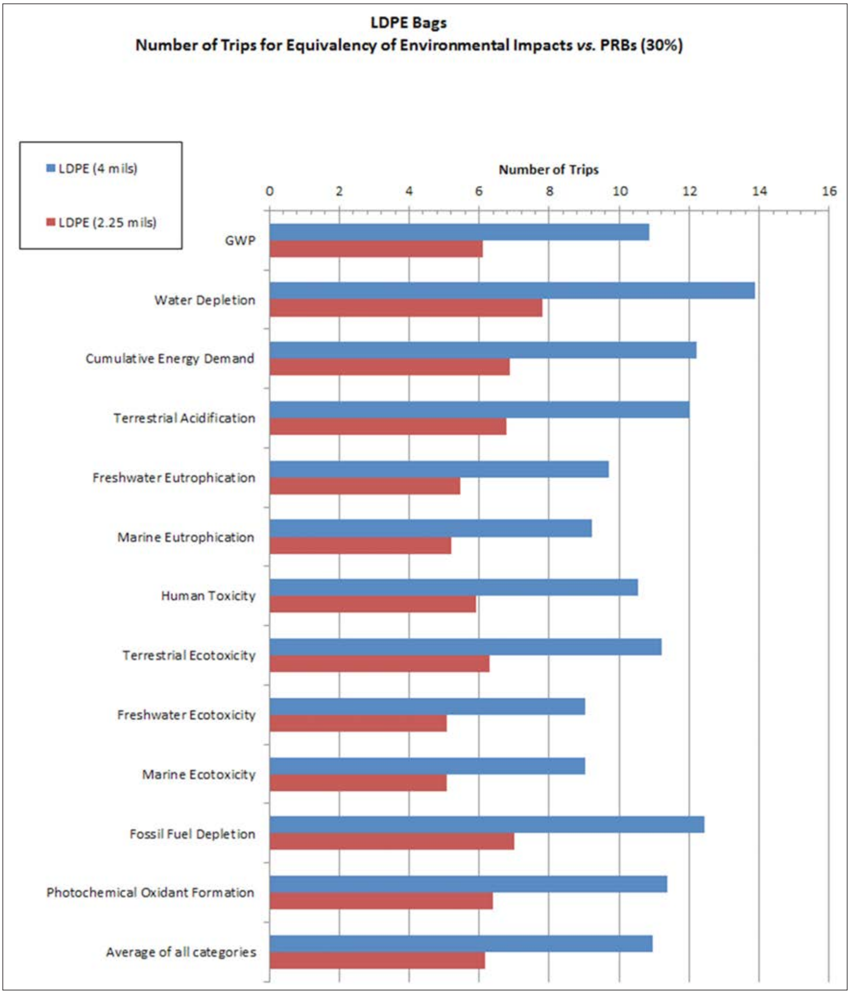
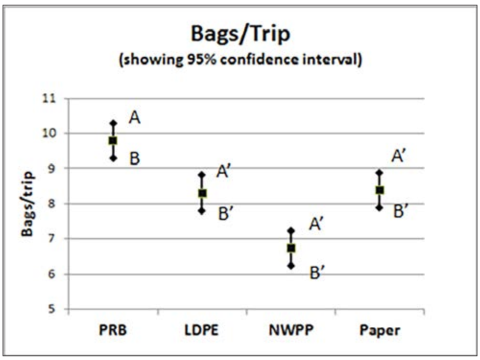


Figure 6.9 Estimated effects on Environmental Impact Categories of LDPE Bag thickness

6.5 Effects on environmental impact categories of statistical variability in bags required per trip

Section 3 presented the bagging study carried out to determine the number of bags of each type required per trip to transport the groceries for that trip (52 items). Figure 3.1 shows the 95% confidence intervals around the mean values of bags/trip used in the base case of this study. In order to assess the sensitivity of the comparative potential environmental impacts of each type of bag to the variability in number of bags required per trip, values of GWP were calculated as follows:

- Confidence interval maximum of reusable or paper bags vs. confidence interval minimum of PRBs (30%) – designated as "Maximum"– [A' – B] in Fig. 3.1 below
- Confidence interval minimum of reusable or paper bags vs. confidence interval maximum of PRBs (30%) – designated as "Minimum" – [B' – A] in Fig. 3.1 below



Annotated Copy of Fig. 3.1

The results are shown in Figure 6.10. "Mean" is the original case.

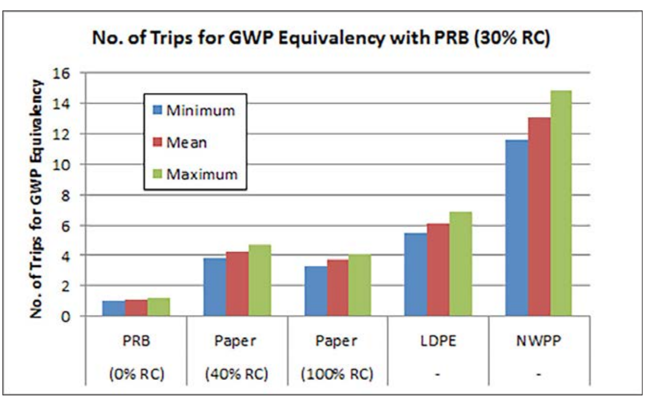
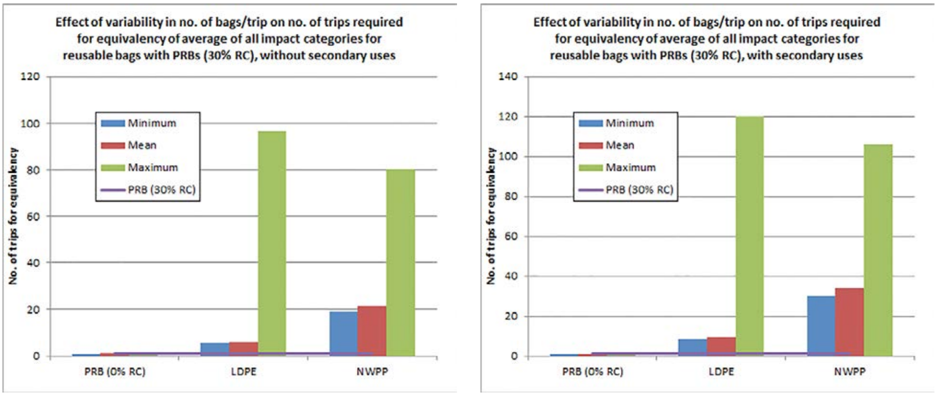
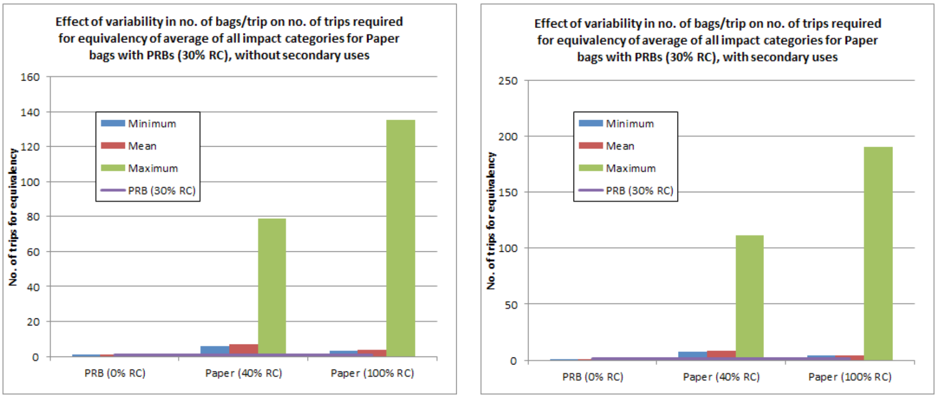


Figure 6.10 Effect of variability in number of bags/trip on number of trips required for equivalency of GWP of bag types with GWP of PRBs (30%), secondary uses not included

For some of the environmental impact categories, the variations between minimum and maximum are much greater (e.g., Water Depletion, Human Toxicity, Freshwater Ecotoxicity, Marine Eutrophication), resulting in a much larger spread for the data showing the average number of trips for all of the environmental categories. These are shown in Figures 6.11–6.14, both for the Base Case and the Alternative Case (without and with secondary uses included). In all cases, the differences between "minimum" and "mean" are small, while the differences between "maximum" and "mean" can be quite large, especially if secondary uses are included. From this analysis, we can conclude that variation on one side of mean ("minimum") has little impact on the qualitative key findings of this study. Variation on the other side of mean ("maximum") increases the number of trips required for equivalence of either paper or reusable bags with PRB (30% RC).



Figures 6.11 and 6.12 Effect of variability in number of bags/trip on number of trips required for of average of all impact categories for reusable bags with those of PRBs (30%), without and with secondary uses included



Figures 6.13 and 6.14 Effect of variability in number of bags/trip on number of trips required for all average of all impact categories for Paper bags with those of PRBs (30%), without and with secondary uses included

6.6 Effects on environmental impact categories of alternative assessment methods

Several different methods are available for assessing environmental impacts. These rely on different assumptions, calculation methods and databases. The impacts calculated and the units used are not totally comparable from method to method. Nevertheless, employing alternative methods provides additional insights into the environmental impacts of the bags that are the subjects of the present study. Table 6.4 shows the various methods employed in this sensitivity analysis.

Methods used to calculate impact categories (Sensitivity)		
Impact category	Unit	Methods
Global warming potential	kg CO_2 eq	IPCC 2007 20-year V1.02; IPCC 2007 500-year V1.02; Greenhouse Gas Protocol V1.01
Terrestrial acidification	g SO_2 eq	TRACI 2.1 V1.00; IMPACT 2002+ V2.10
Freshwater eutrophication	g P eq	
Marine eutrophication	g N eq	
Human toxicity	g 1,4-DB eq	
Terrestrial ecotoxicity	g 1,4-DB eq	
Freshwater ecotoxicity	g 1,4-DB eq	
Marine ecotoxicity	g 1,4-DB eq	
Fossil fuel depletion	g oil eq	
Photochemical oxidant formation	g NMVOC	
Water depletion	gal	

Table 6.4 Alternative impact assessment methods used for sensitivity

Table 6.5 and Figure 6.15 show the effect of assessment method on the global warming potential (GWP) for each type of bag.

	GWP for 1 trip to grocery store (kg CO_2 eq)					
	PRB	PRB	Paper	Paper	LDPE	NWPP
Method Used	(30% RC)	(0% RC)	(40% RC)	(100% RC)		
IPCC 2007 100-year V1.02*	0.208	0.231	0.881	0.769	1.27	2.71
IPCC 2007 20-year V1.02	0.266	0.311	1.33	1.21	1.670	3.520
IPCC 2007 500-year V1.02	0.187	0.2	0.712	0.604	1.120	2.410
Greenhouse Gas Protocol V1.01	0.203	0.226	0.539	0.952	1.240	2.640

* Base case values

Table 6.5 Effect on alternative impact assessment methods on GWP (one trip)

The Greenhouse Gas Protocol is the only method that gives virgin paper credit for trees' uptake of CO_2 that is embodied in paper. All other methods recognize that in a life cycle approach, this biogenic carbon will eventually be returned to the atmosphere and will "net out" to zero. Therefore, the GWP values for Paper (40% RC) calculated by the Greenhouse Gas Protocol are lower than those calculated in the Base Case and the alternative methods, while the GWP values for Paper (100% RC) are higher than two of the three other methods. GWP for the polymer-based PRBs and reusable bags is virtually independent of assessment method.

Tables 6.6, 6.7 and 6.8 show the measured impact categories for the six studied bags for one trip to the grocery store calculated by three different assessment methods. Each method defines the impact categories somewhat differently and expresses the impacts in different units. Following each table is a figure showing the number of trips for impact category equivalency with PRBs (30% RC) for each of the bag types. The reader should refer to the table immediately above each set of figures to determine the units of measurement for each of the impact categories, but recognizing that "No. of Trips" is a dimensionless number.

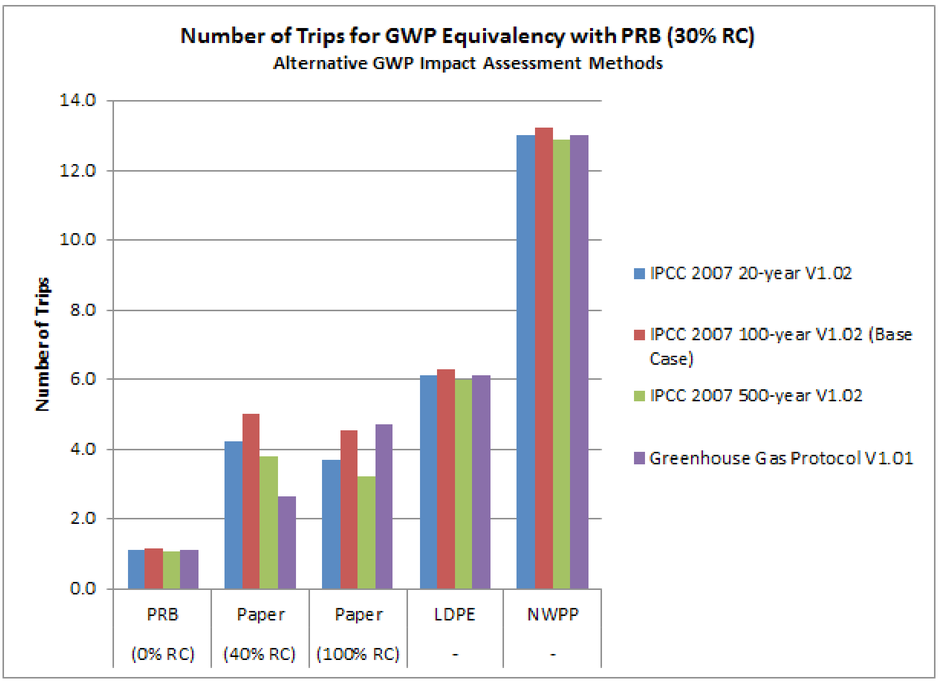


Figure 6.15 Number of trips for GWP Equivalency of Bag Types with PRB (30%) using alternative GWP impact assessment methods

Impact category	Unit	PRB (30% RC)	PRB (0% RC)	LDPE	NWPP	Paper (40% RC)	Paper (100% RC)
Terrestrial acidification	g SO_2 eq	2.01	2.76	3.65	1.63	13.6	25.9
Freshwater eutrophication	g P eq	0.0343	0.0347	0.199	0.068	0.187	0.231
Marine eutrophication	g N eq	0.0972	0.0951	1.07	0.946	0.505	1.35
Human toxicity	g 1,4-DB eq	88.3	104	344	116	523	1110
Terrestrial ecotoxicity	g 1,4-DB eq	0.0116	0.0119	0.163	0.0719	0.0731	0.556
Freshwater ecotoxicity	g 1,4-DB eq	4.69	4.52	6.14	3.22	23.8	51.8
Marine ecotoxicity	g 1,4-DB eq	4.54	4.38	5.14	2.62	23.1	50.5
Fossil fuel depletion	g oil eq	101	138	228	207	706	1110
Photochemical oxidant formation	g NMVOC	0.592	0.661	2.87	1.65	3.79	10.5

Table 6.6 Environmental impact categories for 1 trip to grocery store using World ReCiPe Midpoint H/A V1.07 (Base Case)

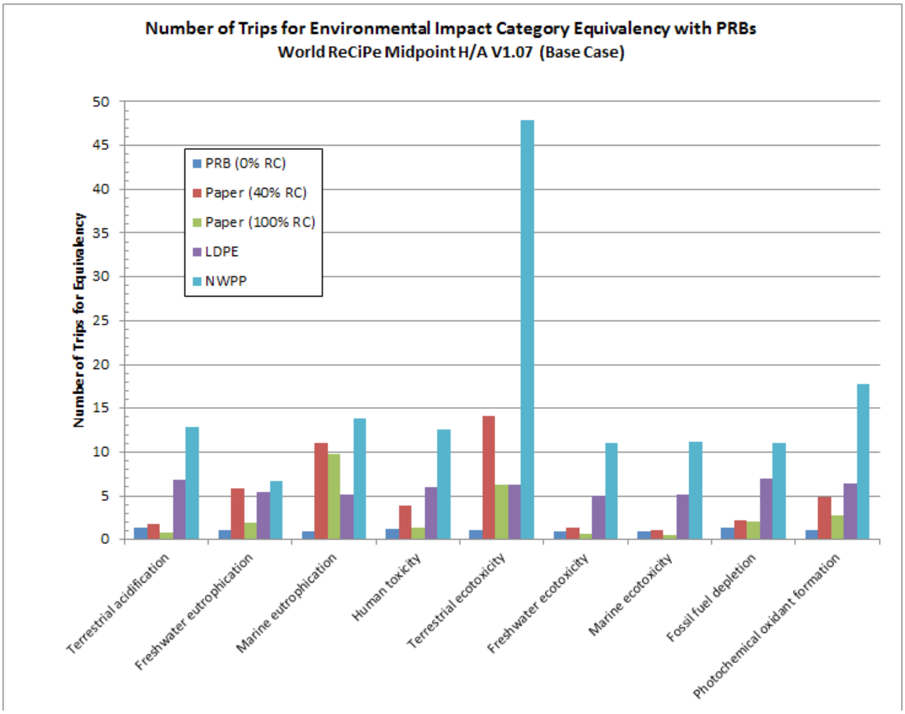


Figure 6.16 Number of Trips for Environmental Impact Category Equivalency vs. PRBs (30% RC) using World ReCiPe Midpoint H/A V1.07 (Base Case)[1]

Impact category	Unit	PRB (30% RC)	PRB (0% RC)	Paper (40% RC)	Paper (100% RC)	LDPE	NWPP
Smog	g O_3 eq	8.90	8.94	51.3	27.5	53.8	188
Acidification	g SO_2 eq	2.08	2.83	3.97	1.79	13.9	27.2
Eutrophication	g N eq	1.07	1.01	3.58	2.47	5.44	11.2
Carcinogens	CTUh	6.59E-9	7.24E-9	3.34E-8	2.02E-8	4.06E-8	7.59E-8
Non carcinogens	CTUh	2.7E-8	3.19E-8	1.62E-7	1.12E-7	1.67E-7	4.11E-7
Respiratory effects	g PM2.5 eq	0.129	0.176	0.373	0.130	0.884	2.11
Ecotoxicity	CTUe	0.411	0.540	1.08	0.991	2.68	5.57
Fossil fuel depletion	MJ surplus	0.530	0.773	1.08	1.17	3.95	5.26

Table 6.7 Environmental impact categories for 1 trip to grocery store using TRACI 2.1 V1.00

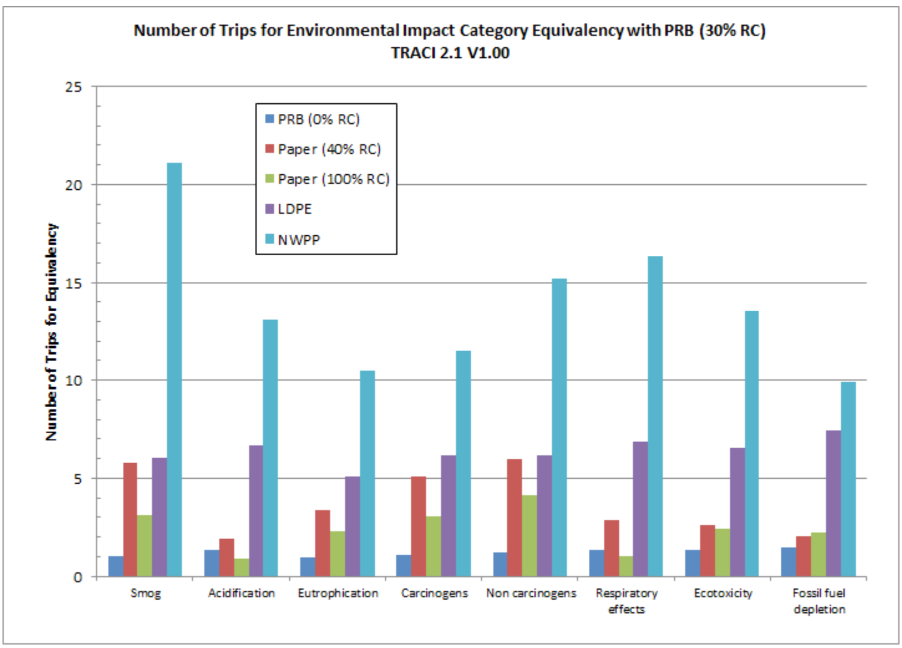


Figure 6.17 Number of Trips for Environmental Impact Category Equivalency of Bag Types with PRB (30% RC) using TRACI 2.1 V1.00

Impact category	Unit	PRB (30% RC)	PRB (0% RC)	Paper (40% RC)	Paper (100% RC)	LDPE	NWPP
Ionizing radiation	Bq C-14 eq	1.91	1.93	8.20	2.52	10.6	5.05
Respiratory organics	g C_2H_4 eq	0.0699	0.0844	0.297	0.221	0.500	0.786
Respiratory inorganics	g PM2.5 eq	0.198	0.257	0.647	0.271	1.31	3.36
Aquatic ecotoxicity	kg TEG water	34.7	48.0	59.7	39.1	229	506
Terrestrial ecotoxicity	kg TEG soil	2.12	2.20	19.1	15.4	14.3	18.2
Carcinogens	g C_2H_3Cl eq	4.63	4.76	24.4	10.8	23.4	17.0
Non carcinogens	g C_2H_3Cl eq	7.14	9.53	21.1	13.8	46.0	125.0
Aquatic acidification	g SO_2 eq	2.09	2.84	4.02	1.82	14.0	27.3
Aquatic eutrophication	g PO_4 p-lim	0.017	0.019	0.150	0.0851	0.103	0.194

Table 6.8 Measured impact categories for 1 trip to grocery store using IMPACT 2002+V2.10

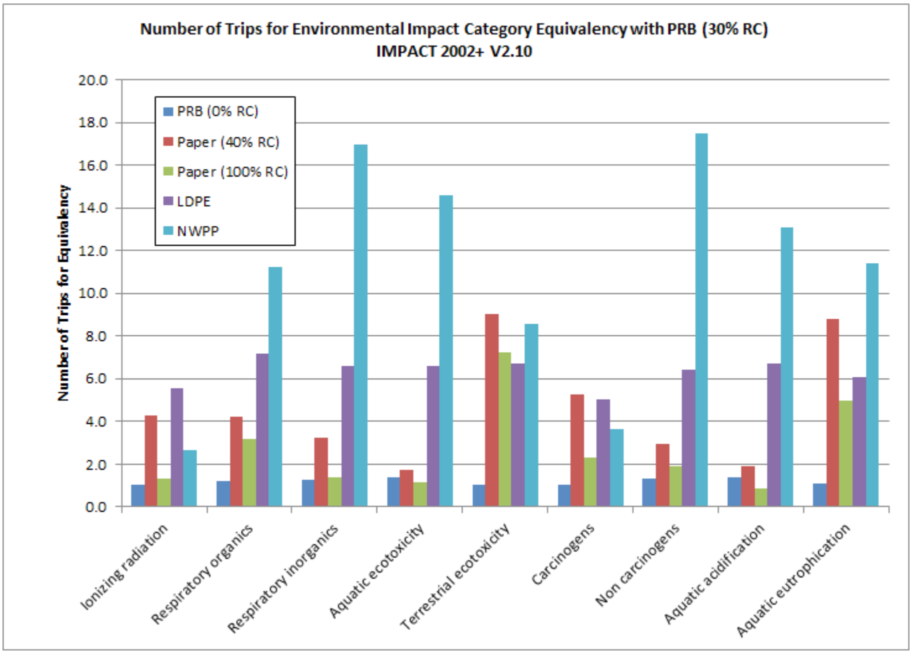


Figure 6.18 Number of Trips for Impact Category Equivalency of Reusable Bags with PRB (30% RC) using IMPACT 2002+V2.10

As stated above, each of the assessment methods evaluates somewhat different impact categories using various units of measurement. This makes direct comparison difficult. Table 6.9 presents comparisons between three similar environmental impact categories calculated using different assessment methods. For these categories, there appears to be good agreement between the methods.

			No. of Trips for equivalency to PRB (30%)				
Environmental Impact Category	**Category Units**	**Assessment Method**	**PRB (0% RC)**	**Paper (40% RC)**	**Paper (100% RC)**	**LDPE**	**NWPP**
Photochemical oxidant formation	g NMVOC	World ReCiPe Midpoint H/A V1.07 (Base Case)	1.1	4.8	2.8	6.4	17.7
Smog	g O_3 eq	TRACI 2.1 V1.00	1.0	5.8	3.1	6.0	21.1
Terrestrial acidification	g SO_2 eq	World ReCiPe Midpoint H/A V1.07 (Base Case)	1.4	1.8	0.8	6.8	12.9
Acidification	g SO_2 eq	TRACI 2.1 V1.00	1.4	1.9	0.9	6.7	13.1
Fossil fuel depletion	g oil eq	World ReCiPe Midpoint H/A V1.07 (Base Case)	1.4	2.3	2.0	7.0	11.0
Fossil fuel depletion	MJ surplus	TRACI 2.1 V1.00	1.5	2.0	2.2	7.5	9.9

Table 6.9 Comparision of no. of trips for equivalency of environmental impacts with PRB (30% RC) using different assessment methods

Note

1. Data shown in Figure 6.16 are identical with the values shown for the same impact categories in Figure 5.3.1.

7. Discussion

7.1 Relationships of environmental impacts to consumer reuse behavior

The key findings of the Edelman Berland study of consumer reuse of reusable bags were summarized in Section 4.5.4 above. (Edelman Berland, 2014) [See also (Reuters, 2014)]

These findings, as they relate to the present study, are shown graphically as Figure 7.1.

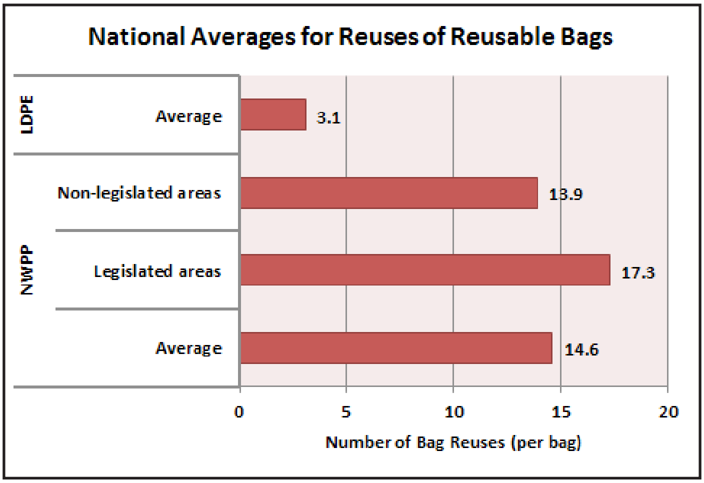


Figure 7.1 Key findings for reuse of reusable LDPE and NWPP Bags from the Edelman Berland Study

7.1.1 LDPE Bags

Figures 7.2 and 7.3 show the national average for LDPE bag reuse compared with the number of trips for equivalency of the environmental impact categories studied for PRB (30% RC) and Paper (40% RC) discussed in Section 4.5.4 above.

Figure 7.2 shows that 50% of people who reported using LDPE reusable bags are not reusing them enough times to make their environmental impacts equal to those of PRBs (30% RC). For equivalency, they would have to reuse them twice to more than three times as many times, depending on whether secondary uses of PRBs are included in the environmental impact category calculations.

Figure 7.3 shows that more than 50% of people who reported using LDPE reusable bags are reusing them enough times to make their environmental impacts, on average, less than those of Paper (40% RC) bags. However, for four impact categories—Terrestrial Acidification, Freshwater and Marine Ecotoxicity and Fossil Fuel Depletion—they would need to use their LDPE bags one to two times more for equivalency. Excluding the Water Depletion Category from the averages does not change these conclusions.

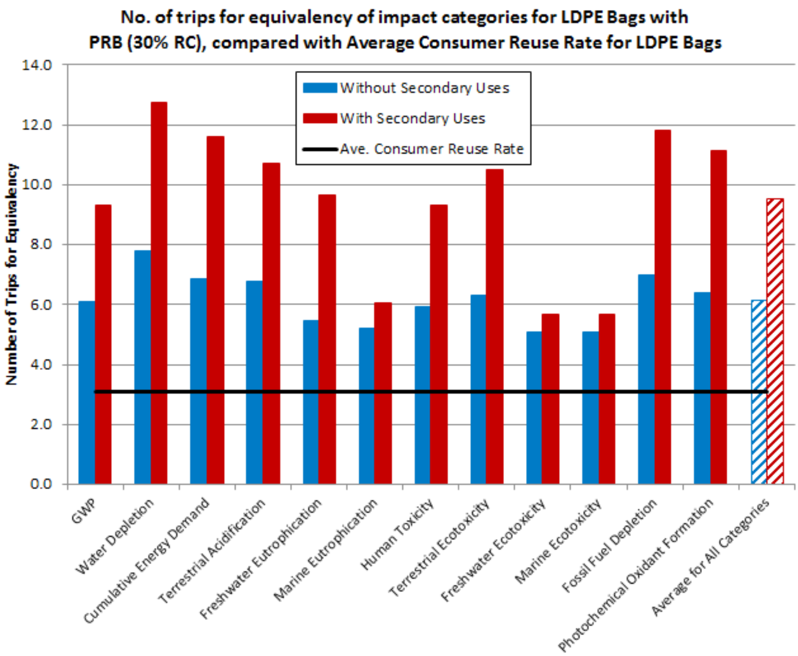


Figure 7.2 Average Consumer Rate of LDPE bags compared with Number of Trips for Equivalency of Environmental Impacts of LDPE Bags with Environmental Impacts of PRBs (30% RC)

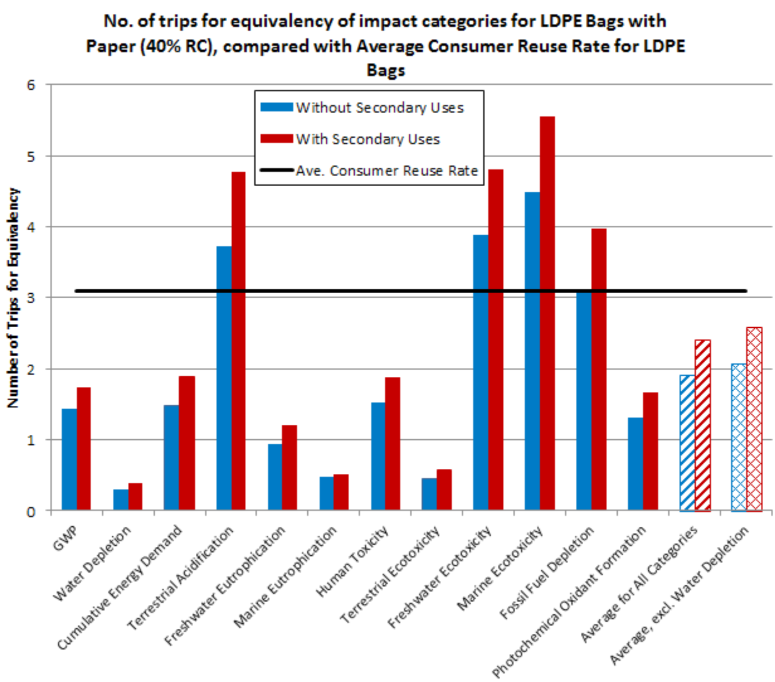


Figure 7.3 Average Consumer Reuse Rate of LDPE bags compared with Number of Trips for Equivalency of Environmental Impacts of LDPE Bags with Environmental Impacts of Paper (40% RC) Bags

Figure 7.4 shows the averages for all categories from Figures 7.2 and 7.3.

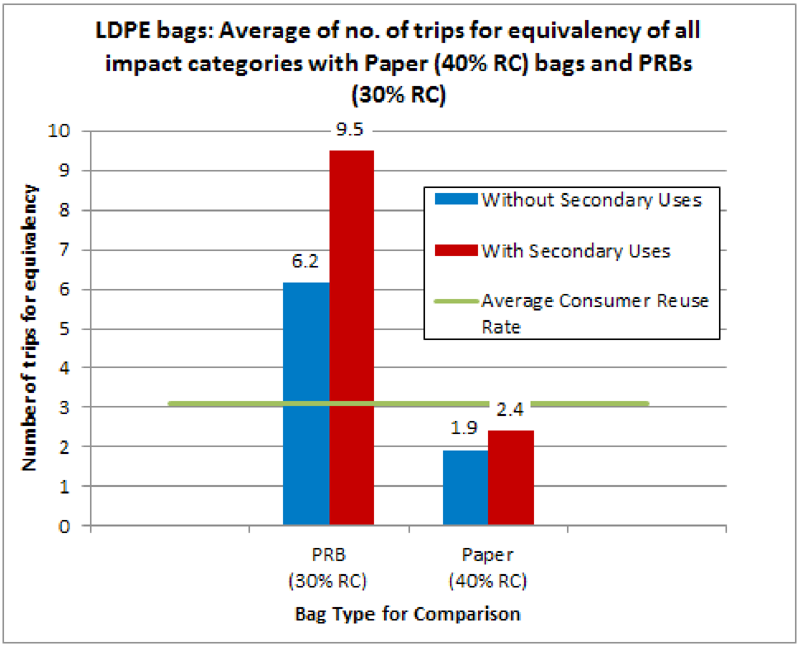


Figure 7.4 Average Consumer Reuse Rate of LDPE bags compared with average of Number of Trips for Equivalency of Environmental Impacts of LDPE Bags with Environmental Impacts of Paper (40% RC) Bags and PRBs (30% RC)

7.1.2 NWPP Bags

Figures 7.5 and 7.6 show the national average for NWPP bag reuse compared with the number of trips for equivalency of the environmental impact categories studied for PRB (30% RC) and Paper (40% RC) discussed in Section 4.5.4 above.

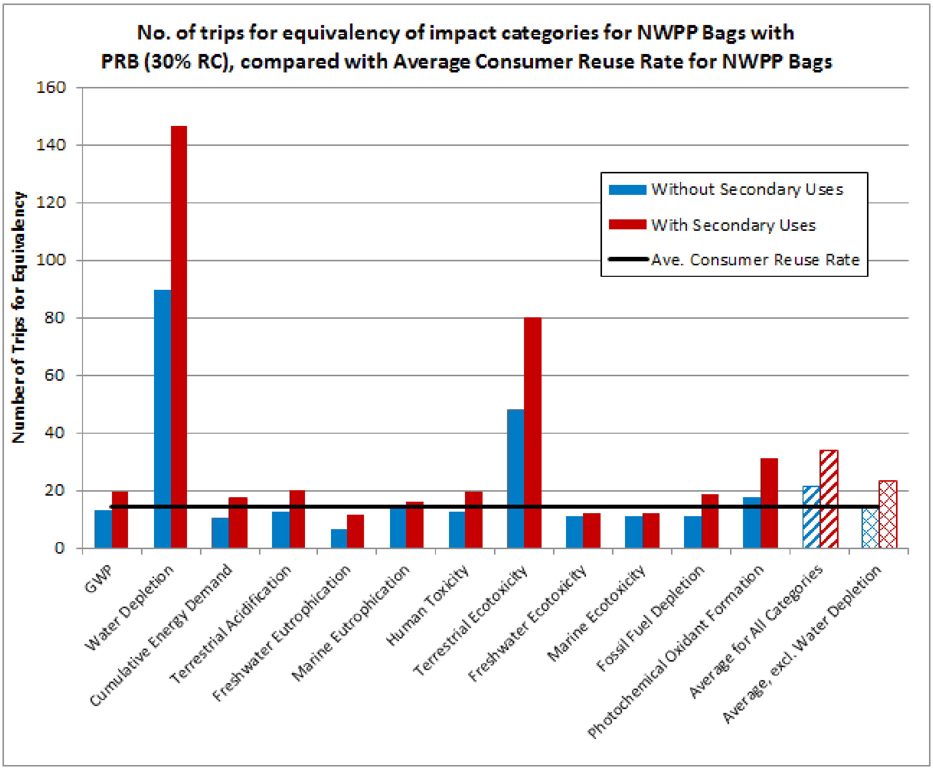


Figure 7.5 Average Consumer Reuse Rate of NWPP bags compared with Number of Trips for Equivalency of Environmental Impacts of NWPP Bags with Environmental Impacts of PRBs (30%RC)

For NWPP bags, Figure 7.5 shows that 50% of people who reported using NWPP bags do not use them enough times to make the average number of trips for equivalency of their environmental impacts equal to those of PRBs (30% RC). With secondary uses included, 9 of the 12 environmental impact categories require more trips than the average reuse rate for equivalency. Excluding the Water Depletion category from the averages shows that, without secondary uses of PRBs included, the average reuse rate of NWPP bags makes their average environmental impact about equal to that of the PRBs required for the same number of supermarket trips.

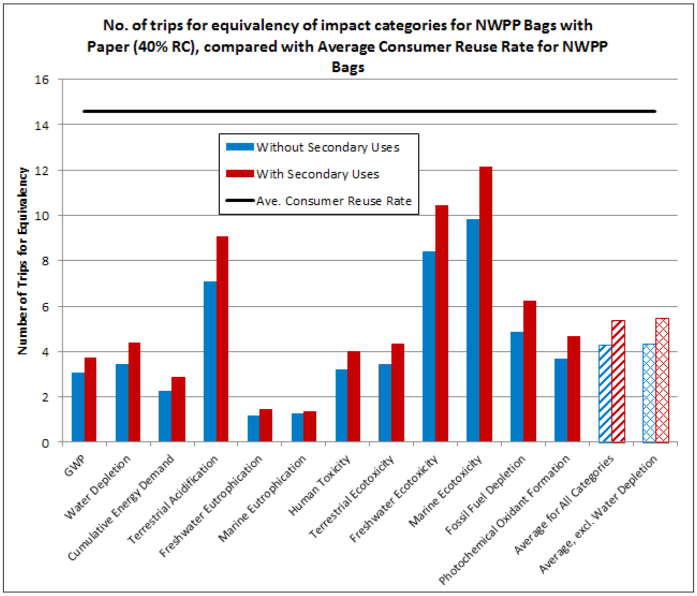


Figure 7.6 Average Consumer Rate of NWPP bags compared with Number of Trips for Equivalency of Environmental Impacts of NWPP Bags with Environmental Impacts of Paper (40% RC) Bags

Figure 7.6 shows that 50% of people reporting use of NWPP bags reuse them more than enough times for equivalency of their environmental impact categories with those of Paper (40% RC) bags. Figure 7.7 shows the averages for all categories from Figures 7.5 and 7.6.

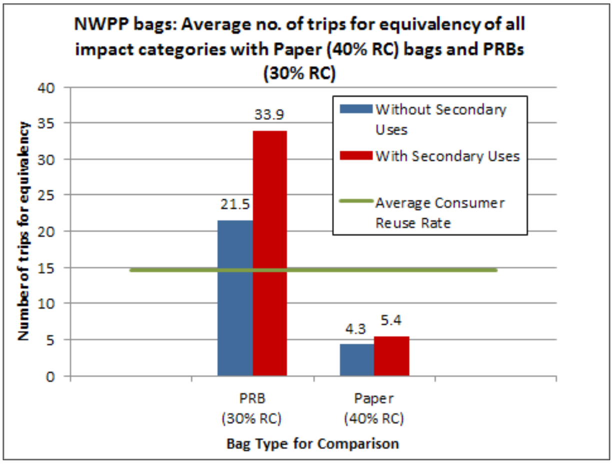


Figure 7.7 Average Consumer Reuse Rate of NWPP bags compared with average of Numer of Trips for Equivalency of Environmental Impacts of NWPP Bags with Environmental Impacts of Paper (40% RC) Bags and PRBs (30% RC)

Figure 7.8 compares the averages for the number of consumer reuses of NWPP bags with the average number of grocery trips for equivalency of the environmental impact categories for NWPP with those of PRBs (30% RC), with and without secondary uses of the PRBs included..

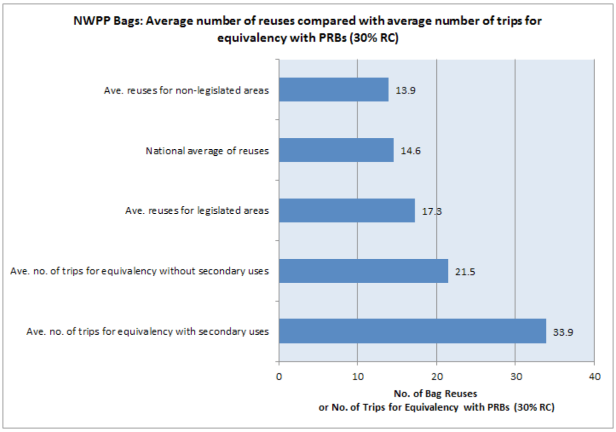


Figure 7.8 Average Consumer Reuse Rate of NWPP bags compared with Number of Trips for Equivalency of Average Environmental Impacts of NWPP Bags with Environmental Impacts of PRBs (30% RC), with and without secondary uses included

Referring to Figure 4.5, which shows the cumulative % of people vs. number of NWPP bag reuses, we note the following:

- 50% of people reporting NWPP bag use reuse their NWPP bags 14.6 times or more
- 41% of people reporting NWPP bag use reuse their NWPP bags 21.5 times or more
- 25% of people reporting NWPP bag use reuse their NWPP bags 33.9 times or more

In other words, only 25% or 41% of people using NWPP bags (depending on whether secondary uses of PRBs are included in the calculations or not) reuse their NWPP bags enough times so that the average of the environmental impact categories for NWPP bags is less than the average of the environmental impact categories for the number of PRBs (30% RC) required to make the same number of grocery trips.

7.1.3 Paper bags

Although Paper bags are not intended to be reusable as grocery carrier bags, comparing the calculated number of "trips" for equivalency of their environmental impacts with those of PRBs is nevertheless a meaningful comparison technique. Figure 7.9 shows the number of trips for equivalency of Paper bags (both recycle contents) with PRBs (30%). In Figure 7.9, secondary uses of neither the paper bags nor of the PRBs are included.

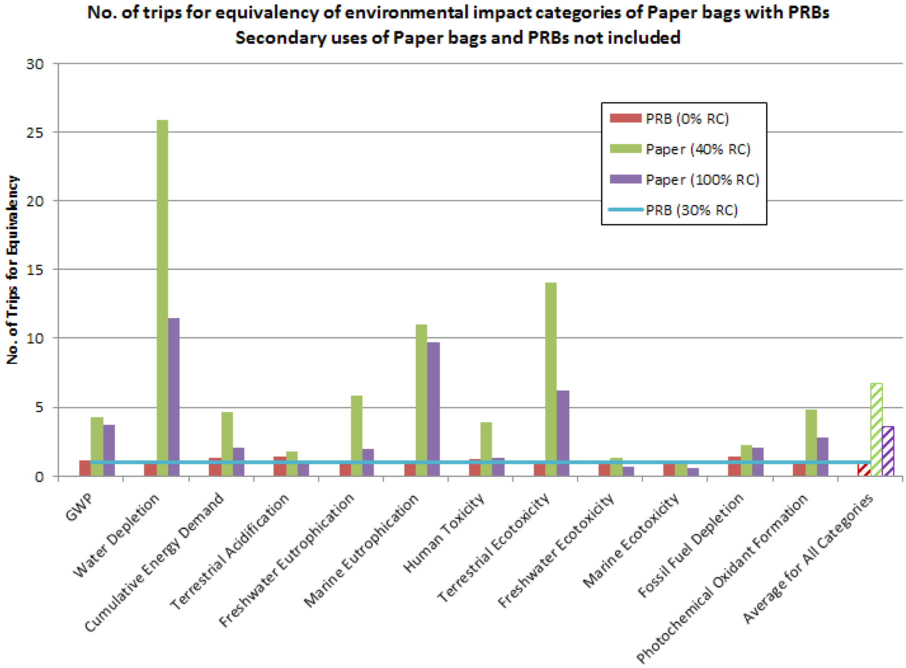


Figure 7.9 Number of Trips for Equivalency of Environmental Impacts of Paper Bags with Environmental Impacts of PRBs, secondary uses not included

As discussed above in Section 5, Paper (40% RC) bags have higher impacts than PRBs for all of the categories. Paper (100% RC) bags have higher impacts than PRBs for all categories except Terrestrial Acidification and Freshwater and Marine Ecotoxicity. The categories of Water Depletion, Terrestrial Ecotoxicity and Marine Eutrophication are substantially higher than those of PRBs.

Figure 7.10 shows the number of trips for equivalency of Paper bags (both recycle contents) with PRBs (30%). In Figure 7.10, secondary uses of both Paper bags and PRBs are included.

With secondary uses included, Paper (40% RC) bags have higher impacts than PRBs for all of the categories. Paper (100% RC) bags have higher impacts than PRBs for all categories except Freshwater and Marine Ecotoxicity. The categories of Water Depletion, Terrestrial Ecotoxicity and Marine Eutrophication are substantially higher than those of PRBs.

Figure 7.11 shows the averages for all of the categories extracted from Figures 7.9 and 7.10.

Figure 7.11 shows that Paper (40% RC) bags have about 7.5 times the average environmental impacts compared to PRBs. Increasing the recycle content of Paper bags to 100% reduces this factor to about 4 times. As noted in Section 5.2, inclusion of secondary uses of PRBs and Paper bags in the models increases the average environmental impacts by about 25% for both Paper bag recycle contents.

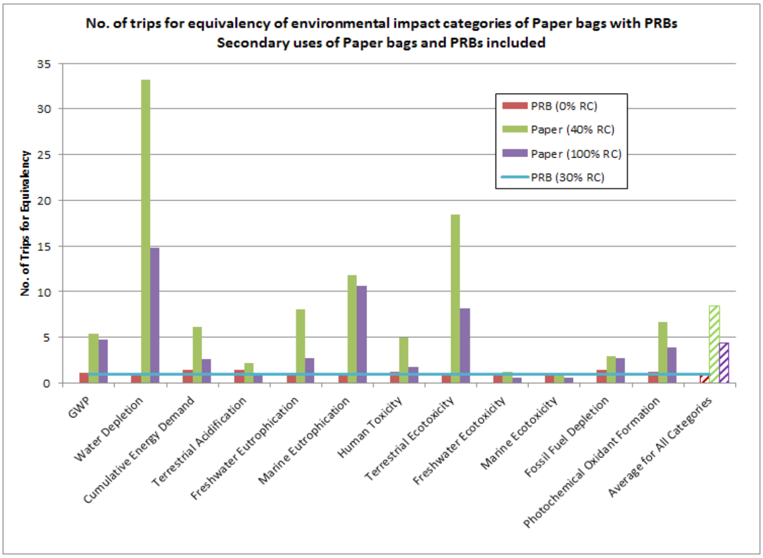


Figure 7.10 Number of Trips for Equivalency of Environmental Impacts of Paper Bags with Environmental Impacts of PRBs, secondary uses included

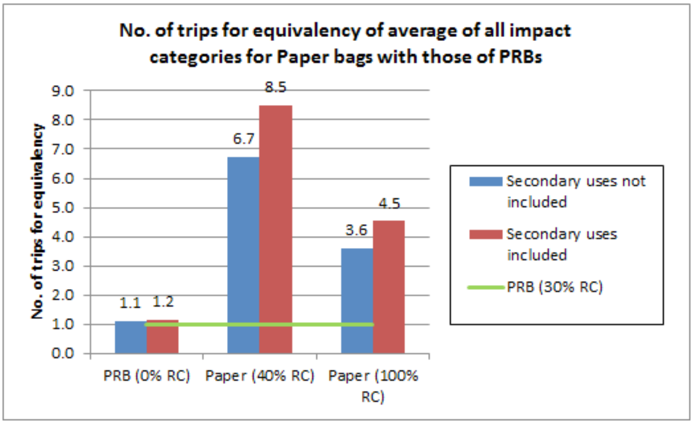


Figure 7.11 Average Number of Trips for Equivalency of Environmental Impacts of Paper Bags with Environmental Impacts of PRBs, with and without secondary uses included

7.2 Comparison with common needs

It helps to understand the magnitude of some of the environmental impacts presented above by comparison with everyday needs and facts.

GWP

Figure 7.12 shows the comparison among the GWP data for the carrier bags studied for the bags needed for 1, 3.1 and 14.6 trips with the GWP attributable to 3 and 5 mile round-trips to a store for the same number of trips.

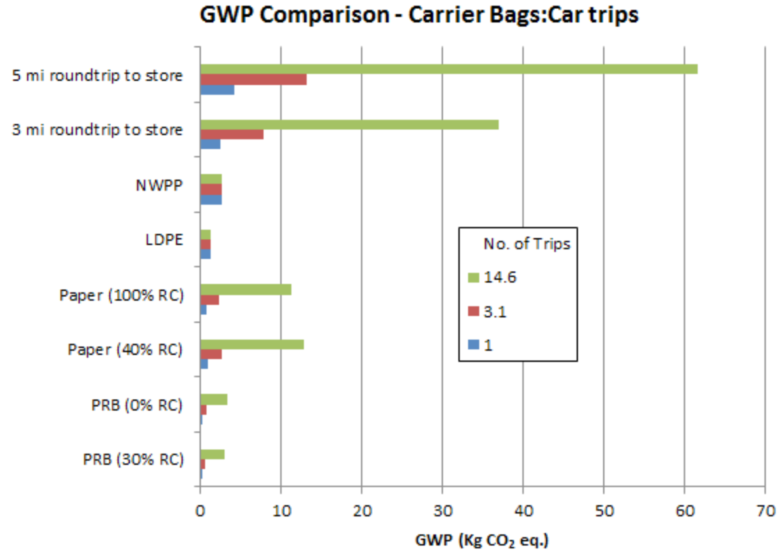


Figure 7.12 Comparision of GWP from carrier bags needed for 1, 3.1 or 14.6 trips with GWP from driving the same number of trips

Figure 7.12 shows that the GWP generated by driving one trip to the store, whether for 3 miles or 5 miles roundtrip is greater than that generated in any of the life cycles of the carrier bags studied, except for NWPP bags. For more than one trip, the GWP from driving is much greater than that from any of the carrier bags studied needed for the same number of trips. (Office of Transportation and Air Quality, 2011).

Water depletion

Water depletion measures the total amount of water lost during the life cycle. For comparison, Figure 7.13 compares water depletion for the carrier bags to the typical,

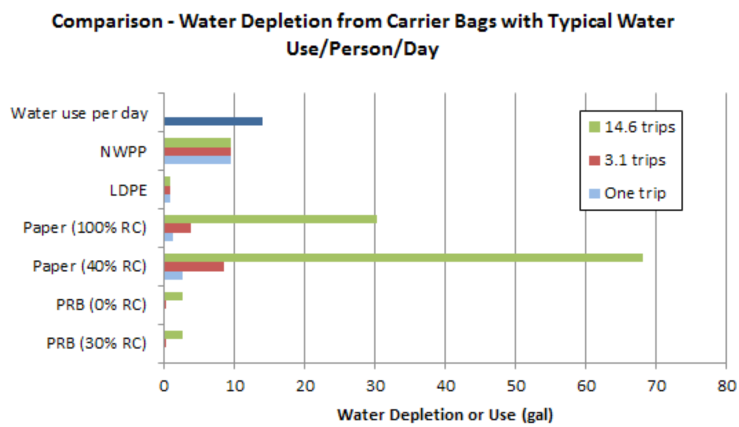


Figure 7.13 Comparision of water depletion from carrier bags for one trip and for 20 trips with water use per person per day

average water use of one person for one day in Louisville, KY. (Louisville Water Company, 2012)

The water depletion from the bags needed for one trip for all of the bag types is less than one typical person's daily water use. However, the water depletion during the life cycle of the paper bags needed for 14.6 trips is about two to about five times the typical person's daily water use.

Cumulative Energy Demand

Cumulative energy demand is the total amount of energy from all sources required for all stages of the life cycle of the particular carrier bag. In the present study, it is expressed in MJ equivalents. By converting kWh to MJ, a comparison can be made with the electricity use of a typical home. The average residential utility customer has been reported to use 940 kWh/month of electricity. (U. S. Energy Information Administration, 2011) Figure 7.3 compares the cumulative energy demand per 1, 3.1 and 14.6 trips of the carrier bags with the average daily electricity use of an American home.

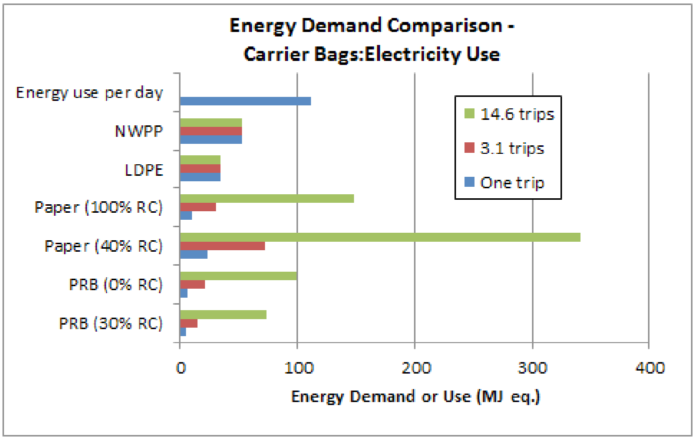


Figure 7.14 Comparision of cumulative energy demand of carrier bags per 1, 3.1 and 14.6 trips with average daily home electricty use

As shown in Figure 7.14, the cumulative energy demand from the life cycle of each of the bag types needed for one trip is 50% or less than the typical home energy use per day. For 14.6 trips, the cumulative energy demand for the PRBs is about equal to daily home energy use, while the Paper bags needed for 14.6 trips require cumulative energy demand about 50% more than daily home energy use for Paper (100% RC) bags and more than three times daily home energy use for Paper (40% RC) bags.

7.3 General Discussion

In evaluating the above data, it is important to remember that any cradle to grave life cycle analysis requires hundreds of assumptions and dozens of decisions about which databases to use and which calculation methods to employ. The databases available as inputs to a life cycle analysis are constantly being improved and extended.

Some of them provide information on the uncertainties inherent in the data. Some state that the uncertainties cannot be determined. As discussed in Section 3.8.2, the available data are from various years, all after 2000, but weighted toward the present. Undoubtedly, some changes in processes and assumptions have occurred during this time period, introducing another variability factor.

The present study, like others that have preceded it, focuses on a selected set of bag types and sizes. Furthermore, the way these bags are used by consumers to carry groceries is inherently a highly variable process. Because the bagging study was conducted in the authors' laboratories, we were able to conduct a statistical analysis of the variability in these data, as shown in Sections 3.3 and 6.5. Nevertheless, the variability underlying the specific and precise numbers shown in many of the tables in this report must be recognized by anyone who wishes to use these data. Nevertheless, wherever possible, this study relies on assumptions and data that have resulted from properly conducted, scientifically-based studies.

In addition to the discussions in the previous sections of this report, there are several additional points that should be noted.

- NWPPs were assumed to be assembled with cotton thread, based on NWPP bags collected by the authors from around the country, all of which were assembled with cotton thread. Even though only a small amount of thread is used compared to the weight of the bag, the processes of growing, harvesting and processing cotton into thread place severe strains on the environment. As discussed above, some of these show up in the potential environmental impacts of NWPPs. In particular, the terrestrial ecotoxicity and water depletion impacts of NWPPs would be reduced if cotton thread were not used. However, as noted above in Section 4.2, Muthu and Li concluded that sewn bags were preferable to thermally-bonded bags from an environmental perspective. (Muthu, 2014, p. 33)
- The glue used to assemble paper bags is about 3% of the total bag weight. It is recognized that for reasons of improved sustainability and cost, the trend in the U.S. is toward water-compatible or water-soluble glues, rather than the hot-melt adhesive used in this study. Hot-melt adhesive was used in this study because data on the water-compatible or water-soluble adhesives needed for the life cycle analyses could not be located. This decision is believed to have an insignificant effect on the conclusions regarding the potential environmental impacts of Paper bags, especially in comparison to the other types of bags.
  Since the purpose of the bagging study was to determine the number of bags of each type required for a typical shopping trip, the exact set of items used for the study is considered of much less importance than the use of the same set of representative items for all of the bags studied.
- During the preparation of this study, potential environmental impacts associated with the use of lightweight plastic bags to contain fresh products within carrier bags were calculated. These impacts are very small compared to

the impacts of the carrier bags themselves. Because, in practice, lightweight bags are used with most, if not all, of the carrier bags, it was decided not to include use of lightweight bags in the impact data for any of the bags studied.

8. Conclusions

Functional units

Four functional units were selected for the present study. Selection was based on the national survey of reusable bag use published in May, 2014 by Edelman Berman. The functional units and the rationale for their selection are shown in Table 8.1.

Functional Unit	Selection Rationale
No. of bags used for one grocery shopping trip	Comparison of bags intended for one grocery bag use
No. of bags used for 3.1 grocery shopping trips	Comparison with the average National rate of reuses of LDPE bags
No. of bags used for 14.6 grocery shopping trips	Comparison with the average National rate of reuses of NWPP bags
No. of bags used for 44 grocery shopping trips	Comparison with the number of reuses of NWPP bags that 20% of people exceed.

Table 8.1 Selection of Functional Units

Reference flow

In order to determine the specific number of bags needed to carry out the demands of the four functional units defined for this study, an original bagging study was carried out on the campus of Clemson University to provide quantitative information on the number of bags used by a typical American family for a trip to the grocery store. The resulting data are shown in Table 8.2.

	One Trip		3.1 Trips		14.6 Trips		44 Trips	
	No. Bags	Wt. of Bags (g)	No. Bags	Wt. of Bags (g)	No. Bags	Wt. of Bags (g)	No. Bags	Wt. of Bags (g)
PRBs	9.8	61.0	30.5	189.1	143.7	890.7	433.0	2684
LDPE	8.3	295.6	8.3	295.6	8.3	295.6	8.3	295.6
NWPP	6.7	621.9	6.7	621.9	6.7	621.9	6.7	621.9
Paper	8.4	457.2	26.1	1417	122.7	6675	369.8	20116

Table 8.2 Average no. and weight of bags used per functional unit

A statistical analysis of the bagging data from 60 baggers showed that there is high confidence that, where differences exist in the average number of bags used by type, these differences are significant.

The sensitivity analysis conducted (see Section 6.5) to determine the effects on the comparisons among the environmental impact category data for different types of bags resulting from the statistical variability in the number of bags per functional unit showed that in all cases, the differences between "minimum" and "mean" are small, while the differences between "maximum" and "mean" can be quite large, especially if secondary uses are included. From this analysis, we can conclude that variation on one side of mean ("minimum") has little impact on the qualitative key findings of this study. Variation on the other side of mean ("maximum") increases the number of trips required for equivalence of either paper or reusable bags with PRB (30% RC).

Environmental impacts

Twelve environmental impact categories have been studied in two cases and in three scenarios for each case, as shown in Table 8.3.

	Base Case	Alternative Case
Secondary uses of PRBs and Paper bags	Not included	Included
Scenario 1	One trip	
Scenario 2	3.1, 14.6 and 44 trips	
Scenario 3	Number of trips for equivalence of environmental impacts for reusable bags with environmental impacts of either PRBs (30% RC) or Paper (40% RC) bags	

Table 8.3 Cases and scenarios studied

PRBs and Paper bags that have been used once for grocery shopping are commonly reused for secondary purposes, the most common of these being trash can liners. These secondary uses were modeled in the present study using an avoided burden approach; that is, it was assumed that reusing PRBs or paper bags for secondary uses avoided the purchase of new, similar bags for the secondary uses.

Studies of secondary uses of PRBs in the U.S. and the U.K. have reported that 60% or more of these bags are reused. A reuse rate of 40% was used for the Alternative Case. No studies of Paper bag reuse were located. It was therefore assumed that Paper bags would be reused in the same ratio to bags not recycled as for PRBs. With this assumption, a reuse rate for Paper bags of 22.1% was calculated and used for the Alternative Case.

Key findings—Scenarios 1 and 3—PRBs and Paper bags

Base Case (secondary uses not included): Paper (40% RC) bags have higher environmental impacts than PRBs for all of the categories. Paper (100% RC) bags have higher impacts than PRBs for all categories except Terrestrial Acidification and Freshwater and Marine Ecotoxicity. The categories of Water Depletion, Terrestrial Ecotoxicity and Marine Eutrophication are substantially higher than those of PRBs.

Alternative Case (secondary uses included): Paper (40% RC) bags have higher impacts than PRBs for all of the categories. Paper (100% RC) bags have higher impacts than PRBs for all categories except Freshwater and Marine Ecotoxicity. The categories of Water Depletion, Terrestrial Ecotoxicity and Marine Eutrophication are substantially higher than those of PRBs.

Increasing the recycle content of PRBs from 0% to 30% reduces the environmental impacts by an average of about 12%. Increasing the recycle content of Paper bags from 40% to 100% reduces the environmental impacts by an average of about 53%.

Incorporating secondary uses into the environmental impact category calculations reduces the environmental impacts on average of PRBs about 32% (40% secondary uses) and of paper about 19% (22.1% secondary uses).

Figure 8.1 shows the comparison of Paper bags with PRBs on the basis of the number of "trips" required for each of the Paper bag types to be equivalent for the average of all of the environmental impact categories with PRBs containing 30% RC.

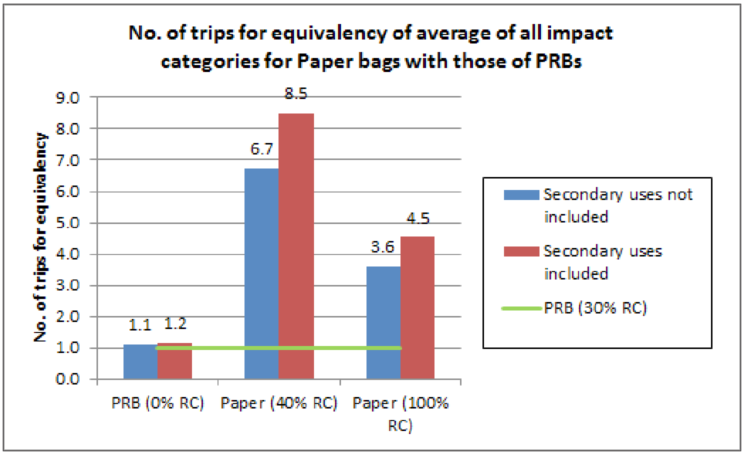


Figure 8.1 Average Number of Trips for Equivalency of Environmental Impacts of Paper Bags with Environmental Impacts of PRBs, with and without secondary uses included

Figure 8.1 shows that Paper (40% RC) bags have about 7.5 times the average environmental impacts compared to PRBs. Increasing the recycle content of Paper bags to 100% reduces this factor to about 4 times. Inclusion of secondary uses of PRBs and Paper bags in the models increases the average environmental impacts of Paper bags relative to PRBs by about 25% for both Paper bag recycle contents.

Key findings—Scenarios 2 & 3 Reusable bags

Table 8.4 summarizes the key environmental impact findings for LDPE bags compared to Paper bags and PRBs.

<table>
<tr><th></th><th colspan="6">LDPE bags</th></tr>
<tr><td>Compared to:</td><td colspan="2">3.1 trips</td><td colspan="2">14.6 trips</td><td colspan="2">44 trips</td></tr>
<tr><td>Secondary uses?</td><td>No</td><td>Yes</td><td>No</td><td>Yes</td><td>No</td><td>Yes</td></tr>
<tr><td>PRBs (30% RC)</td><td colspan="2" rowspan="2">Higher for all categories</td><td colspan="2" rowspan="4">Lower for all categories</td><td colspan="2" rowspan="4">Lower for all categories</td></tr>
<tr><td>PRBs (0% RC)</td></tr>
<tr><td>Paper (40% RC) bags</td><td>Higher for Terrestrial Acidification, Freshwater & Marine Ecotoxicity</td><td>Higher for Terrestrial Acidification, Freshwater & Marine Ecotoxicity, Fossil Fuel Depletion</td></tr>
<tr><td>Paper (100% RC) bags</td><td>Higher for Cum. Energy Demand, Terrestrial Acidification, Human Toxicity, Freshwater & Marine Ecotoxicity, Fossil Fuel Depletion</td><td>Higher for Cum. Energy Demand, Terrestrial Acidification, Freshwater Eutrophication, Human Toxicity, Freshwater & Marine Ecotoxicity, Fossil Fuel Depletion</td></tr>
</table>

Table 8.4 Environmental Impact categories for LDPE bags compared to PRBs amd Paper bags

Table 8.5 summarizes the key environmental impact findings for NWPP bags compared to Paper bags and PRBs.

<table>
<tr><th></th><th colspan="6">NWPP bags</th></tr>
<tr><td>Compared to:</td><td colspan="2">3.1 trips</td><td colspan="2">14.6 trips</td><td colspan="2">44 trips</td></tr>
<tr><td>Secondary uses?</td><td>No</td><td>Yes</td><td>No</td><td>Yes</td><td>No</td><td>Yes</td></tr>
<tr><td>PRBs (30% RC)</td><td colspan="2" rowspan="2">Higher for all categories</td><td rowspan="2">Higher for Water Depletion, Terrestrial Ecotoxicity, Photochemical Oxidant Formation</td><td>Lower for Freshwater Eutrophication, Freshwater & Marine Ecotoxicity</td><td colspan="2" rowspan="2">Higher for Water Depletion, Terrestrial Ecotoxicity</td></tr>
<tr><td>PRBs (0% RC)</td><td>Lower for Cum. Energy Demand, Terrestrial Acidification, Freshwater Eutrophication, Freshwater & Marine Ecotoxicity, Fossil Fuel Depletion</td></tr>
<tr><td>Paper (40% RC) bags</td><td>Lower for GWP, Cum. Energy Demand, Freshwater & Marine Eutrophication</td><td>Lower for Cum. Energy Demand, Freshwater & Marine Eutrophication</td><td colspan="2">Lower for all categories</td><td colspan="2" rowspan="2">Lower for all categories</td></tr>
<tr><td>Paper (100% RC) bags</td><td>Lower for Marine Eutrophication</td><td>Lower for Marine Eutrophication</td><td>Higher for Terrestrial Acidification, Freshwater & Marine Ecotoxicity</td><td>Higher for Terrestrial Acidification, Freshwater & Marine Ecotoxicity</td></tr>
</table>

Table 8.5 Environmental Impact categories for NWPP bags compared to PRBs amd Paper bags

	NWPP bags		
Compared to:	3.1 trips	14.6 trips	44 trips
LDPE bags	Higher for all categories	Higher for all categories	Higher for all categories

Table 8.6 Environmental Impact categories for NWPP bags compared to LDPE bags

Figures 8.2 and 8.3 show the comparison of LDPE and NWPP bags with PRBs and with Paper (40% RC) bags on the basis of the number of "trips" required for the average of all of the environmental impact categories for LDPE or NWPP bags to be equivalent to the average of all of the environmental impact categories for PRBs containing 30% RC or for Paper bags containing 40% RC. The impacts of including secondary uses are also shown in the figures.

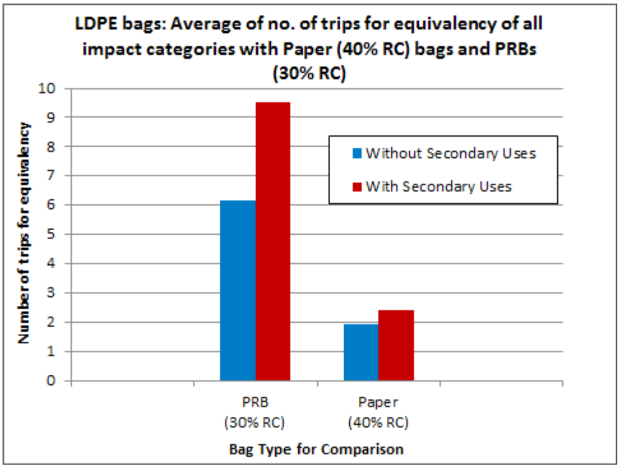


Figure 8.2 Average Number of Trips for Equivalency of Environmental Impacts of LDPE Bags with Environmental Impacts of Paper (40% RC) Bags and PRBs (30% RC), with and without secondary uses included

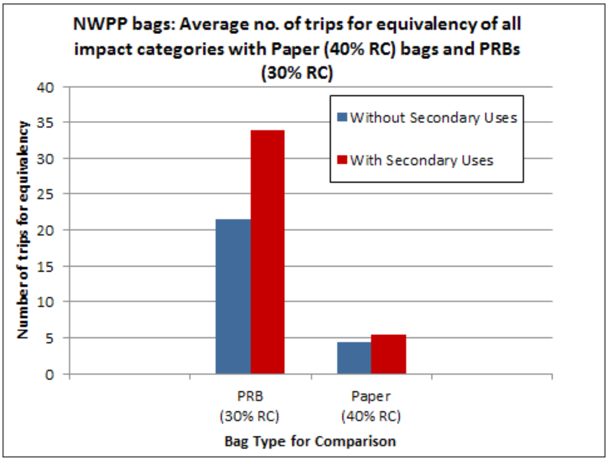


Figure 8.3 Average Number of Trips for Equivalency of Environmental Impacts of NWPP Bags with Environmental Impacts of Paper (40% RC) Bags and PRBs (30% RC), with and without secondary uses included

Summary of LCA study findings

From an environmental impact point of view,

- Reusable LDPE and NWPP bags have lower average impact on the environment than PRBs if reused a "sufficient" number of times. Quantitatively, what "sufficient" is will be determined by which environmental impact categories are important to the decision-maker.
- LDPE reusable bags should be preferred over NWPP bags.
- Other bag types (PRB, NWPP, LDPE) have lower environmental impacts than paper bags and are preferred 9 to 1 vs. paper bags by consumers.
- For either PRBs or Paper bags, higher recycle content results, on average, in lower environmental impacts, but these differences are much smaller than the differences among the various types of bags.
- Including secondary uses of single use bags in the LCA models does not change these qualitative conclusions, but does have significant effects on the quantitative environmental impacts.

Relationships to consumer behavior

The key findings of the Edelman Berland study of consumer reuse of reusable bags are reproduced graphically as Figure 8.4.

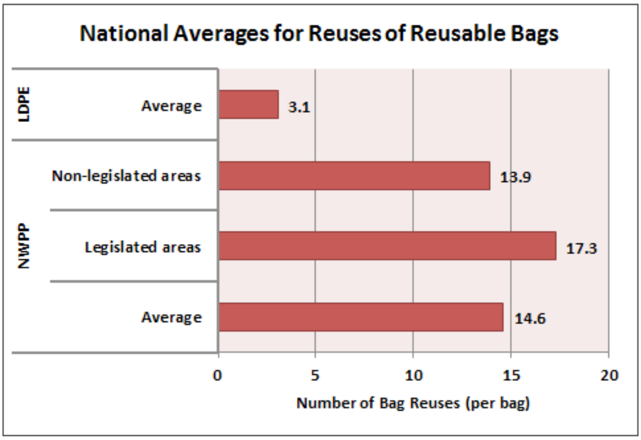
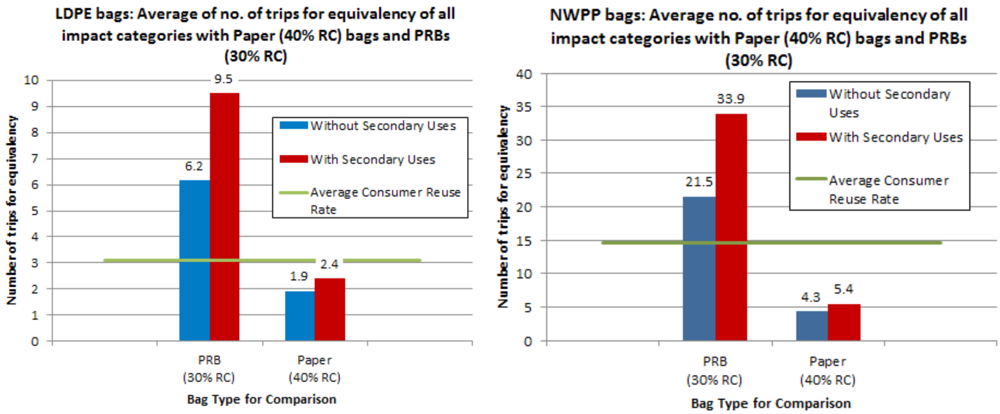


Figure 8.4 Key findings for reuse of reusable LDPE and NWPP Bags from the Edelman Berland Study

The combination of these data with Figures 8.2 and 8.3 results in Figures 8.5, 8.6 and 8.7.



Figures 8.5 and 8.6 Average Consumer Reuse Rate of LDPE and NWPP bags compared with average of Numbers of Trips for Equivalency of Environmental Impacts of LDPE or NWPP Bags with Environmental Impacts of Paper (40% RC) Bags and PRBs (30% RC)

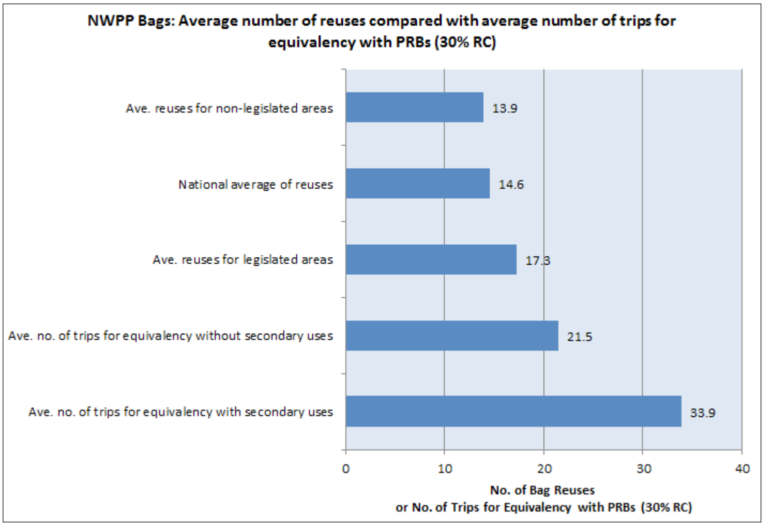


Figure 8.7 Average Consumer Reuse Rates of NWPP bags compared with Number of Trips for Equivalency of Average Environmental Impacts of NWPP Bags with Environmental Impacts of PRBs (30% RC), with and without secondary uses included

From these charts and other data reported by Edelman Berland:

• More than 50% of people reporting use of NWPP bags reuse them more than enough times for equivalency of their environmental impact categories with those of Paper (40% RC) bags.
• More than 50% of people who reported using LDPE reusable bags are re-using them enough times to make their environmental impacts, on average,

less than those of Paper (40% RC) bags. However, for four impact categories—Terrestrial Acidification, Freshwater and Marine Ecotoxicity and Fossil Fuel Depletion—they would need to reuse their LDPE bags one to two times more for equivalency.

• 50% of people who reported using NWPP bags do not use them enough times to make the average number of trips for equivalency of their environmental impacts equal to those of PRBs (30% RC). However, if secondary uses of PRBs are not included, the results are weighted by the large impacts of the Water Depletion and Terrestrial Ecotoxicity categories on the average. This is also true with secondary uses included, but, in this case, 9 of the 12 environmental impact categories require more trips than the average reuse rate for equivalency.

• Only 25% or 41% of people using NWPP bags (depending on whether secondary uses of PRBs are included in the calculations or not) reuse their NWPP bags enough times so that the average of the environmental impact categories for NWPP bags is less than the average of the environmental impact categories for the number of PRBs (30% RC) required to make the same number of grocery trips.

• More than 50% of people who reported using LDPE reusable bags are not reusing them enough times to make average number of trips for equivalency of their environmental impacts equal to those of PRBs (30% RC). For equivalency, they would have to reuse them twice to more than three times as many times, depending on whether secondary uses of PRBs are included in the environmental impact category calculations.

• Paper bags are given preference, often to the total exclusion of PRBs, by most plastic bag legislation, by "organic" food stores and by many environmentally conscious organizations and individuals. This preference originates because paper bags are perceived as coming from a renewable resource (trees), as being recyclable and as being compostable in an appropriate composting environment.

• However, the data in the present study, in which the entire Life Cycles of both Paper bags and PRBs have been examined, show that Paper bags are more detrimental to the environment in ten of the twelve environmental impact categories studied and, on average, are 4 to 7.5 times more detrimental to the environment vs. PRBs.

Supplemental findings

During the development and compilation of information for this study, we had the opportunity to collect and evaluate data in several areas directly relevant to consumer and legislative perceptions about grocery carrier bags. This information is found either in the main text of this report or in Annexes G and H.

Polyethylene Raw Materials used for PRBs

98% of the ethane used to make the high density polyethylene and LLDPE from which PRBs are manufactured in the U.S. comes from a by-product of domestic natural gas production. Natural gas is in plentiful supply today in the U.S. Making and using PRBs therefore does not affect imports of either oil or natural gas, nor does it take away oil, gasoline or natural gas from uses such as heating or transportation.

Grocery bags and recycling

As documented in various sections of this report, the main sources of recycled materials used in the manufacture of Paper bags, PRBs and NWPP bag inserts are not recycled bags, but other sources of paper and ethylene polymers. Paper bags can be recycled through municipal curbside collection and get mixed with other sources of recycled Kraft paper, especially corrugated boxes. PRBs, like other plastic films, cannot be recycled in most curbside collection systems because they interfere with the processing machinery at the Materials Recycling Facilities. PRB manufacturers would, however, very much like to source material for recycling from used PRBs. PRB manufacturers and manufacturers of other films have cooperated to establish recycling points at retail establishments. Such recycling facilities are now available to about 95% of the U.S. population. The Sustainable Packaging Coalition has recently initiated a program called "how2recycle" to provide consumers information on how and where to recycle grocery bags, plastic and multi-material packages.[1]

Litter

A compilation of all of the statistically-based, scientific studies of litter in the U.S. and Canada over an 18 year period shows consistently that "plastic bags" (which includes trash bags, grocery bags, retail bags and dry cleaning bags) make up a very small portion of litter, usually less than 1%. Neither plastic bags nor Kraft bags are a significant component of roadway litter. Plastic bags are a very small component of litter found in storm drains and around retail areas. (See Annex G for details)

Safe Use of Reusable bags

Many municipal, state and federal government web sites, as well as those of other "advice to consumer" type websites, strongly recommend that consumers should frequently clean their reusable bags by washing NWPP types in a washing machine and by wiping (with hot water or perhaps disinfecting wipes) their LDPE types. Cleaning is recommended to avoid the transfer and growth of viral and bacterial contamination from food and supermarket sources to the consumer's home and person. Direct evidence of the types of contamination that can occur is documented in Annex G to this report. The Edelman survey reports that only 15% of consumers wash their NWPP bags frequently and 23% never wash them. (See Section 6.3 and Annex H)

Summary and recommendations

The authors are satisfied that they have achieved their goal to provide a comparative assertion among the six types of grocery carrier bags included in the report based on their respective potential environmental impacts. The carrier bags selected were those in most common use in the United States and the underlying data were, as far as is possible, based on United States data.

Our results are based on a study of twelve environmental impact categories. Our results show that reusable LDPE and NWPP bags will have lower average impacts on the environment compared to PRBs if the reusable bags are reused for a *sufficient* number of grocery shopping trips. However, according to a recent national survey, a majority of consumers do not reuse their reusable bags for this *sufficient* number of trips, especially for LDPE bags. Moreover, 40% of people forget to bring their reusable bags with them to the store and half the people who prefer NWPP bags used PRBs at their most recent shopping trip. In addition, only 15% of people follow the recommended cleaning procedures to ensure safe use of reusable bags.

Our results also show that Paper bags, even with 100% recycle content, have significantly higher average impacts on the environment than either of the reusable bags or PRBs.

Many of the regulations now in place or being considered in the United States encourage consumers to use reusable bags through banning PRBs and imposing a fee on the use of Paper bags. (Californians Against Waste, 2013) (Florida Department of Environmental Protection, 2013) A number of grocery chains in non-legislated areas provide Paper bags and sell various reusable bags. Our results in this study show that these regulations and policies may result in negative impact on the environment rather than positive. Even though Paper bags come from a renewable resource and are easily recycled, it is likely that they are not the best environmental choice. Reusable bags should only be preferred if consumers are educated to use them safely and consistently, and reuse them enough times to lower their relative environmental impacts compared to PRB alternatives.

Our recommendation, based on our work in this study, is that consumers should be given a choice between reusable bags and PRBs and that any of these should be preferred over Paper bags. Most important is that much more attention should be focused on educating consumers to make an informed choice of which bags to use by providing them facts—facts about reusable bag use, facts about proper recycling or disposal of PRBs, facts about the potential environmental impacts of their choices—based on sound scientific evidence.

Note

1. http://www.how2recycle.info/
   http://www.plasticfilmrecycling.org/s00/index.html

9. References

Adhesives Products, Inc. (2011). *Bag Making*. Retrieved September 9, 2013, from adhesive-products.com: http://www.adhesiveproductsinc.com/applications/bag-making

Andrew Irving Associates. (2005, March). *Carrier Bag Usage and Attitudes.* Retrieved August 5, 2013, from www.WRAP.org: http://www.wrap.org.uk/sites/files/wrap/CarrierBagUsage.pdf

APCO Insight. (2007, March). *National Plastic Shopping Bag Recycling Signage Testing.* Retrieved January 21, 2013, from www.bagtheban.com: http://www.bagtheban.com/assets/content/bag-recycling-signage-testing.pdf

Association of Post-Consumer Plastic Recyclers. (2012, October 1). *2011 United States National Post-Consumer Plastics Bottle Recycling Report.* Retrieved January 16, 2013, from www.plasticsrecycling.org: http://www.plasticsrecycling.org/: http://plastics.americanchemistry.com/Education-Resources/Publications/2011-National-Post-Consumer-Plastics-Bottle-Recycling-Report.pdf

Avebe. (2013). *Starch Adhesive Applications*. Retrieved October 13, 2013, from avebe.com: http://www.avebe.com/adhesives/Adhesiveapplications.aspx

California Energy Commission. (2013). *Consumer Energy Center.* Retrieved September 13, 2013, from consumerenergycenter.org: http://www.consumerenergycenter.org/home/appliances/washers.html

Californians Against Waste. (2013, September 8). *National List of Local Plastic Bag Ordinances.* Retrieved September 8, 2013, from Californians Against Waste: http://www.cawrecycles.org/issues/plastic_campaign/plastic_bags/national

Canadian Plastics Industry Association. (1999, November). *Technical Report: Processing Options for the Use of Curbside-Collected PE Bags and Films in Composite Applications in North America.* Retrieved January 24, 2013, from www.plastics.ca: http://www.plastics.ca/_files/file.php?fileid=itemwCGjIUNVlj&filename=file_files_curbside_bags_films.pdf

Carter, S. J. (2009). Polyethylene, High-Density. In K. L. Yam, *The Wiley Encyclopedia of Packaging Technology* (p. 979). Hoboken, NJ: John Wiley & Sons.

City Council of the City of Boulder, Colorado. (2012, November 15). *Ordinance No. 7870.* Retrieved September 2, 2013, from bouldercolorado.gov: https://www-static.bouldercolorado.gov/docs/disposable-bag-fee-ordinance-1-201304101735.pdf

City of Austin. (2013). *Bring It Austin.* Retrieved September 2, 2013, from bring.it.austin.com: http://www.bringitaustin.com/faqs

City of Eugene, OR. (2013, June 14). *City of Eugene Bring Your Bag FAQ—Shoppers.* Retrieved September 2, 2013, from eugene-or.gov: http://www.eugene-or.gov/documentcenter/view/10990

City of Fort Collins Environmental Services Department. (2004, March 26). *Recycling*. Retrieved September 3, 2013, from fcgov.com: http://www.fcgov.com/recycling/pdf/kereuse.pdf

County of Los Angeles Department of Public Works, Environmental Programs Division. (2012, September). *For Stores*. Retrieved January 23, 2013, from About the Bag: http://dpw.lacounty.gov/epd/aboutthebag/ordinance_stores.cfm

Daphne Lofquist, T. L. (2012, April). *Households and Families: 2010.* Retrieved September 2, 2013, from census.gov: http://www.census.gov/prod/cen2010/briefs/c2010br-14.pdf

Department of Public Works, Environmental Programs Division. (2013). *Reusable Bag Tips.* Retrieved September 2, 2013, from dpw.lacounty.gov: http://dpw.lacounty.gov/epd/aboutthebag/tips.cfm

Department of the Environment, City and County of San Francisco. (2012, August 9). *How To Verify If A Reusable Bag Meets The Checkout Bag Ordinance Requirements.* Retrieved March 13, 2013, from SF Environment: http://www.sfenvironment.org/sites/default/files/editor-uploads/zero_waste/pdf/sfe_zw_check_out_bag_verification.pdf

Department of the Environment, City and County of San Francisco. (2012, August 9). *How To Verify If A Reusable Bag Meets The Checkout Bag Ordinance Requirements.* Retrieved March 13, 2013, from www.SFenvironment.org: http://www.sfenvironment.org/sites/default/files/editor-uploads/zero_waste/pdf/sfe_zw_check_out_bag_verification.pdf

Duro Bag Co. (2011, 10 4). *Duro Bag Co. Standard Products.* Retrieved March 15, 2013, from www.durobag.com: http://www.durobag.com/SellSheets/Standard/One Sixth, Seventh & Eighth Bbl Sacks v1.0.pdf

Duro Bag Mfg. (2005). *Handle Bags.* Retrieved September 3, 2013, from durobag.com: http://www.durobag.com/Standard/Products.aspx?p=13&f=10

Edelman Berland. (2014, May 15). *Reusable Bag Study*. Retrieved May 15, 2014, from www.slideshare.net: http://www.slideshare.net/EdelmanBerland/reusable-bag-study-results#

FMI. (2013). *Supermarket Facts.* Retrieved February 15, 2013, from www.fmi.org: http://www.fmi.org/research-resources/supermarket-facts

Food Marketing Institute. (2012). *U.S. Grocery Shopper Trends 2012 Executive Summary.* Retrieved January 7, 2013, from icn-net.com: http://www.icn-net.com/docs/12086_FMIN_Trends2012_v5.pdf

Foster, L. (2010). *Recycled Bags.* Retrieved January 24, 2013, from www.onebagatatime.com: http://www.onebagatatime.com/products/our-products/recycled-bags/

Franklin Associates, Ltd. (1990). *Resource and Environmental Profile Analysis of Polyethylene and Unbleached Paper Grocery Sacks.* Prairie Village, KS : Franklin Associates.

Frisman, P. (2008, December 2008). *Effect of Plasic Bag Sales and Bans on Garbage Bag Sales.* Retrieved September 3, 2013, from cga.ct.gov: http://www.cga.ct.gov/2008/rpt/2008-R-0685.htm

Fry, C. E. (2011). *Life Cycle Assessment of Supermarket Carrier Bags.* Bristol UK: Environment Agency.

G. Gierenz, W. K. (2008). *Adhesives and Adhesive Tapes.* Hoboken, NJ: John Wiley & Sons.

Gerba, C. P., Williams, D., & Sinclair, R. G. (2010, June 9). *Assessment of the Potential for Cross Contamination of Food Products by Reusable Shopping Bags.* Retrieved January 24, 2013, from Loma Linda University: School of Public Health: http://www.llu.edu/assets/publichealth/documents/grocery-bags-bacteria.pdf

Greene, J. (2010). *Survey of Reusable and Single-use Grocery Bags in Northern California.* Chico, CA: California State University, Chico, Institute for Sustainable Development.

Greene, J. (2011). *Life Cycle Assessment of Reusable and Single-Use Plastic Bags in California.* Chico CA: California State University, Institute for Sustainable Development.

Guilford, G. (2013, September 16). *A lot of US plastic isn't actually being recycled since China put up its Green Fence.* Retrieved December 2013, from qz.com: http://qz.com/122003/plastic-recycling-china-green-fence/

International Paper. (2013, Jan 22). *Kraft Paper Bags - Carry Sacks*. Retrieved Jan 22, 2013, from International Paper: United States: Products: http://www.internationalpaper.com/US/EN/Products/KraftBags/CarrySacks.html

Louisville Water Company. (2012). *Louisville Water Company 2011 Annual Report.* Retrieved February 19, 2013, from www.louisvilleky.gov: http://www.louisvilleky.gov/NR/rdonlyres/69CC2760-4685-4A7E-845F-6304CC45DAF3/0/LouisvilleWater2011AnnualReport_Full.pdf

Minnesota Department of Health. (2010, November 2010). *Prevent Cross-Contamination.* Retrieved December 12, 2012, from Minnesota Department of Health: http://www.health.state.mn.us/foodsafety/clean/xcontamination.html

Moore, P. (2011?). *Film, PET and Mixed Plastic Recycling in China.* Retrieved December 2013, from Moore Recycling Associates: http://moorerecycling.com/ChinaReport_Final.pdf

Mouw, S. a. (2013). *Plastic Recycling Collection National Reach Study: 2012 Update.* Sonoma, CA: Moore Recylcing Associates.

MSW Consultants. (2009, September 18). *2009 National Visible Litter Survey.* Retrieved October 6, 2013, from kab.org: http://www.kab.org/site/DocServer/Final_KAB_Report_9-18-09.pdf?docID=4561

MSW Consultants. (2009, September 18). *2009 National Visible Litter Survey and Litter Cost Study.* Retrieved January 31, 2013, from Keep American Beautiful: http://www.kab.org/site/DocServer/Final_KAB_Report_9-18-09.pdf?docID=4561

Muthu, S. a. (2014). *Assessment of Environmental Impact by Grocery Shopping Bags: An Eco-Functional Approach.* Singapore: Springer.

Natural Grocers. (2013, September 3). *Paper or Plastic? Frequently asked questions about recycling and reusable bags.* Retrieved September 3, 2013, from naturalgrocers.com: http://www.naturalgrocers.com/store-info/paper-or-plastic-frequent-asked-questions-about-recylcing-and-reusable-bags

Office of Transportation and Air Quality. (2011, December). *Greenhouse Gas Emissions from a Typical Passenger Vehicle.* Retrieved September 14, 2013, from epa.gov: http://www.epa.gov/otaq/climate/documents/420f11041.pdf

Repp, K. K., & Keene, W. E. (2012). A point-source norovirus outbreak caused by exposure to fomites. *The Journal of Infectious Diseases*, 1639-1641.

Reuters. (2014, May 15). *Amidst Bag Legislation Trend, Survey Shows 'Reusable' Shopping Bags are Minimally Reused.* Retrieved May 15, 2014, from www.reuters.com: http://www.reuters.com/article/2014/05/15/edelman-survey-idUSnPn6l3QRk+86+PRN20140515

Roplast Industries. (2013). *Grocery & Reusable Bags: Front-End Wave Tops*. Retrieved January 23, 2013, from http://www.roplast.com/: http://www.roplast.com/grocery-reusable-bags/front-end-wave-tops/

San Francisco Department of the Environment. (2013, January 9). *Suppliers of Reusable Checkout Bags—Ordinance effective October 1st, 2012.* Retrieved March 13, 2013, from www.sfenvironment.org: http://www.sfenvironment.org/sites/default/files/editor-uploads/zero_waste/pdf/sfe_zw_checkout_bag_list_reusable_0.pdf

Seattle Public Utilities. (2013, September 2). *Plastic Bag Ban - Seattle Utilities*. Retrieved September 2, 2013, from seattle.gov: http://www.seattle.gov/util/MyServices/Recycling/ReduceReuse/PlasticBagBan/index.htm

Silva, E. (2010). *The Spunbond Process.* Retrieved January 24, 2013, from Academia.edu: http://www.academia.edu/440290/The_Spunbond_Process

Staff, R. T. (2012, October 16). *Paper Recycling Conference: The Future is Plastics.* Retrieved October 14, 2013, from recyclingtoday.com: http://www.recyclingtoday.com/future-is-plastics.aspx

Stein, S. R. (2013, January 7). *ER Planning Report Brief: Plastic Retail Bags in Litter.* Retrieved October 6, 2103, from erplanning.com: http://www.erplanning.com/uploads/Plastic_Retail_Bags_in_Litter.pdf

Stein, S. R. (2013, January 4). *ER Planning Report Brief: Plastic Retail Bags in Litter.* Retrieved January 31, 2013, from ER Planning: http://www.erplanning.com/uploads/Plastic_Retail_Bags_in_Litter.pdf

Summerbell, R. (2009, May 20). *Grocery Carry Bag Sanitation.* Retrieved January 24, 2013, from EPIC-Environmental and Plastics Industry Council: http://www.plastics.ca/_files/file.php?fileid=0&filename=file_A_Microbiological_Study_of_Reusable_Grocery_Bags_May20_09.pdf

Swiss Centre for Lifecycle Inventories. (2007). *Ecoinvent Version 2.* Retrieved 2012, from ecoinvent.org: http://www.ecoinvent.org/database/ecoinvent-version-2/

TAPPI. (2001). *Paper University–All About Paper.* Retrieved October 14, 2013, from tappi.org: http://www.tappi.org/paperu/all_about_paper/earth_answers/recycle10.htm

Twede, D., & Selke, S. E. (2005). *Cartons, Crates and Corrugated Board: Handbook of Paper and Wood Packaging Technology.* Lancaster, PA: DEStech Publications.

U. S Dept. of Health and Human Services. (2012, December 24). *Reusable Grocery Bags: Keep 'em clean while going green.* Retrieved May 17, 2014, from Foodsafety.gov: http://www.foodsafety.gov/blog/reusable_bags.html

U. S. Department of Agriculture. (2010, December). *Dietary Guidelines for Americans 2010.* Retrieved September 2, 2013, from www.dietaryguidelines.gov: http://www.cnpp.usda.gov/Publications/DietaryGuidelines/2010/PolicyDoc/PolicyDoc.pdf

U. S. Energy Information Administration. (2011, December 6). *Frequently Asked Questions.* Retrieved February 15, 2013, from www.eia.gov: http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3

U. S. Energy Information Administration. (2012, September 27). *Ethane/ethylene*. Retrieved January 13, 2013, from Petroleum and Other Liquids: Supply and Distribution: http://www.eia.gov/dnav/pet/PET_SUM_SND_A_EPLLE_MBBL_A_CUR.htm

U. S. Energy Information Administration. (2013, April). *Table HC3.4 Appliances in U.S. Homes.* Retrieved September 15, 2013, from eia.gov: http://www.eia.gov/consumption/residential/data/2009/#undefined

U. S. Environmental Protection Agency. (2011, December). *Municipal Solid Waste Generation, Recycling and Disposal in the United States: Tables and Figures for 2010.* Retrieved January 15, 2013, from www.epa.gov: http://www.epa.gov/epawaste/nonhaz/municipal/pubs/2010_MSW_Tables_and_Figures_508.pdf

U. S. Environmental Protection Agency. (2013). *Clothes Washers.* Retrieved September 13, 2013, from energystar.gov:http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=CW

U. S. Environmental Protection Agency. (2013, June 17). *Municipal Solid Waste Generation, Recycling, and Disposal in the Inited States: Facts and Figures for 2011*. Retrieved August 5, 2013, from www.epa.gov: http://www.epa.gov/osw/nonhaz/municipal/pubs/MSWcharacterization_508_053113_fs.pdf

U. S. Environmental Protection Agency. (2013, June 17). *Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2011, p. 10.* Retrieved August 5, 2013, from www.epa.gov: http://www.epa.gov/osw/nonhaz/municipal/pubs/MSWcharacterization_508_053113_fs.pdf

U. S. Environmental Protection Agency. (2013, April 4). *Vocabulary Catalog List Detail - Reducing Solid Waste: Reusable Vocabulary*. Retrieved April 4, 2013, from Terminology Services: http://ofmpub.epa.gov/sor_internet/registry/termreg/searchandretrieve/glossariesandkeywordlists/search.do;jsessionid=GQGWRpJf2h8GCtDBpymGjtnMS7sBdZfPp23n2z05m3vYpnmzzJLH!203807266?details=

U. S. International Trade Commission. (2009, May). *Intl Trade Com Pub 4080.* Retrieved January 14, 2013, from USITC DataWeb: http://dataweb.usitc.gov

United States Census Bureau. (2012, June 12). *The 2012 Statistical Abstract: Prices: Food Cost and Prices Table 732.* Retrieved March 13, 2013, from www.census.gov: http://www.census.gov/compendia/statab/cats/prices/food_cost_and_prices.html

UW Extension. (2012, 10 21). *www4.uwm.edu/shwec/publications.* Retrieved March 15, 2013, from www4.uwm.edu: http://www4.uwm.edu/shwec/publications/cabinet/recycling/Material Manufacturing and Recycling-Paper.pdf

Yaros, C. C. (2007). *Life Cycle Assessment for Three Types of Grocery Bags - Recyclable Plastic; Compostable, Biodegradable Plastic; and Recycled, Recyclable Paper.* Ardmore PA: Boustead Consulting & Associates Ltd.

Annex A—List of 52 Items for Typical Shopping Trip

Food

1 1 lb. 4 oz. loaf bread—Southern Home, King-sized sandwich sliced
1 gallon milk—Southern Home, 1%
1 8 oz. pouch cheese—Borden, Colby blend sliced cheese
1 9 oz. pouch deli meat—Land O'Frost, Shaved turkey
1 dozen eggs—Southern Home, Extra large
1 1 lb. pkg. chicken thighs—Meat department
1 1 lb. pkg. ground beef—Meat department
2 liter soda—7UP Ten
1/2 gallon orange juice–Southern Home
5 bananas
4 apples
3 tomatoes
1 head lettuce—Foxy, Iceberg
1 1 lb. bag carrots—Bolthouse Farm
1 8 oz. plastic bottle salad dressing–Southern Home, Ranch
1 18 oz. box cereal—Cheerios
2 cans soup—Hungry Man,
  1 beef sirloin stew (18.6 fl. oz.) and 1 cream of mushroom (10.75 fl. oz.)
1 12 oz. box crackers—Wheat Thins
1 13.1 oz. box cookies—Oreo
1 1 lb. box pasta—Southern Home, spaghetti
1 24 oz. glass jar pasta sauce—Southern Home, traditional marinara
1 10.5 oz. bag chips—Lays Potato Chips, Original
1 1 lb. bag pretzels—Rold Gold Pretzel Sticks
1 22 oz. bag frozen Waffle Fries—Ore Ida
2 frozen dinners—
  1 40 oz. Swanson's Family Size, Lasagna with meat and cheese and
  1 25 oz. Banquet, Zesty marinara sauce and meatballs
1 14 oz. bag frozen peas—PictSweet
1 16 oz. plastic jar peanut butter—Southern Home, Chunky
1 16 oz. jar jelly—Southern Home, Strawberry
1 1lb. Coffee—Eight O'Clock
1 32 oz. plastic bottle cooking oil—Southern Home, Vegetable Oil
1 1oz. plastic jar spice—Ground Cinnamon

Household

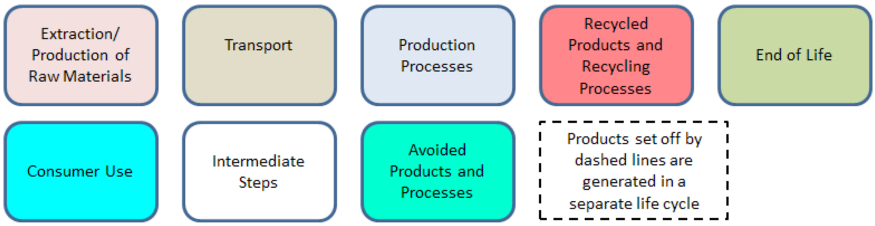
1 8.8 lb. bag pet food—Purina, Adult
1 48 fl. oz. bottle laundry detergent—Tide
1 2 roll pack Paper towels—Brawny
1 8 roll pack of Toilet paper—Scott 1000
1 25 fl. oz. bottle dish detergent—Clear Choice, Ocean Breeze

Personal Care

1 8 oz.–2 (4oz.) bar pack of soap—Caress
1 23.7 fl. oz. bottle shampoo—Top Care, Dandruff control
1 2.2 oz. stick deodorant—Tom's, Long-lasting
1 4.6 oz. tube toothpaste—Crest, Cavity Protection

Annex B—Material Balance Charts for Bags Studied

The following figures show the flow of materials and the material balance through the life cycle of each bag. Transport details are shown in Table 4.3 in the body of the report.



Key to symbols

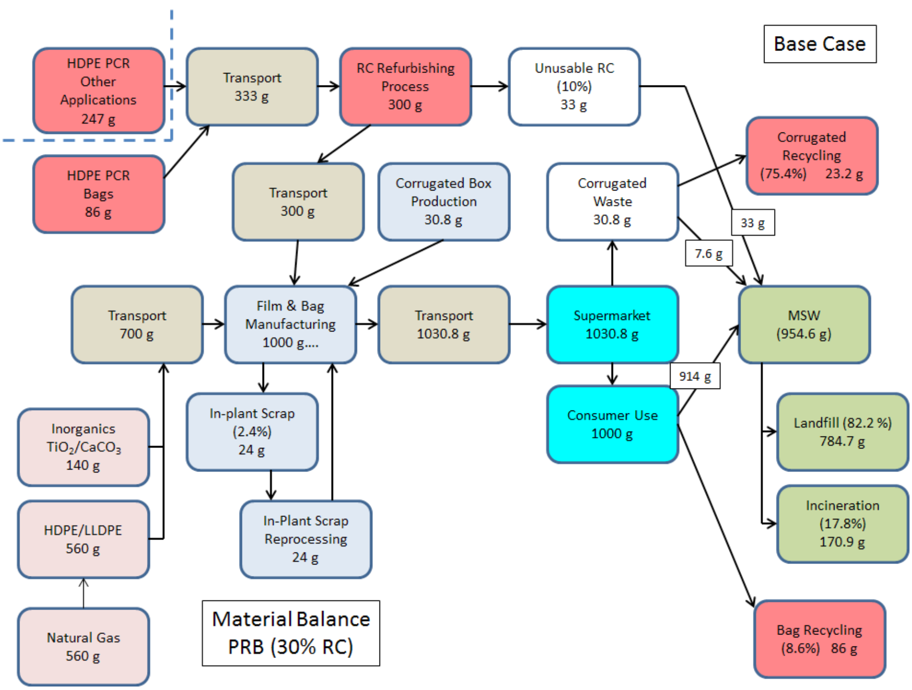


Figure B.1 PRB (30% RC)–Base Case

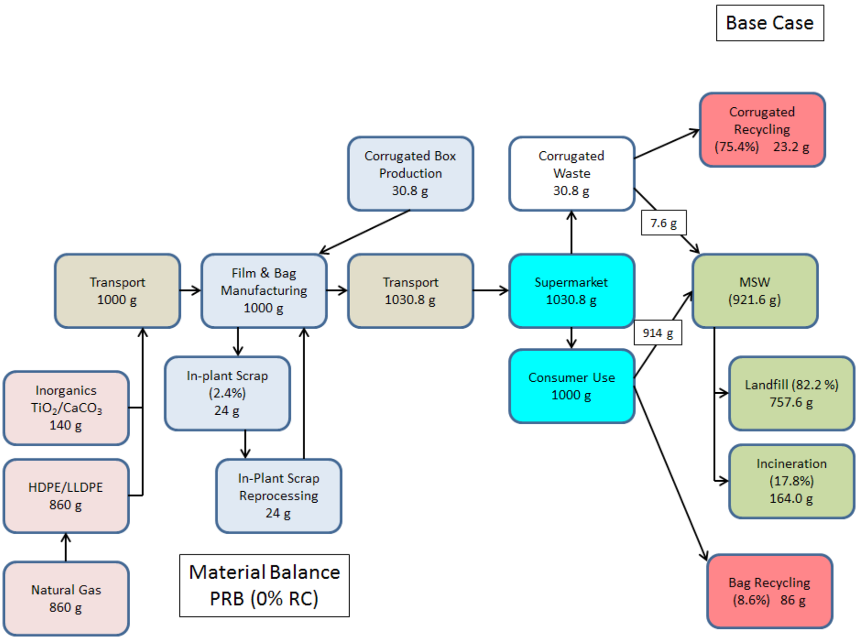


Figure B.2 PRB (0% RC)–Base Case

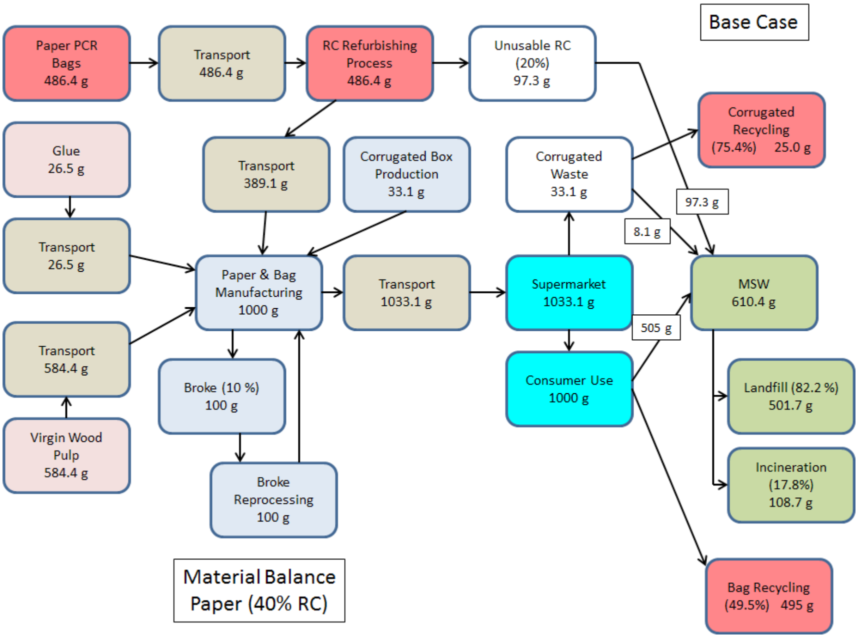


Figure B.3 Paper Bags (40% RC)–Base Case

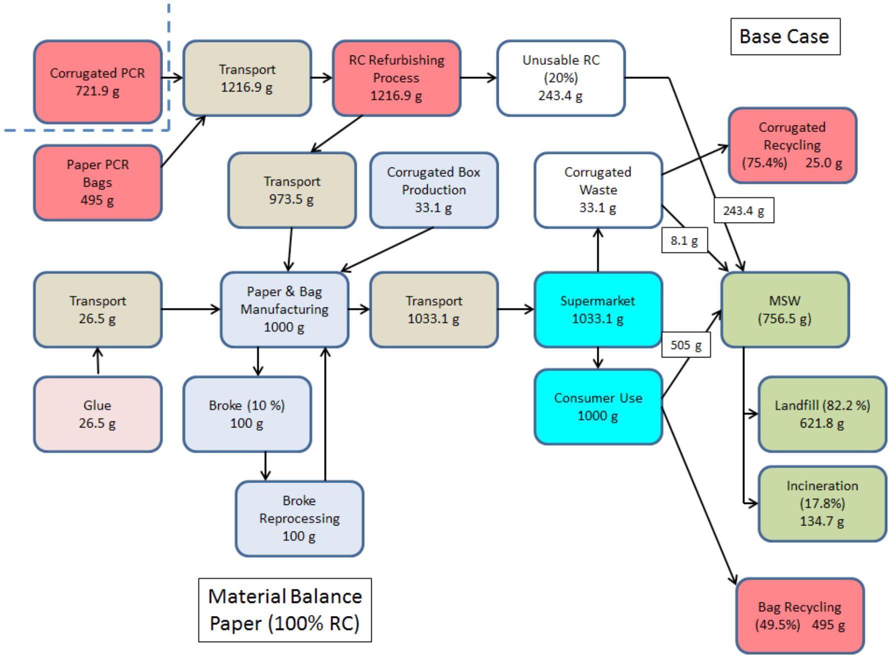


Figure B.4 Paper Bags (100% RC)–Base Case

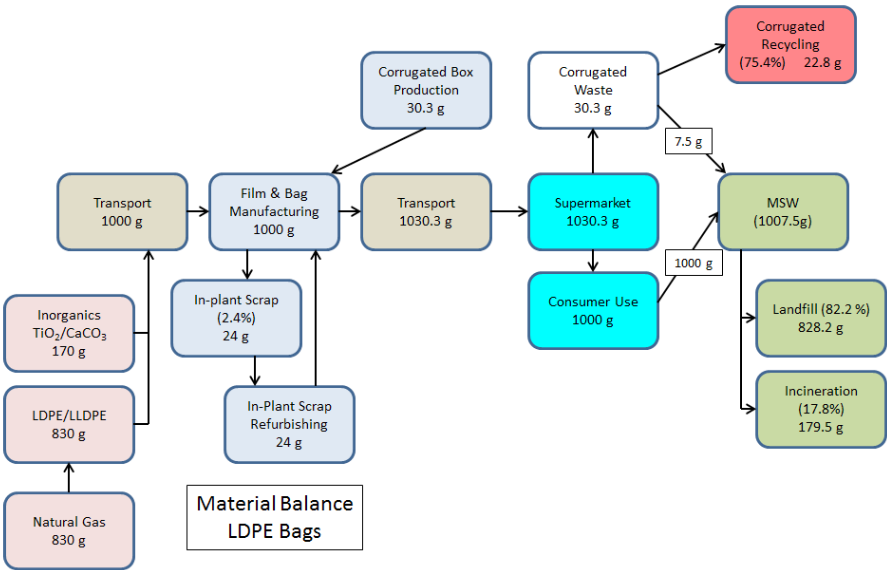


Figure B.5 LDPE Bags

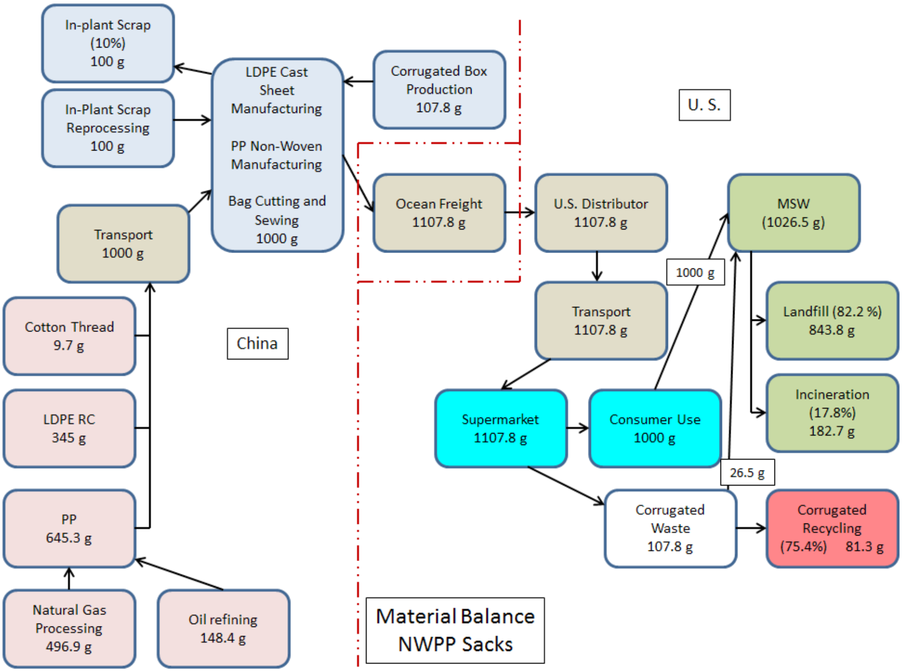


Figure B.6 NWPP Bags

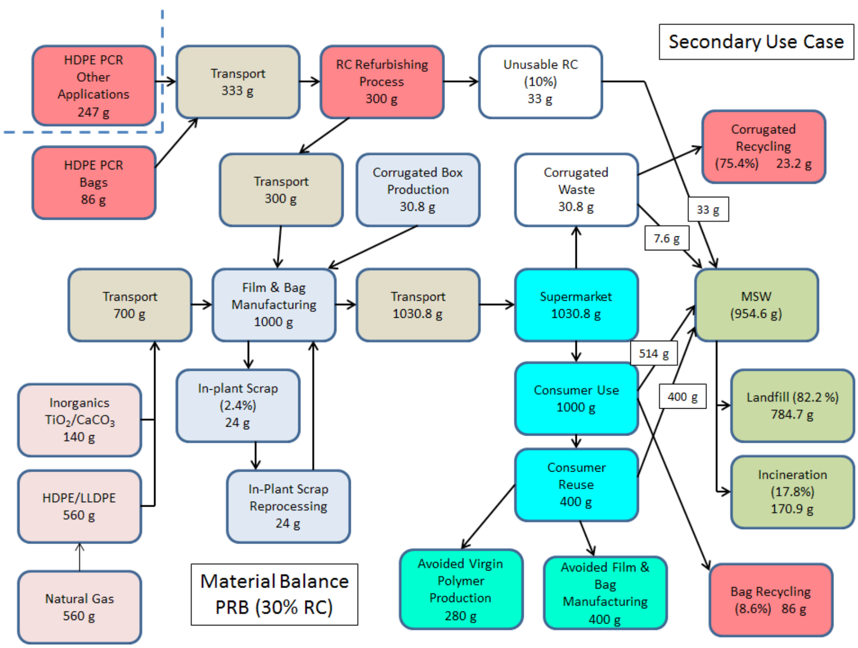


Figure B.7 PRB (30% RC)–Secondary Use Case

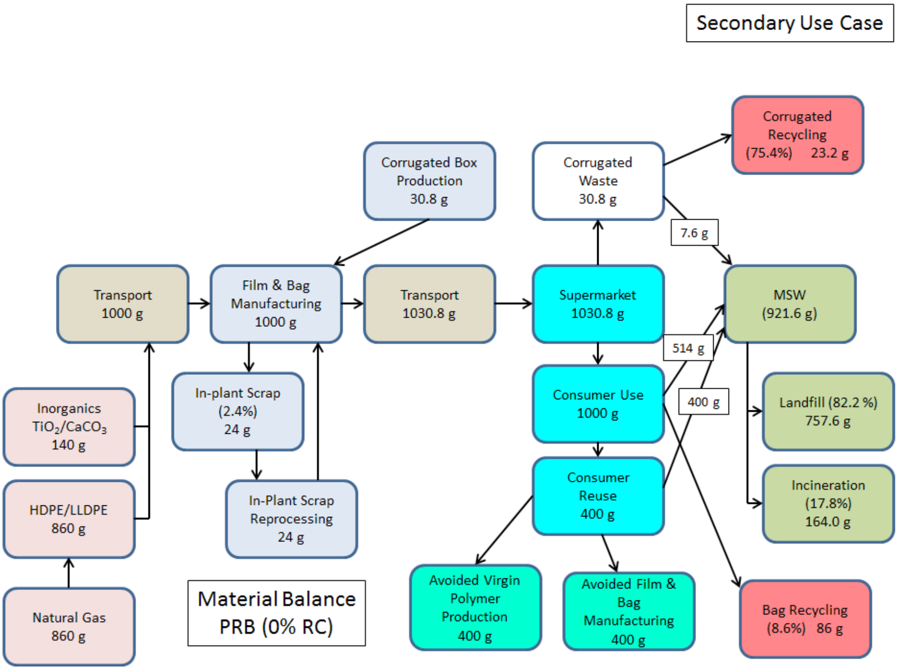


Figure B.8 PRB (0% RC)–Secondary Use Case

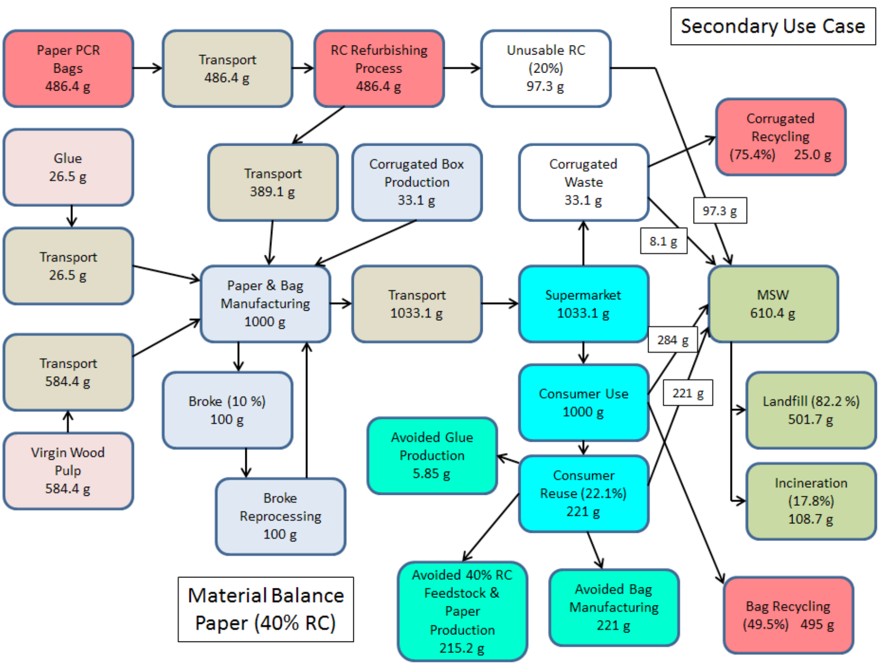


Figure B.9 Paper Bags (40% RC)–Secondary Uses included

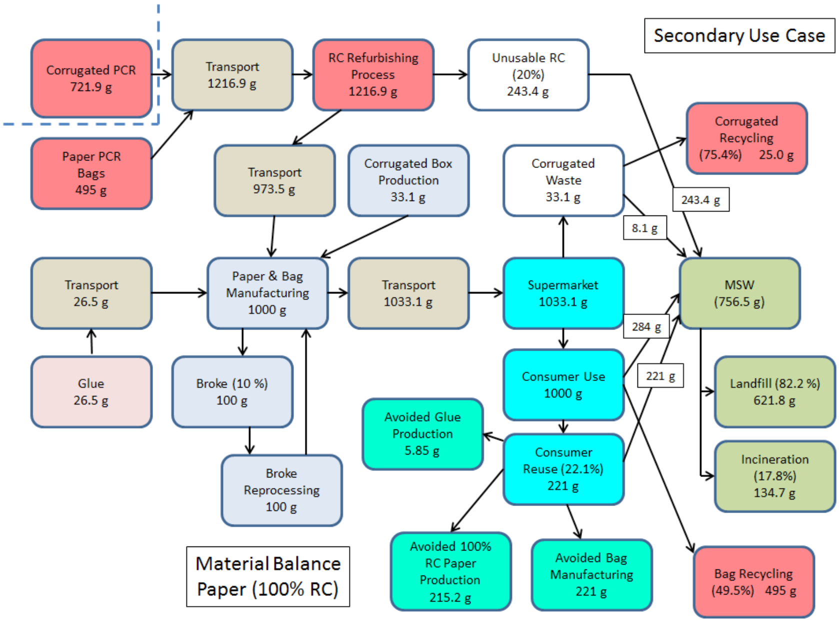


Figure B.10 Paper Bags (100% RC)–Secondary Use Case

Annex C—Description of Environmental Impact Categories (Base Case)

Impact Category Midpoint Indicators		
Impact Category	**Explanation**	**Measurement**
Global Warming Potential	The amount of greenhouse gas (for example carbon dioxide-CO_2, nitrous oxide, methane) that is estimated to contribute to global warming by accumulating in the atmosphere and absorbing infrared radiation	Kg CO_2 equivalents
Water Depletion	The total amount of water lost during the life cycle	gal
Cumulative Energy Demand	The total amount of energy from all sources required for manufacture, transport, reprocessing and disposal	MJ eq.
Terrestrial Acidification	Pollutants such as sulfur dioxide (SO_2), nitrates, phosphates, hydrochloric acid and ammonia deposited in the soil make the soil more acidic, decrease its mineral content and increase potentially toxic elements.	g SO_2 eq.
Freshwater Eutrophication	Nutrients such as phosphorous (P) and nitrogen promote an increase in biomass, damaging other life forms.	g P eq.
Marine Eutrophication	Nutrients such as phosphorous and nitrogen (N) promote an increase in biomass, damaging other life forms.	g N eq.
Human Toxicity	The amount of organic compounds such as dichlorobenzene (1,4-DB) that is able to cause illnesses or damage an exposed organism	g 1,4-DB eq.
Terrestrial Ecotoxicity	The amount of organic compounds such as dichlorobenzene (1,4-DB) that is able to cause illnesses or damage an exposed organism	g 1,4-DB eq.
Freshwater Ecotoxicity	The amount of organic compounds such as dichlorobenzene (1,4-DB) that is able to cause illnesses or damage an exposed organism	g 1,4-DB eq.
Marine Ecotoxicity	The amount of organic compounds such as dichlorobenzene (1,4-DB) that is able to cause illnesses or damage an exposed organism	g 1,4-DB eq.
Fossil Fuel Depletion	The amount of fossil fuel (such as natural gas or oil) that is used up	g oil eq.
Photochemical Oxidant Formation	The amount of nitrogen oxides and volatile organic compounds that form in smog and react under the action of sunlight to form ozone	g NMVOC

Annex D—Summary of Key Assumptions

Key Assumptions and References to Report Location							
Topic	Item	Base Case - Case 1		Case 2		Sensitivities	
		Assumptions	Section (Page)	Assumptions	Section (Page)	Assumptions	Section (Page)
Feedstock							
	NWPP	23% oil, 77% nat'l gas	4.1 (35)				
	LDPE,LLDPE,HDPE	100 % natural gas	4.1 (34)				
	Paper	wood pulp	4.1 (34)				
Recycle Content							
	PRB	0%, 30%	3.1 (19)				
	Paper	40%, 100%	3.1 (20)				
	LDPE	0%	3.1 (20)				
	NWPP	0% bag, 100% insert	3.1 (21)				
Additives							
	PRB	TiO_2, $CaCO_3$	4.2 (36)				
	LDPE	TiO_2, $CaCO_3$	4.2 (38)				
Other raw materials							
	NWPP	Cotton thread	4.2 (38)				
	Paper sacks	Hot-melt adhesive	4.2 (38)				
Bag wall thickness							
	LDPE	2.25 mils	3.1 (20)			4 mils	6.4 (103-104)
In-plant recycle							
	PRB	2.40%	4.2 (36)				
	LDPE	2.40%	4.2 (38)				
	Paper	10%	4.2 (37)				
	NWPP/LDPE	10%	4.2 (38)				
SimaPro assumptions and notes			3.8 (30-32)				
Energy requirements for conversion to bags			4.2 (40)				
Transport scenarios			4.3 (40-41)				
Distribution packaging			4.3 (41)				
Recycling							
	PRBs	8.60%	4.41 (41)				
	Paper	49.50%	4.41 (43)				
	Corrugated	75.40%	4.41 (43)				
	LDPE/NWPP	0%	4.41 (43-44)				
De-inking							
	Paper	0%	3.1 (20)			25%, 50%	6.2 (100-101)
Recycling losses							
	PRBs	10%	4.41 (41)				
	Paper	20%	4.41 (43)				
Secondary uses							
	PRBs	0%	5.2.1 (73)	40%		0%, 20%, 60%	6.1 (96-100)
	Paper bags	0.00%	5.2.1 (74)	22.10%		0%, 11.05%	6.1 (96-100)
End-of-Life							
	Landfill	82.20%	4.44 (44-45)				
	Incineration	17.80%	4.44 (44-45)				
	Litter	0%	4.44 (44-45)				
Washing							
	NWPP	None	4.5 (40)			0%, 2.5%, 5%, 10%, 100%	6.3 (101-103)

Annex E—Detailed Results

Base Case—Case 1—Secondary uses of PRBs and Paper bags not included

Scenario 1—One trip

Potential Environmental Impact Categories per Trip							
		(30% RC)	(0% RC)	(40% RC)	(100% RC)	-	-
Impact category	Unit	PRB	PRB	Paper	Paper	LDPE	NWPP
	No. bags	9.8	9.8	8.4	8.4	8.3	6.7
GWP	Kg CO_2 eq	0.208	0.231	0.881	0.769	1.27	2.71
Water Depletion	gal	0.1070	0.1090	2.77	1.230	0.835	9.59
Cumulative Energy Demand	MJ eq.	5.02	6.78	23.4	10.13	34.5	52.5
Terrestrial Acidification	g SO_2 eq	2.01	2.76	3.65	1.63	13.6	25.9
Freshwater Eutrophication	g P eq	0.0343	0.0347	0.199	0.068	0.187	0.231
Marine Eutrophication	g N eq	0.0972	0.0951	1.07	0.946	0.505	1.35
Human Toxicity	g 1,4-DB eq	88.3	104.0	344	116	523	1110
Terrestrial Ecotoxicity	g 1,4-DB eq	0.0116	0.012	0.163	0.0719	0.073	0.556
Freshwater Ecotoxicity	g 1,4-DB eq	4.69	4.52	6.14	3.22	23.8	51.8
Marine Ecotoxicity	g 1,4-DB eq	4.54	4.38	5.14	2.62	23.1	50.5
Fossil Fuel Depletion	g oil eq	101	138.0	228	207	706	1110
Photochemical Oxidant Formation	g NMVOC	0.592	0.661	2.87	1.65	3.79	10.6

Ref: EIF (rev 7) (3a)

Potential Environmental Impact Categories for One Trip by Life Cycle Process (Base Case)						
	GWP (kg CO_2 eq.)					
Life Cycle Process	(30% RC)	(0% RC)	(40% RC)	(100% RC)	-	-
	PRB	PRB	Paper	Paper	LDPE	NWPP
Raw material extraction/production	0.0699	0.109	0.395	0.0465	0.552	0.763
Production processes	0.0973	0.0798	0.213	0.449	0.339	1.29
Transportation	0.0246	0.0262	0.088	0.0882	0.191	0.252
Waste processing/disposal	0.0162	0.0162	0.185	0.186	0.188	0.405
Avoided products						
	Water Depletion (gal)					
Life Cycle Process	(30% RC)	(0% RC)	(40% RC)	(100% RC)	-	-
	PRB	PRB	Paper	Paper	LDPE	NWPP
Raw material extraction/production	0.0307	0.0319	2.20	0.0846	0.404	8.64
Production processes	0.0546	0.0541	0.477	1.05	0.244	0.716
Transportation	0.0187	0.0199	0.0714	0.0724	0.154	0.156
Waste processing/disposal	0.0027	0.0027	0.0287	0.0291	0.0334	0.0799
Avoided products						
	Fossil Fuel Depletion (g oil eq.)					
	(30% RC)	(0% RC)	(40% RC)	(100% RC)	-	-
Life Cycle Process	PRB	PRB	Paper	Paper	LDPE	NWPP
Raw material extraction/production	67.2	109	127	29.3	536	737
Production processes	25.5	20.3	68.1	145	96.4	285
Transportation	8.18	8.81	30.2	30.4	71.3	83.2
Waste processing/disposal	0.17	0.17	2.31	2.32	2.21	4.83
Avoided products						

Ref: Breakdown (rev 7)

Base Case—Case 1—Secondary uses of PRBs and Paper bags not included

Scenario 2—multiple trips

Potential Environmental Impact Categories per Multiple Trips

Impact category	Unit	PRB (30% RC)	PRB (0% RC)	Paper (40% RC)	Paper (100% RC)	LDPE	NWPP	PRB (30% RC)	PRB (0% RC)	Paper (40% RC)	Paper (100% RC)	LDPE	NWPP	PRB (30% RC)	PRB (0% RC)	Paper (40% RC)	Paper (100% RC)	LDPE	NWPP
	No. Trips	3.1	3.1	3.1	3.1	3.1	3.1	14.6	14.6	14.6	14.6	14.6	14.6	44	44	44	44	44	44
	No. bags	30.4	30.4	26.0	26.0	8.3	6.7	143.1	143.1	122.6	122.6	8.3	6.7	431.2	431.2	369.6	369.6	8.3	6.7
	No. uses/bag	1	1	1	1	3.1	3.1	1	1	1	1	14.6	14.6	1	1	1	1	44	44
GWP	kg CO2 eq	0.645	0.716	2.73	2.38	1.27	2.71	3.04	3.37	12.9	11.2	1.27	2.71	9.15	10.2	38.8	33.8	1.27	2.71
Water Depletion	gal	0.332	0.338	8.59	3.81	0.835	9.59	1.56	1.59	40.4	18.0	0.835	9.59	4.71	4.80	122	54.1	0.835	9.59
Cumulative Energy Demand	MJ eq.	15.6	21.0	72.4	31.4	34.5	52.5	73.4	99.0	341	148	34.5	52.5	221	298	1028	446	34.5	52.5
Terrestrial Acidification	g SO2 eq	6.23	8.56	11.3	5.05	13.6	25.9	29.3	40.3	53.3	23.8	13.6	25.9	88.4	121	161	71.7	13.6	25.9
Freshwater Eutrophication	g P eq	0.106	0.108	0.617	0.211	0.187	0.231	0.501	0.507	2.91	0.993	0.187	0.231	1.51	1.53	8.76	2.99	0.187	0.231
Marine Eutrophication	g N eq	0.301	0.295	3.32	2.93	0.505	1.35	1.42	1.39	15.6	13.8	0.505	1.35	4.28	4.18	47.1	41.6	0.505	1.35
Human Toxicity	g 1,4-DB eq	274	322	1066	360	523	1110	1289	1518	5022	1694	523	1110	3885	4576	15136	5104	523	1110
Terrestrial Ecotoxicity	g 1,4-DB eq	0.0360	0.0369	0.505	0.223	0.0731	0.556	0.169	0.174	2.38	1.05	0.0731	0.556	0.510	0.524	7.17	3.16	0.0731	0.556
Freshwater Ecotoxicity	g 1,4-DB eq	14.5	14.0	19.0	9.98	23.8	51.8	68.5	66.0	89.6	47.0	23.8	51.8	206	199	270	142	23.8	51.8
Marine Ecotoxicity	g 1,4-DB eq	14.1	13.6	15.9	8.12	23.1	50.5	66.3	63.9	75.0	38.3	23.1	50.5	200	193	226	115	23.1	50.5
Fossil Fuel Depletion	g oil eq	313	428	707	642	706	1110	1475	2015	3329	3022	706	1110	4444	6072	10032	9108	706	1110
Photochemical Oxidant Formation	g NMVOC	1.84	2.05	8.90	5.12	3.79	10.6	8.64	9.65	41.9	24.1	3.79	10.6	26.0	29.1	126	72.6	3.79	10.6

Ref: Sheet 2 (2)

Base Case—Case 1—Secondary uses of PRBs and Paper bags not included

Scenario 3—Number of trips for equivalency

No. of Trips for Equivalency to PRB (30% RC)							
		No. of Trips					
Impact category	Unit	PRB (30% RC)	PRB (0% RC)	LDPE	NWPP	Paper (40% RC)	Paper (100% RC)
GWP	Kg CO_2 eq	1	1.1	6.1	13.0	4.2	3.7
Water Depletion	gal	1	1.0	7.8	89.6	25.9	11.5
Cumulative Energy Demand	MJ eq.	1	1.3	6.9	10.5	4.7	2.0
Terrestrial Acidification	g SO_2 eq	1	1.4	6.8	12.9	1.8	0.8
Freshwater Eutrophication	g P eq	1	1.0	5.5	6.7	5.8	2.0
Marine Eutrophication	g N eq	1	1.0	5.2	13.9	11.0	9.7
Human Toxicity	g 1,4-DB eq	1	1.2	5.9	12.6	3.9	1.3
Terrestrial Ecotoxicity	g 1,4-DB eq	1	1.0	6.3	47.9	14.1	6.2
Freshwater Ecotoxicity	g 1,4-DB eq	1	1.0	5.1	11.0	1.3	0.7
Marine Ecotoxicity	g 1,4-DB eq	1	1.0	5.1	11.1	1.1	0.6
Fossil Fuel Depletion	g oil eq	1	1.4	7.0	11.0	2.3	2.0
Photochemical Oxidant Formation	g NMVOC	1	1.1	6.4	17.9	4.8	2.8
Average Number of Trips			**1.1**	**6.2**	**21.5**	**6.7**	**3.6**

Ref: EIF (rev 7) (3)

No. of Trips for Equivalency to Paper (40% RC)							
		No. of Trips					
Impact category	Unit	Paper (40% RC)	PRB (30% RC)	PRB (0% RC)	LDPE	NWPP	Paper (100% RC)
GWP	Kg CO_2 eq	1.0	0.2	0.3	1.4	3.1	0.9
Water Depletion	gal	1.0	0.0	0.0	0.3	3.5	0.4
Cumulative Energy Demand	MJ eq.	1.0	0.2	0.3	1.5	2.2	0.4
Terrestrial Acidification	g SO_2 eq	1.0	0.6	0.8	3.7	7.1	0.4
Freshwater Eutrophication	g P eq	1.0	0.2	0.2	0.9	1.2	0.3
Marine Eutrophication	g N eq	1.0	0.1	0.1	0.5	1.3	0.9
Human Toxicity	g 1,4-DB eq	1.0	0.3	0.3	1.5	3.2	0.3
Terrestrial Ecotoxicity	g 1,4-DB eq	1.0	0.1	0.1	0.4	3.4	0.4
Freshwater Ecotoxicity	g 1,4-DB eq	1.0	0.8	0.7	3.9	8.4	0.5
Marine Ecotoxicity	g 1,4-DB eq	1.0	0.9	0.9	4.5	9.8	0.5
Fossil Fuel Depletion	g oil eq	1.0	0.4	0.6	3.1	4.9	0.9
Photochemical Oxidant Formation	g NMVOC	1.0	0.2	0.2	1.3	3.7	0.6
Average Number of Trips		**1.0**	**0.3**	**0.4**	**1.9**	**4.3**	**0.6**

Ref: EIF (rev 7) (3a)

Alternate Case—Case 2—Secondary uses of PRBs and Paper bags included

Scenario 1–One trip

Potential Environmental Impact Categories per Trip							
		(30% RC)	(0% RC)	(40% RC)	(100% RC)	-	-
Impact category	Unit	PRB	PRB	Paper	Paper	LDPE	NWPP
	No. bags	9.8	9.8	8.4	8.4	8.3	6.7
GWP	Kg CO_2 eq	0.136	0.152	0.729	0.642	1.27	2.71
Water Depletion	gal	0.0655	0.0668	2.17	0.972	0.835	9.59
Cumulative Energy Demand	MJ eq.	2.98	4.32	18.2	7.90	34.5	52.5
Terrestrial Acidification	g SO_2 eq	1.270	1.87	2.85	1.28	13.6	25.9
Freshwater Eutrophication	g P eq	0.0194	0.0197	0.156	0.053	0.187	0.231
Marine Eutrophication	g N eq	0.0834	0.0811	0.985	0.890	0.505	1.35
Human Toxicity	g 1,4-DB eq	56.10	66.1	277	99	523	1110
Terrestrial Ecotoxicity	g 1,4-DB eq	0.007	0.007	0.128	0.057	0.073	0.556
Freshwater Ecotoxicity	g 1,4-DB eq	4.18	4.02	4.96	2.68	23.8	51.8
Marine Ecotoxicity	g 1,4-DB eq	4.06	3.91	4.16	2.20	23.1	50.5
Fossil Fuel Depletion	g oil eq	59.8	88.5	178	161	706	1110
Photochemical Oxidant Formation	g NMVOC	0.340	0.402	2.27	1.320	3.79	10.6

Ref: EIF (rev 7) (4)

Potential Environmental Impact Categories for One Trip by Life Cycle Process (Alternate Case)						
	GWP (kg CO_2 eq.)					
Life Cycle Process	(30% RC)	(0% RC)	(40% RC)	(100% RC)	-	-
	PRB	PRB	Paper	Paper	LDPE	NWPP
Raw material extraction/production	0.0702	0.109	0.397	0.047	0.552	0.763
Production processes	0.0978	0.0802	0.214	0.451	0.339	1.29
Transportation	0.0247	0.0263	0.088	0.0887	0.191	0.252
Waste processing/disposal	0.0269	0.027	0.186	0.187	0.188	0.405
Avoided products	-0.0836	-0.0909	-0.157	-0.132		
	Water Depletion (gal)					
Life Cycle Process	(30% RC)	(0% RC)	(40% RC)	(100% RC)	-	-
	PRB	PRB	Paper	Paper	LDPE	NWPP
Raw material extraction/production	0.0313	0.0326	2.20	0.0853	0.404	8.64
Production processes	0.0557	0.0552	0.479	1.06	0.244	0.716
Transportation	0.0191	0.0203	0.0717	0.0731	0.154	0.156
Waste processing/disposal	0.0046	0.0046	0.0288	0.0294	0.0334	0.0799
Avoided products	-0.045	-0.0458	-0.61	-0.272		
	Fossil Fuel Depletion (g oil eq.)					
Life Cycle Process	(30% RC)	(0% RC)	(40% RC)	(100% RC)	-	-
	PRB	PRB	Paper	Paper	LDPE	NWPP
Raw material extraction/production	72.6	117	128	29.4	536	737
Production processes	27.5	21.9	68.6	145	96.4	285
Transportation	8.84	9.52	30.4	30.5	71.3	83.2
Waste processing/disposal	0.3	0.3	2.32	2.33	2.21	4.83
Avoided products	-49.5	-60.8	-51.7	-46.8		

Ref: Breakdown (rev 8)

Alternate Case—Case 2—Secondary uses of PRBs and Paper bags included

Scenario 2—Multiple trips

Potential Environmental Impact Categories per Multiple Trips

Impact category	Unit	PRB (30% RC)	PRB (0% RC)	Paper (40% RC)	Paper (100% RC)	LDPE	NWPP	PRB (30% RC)	PRB (0% RC)	Paper (40% RC)	Paper (100% RC)	LDPE	NWPP	PRB (30% RC)	PRB (0% RC)	Paper (40% RC)	Paper (100% RC)	LDPE	NWPP
	No. Trips	3.1	3.1	3.1	3.1	3.1	3.1	14.6	14.6	14.6	14.6	14.6	14.6	44	44	44	44	44	44
	No. bags	30.4	30.4	26.0	26.0	8.3	6.7	143.1	143.1	122.6	122.6	8.3	6.7	431.2	431.2	369.6	369.6	8.3	6.7
	No. uses/b	1	1	1	1	20	20	1	1	1	1	30	30	1	1	1	1	75	75
GWP	kg CO2 eq	0.422	0.471	2.26	1.99	1.27	2.71	1.99	2.22	10.6	9.37	1.27	2.71	5.98	6.69	32.1	28.2	1.27	2.71
Water Depletion	gal	0.203	0.207	6.74	3.01	0.835	9.589	0.956	0.975	31.7	14.2	0.835	9.59	2.88	2.94	95.7	42.8	0.835	9.59
Cumulative Energy Demand	MJ eq.	9.23	13.4	56.5	24.5	34.5	52.5	43.4	63.1	266	115	34.5	52.5	131	190	802	348	34.5	52.5
Terrestrial Acidification	g SO2 eq	3.94	5.80	8.84	3.97	13.6	25.9	18.5	27.3	41.6	18.7	13.6	25.9	55.9	82.3	125	56.3	13.6	25.9
Freshwater Eutrophication	g P eq	0.0601	0.0611	0.484	0.164	0.187	0.231	0.283	0.288	2.28	0.774	0.187	0.231	0.854	0.867	6.86	2.33	0.187	0.231
Marine Eutrophication	g N eq	0.259	0.251	3.05	2.76	0.505	1.35	1.22	1.18	14.4	13.0	0.505	1.35	3.67	3.57	43.3	39.2	0.505	1.35
Human Toxicity	g 1,4-DB e	174	205	859	306	523	1110	819	965	4044	1442	523	1110	2468	2908	12188	4347	523	1110
Terrestrial Ecotoxicity	g 1,4-DB e	0.0215	0.0221	0.397	0.176	0.0731	0.556	0.101	0.104	1.87	0.831	0.0731	0.556	0.306	0.314	5.63	2.50	0.0731	0.556
Freshwater Ecotoxicity	g 1,4-DB e	13.0	12.5	15.4	8.31	23.8	51.8	61.0	58.7	72.4	39.1	23.8	51.8	184	177	218	118	23.8	51.8
Marine Ecotoxicity	g 1,4-DB e	12.6	12.1	12.9	6.82	23.1	50.5	59.3	57.1	60.7	32.1	23.1	50.5	179	172	183	96.8	23.1	50.5
Fossil Fuel Depletion	g oil eq	185	274	552	499	706	1110	873	1292	2599	2351	706	1110	2631	3894	7832	7084	706	1110
Photochemical Oxidant Formation	g NMVOC	1.05	1.25	7.04	4.09	3.79	10.6	4.96	5.87	33.1	19.3	3.79	10.6	15.0	17.7	99.9	58.1	3.79	10.6

Ref: Sheet 2

Alternate Case—Case 2—Secondary uses of PRBs and Paper bags included

Scenario 3—Number of trips for equivalency

No. of Trips for Equivalency to PRB (30% RC)							
		No. of Trips					
Impact category	Unit	PRB (30% RC)	PRB (0% RC)	Paper (40% RC)	Paper (100% RC)	LDPE	NWPP
GWP	Kg CO_2 eq	1	1.1	5.4	4.7	9.3	19.9
Water Depletion	gal	1	1.0	33.2	14.8	12.7	146
Cumulative Energy Demand	MJ eq.	1	1.5	6.1	2.7	11.6	17.6
Terrestrial Acidification	g SO_2 eq	1	1.5	2.2	1.0	10.7	20.4
Freshwater Eutrophication	g P eq	1	1.0	8.0	2.7	9.6	11.9
Marine Eutrophication	g N eq	1	1.0	11.8	10.7	6.1	16.2
Human Toxicity	g 1,4-DB eq	1	1.2	4.9	1.8	9.3	19.8
Terrestrial Ecotoxicity	g 1,4-DB eq	1	1.0	18.4	8.2	10.5	80.0
Freshwater Ecotoxicity	g 1,4-DB eq	1	1.0	1.2	0.6	5.7	12.4
Marine Ecotoxicity	g 1,4-DB eq	1	1.0	1.0	0.5	5.7	12.4
Fossil Fuel Depletion	g oil eq	1	1.5	3.0	2.7	11.8	18.6
Photochemical Oxidant Formation	g NMVOC	1	1.2	6.7	3.9	11.1	31.2
Average For All Categories		**1**	**1.2**	**8.5**	**4.5**	**9.5**	**33.9**

Ref: EIF (rev 7) (4)

No. of Trips for Equivalency to Paper (40% RC)							
		No. of Trips					
Impact category	Unit	Paper (40% RC)	PRB (30% RC)	PRB (0% RC)	LDPE	NWPP	Paper (100% RC)
GWP	Kg CO_2 eq	1.0	0.2	0.2	1.7	3.7	0.9
Water Depletion	gal	1.0	0.0	0.0	0.4	4.4	0.4
Cumulative Energy Demand	MJ eq.	1.0	0.2	0.2	1.9	2.9	0.4
Terrestrial Acidification	g SO_2 eq	1.0	0.4	0.7	4.8	9.1	0.4
Freshwater Eutrophication	g P eq	1.0	0.1	0.1	1.2	1.5	0.3
Marine Eutrophication	g N eq	1.0	0.1	0.1	0.5	1.4	0.9
Human Toxicity	g 1,4-DB eq	1.0	0.2	0.2	1.9	4.0	0.4
Terrestrial Ecotoxicity	g 1,4-DB eq	1.0	0.1	0.1	0.6	4.3	0.4
Freshwater Ecotoxicity	g 1,4-DB eq	1.0	0.8	0.8	4.8	10.4	0.5
Marine Ecotoxicity	g 1,4-DB eq	1.0	1.0	0.9	5.6	12.1	0.5
Fossil Fuel Depletion	g oil eq	1.0	0.3	0.5	4.0	6.2	0.9
Photochemical Oxidant Formation	g NMVOC	1.0	0.1	0.2	1.7	4.7	0.6
Average For All Categories		**1**	**0.3**	**0.3**	**2.4**	**5.4**	**0.6**

Ref: EIF (rev 7) (4a)

Sensitivities

Secondary use of PRBs and Paper bags

Effect of Secondary Reuse Rate on GWP and Fossil Fuel Depletion of PRBs (30% RC)

Impact category	Units	One Trip				3.1 Trips				14.6 Trips				44 Trips			
% Secondary Uses		0%	20%	40%	60%	0%	20%	40%	60%	0%	20%	40%	60%	0%	20%	40%	60%
GWP	kg CO_2 eq	0.208	0.172	0.136	0.1	0.645	0.533	0.422	0.31	3.04	2.51	1.99	1.46	9.15	7.57	5.98	4.40
Fossil fuel depletion	g oil eq	138	113	88.5	63.5	428	350	274	197	2015	1650	1292	927	6072	4972	3894	2794

Effect of Secondary Reuse Rate on GWP and Fossil Fuel Depletion of PRBs (0% RC)

Impact category	Units	One Trip				3.1 Trips				14.6 Trips				44 Trips			
% Secondary Uses		0%	20%	40%	60%	0%	20%	40%	60%	0%	20%	40%	60%	0%	20%	40%	60%
GWP	kg CO_2 eq	0.231	0.191	0.152	0.113	0.716	0.592	0.471	0.350	3.37	2.79	2.22	1.65	3.37	2.79	2.22	1.65
Fossil fuel depletion	g oil eq	138	113	88.5	63.5	428	350	274	197	2015	1650	1292	927	6072	4972	3894	2794

Effect of Secondary Reuse Rate on GWP and Fossil Fuel Depletion of Paper Sacks

40 % recycle content

		One Trip			3.1 Trips			14.6 Trips			44 Trips		
		Secondary Uses			Secondary Uses			Secondary Uses			Secondary Uses		
Impact Category	Units	0%	11.05%	22.10%	0%	11.05%	22.10%	0%	11.05%	22.10%	0%	11.05%	22.10%
GWP	kg CO_2 eq	0.881	0.805	0.729	2.73	2.5	2.26	12.9	11.8	10.6	38.7	35.4	32.1
Fossil fuel depletion	g oil eq	228	203	178	707	629	552	3329	2964	2599	10032	8932	7832

100 % recycle content

		One Trip			3.1 Trips			14.6 Trips			44 Trips		
		Secondary Uses			Secondary Uses			Secondary Uses			Secondary Uses		
Impact Category	Units	0%	11.05%	22.10%	0%	11.05%	22.10%	0%	11.05%	22.10%	0%	11.05%	22.10%
GWP	kg CO_2 eq	0.769	0.705	0.642	2.38	2.19	1.99	11.2	10.3	9.37	33.8	31	28.2
Fossil fuel depletion	g oil eq	207	184	161	642	570	499	3022	2686	2351	9108	8096	7084

Ref: Sensitivities (rev 7) (2)

Sensitivities

Effects of LDPE bag thickness

Effect on Potential Environmental Impact Categories of LDPE Bag Thickness

		One Trip			3.1 Trips			14.6 Trips			44 Trips			No. Trips for Equivalency to PRB (30%)	
		PRB	LDPE	LDPE	PRB	LDPE	LDPE	PRB	LDPE	LDPE	PRB	LDPE	LDPE	LDPE	LDPE
	Units	(30% RC)	-	-	(30% RC)	-	-	(30% RC)	-	-	30% RC	-	-	-	-
Thickness	mil		2.25	4		2.25	4		2.25	4		2.25	4	2.25	4
	No. bags	9.8	8.3	8.3	30.38	8.3	8.3	143.08	8.3	8.3	431.2	8.3	8.3		
	No. uses/bag	1	1	1	1	3.1	3.1	1	14.6	14.6	1	44	44		
GWP	kg CO2 eq	0.208	1.27	2.26	0.645	1.27	2.26	3.04	1.27	2.26	9.15	1.27	2.26	6.1	10.9
Water Depletion	gal	0.107	0.835	1.48	0.332	0.835	1.48	1.56	0.835	1.48	4.71	0.835	1.48	7.8	13.9
Cumulative Energy Demand	MJ eq.	5.02	34.5	61.3	15.6	34.5	61.3	73.4	34.5	61.3	221.1	34.5	61.3	6.9	12.2
Terrestrial Acidification	g SO_2 eq	2.01	13.6	24.2	6.23	13.6	24.2	29.3	13.6	24.2	88.4	13.6	24.2	6.8	12.0
Freshwater Eutrophication	g P eq	0.0343	0.187	0.332	0.106	0.187	0.332	0.501	0.187	0.332	1.51	0.187	0.332	5.5	9.7
Marine Eutrophication	g N eq	0.0972	0.505	0.898	0.301	0.505	0.898	1.42	0.505	0.898	4.277	0.505	0.898	5.2	9.2
Human Toxicity	g 1,4-DB eq	88.3	523	930	274	523	930	1289	523	930	3885	523	930	5.9	10.5
Terrestrial Ecotoxicity	g 1,4-DB eq	0.0116	0.073	0.130	0.0360	0.073	0.130	0.169	0.073	0.130	0.51	0.073	0.130	6.3	11.2
Freshwater Ecotoxicity	g 1,4-DB eq	4.69	23.8	42.3	14.5	23.8	42.3	68.5	23.8	42.3	206	23.8	42.3	5.1	9.0
Marine Ecotoxicity	g 1,4-DB eq	4.54	23.1	41.1	14.1	23.1	41.1	66.3	23.1	41.1	200	23.1	41.1	5.1	9.0
Fossil Fuel Depletion	g oil eq	101	706	1255	313	706	1255	1475	706	1255	4444	706	1255	7.0	12.4
Photochemical Oxidant Formation	g NMVOC	0.592	3.79	6.74	1.84	3.79	6.74	8.64	3.79	6.74	26.0	3.79	6.74	6.4	11.4
Average of all categories														**6.2**	**11.0**

Ref: Sensitivities (rev 7) (2)

Sensitivities: Effects of Bag Count Variation

Effect of Bag Number Variations on Environmental Impact Factors per Trip (secondary uses not included)

		(30% RC)			(0% RC)			-			-			(40% RC)			(100% RC)		
Impact category	Unit	PRB			PRB			LDPE			NWPP			Paper			Paper		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
No. bags		9.8	9.284	10.28	9.8	9.284	10.28	8.3	7.8	8.8	6.7	6.2	7.2	8.4	7.9	8.9	8.4	7.9	8.9
GWP	Kg CO_2 eq	0.208	0.197	0.218	0.231	0.219	0.242	1.27	1.19	1.35	2.71	2.52	2.92	0.881	0.825	0.930	0.769	0.720	0.812
Water Depletion	gal	0.107	0.101	0.112	0.109	0.103	0.114	0.835	0.785	5.78	9.59	8.92	25.6	2.77	2.60	27.9	1.23	1.15	14.2
Cumulative Energy Demand	MJ eq.	5.02	4.76	5.27	6.78	6.42	7.11	34.5	32.4	364	52.5	48.8	39.6	23.4	21.9	74.8	10.1	9.49	73.1
Terrestrial Acidification	g SO_2 eq	2.01	1.90	2.11	2.76	2.61	2.90	13.6	12.8	3.47	25.9	24.1	3.57	3.65	3.420	1.39	1.63	1.53	1.43
Freshwater Eutrophication	g P eq	0.0343	0.032	0.036	0.0347	0.033	0.036	0.187	0.176	0.121	0.231	0.215	0.064	0.199	0.186	0.484	0.068	0.064	0.370
Marine Eutrophication	g N eq	0.0972	0.092	0.102	0.0951	0.090	0.100	0.505	0.475	23.8	1.35	1.26	42.3	1.07	1.00	47.7	0.946	0.886	123
Human Toxicity	g 1,4-DB eq	88.3	83.7	92.6	104	98.5	109	523	491	9114	1110	1032	5945	344	322	2852	116	109	1088
Terrestrial Ecotoxicity	g 1,4-DB eq	0.0116	0.011	0.012	0.012	0.011	0.012	0.073	0.069	0.001	0.556	0.517	0.004	0.163	0.153	0.004	0.0719	0.067	0.005
Freshwater Ecotoxicity	g 1,4-DB eq	4.69	4.44	4.92	4.52	4.28	4.74	23.8	22.4	2865	51.8	48.2	674	6.14	5.75	334	3.22	3.02	397
Marine Ecotoxicity	g 1,4-DB eq	4.54	4.30	4.76	4.38	4.15	4.59	23.1	21.7	8.54	50.5	47.0	7.05	5.14	4.82	7.43	2.62	2.45	7.22
Fossil Fuel Depletion	g oil eq	101	95.7	106	138	131	145	706	663	269	1110	1032	159	228	214	393	207	194	701
Photochemical Oxidant Formation	g NMVOC	0.592	0.561	0.621	0.661	0.626	0.693	3.79	3.56	0.047	10.6	9.86	0.069	2.87	2.69	0.112	1.65	1.55	0.071

Effect of Bag Number Variations on Environmental Impact Factors per Trip (secondary uses included)

		(30% RC)			(0% RC)			-			-			(40% RC)			(100% RC)		
Impact category	Unit	PRB			PRB			LDPE			NWPP			Paper			Paper		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
No. bags		9.8	9.284	10.28	9.8	9.284	10.28	8.3	7.8	8.8	6.7	6.2	7.2	8.4	7.9	8.9	8.4	7.9	8.9
GWP	Kg CO_2 eq	0.136	0.129	0.143	0.152	0.144	0.159	1.27	1.193	1.347	2.71	2.520	2.924	0.729	0.683	0.770	0.642	0.601	0.678
Water Depletion	gal	0.0655	0.062	0.069	0.0668	0.063	0.070	0.835	0.785	5.78	9.59	8.92	25.6	2.17	2.04	26.5	0.972	0.911	13.4
Cumulative Energy Demand	MJ eq.	2.98	2.82	3.12	4.32	4.09	4.53	34.5	32.4	364	52.5	48.8	39.6	18.2	17.1	74.4	7.90	7.40	72.1
Terrestrial Acidification	g SO_2 eq	1.270	1.20	1.33	1.87	1.77	1.96	13.6	12.8	3.47	25.9	24.1	3.57	2.85	2.67	1.39	1.28	1.20	1.44
Freshwater Eutrophication	g P eq	0.0194	0.018	0.020	0.0197	0.019	0.021	0.187	0.176	0.121	0.231	0.215	0.064	0.156	0.146	0.486	0.053	0.050	0.367
Marine Eutrophication	g N eq	0.0834	0.079	0.087	0.0811	0.077	0.085	0.505	0.475	23.8	1.35	1.26	42.3	0.985	0.923	56.0	0.890	0.834	149
Human Toxicity	g 1,4-DB eq	56.1	53.1	58.8	66.1	62.6	69.3	523	491	9114	1110	1032	5945	277	260	2494	99	92.6	985
Terrestrial Ecotoxicity	g 1,4-DB eq	0.007	0.007	0.007	0.007	0.007	0.007	0.073	0.069	0.001	0.556	0.517	0.004	0.128	0.120	0.004	0.057	0.053	0.005
Freshwater Ecotoxicity	g 1,4-DB eq	4.18	3.96	4.38	4.02	3.81	4.22	23.8	22.4	2865	51.8	48.2	674	4.96	4.65	344	2.68	2.51	418
Marine Ecotoxicity	g 1,4-DB eq	4.06	3.85	4.26	3.91	3.70	4.10	23.1	21.7	8.54	50.5	47.0	7.05	4.16	3.90	7.44	2.20	2.06	7.28
Fossil Fuel Depletion	g oil eq	59.8	56.7	62.7	88.5	83.8	92.8	706	663	269	1110	1032	159	178	167	380	161	151	649
Photochemical Oxidant Formation	g NMVOC	0.340	0.322	0.357	0.402	0.381	0.422	3.79	3.56	0.047	10.6	9.86	0.069	2.27	2.13	0.113	1.32	1.24	0.073

Annex F—Litter Data

Keep America Beautiful in 2008 sponsored a comprehensive study of litter that included among other topics a major effort to measure the quantity and composition of litter along roadways of all types around the country and at a wide variety of non-roadway sites. The study is referred to as the "KAB 2009 Study." (MSW Consultants, 2009) The study measured litter by the number of pieces found, not by weight. It differentiated litter item by size—less than or greater than four inches. It categorized litter in a large number of specific categories, depending on source, material and other factors.

Significant to the present report is that the KAB 2009 Study categories included two specific categories in which grocery bags would have fallen (MSW Consultants, 2009, Appendix A):

> Plastic Bags—Plastic trash bags, and plastic grocery, and other merchandise shopping bags used to contain merchandise to transport from the place of purchase, given out by the store with the purchase (including dry cleaning bags).
>
> Kraft bags—Paper bags and sheets made from Kraft paper. Examples include paper grocery bags, fast food bags, department store bags, and heavyweight sheets of Kraft packing paper.

PRBs and LDPE bags would therefore fall in the "Plastic Bags" category and Paper Bags would fall in the "Kraft bag" category. NWPP bags are not specifically mentioned, but presumably would have been included in "Other – Textiles/Rugs."

The most prevalent categories of litter found at all types of sites were cigarette butts and confection wrappers. Neither category of bags is among the top-ten litter items found on U.S. roadways, in sizes either greater or less than four inches. Although other categories of paper and plastic are very prevalent in the litter counted, neither "Plastic Bags" nor "Kraft Bags" as categories are mentioned anywhere in the charts and tables summarizing roadway litter. (MSW Consultants, 2009, Sections 3.1 and 3.2)

Six non-roadway areas were evaluated in the KAB 2009 Study. These included: transition points (such as bus stops and building entrances); loading docks; storm drains; retail areas; recreational areas (parks, beaches, etc.); and construction sites. "Plastic Bags" were 0.9% of the visible litter found at storm drains. This is equivalent to an average of 0.2 items in the Plastic Bag category per average storm drain (120 square feet). "Plastic Bags" were also identified at a rate of 3/1000 square feet of Retail Area. (MSW Consultants, 2009, pages 3-30–3-34)

The "Kraft Bag" category is not specifically mentioned in any of the charts and tables summarizing non-roadway observations.

One of the principal investigators who designed and managed the KAB 2009 Study for Keep America Beautiful has issued a report brief focusing specifically on PRBs. (Stein, ER Planning Report Brief: Plastic Retail Bags in Litter, 2013) Going deeper into the KAB 2009 Study data revealed that "Plastic Bags" were only 0.6% of all the litter identified in the study. It is important to recognize that, as defined, PRBs are only one component of the defined category (see above).

The same report brief summarizes the results of an analysis of many if not all of the national, city and state litter surveys published between 1994 and 2012. The report brief identifies those studies that were conducted with statistically-based scientific methodologies, "conducted with scientific rigor using trained professionals." The table of results from the report brief is reproduced below.

Retail Plastic Bags in Recent Litter Surveys

#	Survey	Year	Percent	#	Survey	Year	Percent
1	Toronto	2012	0.8%	11	Durham	2003	0.3%
2	Edmonton	2011	1.1%	12	Peel	2003	0.1%
3	Alberta	2009	0.0%	13	York	2003	0.4%
4	San Francisco	2008	0.6%	14	Toronto	2002	0.6%
5	San Jose	2008	0.4%	15	Florida	2002	0.5%
6	KAB	2008	0.6%	16	Florida	2001	0.7%
7	Alberta	2007	2.0%	17	Florida	1997	0.6%
8	San Francisco	2007	0.6%	18	Florida	1996	1.0%
9	Toronto	2006	0.1%	19	Florida	1995	0.7%
10	Toronto	2004	0.2%	20	Florida	1994	0.6%

Retail Plastic Bags in Recent Litter Surverys

In summary, neither plastic bags nor Kraft bags are a significant component of roadway litter. Plastic bags, which includes trash bags, grocery bags, retail bags and dry cleaning bags, are a very small component of litter found in storm drains and around retail areas. A compilation of all of the statistically-based, scientific studies of litter in the U.S. and Canada over an 18 year period shows consistently that "plastic bags" make up a very small portion of litter, usually less than 1%.

Annex G—Bacterial and Viral Contamination of LDPE and NWPP Bags

Reusable bags, whatever their composition, are subject to contamination from viruses and bacterial spores transferred from food products. Bacteria need water to survive and grow, so wet food products, especially those where fluid leakage or water condensation are possibilities require specific attention. These include many meat and dairy products. Even if meat and dairy products are placed in light-weight plastic bags prior to being placed in the reusable bag, as suggested by the Minnesota Department of Health (Minnesota Department of Health, 2010), viruses and bacterial spores can be transferred to reusable bags from bagging station conveyor belts, from shopping carts or from store shelves. Additional contamination of all kinds can occur when reusable bags are used for non-food items and then reused. Some potential problems: wet or dirty clothes, bathing suits, shoes, live plants—the list is endless.

Los Angeles County has recognized the problem. Here is what their web site advises consumers:

> • Remember to clean/wash your reusable bags frequently.
> • Follow the care instructions on the tag of the bag. Most cloth and fabric bags can be machine washed, while durable plastic bags should be wiped clean.
> • Allow bags to dry before folding and storing.
> • Set aside specific reusable bags for packing groceries and use separate bags for raw meat products, being careful with where they are stored. (County of Los Angeles Department of Public Works, Environmental Programs Division, 2012)

The U.S. Department of Health and Human Services echoes this advice, stating "Wash reusable grocery bags often." (U. S Dept. of Health and Human Services, 2012)

Unfortunately, in the opinion of the authors, the reasons for these cautions are not stated. Real world examples have been documented and are discussed below.

A study was conducted in Toronto, Canada, by three independent research labs and interpreted by Dr. Richard Summerbell, Director of Research at Sporometrics, Inc. As part of the study, 24 reusable bags and 4 control bags (reusable bags that had not previously been used) were cultured for total bacterial count, coliform and yeast and mold counts. Most of the bags had been used for 1 to 3 months. 52% of the bags were used for multiple purposes—other items as well as groceries. 42% of the bags were used every day. 64% of the bags showed some level of microbial contamination. One bag (used for two years) measured 300,000 colony forming units (CFU) taken from 16 square inches of bag. The safe level established for drinking water is 500 CFU. Yeasts or molds were found on 37.5% of the bags. Two bags, both of which had been used for over one year and/or had contained packaged meat that had leaked onto the surface of the bag, showed positive identification of coliform bacteria. Coliforms are found in the feces of warm-blooded animals and are an indicator that other pathogenic organisms of fecal origin may be present. *E. coli* is a member of the coliform group.

According to Summerbell, the cross-contamination of food contained in bags with bacterial contamination was not tested but it could be easily postulated that if a wet food product (such as a lettuce leaf) brushed the surface of a bag with even a low level of contamination, the food product would easily pick up the microorganisms which could increase in population based on the dark, moist and warm conditions inside the bag. Overall, the study proved that reusable bags, particularly those which are used frequently and for over six months, can become contaminated with microorganisms and that bags could serve as a vehicle to transfer bacteria of foodborne significance (coliforms) to foods contained within. "Almost all" of the people who surrendered their bags for the study indicated that they never washed their reusable bags. (Summerbell, 2009)

Repp and Keene determined that a reusable grocery bag was the source of an outbreak of Norovirus experienced by 9 members of a soccer team. A soccer tournament was held in King County, Washington, USA where team members who attended the tournament stayed in a hotel in which the reusable bag was stored in the bathroom. The bag contained grapes, potato chips and cookies used by the people who became ill. It was determined that one of the people in the group arrived to the tournament with symptoms consistent with Norovirus-like illness. The mode of transfer of the virus to the bag was not specifically determined but it is known that the virus can become airborne. Therefore, it was possible for a person who was carrying the virus to enter the bathroom and through vomiting or flushing a toilet containing feces from an episode of diarrhea, passed the virus onto the bag surface. Other members entering the bathroom could have touched the bag and picked up the virus. The study clearly established the bag as the vehicle for passing the virus to the other people sharing the hotel bathroom. In addition, the study indicated that "the food contained within the bag was strongly associated with the illness as was handling the bag." (Repp & Keene, 2012)

Gerba, Williams and Sinclair (Gerba, Williams, & Sinclair, 2010) performed a three-part study: (1) measure the extent to which reusable grocery bags were contaminated with bacteria; (2) perform experiments that would demonstrate the potential to which reusable bags could serve as a source of cross-contamination; and (3) test the effectiveness of washing bags to reduce contamination. Here are their conclusions and recommendations:

- Consumers almost never wash reusable bags [97% of study participants never wash their reusable bags]
- Large numbers of bacteria were found in every reusable bag, but none in new bags or plastic bags
- Coliform bacteria including E. coli were found in half of the bags tested
- Bacteria were capable of growth when stored in the trunks of cars

- A potential significant risk of bacterial cross-contamination exists from using reusable bags to carry groceries
- Hand or machine washing reduced the numbers of bacteria in reusable bags by >99.9% (water temperature not specified)
- Requiring printed instructions on reusable bags that they be washed between uses or the need to separate raw foods from other food products

Many grocery stores are now providing or using a lightweight HDPE bag (2.5 gm) inside paper bags and reusable bags to contain raw foods. Some are using these bags in PRBs as well. Other stores are using PRBs inside paper bags and reusable bags to contain raw foods. Although use of these inner bags may avoid contamination of the inside surfaces of the carryout bags, they will not prevent the types of external contamination noted at the beginning of this Annex.

The recent Reusable Bag Study, released by Edelman Berland in May 2014 (Edelman Berland, 2014), surveyed consumer's practices for cleaning NWPP bags, as well as studying reuse.

According to this study, consumers reported that the average age of their oldest NWPP bag was 2.0 years. The chart shown in Figure G.1, reproduced from the study, summarizes consumers' cleaning practices for their NWPP bags.

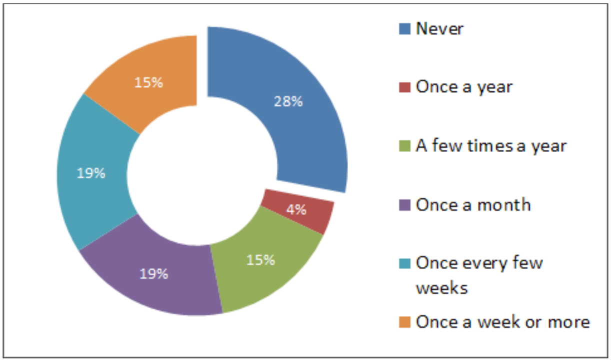


Figure G.1 Consumer responses to the question "How often do you clean your NWPP bags?"

The advice cited at the beginning of this Annex counsels washing reusable bags "frequently" or "often." If this advice is interpreted as "once a week or more," Edelman Berland's survey found that only 15% of people using NWPP bags follow this advice. As shown in Figure G.1, they found that 28% of people have never washed their NWPP bags.

Annex H—Panel Review Report and Comments

Final statement from the critical review panel of the LCA study "Life Cycle Assessment of Grocery Bags in Common Use in the United States"

Dear Dr. Kimmel and Team,

The critical review panel has reviewed the most recent version of your LCA study, dated June 14, 2014. As a panel, our role is ensuring conformance to ISO 14044, and providing recommendations/suggestions towards the improvement of the study based on our expertise. The panel utilized ISO 14044 to assess for conformance, and their knowledge of LCA and packaging materials to critically review the LCA study. The panel also recognizes the considerable research, data collection and data modeling that went into the study and its authors' openness to suggestions for improvement during the review process. The panel would like to report that this study is vastly improved compared to the previous version and that it conforms to ISO 14044 for the purpose of making comparative assertions to be communicated to the public. The panel's comments are categorized into (1) editorial issues that could lead to miscommunication/misinterpretation, and (2) substantive issues that affect the outcomes of the study.

It must be noted that addressing all recommendations/suggestions of the panel does not constitute endorsement of the conclusions/recommendations by the panel. Further, it is not the role of a peer review panel to make such an endorsement. Rather, we believe that your team has presented the LCA model, the results, and included sufficient citations and disclosures to allow a reader to reach an informed opinion about your assertions and conclusions.

In general, editorial issues such as typos, repeated words, and defining acronyms remain an issue in the document. It would benefit the reader to have the document professionally proofread before it is published.

Listed below are the comments/recommendations of the panel:

Editorial issues that could lead to miscommunication/misinterpretation

a. **P. 6. Executive summary.** Rephrase the statement "Comparison of number of reuses of NWPP bags that 20% of people exceed", such that it clear to the reader.

b. **P. 8, Fig. X.5 and X.6 –** the caption within the figures says "per Multiple Trips" which could easily be interpreted as indicating that these are "per trip" values when they are actually totals. The panel suggests the use of the phrase "for Multiple Trips" instead, which is what appears in the body of the report and the figure legend.

- **c. P. 10. Executive summary.** The numbers for water depletion numbers (NWPP) and terrestrial ecotoxicity appear odd. The panel suggests providing additional information explaining the causes for the high values.
- **d. P. 11 paragraph** beginning under table, the phrase "increase of about 25% for Paper bags for the reusable…" is confusing and must be rephrased. This same statement is repeated on p. 96.
- **e. P. 11. Paragraph** A statement in the executive summary reads: "Table X.5 shows that the inclusion of secondary uses for PRBs and Paper bags in the models for calculating the environmental impact categories results in a decrease in the average for all environmental impact categories of about 8% for PRBs, an increase of about 1% for Paper (100% RC) and an increase of about 25% for Paper bags for the reusable bags LDPE and NWPP." The panel recommends that this paragraph be rephrased to address grammatical and logic issues.
- **f. P. 14, 4th bullet, statement** "consumers, by their behavior, do not believe LDPE bags are as convenient or as durable as NWPP bags" should be cited or removed. The panel recommends that the authors not attribute attitudes and beliefs to consumers, when no reference is provided.
- **g. P. 21.** Descriptions of bags – PRBs – the bag weight of 6.2 g is presented as an absolute. The panel suggests rephrasing the appropriate statements akin to "the bags were modeled as having this weight (and that, presumably, it is an average based on some data – which needs to bespecified)"
- **h. P. 19. Section 1.2** implies that LCA is purely objective, which it is not. LCA includes many value judgments in the modeling choices. The panel recommends that the authors include the required ISO language (ISO 14044, p. 30) "a statement that the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks".
- **i. p. 33, Table 3.9.** No "Library" is listed for paper recycling or plastic recycling. One of the inherent difficulties with this LCA is that the plastic recycling portion of the analysis is based largely on confidential data and therefore cannot be examined (or replicated). The panel recommends that this fact should be made clear in the discussion, and the paper "library" should be added to the table
- **j. p. 47, section 4.5.1, 2nd paragraph.** The panel does not understand the relevance of this paragraph. Please rephrase to communicate the intended relevance of this paragraph.

  Additionally, this paragraph brings to focus the "tone" issue that was discussed in length in the previous versions of this study.
- **k. P. 92, next to last bullet**, add "and terrestrial ecotoxicity" at the end.
- **l. P. 97. Table 5.5** should be renamed as Table 5.6.
- **m. P. 108**. The graphs "with" and "without" secondary uses appear to be identical. This makes it difficult for the reader to evaluate the stated conclusions. Please make the necessary adjustments such that clarity is ensured.
- **n. P. 111, Fig. 6.16**. The readers would appreciate if the authors explained the relationship of this figure to Fig. 5.3.1, to aid the reader

- **o. P. 124**. It appears that the bars for NWPP get slightly larger with decreasing trip numbers, when they should all be identical. Please recheck the numbers and ensure clarity in the graph.
- **p. P. 127, paragraph under Table 8.2.** The statistical analysis showed that there is high confidence that there are differences in the number of bags used by type. The statistical analysis did not show "that the average numbers of bags/type are statistically accurate to a 95% level of confidence." This misstatement must be rephrased to reflect the correct interpretation of the statistical analysis.
- **q. P. 128.** The two bullets are difficult to comprehend and therefore require rephrasing. The first bullet refers to comparing "the minimum number of one bag type to the maximum number of another type" and the second to "comparing the maximum number of one bag type to the minimum number of another type" – how do the two bullets differ from each other? The panel also recommends that the relevant data and the comparisons be provided in the report (appendix, if need be).
- **r. P. 136**. statement "Almost all of the regulations now in place or being considered in the United States encourage consumers to use reusable bags through banning PRBs and imposing a fee on the use of Paper bags." Please provide relevant citations for this statement and revise if appropriate; see link for example: http://www.dep.state.fl.us/waste/retailbags/pages/map_USA.htm.

Substantive issues that affect the outcomes of the study

- **a. P. 28.** The author's descriptions of the ANOVA results appear to be misleading. The panel interprets that two levels of confidence are mixed. The panel suggests that the authors state either (1) the authors are confident at the 99.99% level that there is a difference in the average number of bags used for the various bag types, or, (2) the authors fond statistical significance in this difference at the 95% confidence level – currently, both statements are mixed together.
- **b. P. 40–41.** It's clear in the report that cotton thread is a major part of the impacts for the NWPP bag. The authors have cited values from other studies (0.9 g cotton thread per bag, and 0.5 g of unspecified thread per bag) and have used the 0.9 g per bag value without any justification. The panel recommends a sensitivity analysis be performed for thread amount (or type) used or include a section under uncertainty on the rationale for a lack of analysis and a discussion of its implications.
- **c. P. 45.** The discussion on recycling rates for paper bags requires more clarity—especially the last sentence. The authors state that they use the 49.5% recycling rate reported by EPA for bags and sacks. At the same time, the authors also state "75.4% recycle rate was used for all paperboard containers and packaging, under the assumption that supermarkets do not in general separate corrugated boxes from other paper and paperboard recyclables". It is understood from the flow charts that the authors used the 75.4% rate instead of the 91% rate for recycling

of corrugated boxes. The panel recommends that this choice be made explicit, appropriate justification provided and that the relevant sentences be rephrased for more clarity.

d. **P. 58**. The statement that marine eutrophication is not reduced is in contradiction to the graph, where it does go down somewhat, just not as much as for freshwater. Please check the numbers and edit the statement as necessary.

e. **P. 128.** The paragraph after the bullets is difficult to comprehend and require rephrasing. The panel fails to understand how a "10-11% reduction" could not "affect the conclusions" as changes in values will affect the calculation of number of reuses required for equivalency. The statement about "increase in these values would reinforce the conclusions" is similarly unclear and contradicting.

The panel wishes you success in publishing this study and allowing decision makers to make informed choices. To reiterate, this LCA study conforms to ISO 14044 for the purpose of making comparative assertions to be communicated to the public.

Sincerely,
Vairavan (Vee) Subramanian, Panel Chair

For the critical review panel composed of:
Vee Subramanian, PRé North America subramanian@pre-sustainability.com
Susan Selke, Michigan State University sselke@anr.msu.edu
Katherine O'Dea, GreenBlue katherine.odea@greenblue.org

Authors'/Investigators' Response to Review Panel Final Statement

The authors/investigators are very appreciative of the substantial time, effort and energy invested by the members of the review panel in the ISO 14044 review process. We also appreciate their patience in explaining to us details of the ISO regulations and review process with which we were not familiar. We are especially grateful for their attention to detail and commitment to excellence that has had a very positive impact on the organization, quality and accuracy of this report.

We have responded to each of the detailed issues enumerated in the Final Statement. Most of the issues are editorial in nature. A few required more investigation. In the end, we believe that none of them has a substantial effect on the conclusions of our study.

Following are the issues raised and our detailed responses (in italics).

a. **P. 6. Executive summary.** Rephrase the statement "Comparison of number of reuses of NWPP bags that 20% of people exceed", such that it clear to the reader. *Statement has been reworded.*

b. **P. 8, Fig. X.5 and X.6–**the caption within the figures says "per Multiple Trips" which could easily be interpreted as indicating that these are "per trip" values when they are actually totals. The panel suggests the use of the phrase "for Multiple

Trips" instead, which is what appears in the body of the report and the figure legend. *The figures have been recaptioned as suggested.*

c. **P. 10. Executive summary.** The numbers for water depletion numbers (NWPP) and terrestrial ecotoxicity appear odd. The panel suggests providing additional information explaining the causes for the high values. *An explanation has been added.*

d. **P. 11 paragraph** beginning under table, the phrase "increase of about 25% for Paper bags for the reusable…" is confusing and must be rephrased. This same statement is repeated on p. 96. *These typographical errors have been corrected.*

e. **P. 11. Paragraph** A statement in the executive summary reads: "Table X.5 shows that the inclusion of secondary uses for PRBs and Paper bags in the models for calculating the environmental impact categories results in a decrease in the average for all environmental impact categories of about 8% for PRBs, an increase of about 1% for Paper (100% RC) and an increase of about 25% for Paper bags for the reusable bags LDPE and NWPP." The panel recommends that this paragraph be rephrased to address grammatical and logic issues. *This paragraph has been rewritten.*

f. **P. 14, 4th bullet, statement** "consumers, by their behavior, do not believe LDPE bags are as convenient or as durable as NWPP bags" should be cited or removed. The panel recommends that the authors not attribute attitudes and beliefs to consumers, when no reference is provided. *This statement has been rewritten to include the actual consumer data.*

g. **P. 21.** Descriptions of bags–PRBs–the bag weight of 6.2 g is presented as an absolute. The panel suggests rephrasing the appropriate statements akin to "the bags were modeled as having this weight (and that, presumably, it is an average based on some data–which needs to bespecified)" *The statement has been reworded to specify that the authors measured the weights of the bags used on the study.*

h. **P. 19. Section 1.2** implies that LCA is purely objective, which it is not. LCA includes many value judgments in the modeling choices. The panel recommends that the authors include the required ISO language (ISO 14044, p. 30) "a statement that the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks". *The suggested statement has been added.*

i. **p. 33, Table 3.9.** No "Library" is listed for paper recycling or plastic recycling. One of the inherent difficulties with this LCA is that the plastic recycling portion of the analysis is based largely on confidential data and therefore cannot be examined (or replicated). The panel recommends that this fact should be made clear in the discussion, and the paper "library" should be added to the table. *The requested changes have been made.*

j. **p. 47, section 4.5.1, 2nd paragraph.** The panel does not understand the relevance of this paragraph. Please rephrase to communicate the intended relevance of this paragraph.

Additionally, this paragraph brings to focus the "tone" issue that was discussed in length in the previous versions of this study. *This paragraph has been deleted.*

k. **P. 92, next to last bullet**, add "and terrestrial ecotoxicity" at the end. *The statement is correct as originally written.*

l. **P. 97. Table 5.5** should be renamed as Table 5.6. *The Table number has been changed.*

m. **P. 108**. The graphs "with" and "without" secondary uses appear to be identical. This makes it difficult for the reader to evaluate the stated conclusions. Please make the necessary adjustments such that clarity is ensured. *The correct graphs have been substituted and discussion added.*

n. **P. 111, Fig. 6.16**. The readers would appreciate if the authors explained the relationship of this figure to Fig. 5.3.1, to aid the reader *An explanatory footnote has been added.*

o. **P. 124**. It appears that the bars for NWPP get slightly larger with decreasing trip numbers, when they should all be identical. Please recheck the numbers and ensure clarity in the graph. *This Excel artifact has been corrected.*

p. **P. 127, paragraph under Table 8.2.** The statistical analysis showed that there is high confidence that there are differences in the number of bags used by type. The statistical analysis did not show "that the average numbers of bags/type are statistically accurate to a 95% level of confidence." This misstatement must be rephrased to reflect the correct interpretation of the statistical analysis. *The paragraph has been changed to provide the correct interpretation.*

q. **P. 128.** The two bullets are difficult to comprehend and therefore require rephrasing. The first bullet refers to comparing "the minimum number of one bag type to the maximum number of another type" and the second to "comparing the maximum number of one bag type to the minimum number of another type"—how do the two bullets differ from each other? The panel also recommends that the relevant data and the comparisons be provided in the report (appendix, if need be). *A clearer explanation has been provided. The relevant data have been added to Annex E.*

r. **P. 136**. statement "Almost all of the regulations now in place or being considered in the United States encourage consumers to use reusable bags through banning PRBs and imposing a fee on the use of Paper bags." Please provide relevant citations for this statement and revise if appropriate; see link for example: http://www.dep.state.fl.us/waste/retailbags/pages/map_USA.htm. *The statement is correct. Citations are provided.*

Substantive issues that affect the outcomes of the study

a. **P. 28.** The author's descriptions of the ANOVA results appear to be misleading. The panel interprets that two levels of confidence are mixed. The panel suggests that the authors state either (1) the authors are confident at the 99.99% level that there is a difference in the average number of bags used for the various bag types, or, (2) the authors fond statistical significance in this difference at the 95% confidence level–currently, both statements are mixed together. *This is essentially the same issue raised in Issue p above. The paragraph has been reworded to provide the correct interpretation.*

b. **P. 40–41.** It's clear in the report that cotton thread is a major part of the impacts for the NWPP bag. The authors have cited values from other studies (0.9 g cotton thread per bag, and 0.5 g of unspecified thread per bag) and have used the 0.9 g per bag value without any justification. The panel recommends a sensitivity analysis be performed for thread amount (or type) used or include a section under uncertainty on the rationale for a lack of analysis and a discussion of its implications. *The weight of cotton thread in a typical bag was measured and compared with the data used from the UK study (see Section 4.2 NWPP bags and footnote 20). The 0.5g data from the Muthu and Li study has been deleted, since there is not enough information provided to validate a comparison with the NWPP bags used in the present study.*

c. **P. 45.** The discussion on recycling rates for paper bags requires more clarity—especially the last sentence. The authors state that they use the 49.5% recycling rate reported by EPA for bags and sacks. At the same time, the authors also state "75.4% recycle rate was used for all paperboard containers and packaging, under the assumption that supermarkets do not in general separate corrugated boxes from other paper and paperboard recyclables". It is understood from the flow charts that the authors used the 75.4% rate instead of the 91% rate for recycling of corrugated boxes. The panel recommends that this choice be made explicit, appropriate justification provided and that the relevant sentences be rephrased for more clarity. *All of the suggested changes have been made. The data used have not been changed, since the authors continue to believe that their choices are justified.*

d. **P. 58**. The statement that marine eutrophication is not reduced is in contradiction to the graph, where it does go down somewhat, just not as much as for freshwater. Please check the numbers and edit the statement as necessary. *The numbers are correct. The statement has been edited.*

e. **P. 128.** The paragraph after the bullets is difficult to comprehend and require rephrasing. The panel fails to understand how a "10-11% reduction" could not "affect the conclusions" as changes in values will affect the calculation of number of reuses required for equivalency. The statement about "increase in these values would reinforce the conclusions" is similarly unclear and contradicting. *See issue q above*.

Annex I

Acknowledgements

The authors gratefully acknowledge the support of this project by Hilex Poly Co., LLC through the Clemson University Office of Sponsored Research. The authors thank Anna Miller and Marcus Mrazeck for their help with the literature search and grocery packing study, as well as Natalie Quin, Isaac Levin and Alyshia Becco for assisting with the grocery packing study.

The authors are indebted to Clemson University Press for making possible the online publication of their work. Thanks to the following persons at Clemson University Press: executive editor Wayne Chapman, managing editor John Morgenstern, editorial assistant Teneshia Head, and especially layout and web designer Charis Chapman.

Author biographies

Robert M. Kimmel (Principal Investigator) is Associate Professor of Packaging Science at Clemson University and Director of the Clemson University Center for Flexible Packaging. Dr. Kimmel received the Doctor of Science degree in Materials Engineering, as well as B.S., M.S. and Materials Engineer degrees, from the Massachusetts Institute of Technology. During more than thirty years with the Hoechst Celanese Corporation, he had position responsibilities almost equally split among New Business Development, Sales and Marketing, and Research and Development. Over twenty years of this experience was in the packaging industries.

Since joining the Clemson faculty in 1999, he has taught undergraduate and graduate courses in polymers, flexible packaging and package design and development, and supervised research in synthetic and bio-based polymers, flexible package design and sustainable package development. He is widely sought as an expert witness for intellectual property and product liability litigation in flexible and rigid plastic packaging, paperboard and corrugated packaging and plastics. He holds seven patents and has published and presented numerous papers in the fields of polymers, fibers and packaging.

Kay D. Cooksey (Co-principal Investigator) is a Professor and holds the Cryovac Endowed Chair in Packaging Science at Clemson University. Dr. Cooksey received her B.S. in Food Science from Purdue University, M.S. in Industrial Mechanical Technology, with emphasis in Packaging Technology from Indiana State University and Ph.D. in Foods and Nutrition from University of Illinois-Urbana Champagne.

She joined the faculty at Clemson University in October 1998 after working at University of Wisconsin-Stout for 5 1⁄2 years. Dr. Cooksey was a faculty intern at Dupont Packaging and Industrial Polymers Division and had the honor of receiving the Reister-Davis Lifetime Achievement Award from the Food Packaging Division of the Institute of Food Technologists in 2010. Her research focuses on food and packaging interactions and includes active packaging (specifically antimicrobial), biopolymer packaging, shelf life studies and sustainable packaging.

Allison Littman is the principal consultant at Sustainable Ally with experience in life cycle assessment (LCA) tools and software, sustainable manufacturing and supply chain management, and environmental certifications, claims, and marketing.

She studied Packaging Science and Environmental Engineering at Clemson University and completed an M.S. degree in Sustainable Design and Construction at Stanford University. Her research experience has included developing natural resource management tools at Hewlett-Packard Laboratories, mapping out mass and energy flows on the Clemson campus to identify improvement opportunities, and evaluating packaging sustainability claims by performing field tests for biodegradability and compostability.