Environmental and Economic Highlights of the Results of the Life Cycle Assessment of Shopping Bags

RECYC-QUÉBEC December 2017

This document summarizes the results of the environmental and economic life cycle analysis (LCA) of shopping bags ordered by RECYC QUÉBEC and carried out by the Centre international de référence sur le cycle de vie des produits, procédés et services (CIRAIG).

The objective of the study was to evaluate the potential environmental impacts and costs of the different types of shopping bags present in Quebec.

The results of this study provide a scientific, objective and comprehensive basis on which municipalities considering the banning of conventional plastic bags can make an informed decision.

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Québec

Bag categories and types

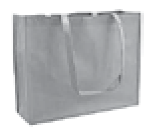
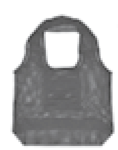
Nine types of shopping bags identified and grouped into two categories were submitted for study.

The environmental profile of the bag life cycle has been established according to four environmental indicators: human health, ecosystem quality, use of fossil resources and abandonment in the environment.

Disposable "or" single-use "bags
Designed to be used only once to carry groceries.

Category	Type of bag	Features
	Conventional plastic	▪ High-density polyethylene (HDPE) ▪ Plastics # 2 ▪ Strapless ▪ 17 microns ▪ Made in Canada
	Oxodegradable Plastic	▪ High-density polyethylene (HDPE) ▪ Plastics # 2 ▪ Strapless ▪ 17 microns ▪ Made in Canada
	Compostable bioplastic	▪ Starch-polyester blend ▪ Straps ▪ 20 microns ▪ Made in United States
	Thick Plastic	▪ Low density polyethylene (LDPE) ▪ Plastic # 4 ▪ 50 microns ▪ With cut-out handles ▪ Made in Québec
	Paper	▪ Unbleached kraft paper ▪ Made in the United States from partially recycled fibre

Bags known as "reusable" bags
Designed to be used for larger shopping. Generally larger and more robust than disposable bags.

Category	Type of bag	Features
	Woven PP	▪ Polypropylene (PP) ▪ Plastic # 5 ▪ Made in China
	Non-woven PP	▪ Polypropylene (PP) ▪ Plastic # 5 ▪ Made in China ▪ Made from 100% post-consumer recycled plastic
	Cotton	▪ Made in China
	Eco-designed bag (Credo bag)	▪ Polyethylene (PE) ▪ Plastic # 1 ▪ Made in Québec (Montréal) ▪ Made from 100% recycled content

Summary of LCA Results - Disposable Bags

For disposable bags, the results of the study illustrated in the table below tell us about the potential impacts alternative or replacement bags have on the environment compared to the conventional plastic 17 micron HDPE bag. Namely are the possible replacement bags equivalent to or weaker environmentally than those of the conventional 17 micron HDPE bag used just once. The conventional plastic HDPE thin plastic bag is the reference bag (17 microns).

LCA Results for Disposables: The bioplastic bag and thick plastic bag have impact scores 2 to 11 times and 4 to 6 times greater respectively than the conventional bag. The paper bag is the least performing bag with 4 to 28 times greater potential impacts than the conventional plastic bag.

Environmental Performance Among the Five Disposable Bags studied.

	Human Health	Quality of ecosystem	Use of fossil resource	Abandonment of the environment
Conventional Plastics	Low	Low	Low	High
Oxodegradable	Low	Low	Low	High
Bioplastics	High	High	Medium	Low
Thick Plastics	Medium	Medium	High	High
Paper	High	High	High	Low

Low impact   Medium impact   High impact

The conventional plastic bag made of thin HDPE is the one with the least environmental impacts among the five disposable bags studied, grouping together the oxodegradable plastic bag, the compostable bioplastic bag, the thick plastic bag and the paper bag. The conventional plastic bag has more environmental impact when abandoned in the environment.

The conventional plastic bag has several environmental and economic advantages. Thin and light, its production requires little material and energy. It also avoids the production and purchase of garbage/bin liner bags since it benefits from a high reuse rate when reused for this purpose (77.7%).

The weakness of this type of bag is related to abandonment in the environment. It's very slow to degrade because of the persistence of plastic (polyethylene). Disposable bags made of source plant materials (such as the compostable bioplastic bag from starch-polyester type and the paper bag) have the advantage of being a limited nuisance when abandoned in the environment.

The oxodegradable bag, on the other hand, does not offer an environmental advantage when compared to its non-degradable equivalent the conventional plastic bag; its life cycle being nearly equal to identical. Except that when it is abandoned in the environment, the oxodegradable bag is subject to an environmental accelerated fragmentation into polyethylene particles (PE) invisible to the naked eye and persistent for a long time in the environment.

Some stores display the thick plastic bag as reusable. In order to make this option more environmentally-

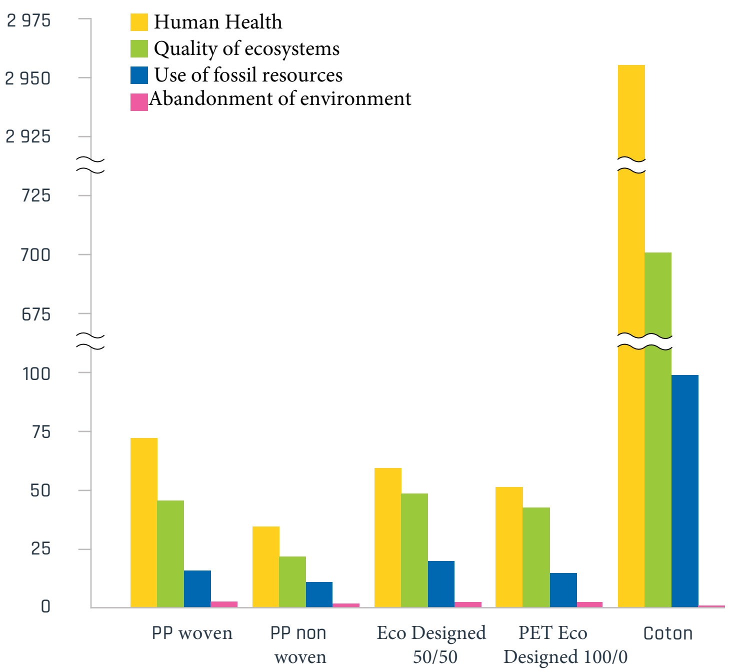
friendly than the conventional plastic bag used just once, the thicker plastic bag should be reused between 3 and 6 times to transport groceries.

Summary of LCA Results Reusable bags

The most common reusable bags in Quebec are woven polypropylene (PP) bags, non-woven, fabric polypropylene (PP) bags and cotton bags. For this study, a prototype ecodesigned bag (the Credo bag) made of 100% recycled PET and manufactured in Quebec has been added. All these bags have the advantage of being generally larger and more robust than disposable bags. LCA Results for reusables: The PP woven and PP non-woven bags need an equivalent number of reuses to equal the thin plastic bag ranging from 16 to 98 and 11 to 59, respectively, depending on the scenario and indicator.

Number of uses needed in order to be better or equivalent than the conventional bag*.

(Number of reuses equivalent to the conventional plastic bag)



As an indicator and on the basis of use by week, the reusable bags must be used at least 35 to 75 times so that their impacts on Life Cycle Environmental Indicators are equivalent to or better than those of the conventional plastic bag.

The cotton bag studied is an option that is not recommended because of its significant impact on the “human health" indicator, requiring between 100 and 2,954 uses for its environmental impact to be equivalent to the environmental impacts of the conventional plastic bag.

What about the cost of shopping bags over their life cycle?

The results show that the main cost of the bag's life cycle occurs at the stage of their acquisition by the retailer or consumer. In the case of conventional plastic bags and the oxodegradable bags, these costs are offset by the avoidance of having to purchase bags to manage household waste when the conventional bag is reused for this purpose. The cost to manage bags at the end of their life are, in turn, low compared to at the total life-cycle cost of the bags.

To view the complete report :

Click here

* *Refer to the Big Shopping Scenario (p. 15) in the full report.

RECYC-QUÉBEC
Québec

CIRAIG

Centre international de référence sur le cycle de vie des produits, procédés et services

FINAL TECHNICAL REPORT
LIFECYCLE ANALYSIS OF SHOPPING BAGS IN QUEBEC

December 2017

Prepared for

RECYC-QUÉBEC
Québec

Original LCA only available in French. The French was carefully translated into English using DeepL. If you want to check against the original, please refer to the french version https://www.recyc-quebec.gouv.qc.ca/sites/default/files/documents/acv-sacs-emplettes-rapport-complet.pdf

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POLYTECHNIQUE MONTRÉAL

This report has been prepared by the International Reference Centre on the Life Cycle of Process Products and Services (CIRAIG)..

Founded in 2001, CIRAIG was set up to provide businesses and governments with cutting-edge academic expertise on sustainable development tools. CIRAIG is one of the world's leading centres on life cycle assessments. It collaborates with many research centres around the world and is an active participant in the United Nations Environment Programme (UNEP) Life Cycle Initiative and the Society for Environmental Toxicology and Chemistry (SETAC).

CIRAIG has developed recognized expertise in life cycle tools including Environmental Life Cycle Assessment (ELCA) and Social Life Cycle Assessment (SLA). In addition to this expertise, its research work also focuses on Life Cycle Cost Analysis (LCCA) and other tools including carbon and water footprints. Its activities include applied research projects in several key sectors including energy, aeronautics, agri-food, waste management, pulp and paper, mining and metals, chemicals, telecommunications, telecommunications, finance, urban infrastructure management, transportation and green product design.

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Caution

The authors are responsible for the selection and presentation of results. The opinions expressed in this document are those of the project team members and do not represent the views of CIRAIG or Polytechnique Montréal.

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Contents

RECYC-QUÉBEC has mandated CIRAIG, the International Reference Centre for the Life Cycle of Products, Processes and Services, to evaluate the potential environmental impacts and costs of shopping bags in Quebec using life cycle assessment (LCA). This study establishes and compares the environmental profile and life-cycle costs of different types of shopping bags. This comparison identifies the solutions with the lowest potential impact and leads to a better understanding of the effects of banning single-use plastic bags.

The study is divided into three parts:

- Component I: Environmental LCA of shopping bags (ELCA)
- Component II: Life Cycle Cost Analysis of shopping bags (LCCA)
- Component III: Consequences of a ban on conventional plastic bags

Component I: Environmental Scan

The first part of this report is based on the life cycle attribution-based environmental analysis in accordance with ISO 14 040 and 14 044. Eight types of shopping bags were selected to represent all the bags currently available in the Quebec marketplace:

- "Disposable" bags
  - Conventional plastic bag (HDPE, 17 microns)
  - Oxodegradable plastic bag (HDPE, 17 microns)
  - Compostable bioplastic bag with straps (starch/polyester blend, 20 microns)
  - Thick plastic bag (LDPE, 50 microns, with cut-out handles)
  - Paper bag (unbleached kraft paper)
- Reusable bags
  - Woven PP bag (polypropylene)
  - Non-woven PP bag (polypropylene)
  - Cotton

In order to take into account different volumes of purchases, the analysis is carried out for a "small shop" scenario and a "large shop" scenario. The small shop models a purchase in a store where only one bag is used to transport it. The relative number of bags needed for a small shop is then a bag divided by its number of uses (life expectancy). As for the large grocery store, the analysis looks at a large shop scenerio with a larger purchase, often planned and made by car, which requires several bags. For this scenario, the relative number of bags required is determined by the capacity of the bag's capacity in addition to its number of uses.

The boundaries of the systems considered include production (materials, bags and packaging), distribution and end-of-life. The consumer usage step is excluded to some extent; the washing of bags which is relatively rare and transport home because the mass of the bags is negligible when transported by car.

The LCA compares products on the basis of the functions they perform. Here, the main function of a bag is to pack and transport products bought by individuals when shopping. The bags also perform other so-called secondary functions, as garbage bags, lunch bags, doggie bags, etc. The use of plastic bags as garbage bags is considered in this study by extending borders to include the impact of garbage bags avoided by the reuse of conventional plastic bags as garbage bags and the impact of their life cycle. For example, 77.7% of conventional plastic bags are reused for garbage and replace the need for consumers to purchase garbage bags. Rates of reuse of conventional plastic bags as garbage bags were measured during the Quebec Characterization of Residual Materials in the 2015-2017 Residential Sector for RECYC-QUÉBEC and Éco Entreprises Québec (ÉEQ) organizations. This secondary function/reuse is also taken into account forthe oxodegradable plastic bag, the bioplastic bag made of starch and polyester, and the thick plastic bag. Other secondary uses for conventional thin plastic bags are considered less common and are excluded from the study.

At the end of their lifespan, bags either go to landfill, are recycled or are left in the wild. Incineration, rare in Quebec, was not considered. The bags studied have varied recycling rates and rates of recycled content. Recycling is then taken into account by combining two approaches: the extension of borders and the cut-off rule. This "50/50" imputation method allocates half of the benefits and impacts associated with end-of-life recycling and half of the benefits and impacts associated with the use of recycled material in manufacturing. This study considers that 4.1% of disposable bags and 0.5% of reusable bags are discarded in the environment.

The potential impacts of the shopping bags studied are evaluated using the IMPACT World+ assessment method for three indicators: Human Health, Ecosystem Quality and Fossil Resource Utilization. A fourth indicator, Abandonment in the Environment, was added to consider the persistence of plastic left in nature.

For the ***Human Health, Ecosystem Quality and Fossil Resource Utilization indicators***, the conventional plastic bag performs better than other disposable bags studied. Because of its thinness and lightness, being designed for a single use, its life cycle requires little material and energy. Moreover, its reuse as an end-of-life garbage bag contributes significantly to reducing its potential impacts for the three indicators mentioned above. The bioplastic bag made of starch and polyester, as well as the thick plastic bag have, respectively, 2 to 11 times and 4 to 6 times more potential impacts than the conventional bag, depending on the indicator and shopping scenario. The paper bag is either the least or among the least efficient of the disposable bags by 4 to 28 times. The potential impacts of the oxodegradable bag are considered equivalent to conventional plastic bags.

For reusable bags, for the same three indicators, the woven PP and non-woven PP bags need an equivalent number of reuses from 16 to 98 and 11 to 59, respectively, depending on the scenario and indicator to equal the conventional thin plastic bag. For example, in the context of a large weekly grocery store at the supermarket, it would take between 16 and 73 weeks (between four months and a year and a half) for the potential life cycle impacts of the woven PP bag studied to be equivalent to those of a conventional plastic bag, if it is used assiduously at each grocery shopping. The cotton bag studied is by far the least efficient of all the bags studied with an equivalent number of reuses ranging from 100 to 3,657 times, depending on the scenario and indicator to match the reference bag, the conventional plastic bag.

For the indicator ***Abandonment to the environment***, bioplastic bags of starch-polyester, paper and cotton bags have benefits, since the biodegradation time of PE and PP is much longer than that of the biosourced materials studied. For this indicator, the conventional plastic bag score is, depending on the shopping scenario and considering a single use, between 425 and537 times, 277 and 388 times, and 599 and 741 times higher than the starch-polyester, paper, cotton and bioplastic bags, respectively.

More scientific research is needed to determine themagnitude of these benefits on human health and ecosystem quality.

Finally, the results show that the place of production, the mode of transport, the design parameters (recycled content) and the end-of-life fate of the bag have a strong influence on the results, which means that each situation is specific and must also be the subject of a specific study.

As a follow-up to this LCA, further study is recommended:

- Conduct sustainability studies on reusable and disposable bags (i. e., how many reuses they can withstand) and on consumer usagehabits to determine whether reusable bags are better for the environment than disposable bags based on usage patterns.
- Quantify the impact of plastic in the environment in order to determine the extent of the end-of-life benefits of biosourced bags on the Human Health and Ecosystem Quality indicators.
- *Conduct complementary studies to validate litter rates and better differentiate them according to bag types.*

The main limitations of this LCA are as follows:

- The conclusions are only applicable to the bags studied and cannot necessarily be generalized to all bags of the same type.
- Lifecycle modelling of the study bags systematically used generic data, which was adapted as much as possible to fit the modelled processes.

Following the LCA of eight shopping bags in a Quebec context, the study of a prototype bag developed using eco-design principles, including the content of recycled materials and the place of manufacture, was carried out. This bag was developed by a local company and was selected following a selection process conducted by MWC, ÉEQ and RECYC-QUÉBEC. It would be manufactured in the Montreal area from 100% recycled PET fibre from the United States, 80% of which would be recycled post-consumer bottles. The environmental analysis was carried out in order to give a rough idea of the impact reduction potential this prototype could offer compared to other bags already on the market. Based on the results presented in Appendix H, the number of equivalent uses of the eco-designed bag ranges from 15 to 74 times for the Human Health, Ecosystem Quality and Fossil Resource Utilization indicators. As for the Abandonment in the Environment indicator, the recycled PET bag is better than the conventional bag if used twice. Several recommendations were made to reduce the life-cycle impacts of the non-commercial eco-designed bag. First, the main advantage of this bag is its high recycled content. This characteristic is therefore unavoidable. Secondly, since production of PET fibre in the United States is the main source of impacts, using a Québec PET recycling line would substantially improve the bag's life cycle impact thanks to cheap Québec hydroelectricity and reduced transportation impacts. If dyeing to decorate the bag is required, a step with potentially particularly high potential impacts, it should be done in processes with low energy and water requirements. In addition, optimization of the fabric to reduce losses during bag making, as well as recycling scrap, are recommended. Finally, end-of-life recycling scenarios were evaluated, confirming the environmental benefits associated with this practice.

Component II: Cost Analysis

The LCCA component consists of an analysis of the costs and revenues associated with each phase of the life cycle of each of the eight types of shopping bags studied.

The boundaries of the systems in this component are consistent with LCA's and include bag acquisition costs -- production of material inputs, bag manufacture and distribution, and end- of-life. Usage (washing reusable bags and transporting bags from retailer to home) is excluded. Since the price data collected showed a high degree of variability, the analysis was carried out using two scenarios: the economic scenario and the expensive scenario.

The LCA results show that the main life-cycle cost of bags is their acquisition by the retailer or consumer. End-of-life costs avoided when the bag is reused as a garbage bag (cost avoided for the consumer) are also important for conventional and oxodegradable plastic bags and may even exceed life-cycle costs. End-of-life management costs are low compared to the total life cycle cost of bags.

Conventional and oxodegradable plastic bags are the least expensive of all disposable bags. For reusable bags: in the case most favourable to the conventional plastic bag (i. e. when the costs avoided by reuse as a garbage bag exceed the other life cycle costs), reusable bags are always more expensive. In the case most unfavourable to the conventional plastic bag, the reusable bags must be used between 7 and 11 times for the non-woven PP bag, between 25 and 33 times for the woven PP bag and between 71 and 88 times for the cotton bag to make them profitable. If the thick plastic bag is considered a reusable bag, it must be used three times when shopping to be cheaper than the conventional plastic bag.

Component III: Consequential environmental analysis

This third component assesses the environmental impacts of a ban on disposable plastic bags in Quebec. This consequential analysis describes the effects of such a measure on the life cycle of the systems studied, taking into account changes in consumer behaviour while considering rebound effects.

The ban scenario under study corresponds to the one adopted by the City of Montreal in August 2016, which bans plastic bags with a thickness of less than 50 microns, oxodegradable, biodegradable and oxobiodegradable plastic bags. Other bags not covered by the ban are not subject to a fee.

The consequences of banning have been assessed by considering the following alternatives to banned bags:

- Thick plastic bag (LDPE, 50 microns, with cut-out handles)
- Paper bag (recycled unbleached kraft paper)
- Woven PP bag
- Non woven PP bag
- Bagless shopping

Cotton bags were excluded from the analysis as they are not significantly offered by retailers nor would they be following a ban based on field information and literature.

And then, the results of the attribution-based LCA (strand I) of these alternatives were analyzed usingtwo consequential scenarios: the best and the worst case. In the best case scenario, plastic no longer used in the manufacture of the banned thin bags is not used to make other plastic products, resulting in reduced hydrocarbon production. In the worst case scenario, the plastic not used in the production of thin plastic bags is used to make other plastic products, so its life cycle is added to the replacement bag (thick plastic, paper, PP woven or PP non-woven) and to the additional garbage bags that consumers will have to purchase in the absence of conventional plastic bags.

According to the results of this part of the study, the banning of conventional plastic bags without pricing of non-banned disposable options would lead to an improvement in the *Abandonment in the Environment* indicator. However, it is unclear whether this ban would lead to improvements in other indicators, such as *human health, ecosystem quality and the use of fossil resources.* For the latter, banning would be beneficial in the "best" case and with reusable bags as an alternative, provided they are reused sufficiently.

These results, which differ according to indicators and scenarios, do not allow a simple conclusion as to whether the potential environmental impacts will increase or decrease as a result of a ban. The pricing of disposable options to consumers not covered by the ban could help to reduce the undesirable effects of a ban, should be studied.

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List of abbreviations and acronyms

LCCA	Life Cycle Cost Analysis
CPIA	Canadian Plastics Industry Association
LCA	Life Cycle Assessment
ELCA	Environmental Life Cycle Assessment
LCVA	Life Cycle Inventory Analysis
CEEPC	Paper and cardboard packaging environment council
CIRAIG	International Reference Centre on the Life Cycle of Products, Processes and Services
CMM	Metropolitan Community of Montreal
DALY	*Disability-Adjusted Life Years*
ÉICV & LCIA	Life Cycle Impact Assessment
GES	Greenhouse gases
GIEC	Intergovernmental Panel on Climate Change (IPCC)
GTP	*Global temperature potential*
GWP	*Global warming potential*
ICV	Life Cycle Inventory
ISO	International Organization for Standardization
micron	Micrometer or thousandth of a millimetre
mil	Thousandth of an inch
PDF*m²*an	Potentially Disapppeared Fraction "on a certain surface and over time
PE	polyethylene data
LDPE	Low-density polyethylene
HDPE	High-density polyethylene
PLA	Polylactic acid
PP	Polypropylene

1 Setting the context

Since the beginning of 2015, several municipalities in Quebec have signalled their intention to ban conventional plastic shopping bags. In particular, on December 10,2015, a resolution was adopted by the council of the Montréal Metropolitan Community, calling on the municipalities in its territory to adopt a resolution announcing their intention to ban the use of single-use plastic bags (CMM, 2016) as of April 22,2018, Earth Day. The ban would apply to light weight plastic bags with a thickness of less than 50 microns and to oxodegradable, oxobiodegradable and biodegradable bags, whether they are offered for a fee or free of charge. These bags, which are provided by retailers to transport products purchased by consumers, are targeted because they can end up in the environment at the end of their lives where they create visual pollution and can have harmful impacts on wildlife. A number of municipalities are currently looking for environmentally and economically viable alternatives to conventional plastic shopping bags. This report is designed to help with that search.

Life Cycle Assessment (LCA) is a decision-making tool in this regard. It is a method of evaluating the potential impacts of a product, process or service over its entire life cycle; from the extraction of raw materials to the end of its life cycle. Several environmental LCAs have already been carried out on shopping bags to study their environmental impacts, but none have been carried out in a Quebec context. In addition to environmental information, economic information which is missing in most current studies, is also needed to support decision-making.

In this context, RECYC-QUÉBEC decided to commission an environmental and economic life cycle analysis that would address issues raised in Quebec around the banning of conventional plastic bags. The purpose of this study is to provide a solid scientific, objective and global basis for municipalities throughout Quebec to use to develop policies on bags if a ban measure should be considered. The study will also provide retailers with information to make responsible decisions on shopping bags and ensure a sustainable supply.

To do this, RECYC-QUÉBEC has mandated CIRAIG to analyze and compare, using the LCA method, the environmental profile and life cycle costs of shopping bags on the market in Quebec. More specifically:

- Assess the environmental impacts and costs of the current situation (2016);
- Assess the environmental impacts and costs of possible alternatives in the event of a ban on thin plastic bags;
- Assess the direct and indirect environmental impacts of the decision to ban conventional thin plastic bags.

The results will provide:

- Data on the environmental impacts and costs of using shopping bags;
- A comparison of the environmental and cost profiles of the different types of bags circulating in the market, taking into account their entire life cycle;

- The identification of the most eco-efficient solutions; those with a low environmental footprint at the lowest cost, in case of a ban;
- A better understanding of the consequences of banning conventional (thin) plastic bags.

The report to achieve these objectives has been structured around the following three components:

- Component I: Environmental Life Cycle Assessment of shopping bags (ELCA)
- Component II: Life Cycle Cost Analysis of shopping bags (LCCA)
- Component III: Consequences of a ban on conventional (thin) plastic bags

Each component includes a description of the methodology adopted, as well as the results and conclusions resulting from the analyses carried out.

Critical review

Because the results of this study must be publicly disclosed and are intended to support a comparative assertion, a critical peer review was conducted by a committee composed of LCA experts and other specialists from the fields involved in the study.

In accordance with ISO 14 040 and 14 044 (2006a, b), the objectives of the critical review were to ensure that:

- The methods used by CIRAIG to carry out the life cycle analysis are:
  - consistent with the international standard ISO 14040
  - valid from a technical and scientific point of view;
  - appropriate and reasonable for the purpose of the study;
- Interpretations by CIRAIG reflect the limitations identified and the purpose of the study;
- The detailed report shall be transparent and consistent.

The critical review process by the committee was scheduled as follows:

1. Review of preliminary report by committee;
2. Correction and accuracy of the points raised by the reviewers;
3. Return of the modified report to the reviewers for validation of compliance with ISO 14 044;
4. Tabling of the revised final report to the Trustee.

The critical review report and CIRAIG responses are presented in Appendix F.

COMPONENT I: ENVIRONMENTAL SCAN OF SHOPPING BAGS (ELCA)

2 Bibliographic review of LCA studies

A review of LCA studies on the environmental comparison of reusable and disposable shopping bags was conducted.

This provided a snapshot of the work that has already been done internationally with respect to LCAs in this area. An analysis of the relevant studies allowed comparison of various methodological choices and data sources used, as well as the main conclusions reached. The most relevant documents for this study; that is, studies comparing both disposable and reusable bags, are summarized in the following sections starting with the most recent.

2.1 Clemson University (Kimmel *et al.*, 2014)

https://monsacintelligent.ca/wp-content/uploads/2017/03/CLEMSON-LCA.pdf

This American study, funded by Hilex Poly Co. compares two types of single-use bags (conventional high-density polyethylene -HDPE- and paper bags) and two reusable bags (low-density polyethylene (LDPE) bags 57 micron thick and non-woven polypropylene (PP) bags in a grocery shopping context. Different recycled content is considered for plastic bags (0% and 30%) and paper bags (40% and 100%). The re-use of plastic bags (40% of cases) and paper (22.1% of cases) as garbage bags was included in the analysis. At end-of-life, 8.6% of HDPE and 49.7% of paper bags are recycled. The study considers that LDPE and non-woven PP are not recycled, but are directly incinerated or buried. It is also assumed that 17.8% of non-recycled bags are incinerated and 82.2% are buried, regardless of the type of bags. The study excluded bags left in the environment at the end of their useful life because, according to an American study, plastic bags make up less than 2% of the items found along highways.

The number of bags required per grocery store visit was empirically determined using a group of 60 participants who were asked to bag 52 typical consumer products. In this way, the study attempted to take into account user behaviour when calculating the actual capacity of each of the bags.

The study interprets its results using reusable bag usage statistics. According to these, a non-woven PP bag would be reused 14.6 times and the LDPE bag 3.1 times (Edelman Berland, 2014). However, the LCA results show that the actual number of reusable uses is not sufficient to make non-woven PP or the LDPE bag options better than conventional plastic bags for all the environmental impact indicators evaluated. The number of reuses required for paper bags, thick plastic bags and non-woven PP bags to match the conventional thin plastic bags when it comes to climate change impact are 3.7,6, and 19.9 times, respectively. Although the paper bag is considered a single-use bag, its number of theoretical reuses does provide comparative information on its environmental performance compared to conventional plastic bags. This LCA has been critically reviewed.

2.2 U.K. Government Environment Agency (Edwards and Fry, 2011)

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/291023/scho0711buan-e-e.pdf

A LCA on shopping bags was carried out in 2011 by the British Environmental Agency. It analysed the lifecycle of four so-called disposable bags (conventional plastic, oxodegradable, bioplastic starch-polyester and paper) and three so-called reusable bags (thick plastic, PP non-woven plastic cotton) available in supermarkets across the country. The reuse of disposable plastic bags as garbage bags is considered to be 40.3%. The number of bags required per functional unit (transport one month of grocery shopping, 483 items) without considering primary reuse is based on the average number of items per conventional plastic bag and extrapolated to all types of bags using volume capacity. The study then calculated a minimum number of uses for each bag type to obtain environmental impact scores equal to those of conventional plastic bags. These figures vary greatly depending on the end-of-life scenario of the plastic bag (valuation as a garbage bag or not): from 3 uses for the paper bag to 393 uses for the cotton bag based on their global warming potential.

The other conclusions of the study are as follows:

- The impacts of the bag lifecycle mainly result from resource extraction and bag manufacturing
- Recycling and composting provide low environmental benefits (border extension method).
- The more a bag is reused in a primary way (as a shopping bag) or secondary way (as a garbage bag), the more its environmental impacts are reduced.
- Reuse of conventional plastic bags as garbage bags provides greater life-cycle benefits than end-of-life recycling.
- Bioplastic bags (polyester starch) generate more greenhouse gases (GHG) than conventional plastic bags over their life cycle.

The study has been critically reviewed and does not consider the abandonment of bags in the environment.

2.3 Carrefour (ECOBILAN PwC, 2004) and Bagherra (Bio Intelligence Service, 2005)

https://monsacintelligent.ca/wp-content/uploads/2017/03/ECOBILAN-CARREFOURS-FRENCH.pdf

In 2004, the French supermarket chain Carrefour published a study on five types of shopping bags: the conventional plastic bag, the 70-micron thick plastic reusable shopping bag (large-size handbag), the recycled paper bag and the 27-micron biodegradable bag (starch-polycaprolactone mix). In the appendix of the study, preliminary results on the woven PP bag are also available. The number of bags of each type corresponding to the functional unit (one-year purchases) was calculated using volume capacity and number of uses. The study has been critically reviewed.

In order to obtain better environmental indicator scores than the conventional plastic bag, 4 and 15 uses are required for the soft bag of thick plastic and woven PP respectively. Several sensitivity analyses were carried out: recovery of the conventional plastic bag by reusing it as a garbage bag, end-of-life treatments, reuse of the paper bag, recycling of used shopping bags and number of reuses. When the disposable bag is reused as a garbage bag (65% of the time), the number of uses required for LDPE and PP woven bags to obtain better environmental indicator scores than the disposable bag increases to 9 for LDPE and 24 times for PP woven bags.

The authors cite a French in-store survey of 2,000 people in France, according to which consumers said that they had used their shopping bags 15 times and estimated that they would reuse them as many times again, for a total of 30 uses.

The issue of the abandonment of bags and shopping bags in the environment was analysed qualitatively using a relative risk indicator taking into account the following four parameters: volume of used bags to be treated at the end of life, probability of abandonment of bags, probability of escape of bags by flight during transport or from the landfill, persistence of bags in the environment (especially at sea). This is one of the very few studies that have done this exercise, with the two Australian studies described in the following section. The qualitative analysis concludes that HDPE disposable bags have the highest risk, having a "high" score for all abandonment parameters, while paper bags have a "low" score. However, the evaluation of some parameters is questionable. Although the plastic bag has the best performance for three of the four parameters; like the paper bag, its relative risk per overall abandonment is considered "medium-low". Finally, for the authors, the persistence of the biodegradable bag in the environment is assessed as "low". Nevertheless, a more recent UK study states that biodegradable bags take a considerable amount of time to degrade in the environment. Thus, it seems inappropriate to assign the same persistence score to biodegradable plastic bags and paper bags.

The year after the Carrefour study, Bagherra, a manufacturer of shopping bags made from bioplastic Mater-Bi (amidon-polycaprolactone), commissioned a LCA study on a biodegradable shopping bag and disposable bag, the latter manufactured in France rather than Italy as considered in the Carrefour study. It was carried out with the aim of supplementing the latter by producing results for these two additional bags, and based on the same methodology. According to the results, the two bioplastic bags analyzed perform better on environmental impact indicators than other bags of the same type.

2.4 Environment Australia (Nolan-ITU et al., 2002; ExcelPlas Australia et al., 2003)

http://www.greenbag.com.au/UserFiles/AU_analysis.pdf
http://s3.amazonaws.com/zanran_storage/www.environment.gov.au/ContentPages/4022773.pdf

Two complementary simplified LCAs were conducted in Australia on shopping bags. First, Nolan-ITU et al. (2002) studied conventional plastic bags (0% and 50% recycled content), thick plastic bags (shop bags with cut-out handles), paper, starch-polyester blends and oxodegradable plastic, as well as LDPE reusable bags (gloves), cotton, HDPE woven and PP. A PP fund was also evaluated. The study by ExcelPlas Australia et al. (2003) adds to the comparison a series of degradable plastic bags: three bags in different starch-polyester blends, one in starch-PE mixture, one in oxodegradable PE and one in polylactic acid (PLA).

The number of bags of each type is determined to correspond to a functional unit (the number of bags it takes to transport approximately 70 household products from the supermarket each week for 52 weeks in Australia). For conventional plastic bags, the weekly number is 10 bags. The number of other types of bags is calculated using their relative capacity and life expectancy. The methodology used to calculate or measure relative capacity is not detailed. The following assumptions were used:

- 19% of conventional plastic bags are reused as garbage bags;
- 0.5% of bags of all types are lost to the environment, with the exception of PP;
- 2% of conventional plastic bags and 60% of paper bags are recycled;

- All the rest is sent to landfill or composted.

The environmental indicators assessed are climate change, resource depletion, eutrophication, material use, primary energy consumption and abandonment in the environment. The latter is quantified differently between the two studies. First, Nolan-ITU et al. (2002) determined three values to quantify abandonment: the mass of abandoned bags, the maximum soil area covered by the bags, and then the covered area multiplied by the time before degradation (m2an). As for ExcelPlas Australia et al. (2003), the authors evaluated this last indicator, as well as a second one concerning marine biodiversity, based on the time spent by the degradable bag floating on the surface of the water and its mass.

Sensitivity analyses were carried out on the recycling of the LDPE reusable bag, the capacity of the HDPE woven reusable bag, the end-of-life treatments of degradable bags and the use of the paper bag at the supermarket a second time.

Based on calculated environmental indicators, the two Australian studies conclude that reusable bags are preferable to single-use bags, particularly LDPE bags. However, compared to other studies, high life expectancies for these bags have been considered, e. g. two years (104 times) for PP and HDPE woven bags. In addition, these are streamlined LCA studies and the authors warn that these conclusions should be considered with caution, particularly due to uncertainty about the number of reuse and abandonment indicators in the environment. Finally, the use of biosourced materials leads to life cycle impact transfers since, while reducing the depletion of non-renewable resources, they cause aquatic eutrophication.

2.5 Conclusion of the literature review

The review of the LCAs described in the previous sections allows certain observations to be made. First, although this is a key parameter, very little is known about the user's behaviour and how many times they reuse their bags. Two studies cite survey results in interpreting their results. The Carrefour study concludes that LDPE shopping bags are sufficiently reused, unlike the Clemson University study. In both cases, the number of uses is directly or indirectly estimated by the respondent. Given the imprecise nature of this information, the resulting estimates are highly uncertain. It is not appropriate to compare different types of bags assuming a fixed number of uses for each separate bag. A sensitivity analysis on this key parameter is therefore required. It follows therefore that the best way to compare bags is to convert the results into the number of uses needed to obtain at least equivalent scores for all environmental indicators. This is an appropriate way of presenting comparative results.

A second key parameter that may be highly uncertain is the relative capacity of the different bags being compared. Different methodologies were used in the reference studies consulted to determine the best way to look at relative capacity on a comparative basis in this LCA: based on volume (ECOBILAN PwC, 2004), based on number of items (Kimmel et al., 2014; Nolan-ITU et al., 2002) or a combination of both (Edwards and Fry, 2011). There are no studies looking at the carrying capacity of bags, probably because it's not a limiting factor. Studies have shown that the relative capacity based on the number of items in each bag best reflects the user's behaviour, because several factors specific to the user come into play when filling the bags such as the volume of the bag and the number of items it will hold, and the user's perception of the bag's strength. However, this information is more difficult to obtain than the relative capacity based on bag volume.

For example, Kimmel et al (2014) empirically obtained values using a group of test packers. This type of test situation provides representative values for a particular case, such as shopping at the supermarket. Conclusion on relative capacity: the uncertainty associated with this parameter must be carefully considered in a LCA, either by obtaining an accurate and representative value, or by sensitivity analyses in the interpretation phase, to ensure that its uncertainty does not affect the study conclusions.

Third, *life cycle impact assessment (LCIA) methods are currently unable to assess the potential impacts on human health and ecosystems of plastic dispersion in the environment.* Despite this, some studies have attempted to assess this issue (Nolan-ITU et al., 2002; ExcelPlas Australia et al., 2003; ECOBILAN PwC, 2004; Bio Intelligence Service, 2005) using a variety of qualitative and quantitative indicators. Two impacts are identified in all these studies: the quantity of abandoned matter, whether it is a volume, an area or a mass, and the time of persistence in the environment. The latter can be very uncertain, depending heavily on the conditions in which the bags are found outdoors.

Finally, the secondary use of conventional plastic bags as garbage bags is a common practice identified in the studies referenced. However, the rate of recovery through reuse varies greatly depending on the geographic context, from 19% to 65%, which greatly influences the results. It is therefore essential to include this secondary function in the LCA and to ensure that the reuse rate is representative of the Quebec context and is subject to a sensitivity analysis.

This key learning from the literature review has been incorporated into the LCA model of this study, as described in the following section.

3 ELCA Study Model

This section outlines the study design and defines the methodological framework for subsequent phases of the LCA.

3.1 Objectives of the study and its intended application

The goal of this component is to identify solutions with the lowest potential environmental impact by conducting an environmental life cycle assessment of the use of existing and potential shopping bags that are or could be on the market in Quebec. Potential means bags that could appear on the Quebec market following a ban on conventional thin plastic bags.

More specifically, the objectives of this component are:

1. Establish the environmental profile of the systems defined by the complete life cycle of the bags studied (i. e. the set of indicator results from different impact categories);

2. Identify the hot spots (the largest contributors to the impact) and key parameters (the parameters that most influence the environmental balance) specific to the different systems under study;

3. Compare the systems with the conventional plastic bag, the reference system.

The description of the systems is presented in the following sections.

This ELCA component is carried out in accordance with the requirements of ISO 14 040 and 14 044 standards .

Definition of "grocery shopping"

According to the Larousse dictionary, the word "grocery shopping" means two things:

1. Purchase of articles or goods for everyday use
2. Purchased Object

Since both of these meanings can be confusing, the terms "purchase" or "commodity" are used instead of "shopping". This means that the term "shopping" when used is this report refers to the action or actual act of shopping.

3.2 General description of the products under study

Shopping bags are those used when shopping in stores. The largest number of them, between 75% and 80%, are used in grocery shopping (RECYC-QUÉBEC, 2007; ÉEQ, 2016a). Depending on retail establishment, they can be a different size, composition and have a different reuse potential. Shopping bags are often divided into two main categories: Disposables "or" single-use ", and" reusable ".

For the “disposables”: although they can be used for a multitude of secondary uses (waste bag, lunch bag, etc.), they are not designed to be used more than once for their main purpose, which is to function as a carry bag transporting goods. Reusable bags, on the other hand, are more robust and allow goods to be transported several times. It goes without saying that some so-called "reusable" bags can resemble disposable bags and vice versa. However, there is no precise definition to differentiate between the two types of bags. The detailed description that follows attempts to best reflect the typology found in documentation and in discussion with stakeholders.

3.2.1 Disposable bags

Plastic bags

Thin plastic bags with handles are the bags analyzed and cited in all shopping bag LCA literature. These bags are considered conventional plastic bags for the purposes of this study. Also called T-shirt bags, the conventional plastic bag is a lightweight bag made of high-density polyethylene (HDPE) with a thickness of about 17 microns. They are used mainly in grocery stores, convenience stores and discount stores. The conventional plastic bags can also be made of low- density polyethylene (LDPE), a less rigid type of polyethylene than HDPE.

The diversity of plastic bags is probably as great as the diversity of retail stores. Because the bags also function as a marketing tool, they are often made to measure, can be made from either LDPE or HDPE, and come in various sizes. Plastic bags with thicker handles are available in non-food stores, including pharmacies. There are also plastic bags with cut-out handles manufactured from LDPE or HDPE often found in the fashion sector. They are generally thicker than conventional 17 micron T-shirt bags and can reach a thickness of 50 microns or more.

According to the Canadian Plastic Industry Association (CPIA), conventional plastic bags are generally made with 25% recycled content; the recycled material (pellets) is either purchased from other plants or generated from reprocessed waste from on-site bag manufacturing (see sections 3.5.2 and 3.7 for details). The CPIA also reports that the conventional plastic 17 micron bags distributed in Quebec are typically made in Canada, with manufacturing concentrated in Quebec and Ontario.

At the end of its useful life as a carry bag, the conventional plastic bag is reused for a variety of secondary purposes, but usually as a garbage bag. According to RECYC-QUÉBEC, 77.7% of non-biodegradable conventional plastic bags are reused to manage household waste and end up in landfill (see section 3.5.1 for more details on this data from measurement campaigns). According to the results of the Characterization of Residential Residual Materials in Quebec 2012-2013 (Quebec EQE and RECYC-QUÉBEC, 2015), the recovery rate of plastic shopping bags is 13%.[1] If they are put into recycling, Quebec sorting centres are usually able to recover them, 18 out of 24 sorting centres in Quebec responded to the survey of centres indicating that they accepted bags and films in 2015 according to RECYC- QUÉBEC.

For several years now, probably with images of floating plastic islands in the middle of the oceans (SRC, 2015; Cózar et al., 2014) and animals suffocated by the ingestion of residues of films and plastics (Bio Intelligence Service, 2011, p. 35; SRC, 2016), disposable plastic bags have earned a reputation for being polluting because of their persistence in the environment.

[1] Mass of material found in selective collection ("recycling") on the total mass of material found in garbage and selective collection.

Whether it is to address the problem of persistence in the environment or concerns about the consumption of non- renewable resources, these types of materials can be used to manufacture plastic bags. One example is bags made of bioplastics (from biosourced materials, made in whole or in part from vegetable materials such as wheat, corn or potatoes) which are generally sold as biodegradable (under certain optimal conditions like, industrial compost). It should be noted, however, that although a bag is made of bioplastics, it does not necessarily mean that it is biodegradable or compostable.

Another example is oxodegradable or oxobiodegradable plastic bags. These degrade by the action of light and oxygen. They are made of conventional plastic to which a catalyst has been added. Although this type of bag is much less persistent in the environment, there are doubts about its complete biodegradability. A British study by the University of Loughborough (Defra, 2010) concluded that oxodegradable plastics are not compostable and that PE degradation after bag fragmentation is much slower than compostable plastics. Finally, these bags are undesirable for recycling because they deteriorate the characteristics of recycled plastic; the recycled plastic will degrade prematurely if it contains too much oxodegradable material.

Paper bags

The paper bag is considered one of the disposable bags in this study, although some are robust enough to be used more than once in a supermarket context. In the food industry, it is made of unbleached kraft paper, without handles, with a large recycled content and is manufactured in Canada or the United States. In a non-grocery environment, it is typically equipped with twisted handles. It can be bleached and personalized to meet retail outlet specifications (sizes, colours, texture, cord handles, etc.). Its recovery rate is 34.4% (ÉEQ and RECYC-QUÉBEC, 2015;"Kraft paper shopping bags" category). The paper bag is compostable.

3.2.2 "Reusable" bags

This category of bags is also very diverse. First, the most popular reusable in common usage is the PP plastic bag, woven and non-woven. They are generally manufactured in China and are sold by major food chains in Quebec. They are laminated to allow printing. Although described as recyclable, they are discarded by sorting centres in Quebec. These bags generally contain several different materials making recycling them more complicated, time-consuming and therefore more expensive. The volume of these bags recovered is too small currently to make recycling economically profitable.

Materials other than polypropylene can be used in the manufacture of reusable bags such as PET plastic fabric, nylon, cotton, hemp and jute. For example, some reusable bags are made of 100% post- consumer recycled PET plastic fabric made from water bottles and soft drink bottles. Others are made from nylon. Cotton bags are also used for shopping in Quebec. In general, these bags are robust and could probably be reused dozens or even hundreds of times. Cotton bags used in Quebec are generally made in Asia although the Canadian textile industry can still make them, but they use American cotton. But it is important to note that cotton bags cannot be recycled in Quebec. Other textile fibres can also used in the manufacture of shopping bags, such as hemp and flax, but this manufacture is on a much smaller scale and they are not included in this LCA study. However, their use in the production of bags could generate less environmental impact than cotton bags through lower water consumption and pesticide use during cultivation (Turunen and van der Werf, 2006).

It is important to note that cities that have adopted a ban on conventional plastic bags, such as Portland and San Francisco, have seen the emergence of thick plastic bags (50-100 microns) with reinforced cut-out handles and so-called "thinner reusable" bags as replacements for the conventional bag. They are recyclable in Quebec like conventional plastic bags, but their ability to be reused multiple times remains low due to their rapid wear and tear. Some retailers in Brossard have clearly identified them as reusable, while others have not. Given the possible ambiguity about the reuse potential of this type of bag, the thick plastic bag is considered in this study to be a disposable shopping bag.

The following sections present in more detail the different bag systems studied and the ELCA model developed for their analysis.

3.3 Functions and functional unit

The systems studied are evaluated on the basis of their main function as a carry bag:"to pack for transport the products bought by individuals when shopping".

The functional unit, i. e. the reference to which the inventory and impact assessment calculations relate, has been defined for two different shopping situations: the "small shop" and the "large shop".

The small shop scenario consists of a visit to a store where only a single bag is needed to transport purchases, regardless of its size. This can be an unplanned purchase, for example in a convenience store, although this can happen in just about any type of business. This situation benefits the small bags. This small shop functional unit is then defined as follows:

"to package for the transport 1 litre of products purchased by the individual when shopping in Quebec in 2016".

The large shop scenario, on the other hand, is often a planned shopping excursion that is frequently carried out by car and requires several bags to transport purchases, for example, visits to supermarkets. The peculiarity of the large shop scenario is that the capacity of the bags has an influence on the results when compared with the small shop scenario: the bigger a bag is, the fewer bags it takes to transport the same volume of purchases. The functional unit for this large shop scenario is then:

"to package for transport 100 litres of goods purchased by the individual when shopping in Quebec in 2016".

The formulation of two functional units is intended to take into account factors specific to certain types of shopping that may affect the LCA results. For example, consumer habits and shopping patterns may be different in an urban, suburban or rural context. In the city, shopping tends to be more frequent and unplanned, while shopping in the suburbs or in the countryside is more often planned and frequent by car.

Thus, the bags retained to meet this function are:

- "Disposable" bags
    - Conventional plastic bag (HDPE, 17 microns)
    - Oxodegradable plastic bag (HDPE, 17 microns)
    - Compostable bioplastic bag with straps
      (starch/polyester blend, 20 microns)

  - Thick plastic bag (LDPE, 50 microns, with cut-out handles)
  - Paper bag (unbleached kraft paper)

- Reusable bags
  - Woven PP bag (polypropylene)
  - Non woven bag (polypropylene)
  - Cotton bag

It should be noted that in an LCA, it is necessary that a functional unit be defined for the products being studied, but that the performance of the products within the functional unit may differ based on the conditions and circumstances under which the function is performed. In this sense, in order to make the bags as comparable as possible, the following hypotheses must be considered:

- Only the type of bag changes: the distance between the place of residence and the place of consumption is the same;
- The same number of items purchased can be included in each bag;
- The total mass of the purchased items does not exceed the strength of the bag;
- Bag defects (e. g. holes) are not considered.

The following paragraphs describe how reference bag flows were calculated for each scenario using key parameters for the same volume of purchases.

3.4 Reference flow and key parameters

Reference flows are the quantities of products required per functional unit. In order to determine the relative number of bags for comparison with each other, several indicators can be used to consider the physical constraints of a shopping bag: the volume, mass or number of items contained in the bag. This study favours the use of volume to consider the physical constraints of a bag since it seems to be the most appropriate indicator for considering the potential of numerous purchases in each shopping trip. In addition, this indicator has been used in most of the LCA studies examining bag comparison. Preference for the use of the number of items contained in a bag versus volume to determine the relative number of bags for comparison would be ill-advised in a general shopping context; for example, can you really compare the number of items contained in a bag when items can vary greatly in volume? As for mass, it is only important if the sum of the items purchased is close to the resistance of the bag in question. Considering that the mass capacity of the conventional plastic bag under study measured by the authors is about 19 kg, we have assumed that the total mass of the purchased items cannot exceed the strength of all bags. The issue of double bagging in order to increase the bags strength profile is discussed qualitatively in the results section.

Therefore, for this study, the number of relative bags for comparison is the number of bags of a given type necessary by Volume (V) per shopping trip compared to the number of reference bags required by the same shopper for that same shopping trip. This number depends on several parameters, which in LCA are called key parameters:

- Capacity (C): Depending on its size and strength, the bag may contain more or fewer items, which affects the number of bags required to pack the items in a single shopping cart. So capacity in this study is based on the volume of bags. It is possible to consider capacities expressed in number of items or mass, but these options were not entertained. Capacities in terms of number of items are generally obtained empirically and no Quebec data is publicly available. As for the load capacity of a bag, it is rarely considered to be the limiting factor for the filling of a bag considered in bag LCA.
- Number of Uses (U): determines the number of bags charged to a shopper. For example, a shopper with a bag with a life span of 15 uses will be assigned 1/15 of a bag. Its value is 1 for so-called disposable bag, the reference bag.

In order to define a common basis for all the bags under study and to allow their comparison, reference flows are calculated for the same volume of purchases in the same scenario. The reference flux "s" can thus be formalized in general as follows for a type "i" bag:

$$s_i = \frac{S_i}{S_{ref}} \qquad (1)$$

Where "Si" is the absolute number of "i"-type bags needed when shopping, and "Sref" is the num ber
of bags for the reference type. "S" depends on the volume of purchases, capacity and number of uses of the bag:

$$S_i = f(V, C_i, U_i) = \frac{V}{C_i U_i} \qquad (2)$$

In the context of small shops, a simplified function can be determined. For a purchase volume smaller than the volume of the smallest bag studied, but whose number of items would be too many to carry by hand, neither the volume nor the capacity of the bags influences the number of bags attributed to a shopping bag, which is therefore worth one bag. For these small purchases, capacity is therefore not a key parameter. Only the number of uses has an influence on the number of reusable bags attributed to a shopper. So, for a small shopping scenario:

$$S_i = f(U_i) = \frac{1}{U_i}, V \leq C_i \forall i \qquad (3)$$

Considering equation 1 and the conventional plastic bag for a single use, we obtain the following expression of the reference flow for the small-scale shopping scenario:

$$s_i = \frac{S_i}{S_{ref}} = \frac{U_{ref}}{U_i} = \frac{1}{U_i} = S_i, V \leq C_i \forall i \qquad (5)$$

For the large-scale shopping scenario i. e. when the volume of purchases of a grocery store is greater than the individual capacity of the bags used, the "Si" can be calculated with equation 2. Then you get it:

$$s_i = \frac{S_i}{S_{ref}} = \frac{C_{ref}U_{ref}}{C_iU_i} = \frac{C_{ref}}{C_iU_i}, V > C_i \forall i \qquad (3)$$

Table 3-1 summarizes the mathematical expressions needed to calculate the relative numbers of bags.

Table 3-1: Relative number of bags

Scenario	Purchase Volume *V*	*Relative # of Bags*
Small Grocery	$V \leq C_i \forall i$	$s_i = \frac{1}{U_i}$
Big Grocery	$V > C_i \forall i$	$s_i = \frac{C_{ref}}{C_iU_i}$

Considering the performance of each system, the following table shows the reference flows for each scenario. Capacities correspond to the maximum volume of water that can be contained in bags with handles held together, except for the bioplastic bag made of starch and polyester for which the manufacturer's value has been used (7 gallons). A plastic garbage bag was inserted into the non-impermeable bags to perform the measurements.

Table 3-2: Performance characteristics and reference fluxes

Product	Capacity *C* (l)	Number of uses *U* (function principal)	Reference flow (number of bags if) Small grocery store	Large grocery store
Conventional plastic bag	21	1	1	1
Oxodegradable	21	1	1	1
BioplasticPlastic (polyester starch)	26,5	1	1	0,79
Plastic bag thick	20,5	1	1	1,02
Paper bag	29,5	1	1	0,71
Woven PP bag	28	Variable	$1/U_i$	$0{,}75/U_i$
Non-woven PP bag	35,5	Variable	$1/U_i$	$0{,}59/U_i$
cotton bag	26	Variable	$1/U_i$	$0{,}81/U_i$

As shown in the previous table, the number of uses for reusable bags is not defined. As shown in the literature review, this is an uncertain and variable key parameter, which significantly influences the results, and there are no statistics on the reuse of bags in a Quebec context. The LCA results are expressed as a function of the number of uses required for a bag to obtain an impact score equal to or lower for all indicators (see section 3.8) than a reference bag, the conventional plastic bag in this case. The mathematical expressions of Ui* are presented in the appendix.

3.5 Processing sub-functions and settlement rules

3.5.1 Secondary functions

The LCA compares products or services on the basis of the quantified function, or the different functions they perform. Secondary functions should be considered with caution. Shopping bags perform a variety of functions in addition to their main function as a carry bag which allows individuals to transport goods purchased while shopping home. Conventional plastic bags are reused at the end of their useful life in many ways, according to a survey conducted by CROP between May 8 and 13, 2015 of 400 residents of the City of Montreal aged 18 and over, and commissioned by the plastic industry (CPIA). These reuses include:

- Household garbage bag (78% of respondents) ;
- Lunch bag (32% of respondents);
- Doggie bag(15% of respondents);
- Other uses (5% of respondents).

In this LCA, the benefits of reusing plastic bags as garbage bags are evaluated. To do this, the so-called "border extension" method has been used: the environmental profile of avoided garbage bags is subtracted from that of plastic shopping bags (see Table 3-6 for more details). Knowing that 87.0% of plastic shopping bags are found in waste collection in Quebec (ÉEQ and RECYC-QUÉBEC, 2015, p. 42) and 77.7% (RECYC-QUÉBEC, 2016) of conventional plastic bags thrown into garbage are used as garbage bags, the extension of borders is then applied to 67.6% of conventional plastic bags. 2 This procedure was also applied to oxodegradable plastic bags made of starch-polyester bioplastics and thick plastic bags using different percentages.

Details of the values used can be found in Table 3-6. Their accuracy is between 5% and 13%. The avoided garbage bag considered in this study is a white thick plastic bag (LDPE) measuring 51 cm wide and 56 cm high (20 "x 22"), 20 micron (0.8 mil) thick and weighs 12 g (see Table 3-9 for more details). Its effective volume, i. e. when tied with a tie, has been measured and is approximately 24 litres. The credit applied is proportional to the ratio of actual bag volumes as shown in Table 3-3. For conventional and oxodegradable plastic bags, the effective volume is when the handles are knotted together. Finally, for the bioplastic bag, its actual volume was extrapolated using the conventional bag and the ratio of volumes in Table 3-2.

[2] 87,0 % x 77,7 % = 67,6 %

Table 3-3 : Actual volumes for reuse credit as garbage bags

Bag	Actual volume (l)
Conventional plastic bag	15
Oxodegradable plastic bag	15
Bioplastic bag (polyester starch)	19
Thick plastic bag	15
Garbage bag	24

Rates of reuse of conventional plastic bags as garbage bags (i. e. the number of bags reused as garbage bags over the number of bags discarded to garbage) is based on the best available data. This is primary data corresponding to the geographic and temporal context of the study, in addition to being specific to each type of bag. It is derived from the Characterization of Residential Residual Materials 2015-2017. Using this characterization, RECYC-QUÉBEC and ÉEQ determined the composition of the three residential curbside collection sites (waste, recyclables and organic matter) of thousands of households throughout Québec. The characterization protocol classifies waste into categories of materials, including degradable and non-degradable plastic shopping bags. For the first time, these bags were identified according to the type of bag (conventional or other) and its use (those used as garbage bags and those that are not). This new approach made it possible to measure the proportion of bags that are thrown away that are
actually reused as garbage bags. The proportions for the different types of bags (degradable or non-degradable, conventional (T-shirt) bags, etc.) used in this study are shown in Table 3-6 and Table 3-7. These are averages calculated from 126 samples. 3
In order to validate these reuse rates, which are among the highest values versus previous LCAs, the authors estimated the proportion of Quebec residential garbage contained annually in shopping bags reused as garbage bags by considering the following values:

- One billion bags of groceries distributed per year (RECYC-QUÉBEC et al., 2012);
- 4.1% of bags abandoned in the environment (Bio Intelligence Service, 2011);
- 67.6% of conventional end-of-life plastic bags reused as garbage bags (see above);
- A mass of 1 kg contained in each bag reused as a garbage bag (hypothesis);
- 2,272,187 tonnes of residential garbage collected in Quebec per year (EEQ and RECYC- QUÉBEC, 2015).

3 Since the LCA study was conducted during the 2016-2017 characterization of RECYC-QUÉBEC and ÉEQ, new values based on more samples (171) were received at the end of this report and were almost identical to those used in the study (e. g. 78.8% for conventional plastic bags).

For example, shopping bags reused as garbage bags would contain 29% of Quebec residential garbage annually, a quantity that seems reasonable to the authors and that supports the rates resulting from the garbage characterization. Other end-of-life secondary uses were not considered because they are less common and do not necessarily replace another product. For the other types of bags, no secondary function was considered. Other uses of reusable bags, such as transporting or storing items, do not have a significant impact on LCA outcomes since it would be surprising if consumers purchased bags exclusively for this purpose. So there would be no substitution.

3.5.2 Recycling

Recycling upstream (recycled bag content) and downstream (recycling at end-of-life) of a product system can be considered in several ways. Two main methods are used: the extension of borders and the cut-off rule.

The first approach relates to the treatment of downstream recycling. It consists of removing the production function of recycled material from the product system by allocating an impact credit corresponding to the avoided virgin material. Under this approach, recycled content is ignored when the product is recycled at the end of its useful life to avoid double counting. It therefore favours products that are recycled at the end of their useful life.

The second approach simply assumes that the recycled material used in manufacturing the product or recovered at the end of its useful life is outside the product system. No environmental impacts or credits are therefore attributed to it. Thus, sorting and recycling operations are included upstream (production) but excluded downstream (end of life). This approach favours products with a high percentage of recycled content but little end-of-life recycling.

Since the bags under study have a wide variety of recycled content and different recycling rates, a method combining the two approaches above has been adopted. This is known as the "50/50" imputation method. It consists of allocating half of the benefits and impacts associated with end-of-life recycling and half of those of using recycled material in manufacturing. A sensitivity analysis will compare the results with those of the Border Extension approach ("0/100") and the cut-off rule approach ("100/0").

3.5.3 Other settlement/imputation rules

When a process is multifunctional (i. e. it generates more than one product or is involved in the recycling of intermediate products), it is necessary to divide its inputs and outputs between its different functions. It is a matter of attributing responsibility for potential impacts to each of the elements involved. Although some examples have been discussed in the previous paragraphs, they do not cover all cases encountered in LCA. ISO 14 044 (ISO, 2006b) prescribes the following general imputation method:

1. Avoid imputation by:
    a. Splitting the basic process into sub-processes by collecting input and output data related to them; or
    b. Extending borders.
2. Where allocation is unavoidable, it must reflect the underlying physical relationships between the different products or functions.

3. Where a physical relationship cannot be established, an imputation reflecting other factors such as mutual relationships can be used, including economic imputation.

3.6 System boundaries

Systems boundaries are used to identify the steps, processes and flows considered in an LCA. They include all activities relevant to the achievement of the study's objectives and therefore necessary to the achievement of the function under study.

The following subsections provide a general description of the system boundaries, as well as the associated geographical and temporal considerations.

3.6.1 General description of the systems

Figure 3-1 shows the general boundaries of the systems studied. They include the production of materials, bag manufacture, distribution, bag use and end-of-life. Details of the systems (quantified flows and processes) are also provided in Appendix C.

It should also be noted that the various stages of the life cycle of the products under study form the front-end systems, while all the procurement and release management processes involved in each of these stages form the back-end systems.

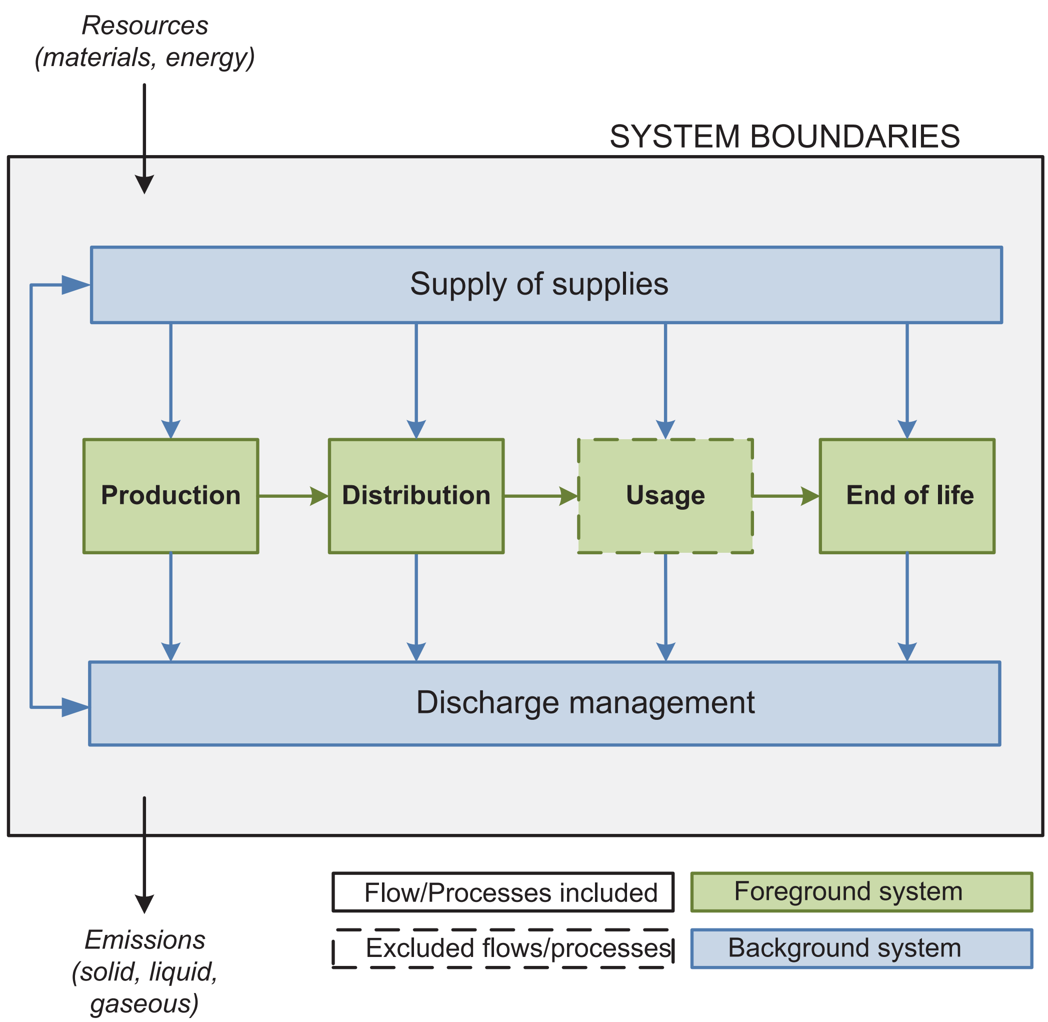


Figure 3-1: General boundaries of the systems under study.

The "**production**" subsystem includes the production of all the materials and packaging necessary for the production stage of the bags, their delivery to the manufacturing site and the manufacture of the product itself. It includes material assembly, packaging, etc.

The "**distribution**" subsystem covers the transport of finished products from their place of production to the retailer. It also includes the handling and storage of products by retailers, wholesalers and other intermediaries.

The "**usage**" subsystem concerns the packaging and transport of purchases when shopping, as well as the washing of bags. However, transport emissions (e. g. from cars) from shopping bags are considered negligible as the bags represent a very small mass compared to the purchases they contain and that of a person. In addition, consumers do not wash their reusable bags very often (CROP, 2015). Therefore, this life cycle stage was excluded from the study.

End-of-life "refers to disposal of the product at the end of its useful life, including transport to the final disposal or management site".

Finally, for each of the four foreground subsystems above, the "**supply**" and "**release management"** background subsystems cover, respectively, all related activities for each of the four foreground subsystems:

- The supply of resources (water, energy, chemicals, materials), including the extraction, processing and transformation of natural resources, as well as the various transports required until they reach the resource use sites (i. e., the sites where materials, manufacturing, and end-of-life are produced).
- The transport and treatment of waste generated at any of these life cycle stages, taking into account possible developments (re-use, recycling, energy recovery or other).

In all subsystems, identifiable "upstream" processes are included so as to provide the most comprehensive view of the system. For example, in the case of energy used for transportation, not only are emissions from fuel combustion considered, but also the processes and materials required to produce that fuel. In this way, the production lines of all inputs are traced back to the extraction of raw materials.

The processes and flows included and excluded from the analysis are summarized in Table 3-4. Supply and release management was divided between the lifecycle stages to simplify the reading of the table.

It should be noted that no inclusion or cut-off criteria were applied for this study: all available data were incorporated into the model.

As presented in Table 3-4, some processes were excluded due to a lack of data or an inability to model a representative generic case. It is also not possible to know the effect of excluding these items on results.

Table 3-4: Processes Included and Excluded from CLSA Borders

Stages of the cycle of life	Processes/Sub-process	Comments
Production	Production of constituent materials for bags	Supplies used in production (materials including bags and inks) included
	Production of energy consumed during bag making	Generation of electricity and generation of electricity fossil fuels
	Production of packaging for bag distribution	Production of materials used in primary packaging (cardboard boxes) included
	Use of recycled material	inclusion of recycling processes according to the 50/50 method
	Transport to the manufacturing site of the bags	Transport of materials, energy and packaging to the bag manufacturing site included. *Secondary and tertiary packaging excluded*
	Bag manufacturing	Water consumption and direct emissions at environment included
	Infrastructure	*Excluded (data not available, process of infrastructure considered to be both similar from one system to another and having little/no impact on results impact indicators)*
Distribution	Transport from the place of production to distribution centre	Included
	Transport to retailers	Included
	Handling and storage	*Excluded (data not available and considered as having little/no impact on the impact indicator results)*
Usage	*Wash reusable bags*	*Excluded from baseline scenarios (considered negligible)*
	Transport of retailer bags to home	*Excluded (considered negligible)*
End of life	End-of-Life Transport	Transport to the processing site
	Landfill	Included
	Sorting and recycling	Included under the 50/50 method
	Abandonment in the environment	Proportion of bags abandoned in The environment considered by the indicator (see section 3.7.1). No industrial process or economic activity involved.
	Production avoided	Recycling materials according to the method 50/50 and secondary function (waste bags) included
All the steps	*Ancillary services (advertising and other) utilities)*	*Excluded (data not available, processes considered to be both similar to a system to each other and as having little/no impact on indicator results)*

3.6.2 Geographical and temporal boundaries

In accordance with the functional unit selected, this study represents a LCA representative of the Quebec context in 2016. Thus, production, distribution and end-of-life activities are modeled to meet this criterion.

Furthermore, it should be noted that certain processes within the boundaries of systems may take place anywhere or at any time if they are necessary to achieve the functional unit. For example, processes associated with the procurement of raw materials and the management of generated discharges can take place in Quebec or elsewhere in the world. In addition, some processes may generate emissions over a longer period of time than the base year. This is the case of waste landfill, which generates emissions (biogas and leachate) over a period of time, the duration of which (from a few decades to more than a century or even millennia) depends on the design and operating parameters of the landfill cells and the modelling of their emissions into the environment.

3.7 Life Cycle Inventory Sources, Assumptions and Data (LCI)

The data required for the LCA include the raw materials used, the energy consumed and the emissions generated at each stage of the life cycle studied.

Data collection is an important step that is carried out iteratively between CIRAIG and the study stakeholders. The quality of LCA results depends on the quality of the data used to conduct the evaluation. Therefore, every effort has been made to ensure that the most credible and representative available information is included in the study.

This study is conducted in such a way that primary data are available and easily accessible at the outset, followed by more detailed data collection for specific key processes or parameters. These data are provided by RECYC-QUÉBEC and the stakeholders designated for data collection. It includes product-specific data and bag manufacturers' practices. These primary data are collected through an electronic questionnaire sent to stakeholders and telephone interviews. Stakeholders include the following organizations:

- Canadian Plastics Industry Association (CPIA)
- Metropolitan Community of Montreal (CMM)
- Council for the Environment of Paper and Cardboard Packaging (CEEPC)
- Conseil québécois du commerce de détail (CQCD)
- Éco Entreprises Québec (ÉEQ)
- Ministry of Sustainable Development, Environment and Climate Change Control (MDDELCC)
- City of Montreal

Missing, incomplete or not easily accessible data are supplemented by secondary data, i. e. from the ecoinvent inventory database, the internal CIRAIG database, available public databases, a literature review and expert judgments.

Most of the secondary data come from the Life Cycle Inventory Data Modules (LCI) available in the ecoinvent version 3.2 database (cut-off model). This European database is particularly recognized by the international scientific community as it far exceeds other commercial databases in terms of both quantity (including number of processes) and quality (quality of validation procedures, completeness of data, etc.). In addition, this database includes Quebec datasets from the Quebec BD-ICV(CIRAIG, 2016). The US-LCI database has also been used for production data in a North American context (NREL, 2013).

As far as possible, the generic data modules used in this study are adapted to increase their representativeness of the products and context analysed. In particular, the generic modules are adapted using the energy supply mixes (grid mix) of the ecoinvent database corresponding to their geographical location, where known. Otherwise, the global grid mix is used. Table 3-5 presents details of the main grid mixes used. The other grid mixes used are accessible from the ecoquery. ecoinvent. org portal. Note that the US-LCI database processes used in this study have their own grid mix, accessible from uslci. lcacommons. gov.

Table 3-5: Major Energy Supply Blends Used

Fashion of generation electric	Québec	Ontario	China	Global
Coal	0,1 %	2,6 %	74,5 %	38,2 %
Oil	0,3 %	0,2 %	0,2 %	5,0 %
Natural gas	0,4 %	13,3 %	2,0 %	22,0 %
Nuclear	0,8 %	50,8 %	2,2 %	11,1 %
Hydroelectric	97,4 %	29,3 %	18,6 %	18,8 %
Wind Turbine	0,6 %	3,0 %	2,3 %	2,4 %
Biomass	0,5 %	0,8 %	0 %	1,8 %
Other	0 %	0 %	0,2 %	0,7 %

Note: Total may differ by 100% due to rounding. Source: ecoinvent v3.2.

Finally, it should be remembered that the collection is limited to the data that are the easiest to access at first. The analysis of the results obtained following this preliminary collection guides, in a second stage, the collection of the data required to achieve the objectives of the study.

The main system assumptions are as follows:

- Bag washing: the washing of reusable bags is not considered in the basic scenarios since 86% of Montrealers occasionally clean their reusable bags, rarely or never according to a CROP survey (2015). However, it is evaluated in sensitivity analysis.
- Abandonment in the environment: 4.1% of disposable bags are considered abandoned in the environment compared to 0.5% for reusable bags (European Bio Intelligence Service, 2011).
- Recycling of oxodegradable plastic and bioplastic bags made of starch and polyester: These types of bags are found selectively in recovery collection. Since they are indistinguishable from conventional plastic bags, they are easily sent for recycling with conventional non-biodegradable bags. The sorting and recycling operations are

therefore included within the system of these bags. However, since oxodegradable plastic and bioplastic, if present in the recycling mix in too large quantities, can degrade the quality of recycled plastic which is nonbiodegradable (Grenier and Côté, 2007), no credit for avoiding the production of virgin material is given to these plastics, unlike conventional plastic bags.

- Recycled content of plastic bags: In the basic scenario, plastic bags (conventional, thick and oxodegradable) will have no recycled content. However, according to the CPIA, conventional plastic bags can contain 25% recycled content from the manufacturing process or purchased from other plants according to the CPIA. Therefore, recycled content is considered for sensitivity analysis.
- Packaging: The packaging considered for all shopping bags is the cardboard box.
- No CO2 or CH4 emissions were considered for the decomposition of bio-sourced bags (starch/polyester bioplastics, paper and cotton) abandoned in the environment.

It should also be noted that all the data used are:

1) Assessed as to their temporal, geographical and technological representativeness;
2) Collected in such a way that they are the least aggregated possible;
3) Documented in accordance with best available practices.

Table 3-6 summarizes the main data sources and assumptions used in this LCA, while details of the data used are presented in Appendix C of this report. In addition, the following figures illustrate the process trees for each study bag. They show the main processes included in the modelling of systems according to the information contained in Table 3-6. Grey processes are those affected by the recycling approach as described in Section 3.5.2. Those marked with an "-" sign constitute credits, i. e. their potential impacts are subtracted from the bag's life cycle.

SimaPro 8.2 software, developed by PRé Consultants, is used to perform system modeling and inventory calculation.

Table 3-6: Key Data, Sources and Assumptions Used in Establishing the Foreground LCI for Shopping Bags

Parameters	Compared systems			Comments
	Plastic bag conventional	Plastic bag oxodegradable	Bioplastic bag	
Production				
Ground (g)	8,6 Source : manufacturers		15,7 (estimation	
Place of manufacture	Toronto, ON		California	Source : manufacturing
Bag manufacturing data	ecoinvent			
Recycled Content	0%		0 %	
Packaging	Corrugated cardboard box of 1,000 units		Cardboard box of 500 units	Source : retailer
Material	HDPE		starch polyester blend	
Provenance	Texas		Terni, Italie	Source : manufacturers
Data from production of materials	US LCI (2016)		ecoinvent	
Distance and means of transport	2,500 km by train from Houston, TX		150 km by truck from Terni (IT) 15 200 km by boat from Italy	Truck and train distances evaluated with Google Maps. Distances by boat evaluated with www.searates.com.
Distribution				
Transportation to retailer (Quebec City)	800 km by truck		4 850 km by truck from Los Angeles (hypothesis)	Truck distances evaluated with Google Maps.

Parameters	Comparative systems			Comments
	Plast bag. conventional	Plast bag. oxodegradable	Bioplastic bag	
End of life				
Distance and mode of travel transport	50 km by truck			Assumption
Bags managed at end-of-life	87% to landfill including 77.7% reused as bags rubbish 13% recycling	86.2% to landfill, of which 72.2% reused as garbage bags 13.8% to recycling		Sources : RECYC-QUÉBEC (2016) ÉEQ & RECYC-QUÉBEC (2015)
Bags abandoned in the environment	4.1% of bags distributed			Source : Bio Intelligence Service (2011)
Appropriations	Secondary use: Production of garbage bags avoided Recycling: HDPE production avoided	Secondary use: Production of garbage bags avoided Recycling: no credit because contaminant	**Secondary use: Production of garbage bags avoided** **Recycling: no credit because contaminant**	

Table 3-7: Key Data, Sources and Assumptions Used in Establishing the Foreground LCI for Shopping Bags (continued)

Parameters	Compared systems		Comments
	Thick plastic bag	Paper bag	
Production			
Ground (g)	23	66	Sources : direct measures
Place manufactured	Saint-Hubert, QC (source : retailer)	Montréal, QC (conjecture)	
Bag manufacturing data	ecoinvent		
Recycled Content	0 %	26% Post-consumer (North American average) Source : US-LCI (2016)	
Packaging	500 unit corrugated cardboard box (hypothesis)	1,000 unit corrugated cardboard box Source: retailer	
Material	LDPE	unbleached kraft paper	
Provenance	Texas	United States	Source : manufacturing
Data from production of materials	US LCI (2016)		
Distance and means of transport	2 500 km by train to Houston, TX	2 200 km by train to Roanoke Rapids, NC (most plausible site according to data import)	Truck and train distances evaluated with Google Maps
Distribution			
Transportation to retailer (Quebec City)	250 km by truck		Distances en camion évaluées avec Google Maps.

Parameters	Comapred systems		Comments
	Thick plastic bag	Paper bag	
Production			
Distance and mode of transport	50 km by truck		Assumption
Bags managed at end-of-life	87% to landfill including 47.3% reused as garbage bags	65.6% to landfill 34.4% to recycling	Sources : RECYC-QUÉBEC (2016) ÉEQ & RECYC-QUÉBEC (2015)
Bags abandoned in the environment	4.1% of bag		Source : Bio Intelligence Service (2011)
Appropriations	Secondary use: Production of garbage bags avoided Recycling: LDPE production avoided	Recycling: Paper production avoided	

Table 3-8: Key Data, Sources and Assumptions Used in Establishing the Foreground LCI for Shopping Bags (continued)

Parameters	Comparative systems			Comments
	Woven PP bag	Non-woven PP bag	Cotton bag	
Production				
Ground (g)	96.5	62	189	Sources : direct measures
Place manufactured	China	China	China	Source : manufacturer
Data from manufacture of bags	ecoinvent			
Recycled Content	100% post-consumer Collection and sorting data: Franklin Associates (2011)	0 %	0 %	Source : manufacturer
Packaging	Corrugated cardboard box of 100 units			Assumption
Material	Polypropylene		Cotton fiber	
Provenance	China			Assumption
Data from production of material	ecoinvent			
Distance and means of	500 km by truck in China (hypothesis)			
Distribution				
Transportation to retailer (Quebec City)	22 000 km by boat from Tianjin 250 km by truck			Truck distances evaluated with Google Maps. Distances by boat evaluated with www.searates.com.
End of life				
Distance and mode of transport	50 km by truck			Assumption
Bags managed at end-of-life	100 % to landfill			Bags sent for selective collection are discarded at the sorting centre
Bags abandoned in the environment	0.5% of bags distributed			Source : Bio Intelligence Service (2011)

Table 3-9: Key data, sources and assumptions used in developing the foreground LCI for shopping bags (continued)

Parameters	Credited system	Comments
	PE garbage bag	
Production		
Ground (g)	12	Source : manufacturer
Place manufactured	United States	According to what is observed in supermarkets and import statistics.
Bag manufacturing data	ecoinvent	
Recycled content	0 %	According to what is observed in the supermarket
Packaging	Flat cardboard box of 50 units	According to what is observed in supermarkets and import statistics.
Material	LDPE	
Provenance	Texas	Assumption
Material production data	US-LCI (216)	
Distance and means of transport	2 500 km by train to Houston, TX	*Assumption: distance equal to that of the conventional plastic bag*
Distribution		
Transportation to retailer (Quebec City)	800 km by truck	Assumption: distance equal to that of the conventional plastic bag

3.7.1 Conventional plastic and oxodegradable plastic bags

Product systems for disposable plastic bags have been defined mainly using information from industry. According to them, plastic shopping bags distributed in Quebec are primarily made in Quebec and Ontario. The Toronto area was chosen as the typical production site for bags because it is home to a major manufacturer of bags of this type that supplies large Quebec food retailers. And since 75% to 80% of this type of bag is consumed by the food industry, the choice of location was considered representative.

The plastic used in the manufacture of these bags comes mainly from Texas by train depending on the industry. This information is supported by the Government of Canada's polyethylene import figures for Ontario (76% of U. S. HDPE imports in 2015). This information is also valid for oxodegradable plastic bags as their manufacture is very similar to conventional bags.

Regarding the end-of-life fate of the additive added to the oxodegradable bag, the metals contained in the latter, i. e. cobalt, zinc, nickel and manganese according to Edwards and Fry (2011), have been taken into account. This was done on the assumption that these metals would be released into water over the long term.

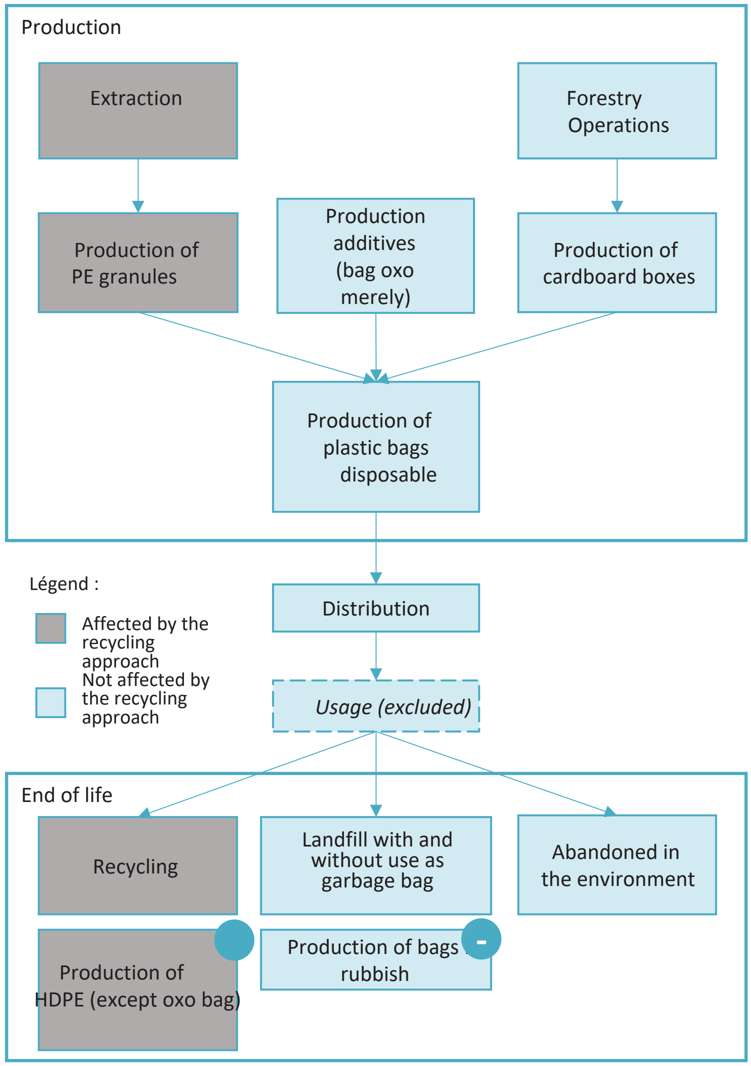


Figure 3-2 : Process treechart "conventional plastic bag","oxodegradable plastic bag" and "thick plastic bag".

3.7.2 Bioplastic bag starch-polyester

Few bioplastic shopping bags are available on the market. The bag selected for the LCA is manufactured in California (hypothesis: Los Angeles) and transported by truck to Quebec according to the Canadian distributor (BioBag®). It consists of "Mater-Bi" type polymer produced by an Italian company from corn starch and a biodegradable polyester of fossil origin; the production site of which is located in Terni. This material has in the past been the subject of an environmental product declaration with which production data have been calculated in order to estimate the impacts of the production of this kind of biopolymer in a European context in the ecoinvent database. These data were included in this study, but adapted to correspond as closely as possible to the material under study. To do this, electricity and natural gas production has been regionalized. In addition, the Agrifootprint database (Blonk Agri-footprint BV, 2015), which specializes in the agri-food sector, was used to model the production of Italian starch from corn (including land use).

Based on searates. com, it is assumed that this plastic is then transported from Italy to California by boat through the Panama Canal. There is no information to favour the case where the goods would be unloaded on the east coast of the United States and then transported by truck or train across the continent. The production of bags was modelled using a generic ecoinvent process of plastic film extrusion with production of electricity adapted to the West American coast of the U.S. The bags are finally shipped to Quebec by truck according to the distributor.

At the end of life, like other plastic bags, landfill, recycling, abandonment in the environment and reuse as garbage bags were evaluated using the parameters presented in Table 3-6. Like the oxodegradable bag, no credit for the recycling of the starch-polyester bioplastic bag was included as the bag is a contaminant to the recycling process.

Due to the biogenic carbon content and biodegradability of this type of bag, biogenic carbon sequestration in landfill sites and decomposition emissions of the non-biogenic portion were considered. For this purpose, a composition of 35% starch and 65% polyester of fossil origin (Gironi and Piemonte, 2011) and the respective carbon (dry basis) content of 47% (PubChem, 2017a) and 64% (PubChem, 2017b). Carbon sequestration and methane emission rates were derived from US EPA data (Staley and Barlaz, 2009). For the bioplastic bag made of starch-polyester, the values for food residues were used (0.08 kg of carbon per dry kg of waste, 300.7 m^3 of methane per dry tonne of waste) and starch was included in this category, with the exception of water content (zero for starch-polyester bioplastics). No sequestration or air emissions for bags abandoned in the environment were considered.

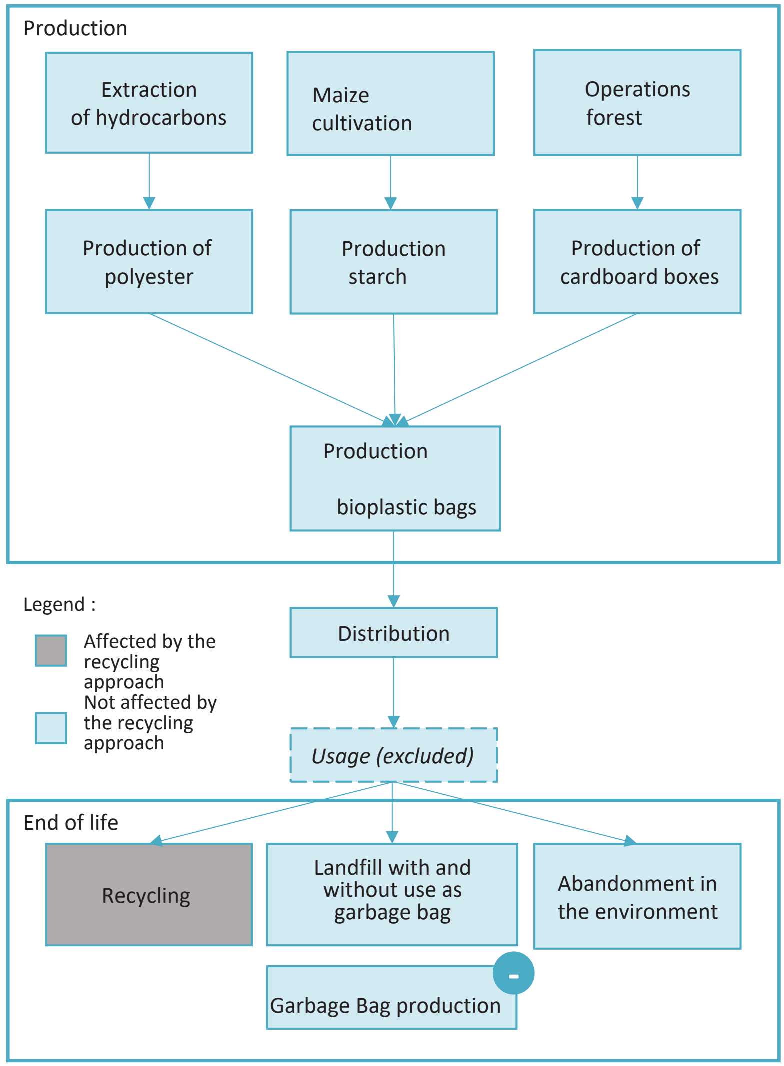


Figure 3-3 : Process tree chart of the "starch-polyester bioplastic bag" system

3.7.3 Thick plastic bag

The thick plastic bag type is difficult to define because of the diversity of dimensions and users. To do this, the authors of the study relied on a bag offered in a large clothing chain in Quebec. Manufactured in the Montreal area, it is assumed to be made from LDPE from Texas, for the same reasons as thin plastic bags; 64% of Quebec's imports of LDPE from the U. S. are produced in this state.

3.7.4 Paper bag

Like plastic bags, Canadian paper bag manufacturing establishments (all categories) are located primarily in Ontario and Quebec (Government of Canada, 2017b). It was not possible to identify a more representative place of manufacture than another. The assembly of bags from kraft paper does not require extensive installations, so they can be manufactured anywhere. Therefore, the local manufacturing hypothesis was adopted. In terms of paper supply, following the closure of a Quebec mill in recent years, there are now only two kraft paper mills in Canada: one in British Columbia, producing bleached kraft paper, and one in Manitoba, where unbleached paper is used primarily for the manufacture of cement bags. Unbleached paper shopping bags distributed in Quebec are not made of Canadian paper. According to Canadian import data, almost all kraft paper imported into Canada comes from the U. S., mainly North Carolina (Government of Canada, 2017a). This site was therefore used to assess the impacts of transporting kraft paper to Montreal to produce grocery bags.

Like the bioplastic bag made of starch-polyester, landfill biogenic carbon sequestration was considered using Staley and Barlaz (2009). The carbon sequestration and methane emission rates for kraft paper bags are 0.26 kg of carbon per dry kg of waste and 152.3 m^3 of methane per dry tonne of waste, respectively, and the water content is 5%. No sequestration for bags abandoned in the environment was considered.

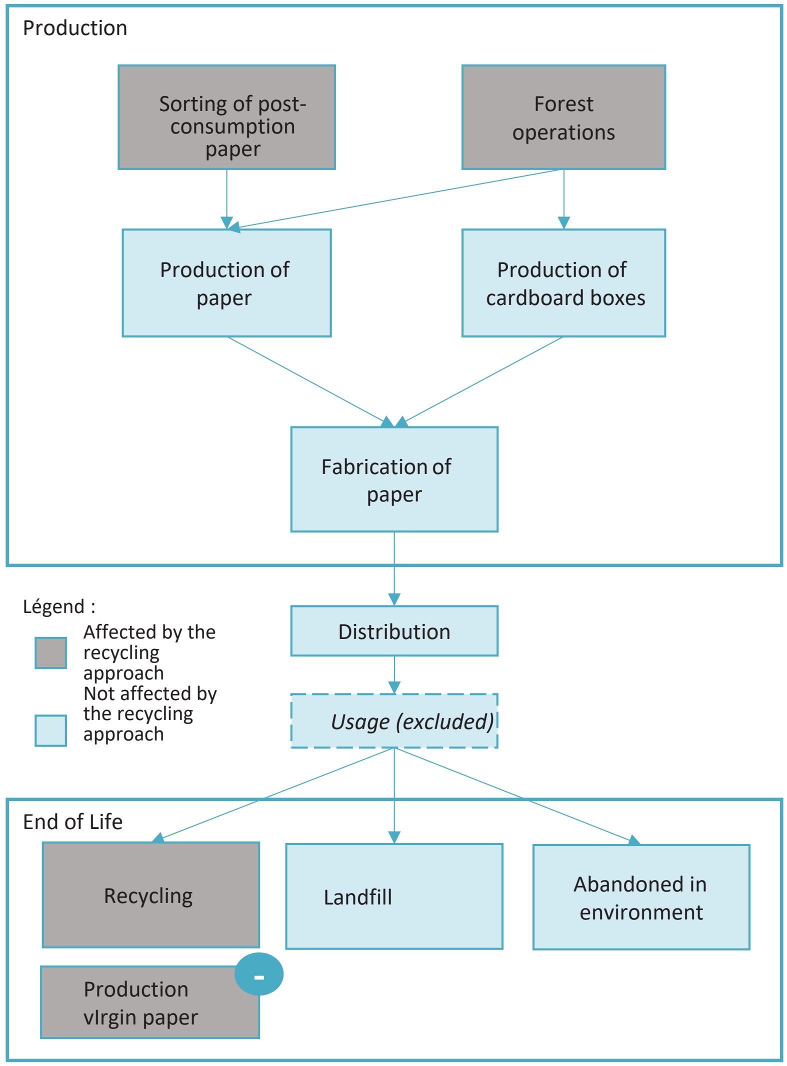


Figure 3-4 : Process tree chart of the paper bag system

3.7.5 Woven PP bags

This type of bag is the first of two PP bags made of thin plastic strips woven together. PP granules are first formed into films. These are then cut into strips and woven into a plastic fabric to make bags. The bag on which the authors of the study relied was that of a large grocery store. It is made in China and consists of 100% post-consumer PP. Despite this, the production of virgin PP is still included in this product system since the recycling approach considers only half the benefits of using recycled material, the other half being considered as virgin (see section 3.5.2). Given that China imports about one third of the plastic it recycles (Velis, 2014), a local source of post-consumer plastic was considered.

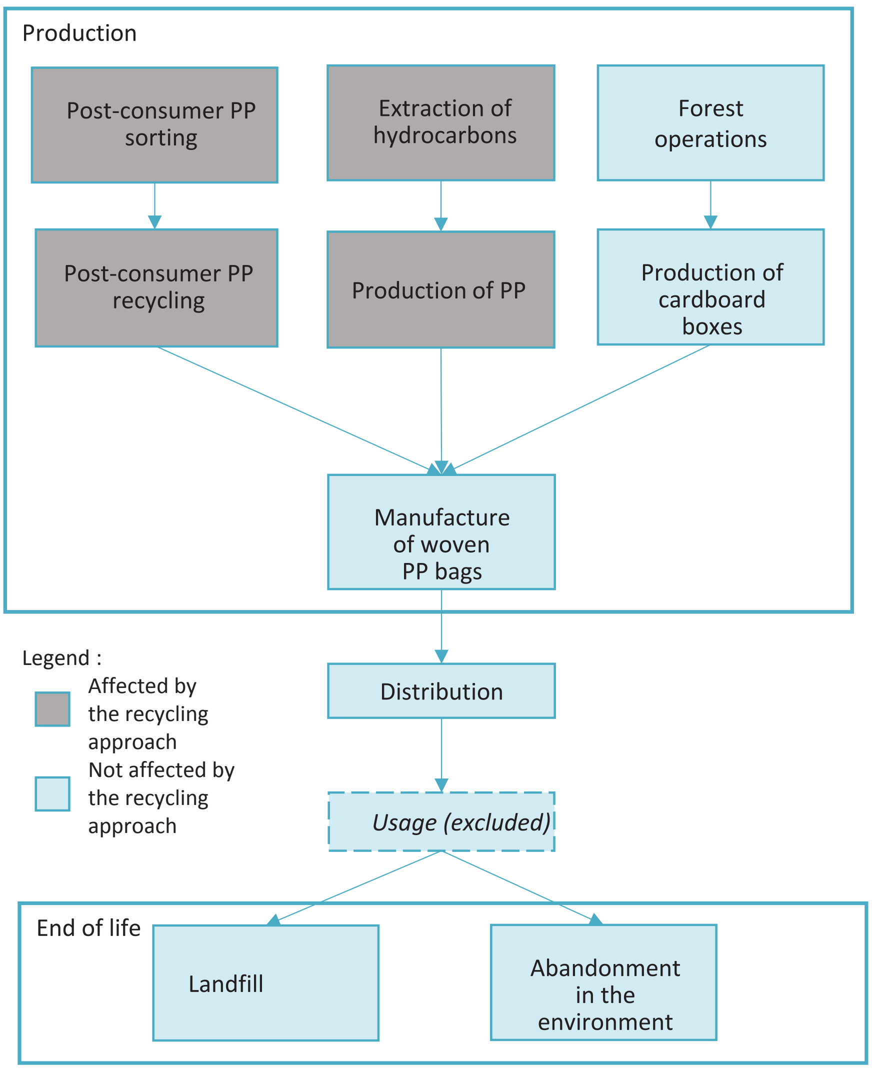


Figure 3-5 : Process tree chart of the "woven PP bag" system

3.7.6 Non-woven PP bags

Non-woven PP bags are made from melted PP granules, transformed into fibres which in turn are hot pressed to form the textile. The latter is then mechanically assembled into bags. All bags of this type observed by the authors come from Asia, mainly China. This country was therefore chosen as the place of production, without considering a specific province. Moreover, since China is a very large world producer, the source of PP considered is also China. The bag used to model the inventory is considered typical by the authors.

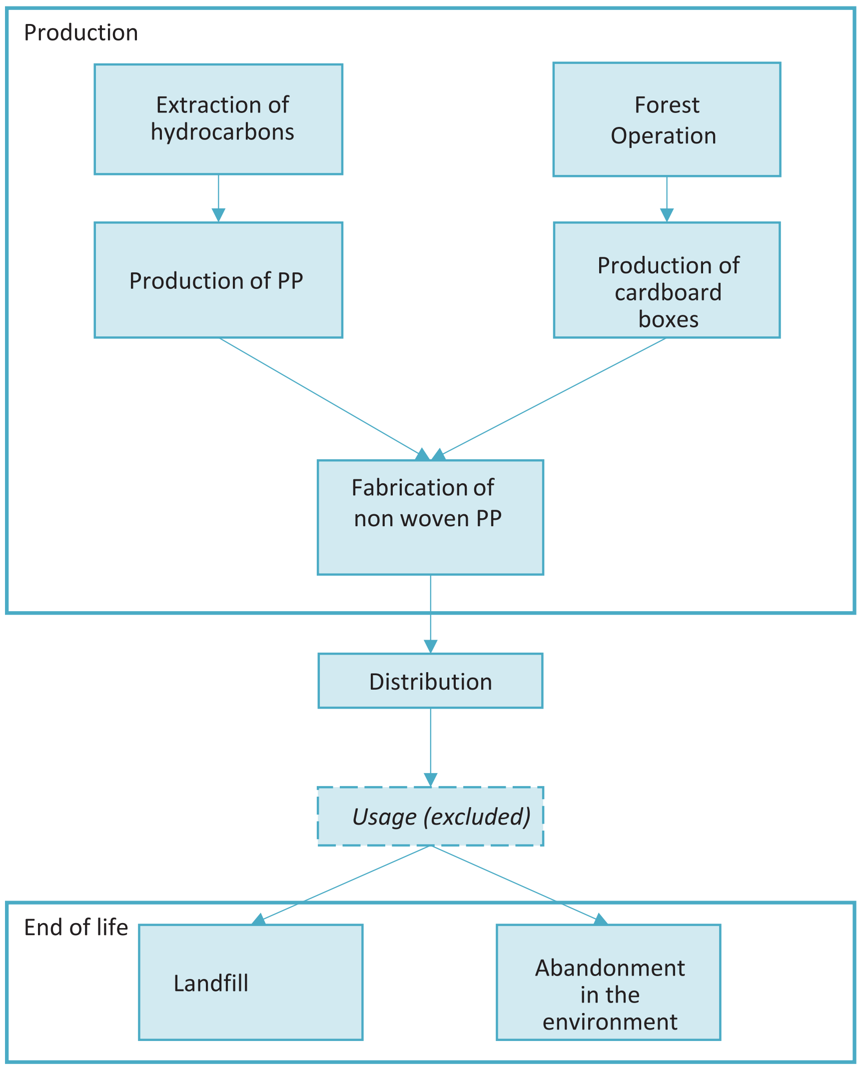


Figure 3-6 : Process tree chart of the "non-woven PP bag" system

3.7.7 *Cotton bags*

Although cotton shopping bags made in India or even in Canada can be observed in circulation, according to Quebec import statistics, cotton bags (all categories) come almost entirely from China (Government of Canada, 2017). It could not be determined whether one Chinese province supplied more bags of cotton than another. As a result, national emission factors have been used, in particular for electricity supply. The electrical consumption during the manufacture of the bag (sewing) was not considered due to a lack of data. A Chinese cotton fibre was considered as a material, with China being the world's largest producer of cotton(Cotton Inc., 2012). Production data for cotton cultivation and textile manufacturing were taken from ecoinvent.

The carbon sequestration and methane emission rates used for the cotton bag are 0.26 kg of carbon per dry kg of waste and 152.3 m^3 of methane per dry tonne of waste, respectively, and the moisture content is 10% (Staley and Barlaz, 2009). No sequestration for bags abandoned in the environment was considered.

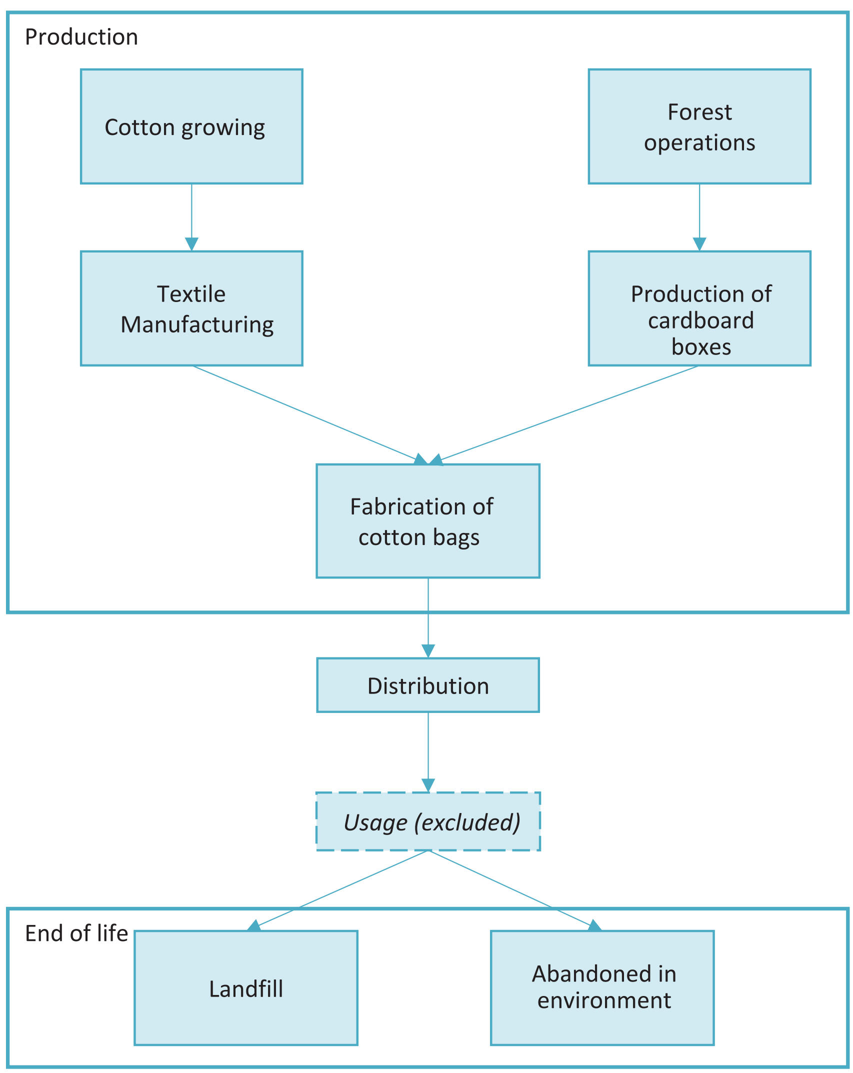


Figure 3-7 : Process tree chart of the cotton bag system

3.8 Environmental Impact Assessment (EIA)

Potential life-cycle environmental impacts were assessed using the IMPACT World+ assessment method (Bulle et al., 2016). In contrast to other existing SIA methods, it allows for the assessment of potential impacts in their respective geographical contexts.

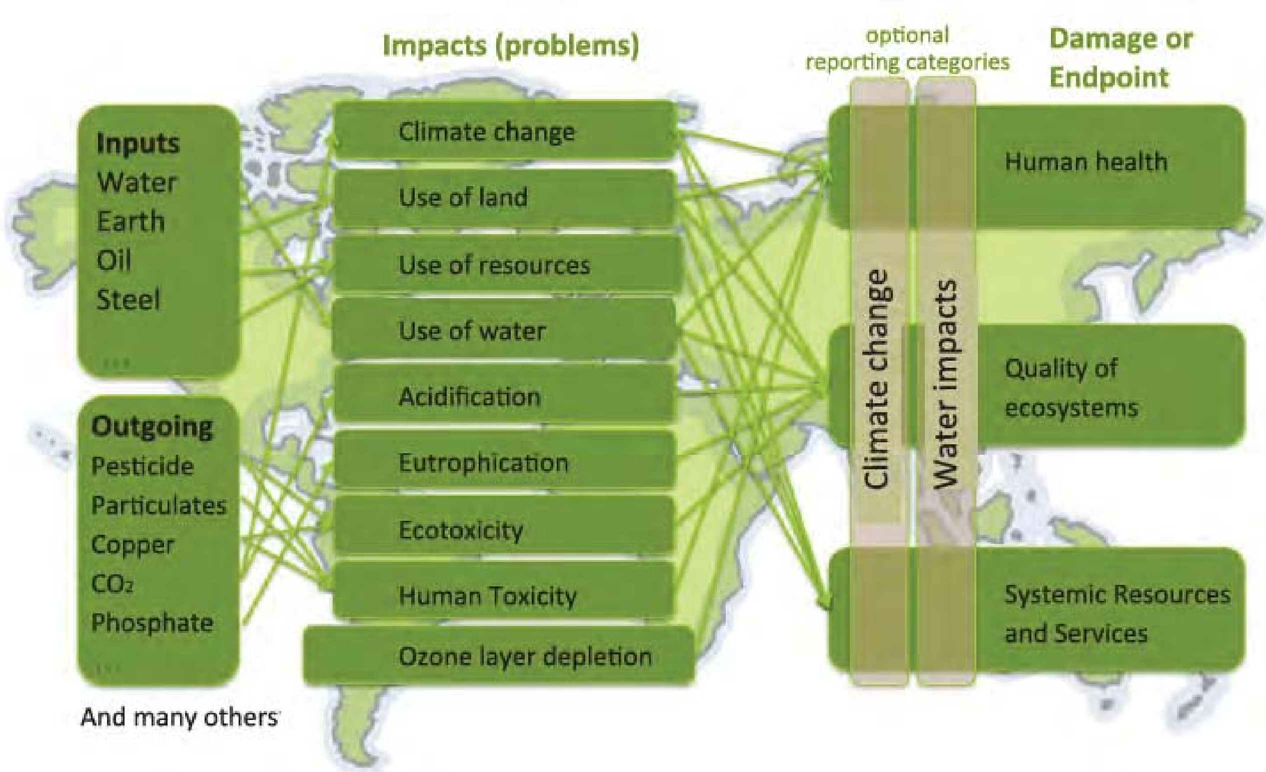


Figure 3-8 : Damage categories and impact categories of the IMPACT World+ method

(Source : http://www.impactworldplus.org/en/methodology.php).

The environmental impact assessment was carried out at the problem and damage levels.

Problem-level assessment does not model all environmental mechanisms linking an emission to a protection area such as human health or ecosystem quality. A "problem" indicator therefore has less environmental relevance than the damage indicator, while displaying a smaller uncertainty inherent in environmental modelling. A disadvantage of the "problem" indicators, however, is that their greater number complicates the interpretation of the results.

Damage level assessment models all environmental mechanisms linking an emission to a protection area such as human health or ecosystem quality. While such an assessment is at the top of environmental relevance, the uncertainty inherent in modelling is greater. As fewer "damage" indicators are available, however, they facilitate the interpretation of results, identifying "problem" indicators with greater environmental relevance.

The multiple problem categories of IMPACT World+ can be summarized as follows:

- Carcinogenic substances (Rosenbaum et al., 2008): The USEtox model is used to determine the toxic impact of carcinogenic substances. The model considers all routes of exposure of contaminants to humans: ingestion, respiration, contact, ingestion of water and fish.

- Carcinogenic substances, pesticide residues (Fantke et al., 2011): This impact category assesses the potential impact of pesticides through various routes of exposure to human contamination. The USEtox model was used to assess these effects.
- Non-carcinogenic substances (Rosenbaum et al., 2008): The USEtox model is used to determine the toxic impact of non-carcinogenic substances. The model considers all routes of exposure of contaminants to humans: ingestion, respiration, contact, ingestion of water and fish.
- Respiratory effects (Humbert, 2011): respiratory effects are caused by fine particles (less than 10 µm in diameter) and are related to impacts on human health when inhaled.
- Ionising radiation (Rosenbaum et al., 2008): assesses the consequences of routine releases of radioactive substances.
- Ozone depletion (Goedkoop, 2009): anthropogenic emissions of ozone depleting substances interact with the ozone layer. They break the ozone molecules into oxygen molecules. The result is an increase in ultraviolet rays reaching the Earth's surface, increasing the risk of skin cancer and cataracts. It can also cause premature aging and weakening of the immune system.
- Short-term (GWP) and long-term (GTP) climate change (IPCC, 2013): greenhouse gas emissions from human activities absorb infrared radiation emitted by the Earth's surface, maintaining thermal energy in the lower atmosphere. The increase in greenhouse gases over the last century has increased the average temperature of the atmosphere and oceans.
- Water consumption (Boulay et al., 2011): this impact category assesses the lack (if any) of water resources to meet the water consumption requirements in a region.
- Terrestrial acidification (Roy et al., 2014): Emissions of anthropogenic acidifying substances are transported to the atmosphere before being deposited on terrestrial media, which has the effect of reducing soil pH and causing impacts on flora and fauna.
- Aquatic acidification (Roy et al., 2013): Emissions of anthropogenic acidifying substances are transported into the atmosphere before being deposited on terrestrial and aquatic environments. Substances deposited on terrestrial environments migrate to aquatic environments. Acidifying substances in aquatic environments have the effect of lowering their pH, which causes impacts on fish.
- Long and short-term aquatic ecotoxicity (Rosenbaum et al., 2008): Pollutants emitted into the environment and found in water can be toxic to aquatic fauna and flora.

- Aquatic (Helmes et al., 2012) and marine (Roy et al., 2012) eutrophication (Helmes et al., 2012): The release of nutrients into the water promotes the proliferation of algae that can asphyxiate a river if they are too numerous. Aquatic environments (i. e., freshwater) are particularly affected by phosphorus emissions, while estuaries and marine environments are particularly affected by nitrogen emissions.
- Land use (Saad et al., 2011): this impact category considers the effect on biodiversity of a transformation and occupation of a certain surface area.
- Fossil resource use: presents the consumption of fossil resources that prevent their use by future generations.
- Mineral Resource Use: presents the consumption of minerals that prevent their use by future generations.

The categories of damage can be summarised as follows:

- Human health: this category includes substances with toxic (carcinogenic and non-carcinogenic) and respiratory effects, which have an impact on climate change, produce ionising radiation, consume water and contribute to the destruction of the ozone layer. In order to assess the injury factor, the severity of the disease potentially caused by these substances is expressed in DALY (Disability-Adjusted Life Years), a unit reflecting th e harm to human health.
- Quality of ecosystems: This category includes impacts related to aquatic ecotoxicity, terrestrial and aquatic acidification, aquatic and marine eutrophication, effects of ionizing radiation emissions on aquatic environments, climate change, ocean acidification, water consumption, thermal water pollution, lowering of groundwater tables and land use. It is quantified as a fraction of potentially extinct species, over a given area and over a period of time, per kilogram of substance emitted (PDF*m^2*year/kg).

It should be noted that :

- The current version of IMPACT World+ does not have a "damage" level indicator for the use of non-renewable resources.
- The results of the Life Cycle Inventory Analysis (LCIA) show potential, not real, environmental impacts. These are relative expressions (particularly for the functional unit) that do not allow us to predict the final impacts or risk to the environment and the impact on safety standards or safety margins.
- These categories do not cover all possible environmental impacts associated with human activities. Several types of impacts, including noise, odours and electromagnetic fields and the effects of the abandonment of non-biodegradable plastic in the environment are not included in this analysis.
- There has been no standardization of results against a baseline. Similarly, no weighting of damage categories to bring the results down to a single score has been done (see Appendix A for more details on weighting and standardization).

In summary, the number of uses for each bag type to obtain an equal score was evaluated for the following indicators:

- Human health (damage category IMPACT World+)
- Quality of ecosystem (damage category IMPACT World+)
- Use of fossil resource (damage category IMPACT World+)

As with the lifecycle inventory, SimaPro 8.2 software was used to calculate the potential impacts associated with the inventoried emissions.

Potential impacts are also assessed using the ReCiPe method (hierarchist perspective; Goedkoop et al., 2009) in sensitivity analysis to verify whether the variability of characterization models has a significant influence on the conclusions. This aims to test the robustness of the results obtained from IMPACT World+.

*3.8.1 Complementary indicator: Abandonment in the environment (kg*year)*

The impacts on health and ecosystems of plastic dispersion in the environment and visual pollution are not characterized by the LCIA indicators presented above. Considering that these impacts play a predominant role in the logic behind some calls to ban bags, this report proposes an indicator which will act as an estimator of the potential impacts of abandoned bags. The proposed indicator is a problem type and reconciles inventory data (e. g., quantity of plastic abandoned in the environment) with presumed persistence of the bag in the environment. The units of this indicator are therefore kg × years. The persistence times in the environment used are as follows:

- Plastics: 500 years with a minimum value of 100 years and a maximum value of 1000 years for the calculation of uncertainty.
- Bioplastic made of starch and polyester: 235 days. This is the average of O' Brine and Thompson (2010), Novamont (2015) and Mohee et al. (2007), extrapolated to 100% decomposition. Minimum and maximum values were used for the uncertainty calculation.
- Paper: 86 days. This is the average between Gómez and Michel (2013) and Mohee et al (2007), extrapolated to 100% decomposition. Individual values were used as minimum and maximum in the uncertainty calculation.
- Cotton: 111 days. This is the average between Warnock et al. (2009) and Li et al. (2010), extrapolated to 100% decomposition. Individual values were used as a minimum and maximum in the uncertainty calculation111 jours.

Therefore, the objective of this indicator is not to determine the consequences of the abandonment of bags in the environment, but only to specify the quantity of undamaged material that may generate a number of potential impacts during its degradation. Indeed, this indicator reflects the possibility that a bag abandoned in the environment could potentially cause harm to human health, ecosystem quality, or visual pollution during its degradation period. This indicator does not attempt to assess the effects of discarding bags and therefore cannot be considered in the same way as the Human Health or Ecosystem Quality endicators =, both of which indicators cause damage.

It is important to note that this indicator is not recognized by an official SIA method.

3.9 Interpretation

This final phase of the LCA provides an opportunity to discuss and put the results of the LCIA into perspective. It includes a comparison of the systems described in the previous sections. The results presented in the next chapter are supported by a comprehensive and in-depth analysis of the inventory and LCIA data. This includes in particular:

- Evaluation of data quality;
- An analysis of coherence and completeness;
- Sensitivity and scenario analyses;
- Uncertainty analyses.

The methodology used for data analysis and interpretation is summarized in the following subsections. But first, a clarification is given as to the analysis of the inventory.

3.9.1 Life Cycle Inventory Analysis (LCIA)

Inventory results in terms of material and energy quantities associated with each of the systems under study are not presented in the body of this report. Comprehensive analysis of entrants and exits does not generally improve understanding of the issues. In fact, the inventory results contain too much information and do not in help with conclusions. In order for the LCIA to be relevant, it must be done in parallel with the impact assessment. Thus, in accordance with ISO 14 044, the results of the LCIA presented and discussed in the following chapter constitute the interpretation of the results of LCI, with the aim of better understanding their environmental impact. A contribution analysis also identifies the inventory flows that are the source of the predominant impacts.

3.9.2 Evaluation of the quality of inventory data

The reliability of the LCA results and conclusions depends on the quality of the inventory data used. It is therefore important to ensure that these data meet certain specified requirements consistent with the purpose of the study.
According to the ISO standard, data quality requirements should at least ensure the validity of the data, which is equivalent to their representativeness in terms of age, geographical origin and technological performance. Thus, the data used should be representative of:

- The period defined by the functional unit, i. e. 2016;
- The geographic context in which the systems under study are located: the production sites of raw materials, the place of manufacture, the practices of Quebec consumers and the place of end of life (Quebec);
- Technological characteristics of bag manufacturing processes and end-of-life treatments.

Although no specific methods are currently prescribed by ISO, two criteria affecting the quality of the inventory have been selected to evaluate the data:

- **Reliability**: concerns sources, acquisition methods and data verification procedures. Data that is considered reliable is verified and measured in the field. This criterion refers mainly to the quantification of flows.
- **Representativity**: deals with geographical and technological correlations. Does the data set reflect reality? Data is considered representative when the technology is directly related to the field of study. This criterion relates mainly to the choice of processes used to model the system

A more detailed description of the criteria and evaluation of data quality are presented in Appendix D.

In parallel to the evaluation of the quality of the data used, an estimation of the contribution of the processes (i. e., the extent to which the processes modelled with these data contribute to the overall impact of the system under study) was carried out. Indeed, lower quality data may be very suitable for a process with minimal input. However, good quality data will have to be sought for processes that greatly influence the study's findings.

In this study, the contribution analysis was limited to observing the relative importance of the different modelled processes to the overall potential impact assessed for each of the damage categories mentioned in section 3.7.1, as well as for the two categories of impact not characterized as damage (non-renewable resources).

3.9.3 Consistency and completeness of the analysis

Consistency: Throughout the study, it has been important to ensure that the systems are represented in a way that is consistent with the definition of the objectives and scope of the study.And that data collection and modelling, boundary definition, assumptions, methods and data are applied in a similar manner to all systems. In this way, coherence between the systems studied is assured with regard to data sources, their precision, their technological, temporal and geographical representativeness. The method of border extension is also the same for all options evaluated.

Completeness: Completeness is ensured through careful definition of the system's boundaries and systematic use of extension rules. Where data are missing, a sensitivity analysis is performed to verify the effect of the assumptions and approximations used. The results of the impact assessment are also validated by a second Life Cycle Impact Assessment (LCIA) method.

3.9.4 Sensitivity analyses

Several of the parameters used in the modelling of the systems have some uncertainty associated with assumptions and the modules of generic data used. The results obtained are related to these parameters and their uncertainty can be transferred to the conclusions drawn.

Sensitivity analyses were therefore carried out on the main contributing processes or parameters identified by the data quality analysis:

- Life Cycle Impact Assessment (LCIA) method: A sensitivity analysis is performed using the ReCiPe LCIA method (hierarchist perspective; Goedkoop et al., 2009).

- Recycling approach: The approach adopted in the basic results is the so-called "50/50" approach combining border extension and cut-off rule approaches. In the sensitivity analysis, a scenario using only border extension and another scenario using only the cut-off rule were considered.
- Bag washing: This practice was not considered in the basic scenarios. Sensitivity analysis is performed with a machine wash (water) frequency of once every 12 uses, about four times a year for weekly use.
- Rates of reuse as garbage bags: Results were calculated in the absence of the reuse credit as garbage bags for plastic bags.
- Recycled Content: The baseline scenario results did not consider recycled content for conventional, oxodegradable and thick plastic bags. According to the CPIA, these plastic bags can contain up to 25% of on-site generated scrap materials and reintroduced into the process or recycled pellets purchased from other plants. Since on-site recovered scrap is not included in the definition of recycled content according to the Canadian Standards Association (Competition Bureau of Canada, 2008) and the proportion of releases from other mills is not known, this sensitivity analysis considers half of the reported recycled content, i. e. 12.5%.

3.9.5 Scenario analysis

The purpose of this study is to examine the issue of shopping bags in a general context. However, the user's behaviour when shopping can influence the life cycle of bags. For this reason, two basic scenarios (small and large shopping) were created to take into account the impact of different shopping patterns on the LCA results. These scenarios are described in Section 3.3. Each can be associated, but not limited, to:

- Small shopping scenario: spontaneous, frequent ("day to day") shopping on foot;
- Scenario "large shop" scenario: planned shopping, in the car, at department stores.

Another potentially important aspect of consumer behaviour not covered by these two scenarios is the forgetting factor around reusable bags. When a consumer forgets their bags, one option is to return home to pick them up at home. Another option is to purchase new bags at store. The potential impacts of this choice are compared with those of the life cycle of shopping bags.

3.9.6 Uncertainty analysis

A Monte-Carlo uncertainty analysis was performed using SimaPro 8.2 software to test the robustness of the results. It is a propagation study of the uncertainty of the inventory data during the calculations, with a number of iterations set at 1,000. The standard deviations obtained were used to interpret the results.

Of the thousands of individual elementary flows inventoried in the basic processes of the scenarios studied, the vast majority come from the ecoinvent database. Most of these have an uncertainty that takes the form of a lognormal distribution around the specified central value (and used in deterministic calculations), characterized by its standard deviation. However, these uncertainties are not statistically determined using concrete measures, but estimated by applying a pedigree matrix describing the quality of a data according to its origin, collection method and geographical, temporal and technological representativeness (Weidema and Suhr Wesnæs, 1996).

For data from other sources other than ecoinvent, uncertainty was treated on a case-by-case basis.

It should be noted that the "problem" indicators related to water use and land transformation were excluded from the uncertainty calculation, as they introduced errors into the uncertainty calculation. In fact, the ecoinvent inventory parameters used to calculate these impact indicators are interrelated. For example, in a process, the water withdrawn must be equal to the evaporated water and the water discharged. However, this link is not explicit in the Simapro software. Therefore, during a Monte Carlo simulation, the values drawn according to their probability density function at each iteration are not forced to respect its links. Outliers result from this for the two categories mentioned above.

Following the presentation of the LCIA study model, the results are presented in the following section.

4 ELCA Outcomes and Discussion

This chapter covers the last two phases of ELCA, i. e. the life cycle impact assessment (LCA) of the shopping bags studied and the interpretation of the results, in accordance with the methodological framework presented in the previous chapter. It presents the environmental profile of the bags under study, a comparison of the number of uses required for a bag to obtain an impact score equal to or smaller than the conventional plastic bag, which is the reference bag. (see Section 3.8).

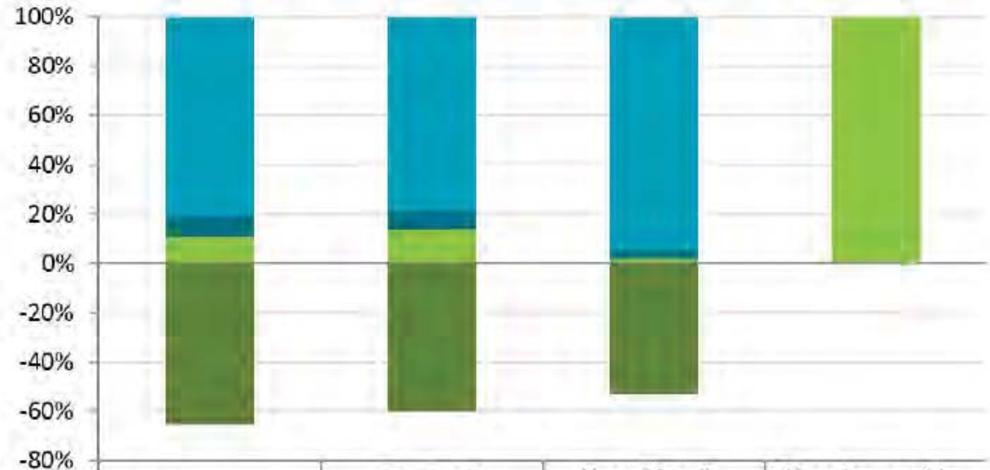
Similarly, data quality analysis and sensitivity studies are discussed.

The raw results of the LCIA are available in Appendix E. These include characterized results, sensitivity analyses and Monte Carlo analyses.

4.1 Shopping Bag Life Cycle Environmental Profile

The following subsections present the environmental profile of each shopping bag, i. e. the set of indicator results for the different impact categories, in the form of percentages of contribution to the life cycle stages (production, distribution and end-of-life with the exception of use). There is no impact associated with the use stage of the life cycle, as bag washing has been excluded due to its unpopularity according to a survey commissioned by the plastic industry (CROP, 2015). However, its influence is studied in a sensitivity analysis. End-of-life credits represent the potential benefits associated with this life cycle stage; that is, the avoided production of virgin material by reusing plastic bags in garbage bags, as well as the recycling of bags. The results presented from Figure 4-1 to Figure 4-8 are valid for both shopping scenarios. The contribution figures for the “problem" indicators (mid-point) are shown in Appendix E.

Generally speaking, the most important step is production. It includes the production of raw materials, their transport, the manufacture of the bag and its packaging for distribution. The contribution analysis of the next sub-sections was carried out using the relative contributions of the various processes mobilized within each life cycle stage in Appendix D.

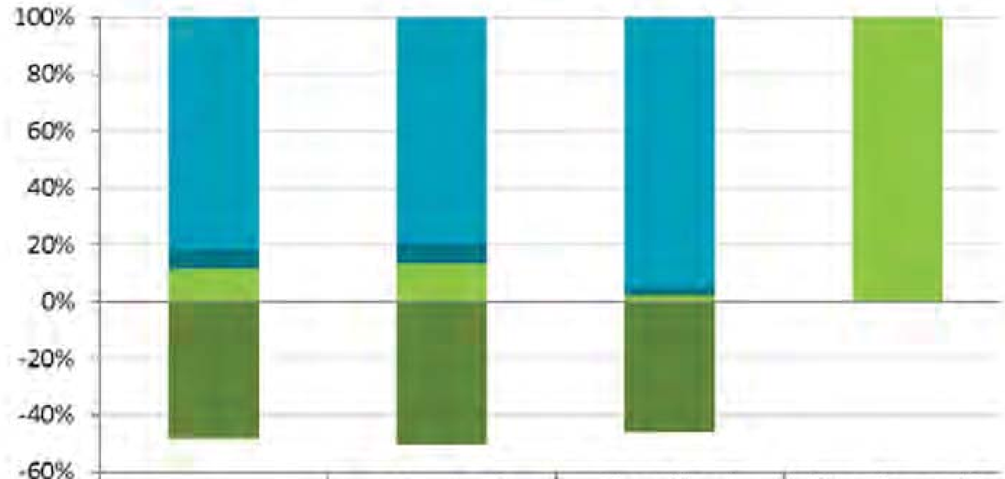


	Human health	Quality of ecosystem	Use of fossil resources	Abandonment in the environment
Output	80.7%	78.8%	94.8%	0.0%
Distribution	8.2%	7.5%	3.3%	0.0%
End of life	11.1%	13.7%	1.9%	100.0%
End of life credits	-65.4%	-60.3%	-53.0%	0.0%

Percentages may not add up to 100% due to rounding.

Figure 4-1: Conventional plastic bag - Contribution of lifecycle stages to environmental indicators.

Manufacturing of HDPE constituting this bag accounts for approximately 80% of the "Production" stage on all indicators (excluding abandonment), followed by bag manufacturing (9-13%) and transportation of HDPE from Texas by train (2-8%). The pollutants involved in the Human Health and Ecosystem Quality categories are greenhouse gas emissions, mainly CO2 from the petrochemical industry. For human health, emissions of sulphur dioxide (SO2) and fine particulate matter during the manufacture of PE (combustion during refining of natural gas and petroleum) also contribute to potential impacts (respiratory effects). Truck bag distribution contributes little to the environmental profile of the plastic bag through its proximity to production (Toronto). Emissions related to bag landfill (long-term waterborne metals) are the main contributors to end-of-life, although not significant over the full life cycle of the bag. Finally, end-of-life credits are important in the case of conventional plastic bags, since 1) they avoid additional PE production by reusing them as garbage bags (90% of the credit) and 2) they are recycled (10% of the credit). The combined credits amount to 68% of the impact scores for the bag's lifecycle. As this is essentially avoided PE, the contributions to the reuse credit as a garbage bag are similar to those of the production stage.



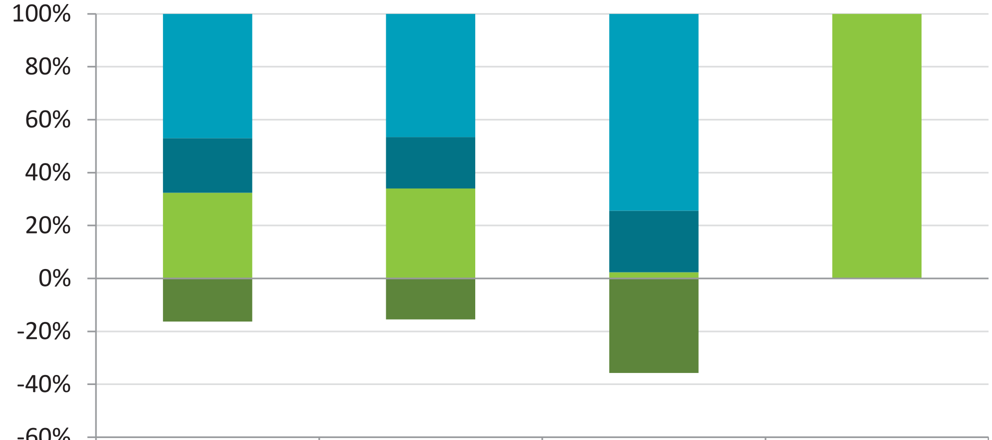
	Human healtl	Quality of ecosystem	Use of fossil resources	Abandonment in the environment
Output	81.4%	79.7%	94.7%	0.0%
Distribution	6.9%	7.2%	3.4%	0.0%
End of life	11.7%	13.1%	1.9%	100.0%
End of life credits	-48.1%	-50.4%	-45.6%	0.0%

Percentages may not add up to 100% due to rounding.

Figure 4-2: Oxodegradable plastic bag - Contribution of life cycle stages to environmental indicators.

The life cycle of the oxodegradable plastic bag is very similar to that of its non-degradable version the conventional plastic shopping bag. The differences between these two bags are only related to the additive and a lower credit at the end of life. First, the potential impacts related to the additive (3% of the bag mass) only slightly increase the contribution of production and end of life to the Human Health indicator. The consumption of water from plant crops that produce stearic acid, the main component of the additive, is responsible for this increase during production, while long-term emissions of metal components are responsible at the end of life. However, the main difference from the conventional bag is the end-of-life credits. In the case of the oxodegradable bag, it avoids the production of PE by its reuse as a garbage bag, but no PE credit is granted to this bag for recycling. Indeed, since it is not distinguished from non-additive bags during sorting, it is recycled along with the rest of the plastic, which negatively affects the properties of the nonbiodegradable recycled material (Grenier and Côté, 2007).

4.1.3 *Bioplastic bag made of starch and polyester*



	Human Health	Quality of Ecosystems	Use of fossil resources	Abandonment in the environment
Production	46.9%	46.6%	74.4%	0.0%
Distribution	20.7%	19.4%	23.2%	0.0%
End of life	32.4%	34.0%	2.3%	100.0%
End of life credits	-16.3%	-15.5%	-35.7%	0.0%

*Percentages may not add up to 100% due to rounding.

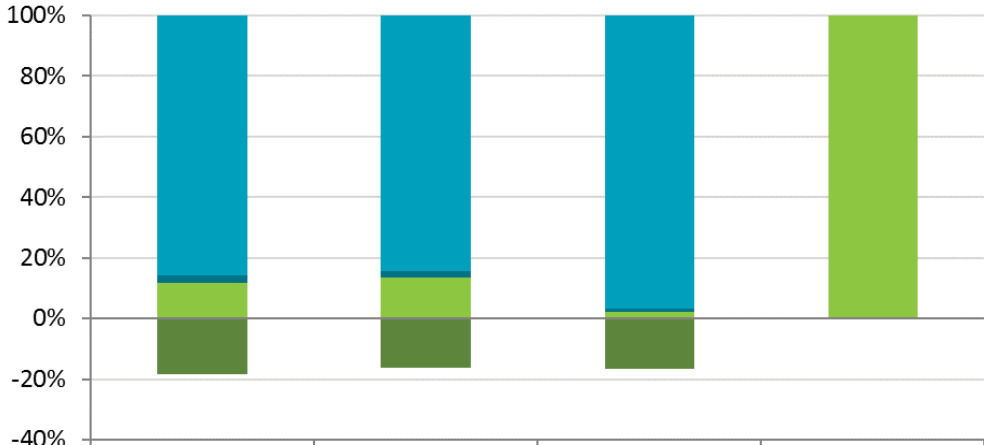
Figure 4-3: Starch-polyester bioplastic bag - Contribution of life cycle stages to environmental indicators.

The environmental profile of the bioplastic bag made of starch and polyester is different from those made of PE. Indeed, the contribution of the potential impacts at the distribution stage are greater than the other stages of the life cycle because of the GHG emissions from the transportation of the bags from California to Quebec by truck, a high carbon intensity means of transport.

In terms of production, the manufacture of starch and polyester bioplastics dominates this stage of the life cycle, followed by the manufacture of bags, for the first three indicators. GHG emissions are primarily responsible for the potential impacts during production and manufacture and result from heat production during the manufacture of the bioplastic, as well as the production of electricity for the manufacture of bags. Being made of vegetable matter, their production is less important related to the use of fossil resources.

Although the bioplastic made of starch and polyester is transported a long distance, from Italy to California, transport at this stage is not a source of significant potential impacts given the low emissions per kilometer traveled maritime transport.
End-of-life credits are relatively lower for Human Health and Ecosystem Quality (15.5-16.3%) compared to PE bags for two reasons. First, no avoided material credits are given for the recycling portion, negatively affecting the properties of the recycled material. Second, the potential life cycle impacts for these two indicators are higher than the other plastic bags studied (see section 4.2), reducing the relative importance of credit. However, being partly made up of plant matter, the credit for the use of fossil resources is slightly higher than other indicators at 37.5%.

4.1.4 Thick Plastic Bags



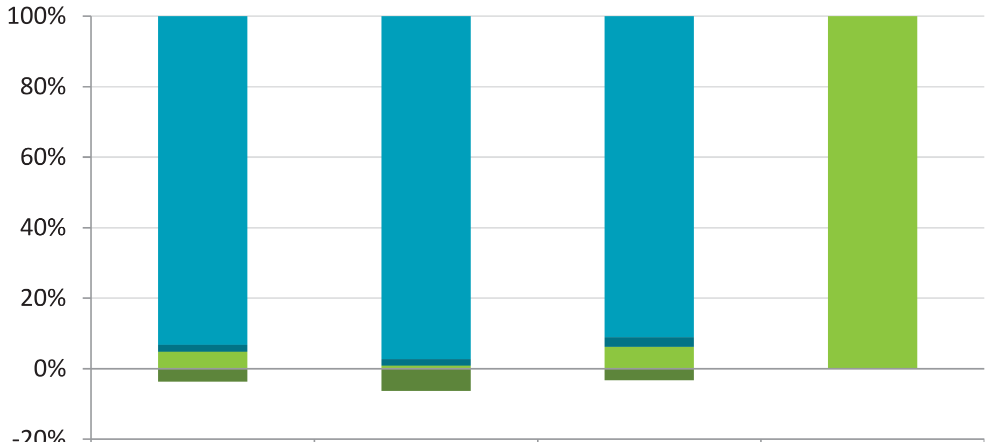
	Santé humaine	Qualité des écosystèmes	Utilisation des ressources fossiles	Abandon dans l'environnement
Production	85.7%	84.3%	96.9%	0.0%
Distribution	2.7%	2.3%	1.1%	0.0%
Fin de vie	11.6%	13.4%	2.0%	100.0%
Crédits de fin de vie	-18.4%	-16.2%	-16.6%	0.0%

*Percentages may not add up to 100% due to rounding.

Figure 4-4 : Thick plastic bag - Contribution of life cycle stages to environmental indicators.

The production of this thicker bag is dominated by PE manufacturing for all indicators, mainly due to GHG emissions. For human health, emissions of SO2 and fine particulate matter during PE manufacture (combustion during refining of natural gas and petroleum) also contribute to potential impacts (respiratory effects). The distribution of bags contributes very little to the indicators given the proximity of their manufacturing location in Quebec. End-of-life credits on these thicker bags are lower than conventional plastic bags because thicker plastic bags have more potential impacts over their life cycle and are less likely to be reused at end-of-life as garbage bags, unlike the thinner 17 micron plastic shopping bag which has reuse as a garbage bag to manage household waste.

4.1.5 Paper Bags



	Human Health	Quality of Ecosystems	Utilisation of Fossil resources	Abandonment in the environment
Production	93.2%	97.3%	91.1%	0.0%
Distribution	1.9%	1.8%	2.7%	0.0%
End of life	4.8%	0.9%	6.2%	100.0%
End of life credits	-3.6%	-6.3%	-3.3%	0.0%

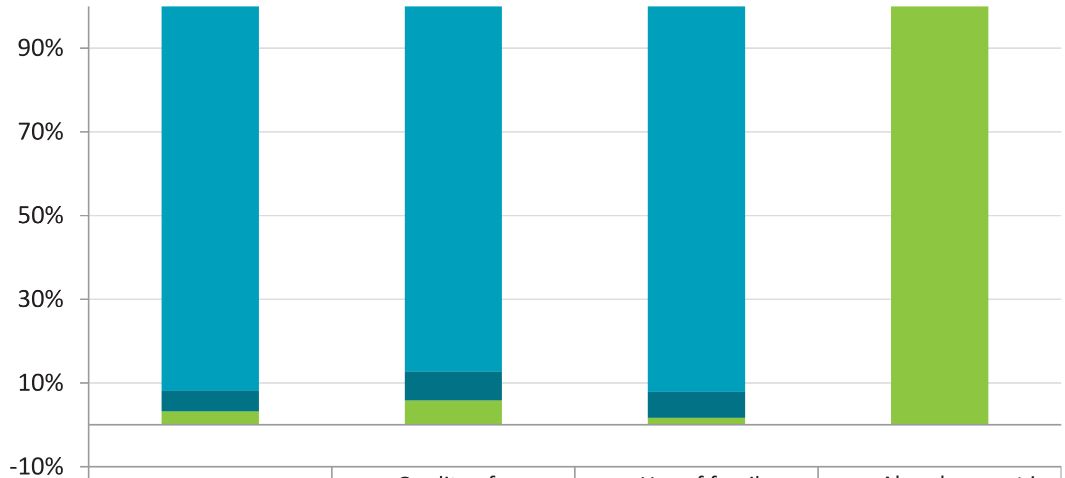
*Percentages may not add up to 100% due to rounding.

Figure 4-5 : Paper bag - Contribution of life cycle stages to indicators environment.

The production of paper to make paper bags is the life cycle stage with the biggest impact for the Human Health indicator. It contributes the most to the environmental indicators (excluding abandonment in the environment). The main reason is the use of fossil fuels (natural gas, residual fuel oil and coal) as a source of heat which generates GHG emissions, SO2 emissions and fine particles. Fine particles emitted during sawmill operations (source of wood chips) and dioxins from biomass combustion during papermaking (e. g., cogeneration) also contribute to this indicator.

For the Ecosystem Quality indicator, land use during forestry activities has significant potential impacts (28%), but the distribution of bags is negligible. The potential end-of-life impacts, on the other hand, are dominated by short-term climate change (methane emissions), although they are low relative to the life cycle of the paper bag. Finally, despite a relatively high recovery rate (34.4%), the bag recycling credit is only 3% to 6% due to the significant potential environmental impacts of recycling operations.

4.1.6 *Woven PP bag*



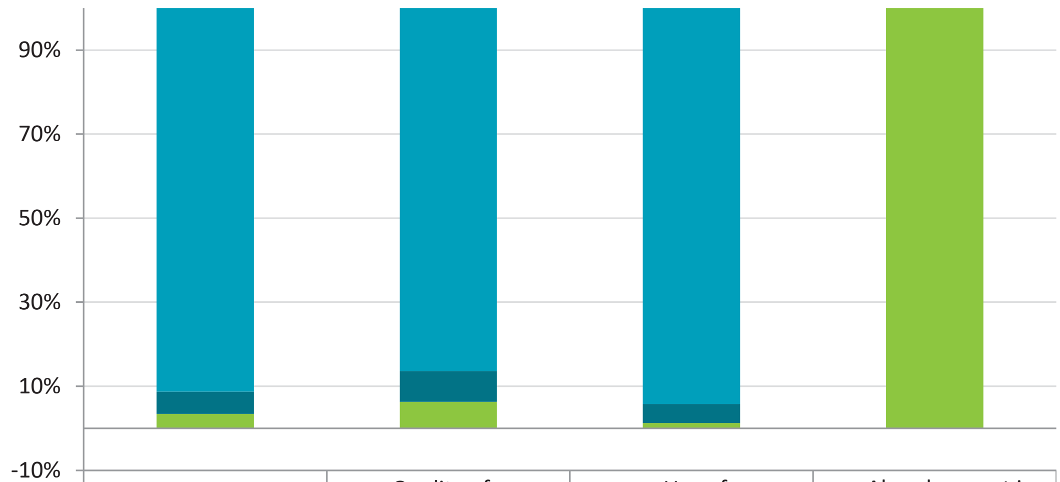
	Human health	Quality of ecosystems	Use of fossil resources	Abandonment in the environment
Production	91.8%	87.3%	92.1%	0.0%
Distribution	5.0%	6.9%	6.2%	0.0%
End of life	3.2%	5.8%	1.7%	100.0%

*Percentages may not add up to 100% due to rounding.

Figure 4-6 : Woven PP bag - Contribution of life cycle stages to environmental indicators.

The distribution of bags made of woven PP contributes little to the environmental indicators. However, the production phase effects all indicators because it is dominated by the generation of Chinese electricity from coal and the production of recycled and virgin PP with the consequent GHG emissions. Emissions of fine particles, SO2 and cooling water consumption for PP film extrusion also contribute to the Human Health indicator. The end of life is relatively unimportant in the life cycle of this type of bag, being simply sent to landfill. However, no end-of-life credits have been granted.

4.1.7 Non-woven PP bag



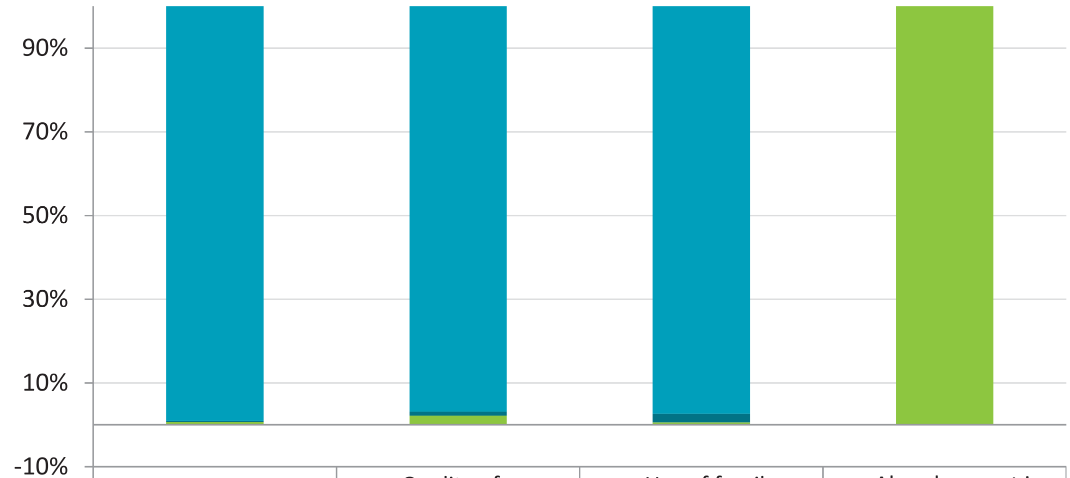
	Human health	Quality of ecosystems	Use of fossil resources	Abandonment in the environment
Production	91.3%	86.3%	94.2%	0.0%
Distribution	5.3%	7.4%	4.5%	0.0%
End of life	3.5%	6.3%	1.3%	100.0%

*Percentages may not add up to 100% due to rounding.

Figure 4-7 : Non-woven PP bag - Contribution of life cycle stages to environmental indicators.

Similar to the woven PP bag, the potential impacts on all indicators combined (excl. Abandonment in the environment), come from Chinese electricity generation and PP production during the life cycle production stage. In addition, for the Human Health indicator, the consumption of cooling water during bag manufacturing is important. As with the woven PP bag, distribution and end-of-life are relatively minor contributors to the life cycle of this type of bag and no end-of- life credit is granted.

4.1.8 *Cotton bag*



	Human health	Quality of ecosystems	Use of fossil resources	Abandonment in the environment
Production	99.1%	96.9%	97.3%	0.0%
Distribution	0.3%	1.0%	2.0%	0.0%
End of life	0.6%	2.2%	0.6%	100.0%

*Percentages may not add up to 100% due to rounding.

Figure 4-8 : Cotton Bag - Contribution of life cycle stages to environmental indicators.

For cotton bags, like other types of bags, production is the most important life cycle stage. However, the source of potential impacts is very different for each indicator for this material. First, for the Human Health indicator, water consumption for irrigation of Chinese cotton crops is the largest contributor (almost 75%). This is the result of two factors: the large amount of water involved and the location of the cotton crops. The ImpactWorld+ method considers water rarer in China than in Canada or the United States, hence the importance of water in the potential life cycle impacts of this bag.

With regard to the indicators on Ecosystem Quality and Fossil Resource Utilization, the use of Chinese electricity from coal in the various stages of textile manufacturing, including the preparation of cotton fibre and its weaving, is the main source of potential impacts.

Overall, we note that...

- GHG emissions during the production stage are the main contributors to the Human Health and Ecosystem Quality indicators, with the exception of the cotton bag for which water consumption in China dominates the Human Health indicator.
- The distribution stage of the bioplastic bag made of starch and polyester is the most important stage in terms of its life cycle impacts on

Human health, Ecosystem quality and Resource use indicators
since it has to be transported by truck from the California to Quebec.

- Air emissions of inorganic pollutants (SO2 and fine particulate matter) and GHG emissions are important contributors to the Human Health Indicator for all bags
- Water consumption is one of the main contributors to the Human Health indicator other than GHG emissions for oxodegradable plastic bags (production of the additive) and bags produced in China (woven PP, non-woven PP and cotton).
- The contribution of water consumption for the cotton bag is by far the most important, accounting for nearly three-quarters of the potential impacts on the Human Health indicator; due to irrigation during Chinese cotton cultivation.
- Forest activities account for nearly a third of the potential impacts of paper bags on ecosystem quality.
- The relative importance of end-of-life credits is highest for conventional plastic bags and lowest for paper bags.
- Reuse of conventional thin plastic bags as garbage bags generates higher end-of-life credits than recycling due to the low recovery rate of disposable plastic bags for recycling purposes and their high reuse as garbage bags.

4.2 Equivalent number of uses

After identifying the lifecycle hot spots for each type of bag, this section compares these hot spots with the number of uses (Uij) required for a bag (i) to obtain an impact score equal to that of the reference bag, i. e. the conventional plastic bag, for an indicator (j), as defined in section 3.4 and Annex B.

Here, use means the use of a bag in its main function, i. e. the transport of purchases during a shopping trip. The results are presented for the two shopping scenarios: the small shopping cart, which requires one bag, and the large shopping cart, which requires several bags. These scenarios are also defined in Section 3.4. During the small shopping trip, only the number of bags determines the relative number of bags needed to carry out a grocery shopping (reference flow), while during the large shopping trip, the relative volume capacity of the bags also plays a role.

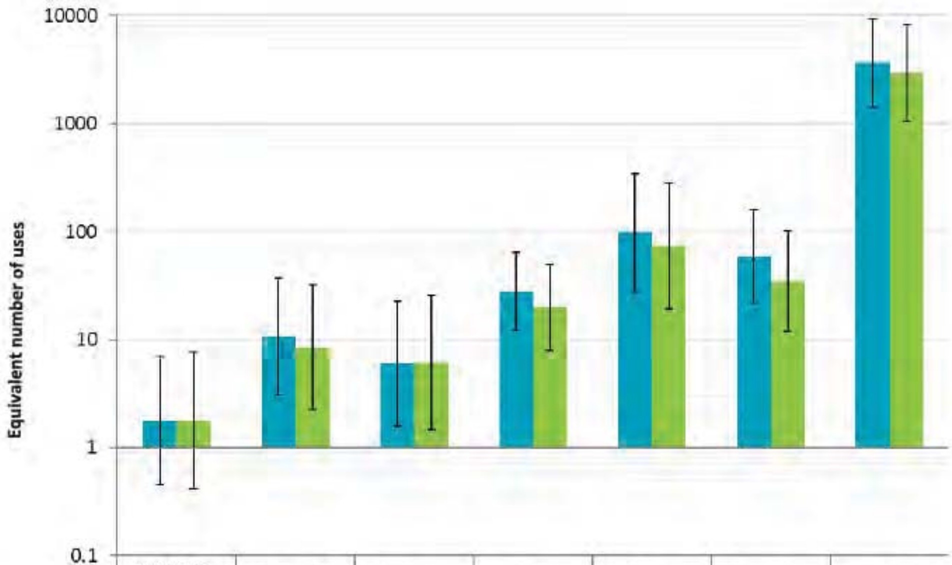
The following figures show the Uij values for both scenarios from Figure 4-9 to Figure 4-12. Columns represent the number of uses of a bag to have the same potential impacts as the conventional plastic bag; they can also be interpreted as the number of conventional plastic bags needed to have the same potential impacts as the various bags under study. These values take into account end-of-life credits, i. e. the potential impacts of material production avoided through end-of-life recycling and reuse as garbage bags have been subtracted from the life cycle scores by taking into account the recovery and reuse rates as garbage bags specific to the bag types.

In order to improve the reading of the graphs, a logarithmic scale was used (base 10). As a result, the vertical axis of the graphs is first divided by order of magnitude (e. g. 1,10,100, etc.). Next orders of magnitude are further subdivided into ten equal value intervals, but are closer in the figure. For example, between 100 and 1,000 subdivisions represent hundreds of 200 to 900.

As described in Section 3.9.6, Monte Carlo simulations were conducted to quantify the uncertainty on the results from the uncertainty of the model's input parameters. In the following figures, the uncertainty of the results is illustrated with uncertainty bars corresponding to the range of results over two standard deviations. Thus, 95% of the Monte Carlo simulation values are within the range defined by the bottom and top of the uncertainty bar.

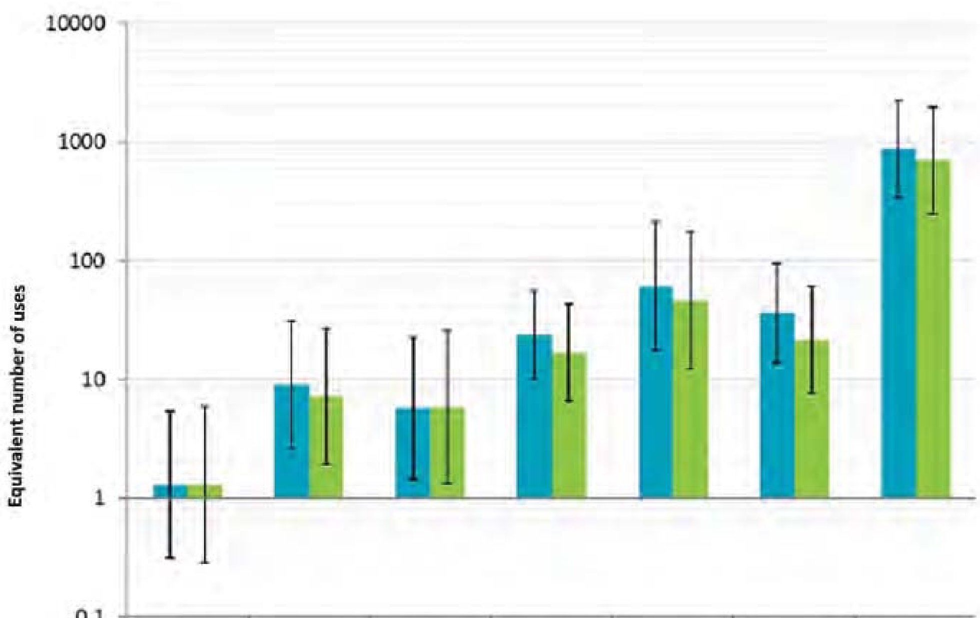
It should be noted that:

The results shown in this report are associated with a typical use, i. e. disposable bags are used only once before being discarded, then reused as garbage bags, recycled or discarded in the environment. If someone packing the bags in a supermarket double bags the single-use bags, the number of equivalent uses shown in the following figures would be affected. In such a situation, the number of equivalent uses would be reduced by 50%. In the reverse situation where a consumer would take his or her disposable bags back to the grocery store, the number of equivalent uses of other bags would double.



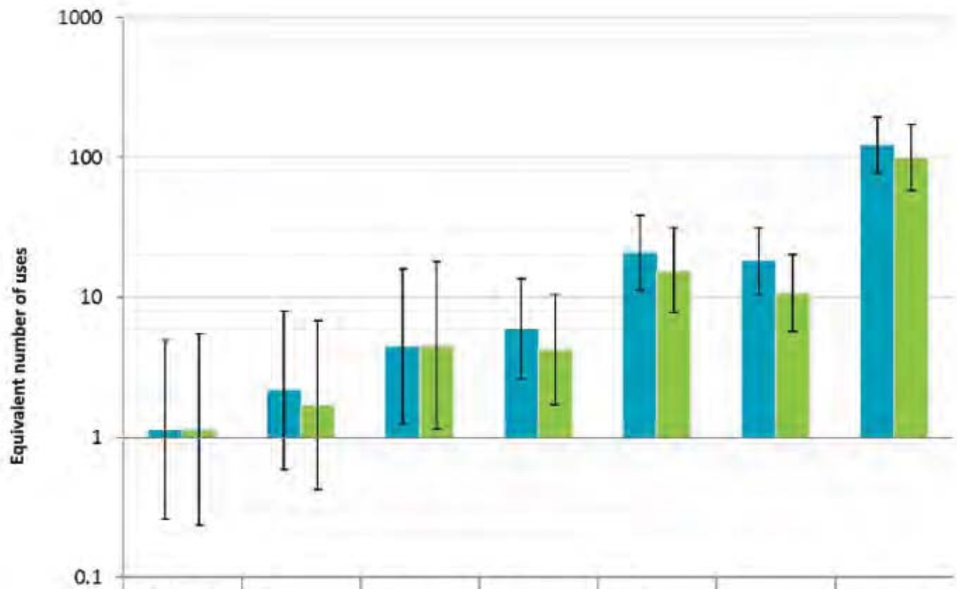
	HDPE thin oxo	Bioplastic	LDPE thick	Paper	PP woven	PP non-woven	Cotton
Small shop	1.8	11	6	28	98	59	3657
Large shop	1.8	8	6	20	73	35	2954
	Disposable bags				Reusable bags		

Figure 4-9 : Number of equivalent uses for the Human Health indicator



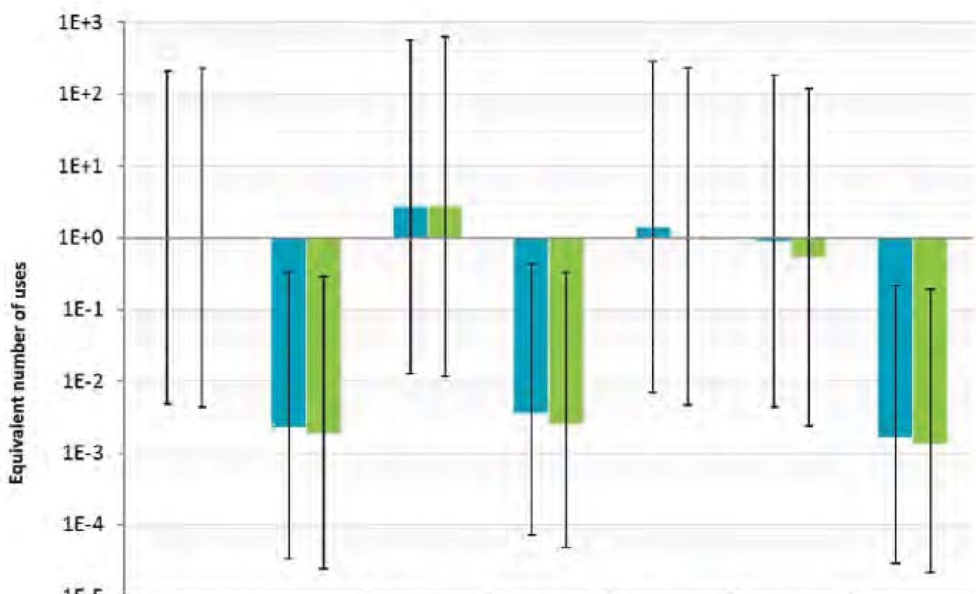
	HDPE thin oxo	Bioplastic	LDPE thick	Paper	PP woven	PP non-woven	Cotton
Small shop	1.3	9	6	24	61	37	870
Large shop	1.3	7	6	17	46	22	702
	Disposable bags				Reusable bags		

Figure 4-10 : Number of equivalent uses for the Ecosystem Quality indicator.



	HDPE thin oxo	Bioplastic	LDPE thick	Paper	PP woven	PP non-woven	Cotton
Small shop	1.1	2	4	6	21	18	124
Large shop	1.1	2	5	4	16	11	100
	Disposable bags				Reusable bags		

Figure 4-11 : Number of equivalent uses for the Fossil Resource Utilization indicator



	HDPE thin oxo	Bioplastic	LDPE thick	Paper	PP woven	PP non-woven	Cotton
Small shop	1.00E+00	2.35E-03	2.67E+00	3.62E-03	1.40E+00	9.01E-01	0.002
Large shop	1.00E+00	1.86E-03	2.74E+00	2.57E-03	1.05E+00	5.33E-01	1.35E-03
	Disposable bags				Reusable bags		

Figure 4-12 : Number of equivalent uses for the Abandonment in the Environment indicator.

Several observations can be made from the preceding figures. First, the "big shopping" scenario benefits: bioplastic bags made of starch and polyester, paper, PP woven, PP non-woven and cotton, because of their greater capacity compared to conventional, oxodegradable and thick plastic bags. However, the ranking of bags according to their number of equivalent uses does not change between the large and small shopping scenarios taking into account uncertainty.

Then, in the following paragraphs, the results are discussed first for the IMPACT World+ damage indicators and second for the Abandonment in the Environment indicator.

Indicators Human Health, Ecosystem Quality and Fossil Resource Utilization

For the oxodegradable bag, its potential impacts are not significantly different from the conventional plastic bag. The two are considered equivalent for these three indicators; an observation which is not surprising considering that the two bags are only differentiated by the value of the environmental credit at the end of life. For the Human Health, Ecosystem Quality and Fossil Utlization indicators, all bags, with the exception of the oxodegradable bag, have values significantly higher than 1, i.e. they do not perform as well on these indicators when compared one to one with the reference conventional plastic bag. They must therefore be reused a number of times by the consumer if the consumer wants to be more environmentally friendly when shopping.

As for bioplastic bags made of starch and polyester, thick LDPE and paper, if only used once for transporting purchases, their use results in greater potential environmental impacts than conventional plastic bags. Therefore, these single-use bags should not be preferred over the reference bag according to the IMPACT World+ method indicators. LDPE bags and bioplastic bags made of starch and polyester have equivalent results (not significant differences), with the exception of the Fossil Resource Utilization indicator. For the latter, the bioplastic bag studied has a lower score because of its partly vegetable composition. The paper bag has greater potential impacts than bioplastics made of starch and polyester and thick LDPE bags, except for the Fossil Resource Utilization indicator in the large shopping scenario where the bioplastic bag made of starch and polyester has a similar result.

For bags designed to be reused, i. e. woven PP, non-woven PP, their potential impacts are greater than bags not designed to be reused. However, in the case of the woven PP bag for the Human Health and Ecosystem Quality indicators, the result is sufficiently close to that of the paper bag to suggest that the potential for the equivalent number of uses of the non-woven PP bag to be lower than that of the paper bag is significant. PP bags should be used between 11 and 343 times in order to be environmentally more efficient than the reference conventional thin plastic shopping bag depending on certainty level, indicator and shopping scenario. Finally, the cotton bag has the highest number of equivalent uses for these indicators at thousands of times. These values are detailed in Table 4-1.

Abandonment in the environment Indicator

For the Abandonment in the Environment indicator, bioplastic bags made of starch and polyester, paper and cotton have an equivalent number of uses and significantly smaller than 1. This means that from the very first use, these bags perform better on this indicator than other bags (conventional plastic, oxodegradable plastic, thick plastic, PP woven and PP non-woven) because their scores are between 425 and 537 times (starch-polyester bioplastic), 277 and 388 times (paper), and 599 and 741 times (cotton) lower than conventional plastic bags, depending on the shopping scenario and considering a single use. Natural gas sourced plastic bags have an equivalent performance on this indicator. It is not possible to determine whether the benefit of bioplastic bags made from starch and polyester, paper and cotton on Abandonment in the environment outweighs the potential additional impacts for the other indicators using current SIA methods.

The following table details the number of equivalent uses per bag, indicator, percent certainty and shopping scenario. Certainty is the estimated probability that the conventional plastic bag will perform equally or less than a given bag. The 50 % certainty corresponds to the basic value represented by the columns in the preceding figures, with the assumption that this is a good approximation of the median value. The 97.5% certainty corresponds to the upper bound of the uncertainty bars shown in the preceding figures.

Table 4-1 : Summary of Equivalent Number of Uses to match the conventional plastic bag, the reference bag

Bag	50% certainty				97.5% certainty			
	Human health	Quality of ecosystems	Use of fossil resources	Abandon in env..	Human health	Quality of ecosystems	iUse of fossil resources	Abandon in environ.
Small Shopping Scenario								
HDPE mince oxo	1,8	1,3	1,1	1,00	7	5	5	205
Bioplastic	11	9	2	0,002	37	31	8	0,3
LDPE thick	6	6	4	2,67	23	23	16	565
Paper	28	24	6	0,004	65	56	14	0,4
Woven PP	98	61	21	1,40	343	214	39	287
Non woven PP	59	37	18	0,90	159	96	32	185
Cotton	3 657	870	124	0,002	9 400	2 248	195	0,2
Large Shopping Scenario								
HDPE mince oxo	1,8	1,3	1,1	1,00	8	6	5	225
Bioplastic	8	7	2	0,002	32	27	7	0,3
LDPE thick	6	6	5	2,74	26	26	18	637
Paper	20	17	4	0,003	50	43	10	0,3
Woven PP	73	46	16	1,05	279	174	31	234
Non woven PP	35	22	11	0,53	102	61	20	118
Cotton	2 954	702	100	0,001	8 272	1 979	172	0,2

Overall, we note that...

- For Human health, Ecosystem quality and Fossil resource use indicators :
  - Conventional and oxodegradable plastic bags perform better than other bags with a single use;
  - The bioplastic bag made of starch and polyester and the thick plastic bag have impact scores 2 to 11 times and 4 to 6 times greater respectively than the conventional plastic bag depending on the indicator and shopping scenario;
  - Depending on the indicator and scenario, the paper bag is the least or the lowest performing disposable bag with 4 to 28 times greater potential impacts than the conventional plastic bag;
  - PP woven and PP non-woven bags need an equivalent number of uses to equal the thin plastic bag ranging from 16 to 98 and 11 to 59, respectively, depending on the scenario and indicator;
  - The cotton bag is by far the worst performing bag with an equivalent number of uses ranging from 100 to 3,657 times depending on the scenario and indicator to equal the thin conventional plastic shopping bag;
- Bioplastic bags made of starch and polyester, paper and cotton are the best performing on the Abandonment in the Environment indicator with scores of 425 and 537 times respectively, 277 and 388 times, as well as 599 and 741 times lower than conventional plastic bags, depending on the shopping scenario and considering a single use.

4.3 Evaluation of the quality of inventory data

The results of the analysis of the quality of inventory data are summarized in Annex D to this report.

Based on these analyses, it was possible to identify processes offering a high potential contribution to the systems and make modelling assumptions using data whose quality in some cases could or should be improved. The processes outlined below represent a limit on and diminish the certainty of results. However, this uncertainty was assessed using Monte Carlo simulations and was taken into account when presenting the results. The main data that needs to be improved in order to increase the robustness of results are related to the following process/parameters:

- **Manufacture of conventional plastic bags, oxodegradable, bioplastic bags made of starch and polyester and LDPE:** the production stage of these bags was modelled using a generic European process of plastic film extrusion from the ecoinvent database, adapting the production of electricity consumed to the geographical context of Quebec. Data from this process was collected in the 1990s and includes the consumption of plastic, water, energy, packaging and waste.
- **Mass of the bioplastic bag made of starch and polyester:** the lower accuracy of the mass of the bioplastic bag studied adds uncertainty to the results for this type of bag.
- **Chinese PP production:** Chinese PP production is modeled using aggregated generic data from the ecoinvent database which covers the production of PP from 28

European sites between 1999 and 2001 (Polypropylene, granulate). It was not possible to adapt the process to the Chinese context (e. g. means of power generation) due to the aggregation of data. However, this process was compared with a US LCI's North American PP production process, whose electricity generation was adapted to the Chinese context. A variation of less than 5% in results was found for the non-woven PP bag with this modified data.

- **Manufacture of woven PP bags**: the manufacture of this type of bag, such as disposable plastic bags, was modelled using a generic plastic film extrusion process from the ecoinvent database, and adapting the production of electricity consumed to the geographical context. In addition, weaving and printing steps have been added, based on cotton weaving and offset printing.
- **Manufacture of paper bags**: this process was estimated from the production of a cardboard box in Quebec context on the basis of the ecoinvent database, incorporating the consumption of paper, energy, chemicals, water, as well as air and water emissions and discharges.
- **Cotton**: the step of making the bag as such (sewing) was not included.
- **Abandonment in the environment:** No production data is required for this end-of-life component. Only a drop-out rate was used and then characterized by persistence in the environment based on the material in the bag. The litter rates for disposable bags and reusable bags, were taken from an extensive study by BIO Intelligence Service (2011) for the European Commission. This is an estimate for the 27 EU Member States at the time. The authors do not detail the method used, but indicate that they have relied on European stakeholder estimates and European scientific literature. They also specify an interval of variation in values, which was used in the uncertainty analysis of this study. It should be noted that the variation on the indicator is, however, mainly due to persistence in the environment and not the drop-out rate.

These processes therefore represent a limit and diminish the certainty of results. However, uncertainty related to most of the items in the previous list was assessed using Monte Carlo simulations and was taken into account when presenting the results in the previous section. Other sources of uncertainty related to the modelling assumptions were tested in the sensitivity analysis in the next section.

In the following list, the most contributing processes of each bag whose quality was judged to be adequate on its own or as a result of improvements described below. Their technological, geographical and temporal representativeness of the data, as well as their completeness and reliability are presented.

- **Production of HDPE and LDPE**: the US-LCI database was used to model the manufacture of these plastics (Polyethylene, high density resin at plant and Polyethylene, low density resin at plant). These data represent North American production in 2002 and 2003 by polymerization of ethylene using standard processes (slurry and UNIPOL gas phase for HDPE, solutions and gas phase for LDPE). The portion of North American production covered is not specified. The data provide the quantities of electricity, fuels, ethylene, pipeline transportation, air and water emissions.

They have been reviewed by Franklin Associates and the American Chemistry Council.

- **Production of starch-polyester bioplastics:** for the modelling of this bioplastic, the LCA analysts started from an ecoinvent European process called Polyester-complexed starch biopolymer based on an environmental declaration by the Novamont company which produces the partially biosourced polymer. Data provided includes estimated amounts of starch, naphtha, natural gas, heat, electricity and air emissions. The analysts found the quality of the process to be inadequate for the purposes of the study and made several changes. First of all, the data was regionalized to correspond to the Italian context, the country where the Novamont plant is located, using Italian processes of electricity production, corn starch and natural gas distribution. In addition, an Italian maize growing process from the specialized ICV Agrifootprint database was used.

- **Paper production**: these data come from the US-LCI database. They describe papermaking for bags (Paper, bag and sack, unbleached kraft, average production, at mill), the product under study, and cover nine mills accounting for 89% of North America's 2006-07 production volume (virgin and recycled paper). These include the requirements for logs and wood chips, recovered paper, other paper ingredients, chemicals (e. g. quicklime, starch, talc, sodium sulphate, etc.), packaging (cardboard boxes, films, etc.), electricity, natural gas, supply transport, sludge treatment, air, water and soil emissions. Unmodelled supplied inputs in the US-LCI were supplemented with ecoinvent database processes. Land tenure of the underlying forest activities was completed using cutting surfaces provided by the Consortium for Research on Renewable Industrial Materials (CORRIM). Bag paper production data were developed for a critically reviewed LCA.

- **Cotton production**: cotton fibre and fabric production data are based on ecoinvent processes. First, the Chinese cotton crop data are based on a large, critically reviewed LCA study by Cotton Inc. (Cotton Inc., 2012). The study drew its information from multiple sources, including literature and directly from Chinese producers dating from various periods between 2000 and 2010. They cover co-products, land use, irrigation water consumption, multiple pesticides and fertilizers, petrol, diesel, electricity, heat, and air, water and soil emissions. This study also produced international data on the production of fabrics, which included 17 factories located in China, India, Turkey and Latin America from 2005 to 2009 and included all the stages of manufacturing, from the opening of cotton packages to sanforising the fabrics. The data provided include co-products, water consumption, cotton fibre, chemical products, electricity, heat, waste, as well as air and water emissions.

4.4 Sensitivity analyses

Sensitivity analyses were conducted to verify the influence of the modeling assumptions on the study findings. Detailed tables of the results of these analyses are presented in Appendix E.

4.4.1 ICDT method

As mentioned above, the VIA was carried out with a second method, ReCiPe (Goedkoop et al., 2009), in order to verify whether the variability of the characterization models had a significant influence on the conclusions and thus, to test the robustness of the results obtained from IMPACT World+. Both methods incorporate the most recent advances made in SIA. However, the IMPACT World+ method is applicable worldwide, while the ReCiPe method considers that all global emissions behave in the same way as in Europe; a hypothesis that is not necessarily realistic. This is why the IMPACT World+ method was selected from the outset. However, it was considered appropriate to test ReCiPe in sensitivity analysis.

Human health, Ecosystem quality and non-renewable resource use indicators are covered by this sensitivity analysis, as abandonment in the environment is not currently part of any LCA method.

As regards the main contributors, the results obtained by the ReCiPe method (hierarchist perspective) generally confirm those obtained with the IMPACT World+ method, with similar trends for the various indicators evaluated:

GHG emissions: they are responsible for most of the potential impacts on the Human Health and Ecosystem Quality indicators for all bags, with the exception of paper bags, where forest activity is more important than GHGs for Ecosystem Quality.

Fine Particle Emissions: These are the second-largest emissions for the Human Health Indicator for all bags.

In terms of the comparison of the number of equivalent uses of bags, the nuances are as follows:

Human health: the rank of bags is unchanged for this indicator. However, the poor performance of the cotton bag is less pronounced due to the lack of characterization of water consumption in the ReCiPe method.

Ecosystem quality: Land use (e. g. for forestry and agriculture) is more important in the ReCiPe method, so that bio-sourced bags (polyester starch), especially paper and cotton bags, have higher numbers of uses. Therefore, for the paper bag, this number exceeds that of PP bags. For the cotton bag, the Ecosystem Quality indicator becomes the one with the highest number of equivalent uses of all indicators.

Use of non-renewable resources: ReCiPe results are in line with those of IMPACT World+.

It should be noted that these observations were made without taking into account the uncertainty of the life cycle inventory in order to isolate the influence of the choice of the LCA method. Overall, the sensitivity analysis using the ReCiPe VIAA method therefore confirms the results of the study and attests to their robustness. The differences observed do not call into question the analyses made in sections 4.1 and 4.2.

4.4.2 Recycling approach

The approach adopted to account for the upstream and downstream recycling of the systems in the basic results is the "50/50" approach combining the approaches of border extension and cut-off rule. The former favours products with high end-of- life recycling rates, while the latter favours products with high recycled content. In the sensitivity analysis, scenarios using either only border extension or the cut-off rule were considered.

The following table shows the change in the number of equivalent uses for each bag and indicator (except for abandonment for the environment not affected by the recycling approach). Results for the small and large shopping scenarios are affected in the same way.

Table 4-2: Change in the number of equivalent uses due to the recycling approach compared to the baseline approach (50/50)

Bag	Border extension approach (0/100)			Approach cut-off rule (100/0)		
	Human health	Quality of ecosystems	Use of fossil ressources	Human health	Quality of ecosystems	Use of fossil resources
Plastic bag oxodegradable	36%	23%	23%	-17%	-12%	-11%
Bioplastic	52%	45%	34%	-25%	-23%	-16%
LDPE thick	48%	41%	42%	-22%	-21%	-20%
Paper	58%	50%	56%	-27%	-25%	-26%
Woven PP	68%	62%	126%	-32%	-31%	-59%
Non woven PP	57%	49%	56%	-27%	-25%	-27%
Cotton	57%	49%	56%	-27%	-25%	-27%

These results show that the number of equivalent uses of all bags are affected by the recycling approach since the scores of conventional plastic bags are affected. In the 0/100 approach, the reference bag scores are lower, resulting in an increase in the equivalent number of uses for all bags. Conversely, with the 100/0 approach, reference bag scores are higher, decreasing the equivalent number of uses for other bags.

The woven PP bag is most affected by the recycling approach. With the 0/100 approach, the advantages of its high recycled content are eliminated, in addition to the upward effect on conventional plastic bags. Its (the woven PP bag) minimal number of uses reaches 165 times (small shop) and 123 times (large shop) but keeps the same position compared to other bags. With the 100/0 approach, the opposite effect occurs: its minimum number of uses decreases to 67 times (small shop) and 50 times (large shop). These values remain higher than the non-woven PP bag. Although this sensitivity analysis provides some nuances regarding the minimum number of uses for the woven PP bag, the main trends are unchanged.

4.4.3 Bag washing

The practice of washing reusable bags was not considered in the basic scenarios. A sensitivity analysis was carried out with a machine wash frequency of once in every 12 uses; approximately four times a year for weekly use. Consumption of water, electricity and detergent was taken from Boulay et al. (2015). The laundry impacts were allocated to the bags on a mass basis assuming a capacity of 5 kg per wash.

The following table shows the maximum variation in the number of equivalent uses for each reusable bag and indicator (except abandonment for the environment not affected by washing).

Table 4-3: Maximum Change in Equivalent Uses Due to Washing of Reusable Bags

Bag	Human health	Quality of ecosystems	Use of fossil resources
Woven PP	19%	20%	1%
Non woven PP	11%	12%	1%
Cotton	45%	49%	2%

The results show that these variations represent only a few more uses for PP woven and PP non-woven bags. For the cotton bag, however, the variation is greater because of its higher mass. In absolute numbers, it is 1,643 (5,299 compared to 3,657) more uses for this bag in the worst-case scenario (human health indicator, small shopping scenario). Although this is a considerable number, the cotton bag is already the one with the highest equivalent number of uses on the three indicators presented in the previous table. In addition, observed variations are below the uncertainty of results.

In all cases, the results of this sensitivity analysis do not change the trends.

4.4.4 Rate of reuse as garbage bags

The secondary function of disposable plastic bags as garbage bags was considered in this study, as explained in Section 3.5.1. Given the importance of this end-of-life reuse to the results, a sensitivity analysis was conducted on this aspect of the life cycle of disposable plastic bags. To do this, the potential impacts of these bags were calculated without reuse credit as garbage bags. The results are presented in the following table.

These results show that even when reuse of plastic bags as garbage bags is not considered, the conventional plastic bag minimizes the indicators of human health, ecosystem quality and fossil resource use, leaving the environment unaffected. For the reusable bags under study, the equivalent numbers of uses are divided by 2 or 3 according to the indicator. This sensitivity analysis does not call into question the conclusions drawn from the main results of the study, as no average number of uses has been defined.

Table 4-4: Equivalent Number of Uses Without Recycling Credit as Garbage Bags

Bag	Human health	Quality of ecosystems	Use of fossil resources	Abandon in environment
Small Shopping Scenario				
Plastic bag	1,2	1,1	1,0	1,00
Bioplastic	5	4	1,7	0,002
Thick plastic bag	3	3	2	2,7
Paper	10	10	3	0,004
Woven PP	35	25	10	1,40
Non woven PP	21	15	9	0,90
Cotton	1 309	358	61	0,002
Large Shopping Scenario				
Plastic bag	1,2	1,1	1,0	1,00
Bioplastic	4	3	1,3	0,002
Thick plastic bag	3	3	3	2,7
Paper	7	7	2	0,003
Woven PP	26	19	8	1,1
Non woven PP	12	9	5	0,5
Cotton	1 058	289	49	0,001

4.4.5 Recycled Content for Conventional, Oxodegradable and Thick Plastic Bags

According to CPIA, plastic bags are generally manufactured with 25% recycled content using either on-site scrap from the manufacturing process and reintroduced into the process or recycled plastic purchased from other plants. Since on-site generated scrap is not included in the definition of recycled content according to the Canadian Standards Association (Competition Bureau of Canada, 2008) and the proportion of scrap at other manufacturing facilities is not known, only half (12.5% pre-consumer recycled content) is considered in this sensitivity analysis.

Table 4-5: Equivalent number of uses to match the conventional plastic bag with and without recycled content in conventional, oxodegradable and thick plastic bags

	No recycled content								Recycled Content							
	Small Shopping Scenerio				Large Shopping Scenerio				Small Shopping Scenerio				Large Shopping Scenerio			
	SH	QE	R	A	SH	QE	R	A	SH	QE	R	A	SH	QE	R	A
Plastic Oxodegradable	2	1	1	1	2	1	1	1	2	1	1	1	2	1	1	1
Bioplastics	11	9	2	0.002	8	7	2	0.002	12	10	2	0.002	9	8	2	0.002
Thick plastic	6	6	4	3	6	6	5	3	6	6	5	3	7	6	5	3
Paper	28	24	6	0.004	20	17	4	0.003	31	26	7	0.004	22	19	5	0.003
Woven PP	98	61	21	1	73	46	16	1	110	68	23	1	83	51	17	1.0
Non woven PP	59	37	18	1	35	22	11	0.5	66	40	20	1	39	24	12	0.5
Cotton	3657	870	124	0.002	2954	702	100	0.001	4111	963	139	0.002	3321	777	112	0.001

4.5 Scenario analysis

An additional scenario analysis was conducted to look at the impact of the forgetting factor on reusable bags on car travel; car trips. When a consumer forgets his or her bags, when for example shopping at the grocery store, one option is to go home and pick them up. The potential impacts of this option are compared with those of the life cycle of shopping bags. The results shows that the potential life-cycle impacts of one conventional plastic bag would represent a one-person car trip of 38 to 113 m. This calculation takes into account a consumption of 6.3 l/100 km4 (emissions from combustion and fuel production) and the indicators Human health, Ecosystem quality and use of fossil resources (IVEC IMPACT World+ method). Other assumptions are the person lives 1.13 km from the store and would use 10 bags of thin HDPE. The findings show that in the event of an oversight (forgetting the reusable bags), the conventional disposable bag substitution would be an option representing less potential impacts than a person getting into their car and driving home to get their reusable bags.

In the context of a ban on thin plastic bags, conventional plastic, oxodegradable plastic and bioplastic bags made of starch and polyester would be excluded. For permitted bags other than cotton, the longest equivalent distance by car is 3.1 km for a woven PP bag without considering its reuse. For cotton, the distances are between 13 and 126 km.

These calculations do not take into account the uncertainties involved and the values presented are only indicative.

4.6 Applications and Limitations of LCA

This LCA aims to analyze the environmental life cycle of existing and potential shopping bags in Quebec. Any conclusions drawn from this study outside its original context should be avoided.

<u>However, the main limitations that can be raised concern the following:</u>

- Variety of bags available on the market: a considerable number of types of shopping bags have been evaluated. However, there is a wide variety of shopping bags available on the market, making it impossible to systematically evaluate all types, sizes, origins and materials of shopping bags.
- User behaviour :
  - Although the study attempted to express the results in two shopping scenarios reflecting the main user behaviours, other behaviours could influence the results. For example, in a shopping context, a consumer could use a single reusable bag for shopping in different stores rather than using one disposable bag per store.
  - The use of additional small plastic bags for meat to prevent contamination of reusable bags was not considered.
- Completeness and validity of inventory data: In particular, the use of secondary data from LCA databases can influence the validity of inventory data

[4] Process US LCI "Transport, passenger car, gasoline powered/personkm/RNA"

results in the different geographical contexts of bag production. Notably:

- The starch-polyester bioplastic bag was modeled on a previous generation of this material. Since then, technological innovations have taken place and certain production conditions have probably changed, particularly as regards the petrosourced polymer content.

- The completeness and validity of the impact assessment method used, among other things because it does not cover all the substances inventoried or all the environmental impacts associated with human activities. Notably:
    - The "carcinogenic","non-carcinogenic" and "ecotoxicity" impact categories are not measures of the risk associated with the systems evaluated. In fact, the different emissions are aggregated over time and space to form an inventory in which a single flow is associated with each of the listed substances (i. e. the total mass emitted by all the processes that produce it). It is therefore not possible to know where and when emissions take place and therefore, to identify the amount to which a given region is exposed; the information on which the risk assessment for a given population is based.
    - The interpretation of the results of the characterization can only be based on the results obtained, i. e. on substances for which characterization factors exist in the database of methods; characterization factors which convert the elementary flows inventoried into units of impact and damage indicators. However, several elementary flows could not be converted into impact scores because no characterization factor was available. Therefore, they were not considered during the assessment phase of potential impacts.
    - *The "Abandonment in the Environment" indicator, which has not been recognized by an official LCA method. The objective is not to determine the consequences of abandoning bags in the environment, but only to specify the quantity of undecomposed matter that could potentially generate a plethora of potential impacts during this period.*
    - Unlike environmental risk analysis conducted in a regulatory context and using a conservative approach, LCA attempts to provide the best estimate possible (Udo-de-Haes et al., 2002). The most likely case is that the models used, i. e., the models for transport, environmental contaminants, and the toxic effects on biological receptors, do not attempt to maximize exposure and environmental damage (worst-case approach), but rather represent an average case.

Finally, it should be recalled that the results of the LCA show potential and not real environmental impacts.

5 Environmental Conclusion

The first part of this study met the objectives set at the outset, namely to establish an environmental profile of shopping bags in a Quebec retail context and to compare them. The analysis included various disposable and reusable bags on the market.

For the Human Health, Ecosystem Quality and Fossil Resource Utilization indicators, the conventional plastic bag performs better than other disposable bags studied. Because of its thinness and lightness, being designed for a single use, its life cycle requires little material and energy. For example, traveling between 38 and 113 m in a car is what it takes to generate larger impacts than the life cycle of a conventional plastic bag. Moreover, its reuse as an end-of-life garbage bag contributes significantly to reducing its potential impacts for the three indicators mentioned above. According to new data collected by RECYC-QUÉBEC and ÉEQ during the characterization of Quebec residential waste, a high proportion of discarded shopping bags contain garbage (77.7% for conventional plastic bags). Nevertheless, these very recent data are based on a small sample (<200). Therefore, a sensitivity analysis was performed. It showed that even without being reused as garbage bags, the conventional plastic bag has the best results out of the three indicators mentioned above, although with a lower margin. The main findings were therefore not affected. The province-wide representativeness of the reuse rate as a measured garbage bag can be confirmed in future waste characterizations.

The other disposable bags studied, with the exception of the oxodegradable bag, obtained higher impact scores on Human Health, Ecosystem Quality and Fossil Resource Utilization than the conventional plastic bag, notably because of their higher mass. The bioplastic bag made of starch and polyester, as well as the thick plastic bag have, respectively, 2 to 11 times and 4 to 6 times more potential environmental impacts than the conventional bag, depending on the indicator and shopping scenario. The paper bag is either the least or among the least efficient of the disposable bags by 4 to 28 times. The potential impacts of the oxodegradable bag are considered equivalent to conventional plastic bags.

As for the reusable bags studied, they generally have higher potential environmental impact scores per bag than the disposable options evaluated. For the same three indicators, woven and non-woven PP bags have an equivalent number of uses of 16 to 98 and 11 to 59, respectively, depending on the scenario and indicator needed to match the environmental impact of a conventional plastic bag. The cotton bag studied is by far the least efficient with an equivalent number of uses to equal the conventional plastic bag ranging from 100 to 3,657 times. These figures alone do not make it possible to rule that reusable bags are better for the environment than disposable bags, as they do not provide information on their durability (i. e. the number of uses they can withstand) or on users' habits; are the bags being reused enough times to be better for the environment. On the other hand, having determined the equivalent numbers of uses, this study establishes the guidelines for the eco-responsible use of this type of bag. Disposing of reusable bags that have been used only a few times, such as accumulated through unplanned shopping, does not constitute good eco-responsible behaviour. Concretely, in the context of a weekly large shop at a grocery store, it would take between 16 and 73 weeks (between four months and a year and a half) for the potential life cycle impacts of the woven PP bag studied to be equivalent to those of a conventional plastic bag, and only if it is used assiduously at each grocery store.

The above conclusions focus exclusively on the three classic LCA indicators evaluated in this study: Human Health, Ecosystem Quality and Fossil Resource Utilization. Although, based on these indicators, bio-based bags of starch-polyester, paper, cotton and bioplastic bags do not have advantages over other bags (disposable or reusable), they do offer benefits for the Abandonment in the Environment indicator: the conventional plastic bag score is, depending on the shopping scenario and considering a single use, between 425 and 537 times, 277 and 388 times, as well as 599 and 741 times higher than the starch-polyester, paper, cotton and bioplastic bags, respectively. The much longer biodegradation time of PE and PP makes environmental persistence the weak point of conventional plastic, thick plastic and PP bags compared to biosourced bags. Quantification of the environmental impacts of plastics is needed to determine the magnitude of these end-of-life benefits on human health and ecosystem quality, with the Abandonment in the Environment indicator simply representing the mass of the abandoned bag multiplied by the persistence period of the material in years. *With respect to the rate of bag abandonment in the environment, it is recommended that further studies be conducted to validate the values used in this report and potentially identify factors that would lead to better differentiated abandonment rates depending on the type of bag (e. g. consumer behaviour, physical behaviour of bags during collection, transportation, landfill, etc.).*

Finally, the environmental conclusions have some limitations. First, they are only applicable to the bags studied and cannot necessarily be generalized to all bags of the same type. Although the bags studied are considered typical in a Quebec context and few previous LCA studies have covered so many different types of bags, it is not possible to represent all bags on the market. Especially since the results show that the place of production, the mode of transport, the design parameters (recycled content) and the end-of-life fate have a strong influence on the results, which means that each situation is specific and must be the subject of separate study (depending on the geographic location, the local context such as population density, the local consumer shopping and usage habits, local manufacturing capability, end-of-life management) etc.

Finally, the life cycle modelling of the study bags systematically used generic data, which were adapted as much as possible to fit the modelled processes, as described in the report.

COMPONENT II: LIFE CYCLE COST ANALYSIS OF SHOPPING BAGS (LCCA)

6 Bibliographic Review of LCCA Studies

A review of LCCA's and other economic studies on the costs of individual shopping bags was carried out based on work already done internationally. The analysis of the relevant studies made it possible to compare the different approaches and data sources used to carry out a cost analysis. The most relevant documents for this study are summarized in the following sections starting with the most recent.

6.1.1 Economic Impact Analysis. Proposed Ban on Plastic Carryout Bags in Los Angeles County (AECOM, 2010)

This study is based on the economic cost of banning plastic bags with pricing on paper bags. The impact on consumers is studied. Only direct costs were considered. The increase in property values due to a cleaner environment, the reduction of taxes associated with waste management and other environmental benefits were not considered.

Only the economic impacts on supermarket, grocery, convenience, drugstore and parapharmacy customers are included in the study.

The manufacturer's price of a single-use plastic shopping bag ranges from US$0.005 to US$0.01 per bag, while paper shopping bags cost between US$0.05 and US$0.15 per bag. The authors consider that this price is indirectly paid by the customer. Thus, the annual hidden cost of purchasing plastic bags is US$3.25 per person, or an average cost of US$0.008 per plastic bag.

The study considers that consumers have to pay for used paper bags at a price of US$0.10, which allows for a change in consumer behaviour towards reusable bags to avoid the cost of paper bags.

For reusable bags, stores sell them for US$0.75 to US$0.99 per bag. Considering 125,165 and 204 uses for shopping, and how much paper bags cost the consumer, they may prefer to turn to reusable bags to avoid the cost of paper bags.

For reusable bags, stores sell them for US$0.75 to US$0.99 per bag. Considering 125,165 and 204 uses for shopping, these bags cost the consumer between US$0.004 and US$0.005 per use. It should be noted that the source cited for the numbers of uses cannot be found and the authors did not indicate how they were determined.

Transport is also examined because paper being heavier and thicker than plastic bags, transporting the same number of paper bags will require more trucks. The study assumes that 8 plastic bags are transported for the same weight as a paper bag. For example, the cost of transporting paper bags from the manufacturer to the market is higher in terms of the number of trucks used, but also in terms of the fuel used. However, the study did not quantify these costs, although it did mention them.

6.1.2 Environment Australia Plastic Shopping Bags – Analysis of Levies and Environmental Impact (Nolan-ITU et al., 2002)

This study, like AECOM (2010), evaluates the economic consequences following a ban on or pricing of shopping bags. It considers that the average price of a single-use plastic shopping bag is AU$0.01 per bag and that a shopping bag used in stores costs approximately AU$0.10 per bag. The authors also assume that this price is indirectly paid by the customer. For reusable bags, stores sell reusable bags for $1.50 AU$.

6.1.3 Impact Assessment: Single-Use Plastic Bag Charge for England (DEFRA, 2010)

This study analyses the costs involved in setting up a pricing system for shopping bags.

The average price of a single-use plastic shopping bag is £0.009 per bag when purchased in bulk by retailers. The cost of transporting these bags and storage is estimated at £0.01 per bag. Thus, the total price of a plastic bag paid by the consumer is £0.019 per bag.

The study considers that retailers have to buy paper bags for £0.20 per bag. Concerning the transport and storage of these bags, the authors consider that a paper bag is about 7 times heavier than a plastic shopping bag, and therefore that the associated costs are seven times higher, i. e. £0.07 per bag. Thus, the price of a paper bag is £0.27 for the consumer.

The report also calculates the economic impacts of plastic one-way disposable bags left in the wild by looking at the fish industry, coastal waste, the cost of rescuing ships damaged by such waste, cleaning up streets and railways. The total rises for 2015 amounted to 14.45 million pounds for 13 billion plastic bags used, i. e. 0.001 pounds per bag. The cost of paper bag waste does not concern marine areas, as the authors assume that paper bags degrade rapidly in water and therefore have no economic impact. For example, cleaning up the streets and railways of paper bags cost £1.54 million for 326 million used paper bags, or £0.005 per bag.

The cost of end-of-life bag processing was calculated per tonne of each bag type. The average price of a landfill is £20.8 per tonne, the collection of residual waste is £40.3 per tonne and the collection and sorting done to recycle it is £377 per tonne. The landfill tax was not taken into account. The authors assumed that 90% of the disposable plastic bags are sent to landfill and 10% is recycled. Each bag weighs an average of 7.5 g. Thus, the end of life of a single-use plastic bag costs £0.000695 per bag. This study considers that the recovery rate for paper bags is the same as for waste paper, 84.8%. The rest goes to landfill. Taking a paper bag weight 7 times higher, the end of life cost of a paper bag is £0.017 per bag. Recycling revenues from these bags are estimated at £0.25 million for plastic bags and £0.9 million for paper bags in 2015.

6.1.4 Conclusion

According to these three studies, the largest share of the costs of single-use and reusable bags comes from consumer purchases of the bags. End-of-life of bags is the second area that has the most influence on the cost of bag life cycle. The transport and storage of the bags need to be consdered, because depending on the weight of the bag chosen, more trucks and more fuel will be needed. The increase in transport impacts directly on the merchant or consumer. Once left in the wild, plastic bags have a higher total cost than paper bags, especially in the marine environment, but less per bag used.

7 LCCA Study Model

7.1 Objectives

The purpose of this economic component is to estimate the total life-cycle costs of shopping bags, including the direct and indirect costs of using bags, in order to compare them. This is not an assessment of the economic consequences of a banning measure. LCCA is harmonized with the ELCA model for bag types, functions, functional unit and reference flows. The differences are mainly in the inventory and LCA phases: instead of emissions into the environment and assessed impacts, the costs and revenues arising at each stage of the life cycle are added up after they have been converted into a single currency and updated for the same year when necessary. Finally, some nuances concerning the boundaries of the systems are discussed in the following section. The LCCA study model is inspired by the approach of Hunkeler et al. (2008).

7.2 System boundaries

Table 7-1 below presents the life cycle costs and revenues included in LCCA in the same steps presented in Table 3-4 for ELCA.

Table 7-1: Costs and Incomes Included and Excluded from ELCA Boundaries

Stages of the cycle of life	Costs/Revenues	Comments
Production, distribution and use	Acquisition of the bag	When the bag is offered free of charge at the checkout is the retailer's cost of acquiring the bag. that is being considered. Otherwise, the acquisition cost per the consumer is used.
	Transportation to retailers	When the bag is offered free of charge at the checkout, the cost of distributing bags is estimated. Otherwise, it is considered to be included in the cost by the consumer.
	Wash reusable bags	
	Transport of retailer bags to home	Excluded (consider
End of life	End-of-Life Transport	Included
	Landfill	Included
	Sorting and recycling	Included
	Sale of sorted material	Included
	Cleaning of abandoned bags	Included in the "expensive" scenario.

7.3 Lifecycle Cost Inventory Sources, Assumptions and Data

This section presents the additional information to that presented in Section 3.7 in order to be able to perform the LCCA calculation.

The main assumption in the LCCA calculation is that bags, when sold to consumers, are profitable. Therefore, it is assumed that the selling price of the bags includes all production and distribution costs.

The following tables show the costs used. Given the high variability of some scenarios, two scenarios were considered: an economic scenario, in which the lowest and highest avoided costs are considered, and an expensive scenario, in which the highest and lowest avoided costs are considered.

Costs five years and under have not been discounted. Where possible, sales taxes were excluded from the costs, i. e., the Goods and Services Tax (GST) and the Quebec Sales Tax (QST) totalling 15% for costs incurred in Quebec. The exchange and discount rates were taken from the Bank of Canada website.

The "payers" shown in the following tables, are those who pay directly for the costs. For example, it does not take into account cost transfers to other stakeholders according to market elasticity or through a legislative framework. For example:

- The studies cited in Section 6 all assume that the cost of bags distributed free of charge by the retailer to its customers is fully transferred to them in the price of the goods sold. The retailer is considered to be the direct payer.
- In Quebec, there is a compensation regime that requires "persons who place containers, packaging, printed matter and newspapers of all kinds on the market to bear most of the costs of selective collection of recyclable materials" (MDDELCC, 2016b). Therefore, for shopping bags, municipalities are mostly compensated by retailers. However, they transfer all or part of the costs to consumers depending on the price elasticity of the goods offered in the market. So some of the costs of selective collection could be attributed to consumers. The municipality is considered to be the direct payer.

Table 7-2: Life Cycle Cost of Shopping Bags

Costs	Direct Payers	Comparative systems			Comments
		Conventional plastic bag	Oxodegradable plastic bag	Bioplastic bag	
Production, distribution and use					
Transport	Retailer	Estimated diesel consumption: $0.87 per litre of diesel (Energy Regime, 2016)			Average price of diesel in Quebec in January and October 2016 without sales taxes, considered only if the bag is given to the consumer.
Acquisition: economic scenario	Retailer	0.036 $/bag (source: retailer)	0.036 $/bag (conjecture)	0.16 per bag (private price; price per case for 6 cases and more (Ecolife products, 2017)	Untaxed
	Consumer	0 $/bag	0 $/bag	0 $ (hypothèse)	Untaxed
Acquisition: expensive scenario	Retailer	Included in the cost to the consumer	Included in the cost to the consumer	0.18 per bag (private price; price for one case (Ecolife products, 2017)	Untaxed
	Consumer	0.05 per bag (source: retailer)	0.05 per bag (conjecture)	0 $ (conjecture)	Untaxed

Costs	Direct payers	Comparative systems			Comments
		Conventional plastic bag	Oxodegradable plastic bag	Bioplastic bag	
End of life					
Garbage bags avoided: economic scenario	Consumer	(0.16)/ garbage bag	(0.16)/ garbage bag	(0.16)/ garbage bag	Maximum price found among 5 Quebec online retailers for a garbage bag as described in section 3.5.1 or similar. Economic scenario = maximum avoided costs.
Garbage bags avoided: expensive scenario	Consumer	($0.06)/ garbage bag	($0.06)/ garbage bag	($0.06)/ garbage bag	Minimum price found among 5 Quebec online retailers for a garbage bag as described in section 3.5.1 or similar. Expensive scenario = minimal avoided costs.
Landfill	Municipality	$89.30/tonne	$89.30/tonne	$89.30/tonne	Medium 2014 (MDDELCC, 2016a). Without taxes.
Selective collection	Municipality	$488.82/tonne	$488.82/tonne	$789.76/tonne	Municipal Compensation Plan, Tariff 2016 (QEQ, 2016b)
Cleaning of abandoned bags: economic scenario	Municipality	-	-	-	
Cleaning abandoned bags: an expensive scenario	Municipality	0.0018 $/bag (0.001 £/bag in 2010)	0.0018 $/bag (0.001 £/bag in 2010)	0.0018 $/bag (0.001 £/bag in 2010)	Source : DEFRA (2010)

Table 7-3: Life Cycle Cost of Shopping Bags (continued)

Cost	Direct Payers	Comparative systems		Comments
		Shop Plastic Bag	Paper Bag	
Production, distribution and use				
Transport	Retailer	Estimated diesel consumption: $0.87 per litre of diesel (Energy Regime, 2016)		Average price of diesel in Quebec in January and October 2016 without sales taxes, considered only if the bag is given to the consumer.
Acquisition: economic scenario	Retailer	$0.10 per bag (source: retailer)	$0.05 per bag (source: retailer)	No taxes.
	Consumer	0 $/bag	0 $/bag	
Acquisition: expensive scenario	Retailer	Included in consumer cost	Included in consumer cost	
	Consumer	0,20 $/bag (source : retailer)	0,25 $ (source : retailer)	
End of life				
Garbage bags avoided: economic scenario	Consumer	(0,16 $)/garbage bags	-	Maximum price found among 5 Quebec online retailers for a garbage bag as described in section 3.5.1 or similar. Economic scenario = maximum avoided costs.
Garbage bags avoided: expensive scenario	Consumer	(0,06 $)/garbage bags	-	Minimum price found among 5 Quebec online retailers for a garbage bag as described in section 3.5.1 or similar. Expensive scenario = minimal avoided costs.
Landfill	Municipality	89.30 $/tonne	89.30 $/tonne	Medium 2014 (MDDELCC, 2016a). Without taxes.
Selective collection	Municipality	488.82 $/tonne	192.46 $/tonne	Municipal Compensation Plan, Tariff 2016
Cleaning of abandoned bags: economic scenario	Municipality	-	-	
Cleaning abandoned bags: an expensive scenario	Municipality	0.0018 $/bag (0.001 £/bag in 2010)	0.0087 $/bag (0.005 £/bag in 2010)	Source : DEFRA (2010)

Table 7-4: Life Cycle Cost of Shopping Bags (continued)

Costs	Direct payers	Comparative systems			Comments
		Woven PP bag	Non woven PP bag	Cotton bag	
Production, distribution and use					
Transport	Retailer	n.d.			
Acquisition: economic scenario	Retailer	Included in consumer cost	Included in consumer cost	Iincluded in the cost to the consumer	No taxes
	Consumer	0,75 $/sac (source : CCCD)	0,25 $/sac (source : retailer)	2 $/sac (source : CCCD)	No taxes
Acquisition: expensive scenario	Retailer	Included in consumer cost	Included in consumer cost	IIncluded in consumer cost	
	Consumer	1 $/sac (source : retailer)	1 $/sac ((source : retailer)	6,90 $/sac (source : retailer)	
End of life					
Landfill	Municipality	89,30 $/tonne	89,30 $/tonne	89,30 $/tonne	Medium 2014 (MDDELCC, 2016a). Without taxes.
Cleaning of abandoned bags: economic scenario	Municipality	-	-	-	
Cleaning abandoned bags: an expensive scenario	Municipality	0,0018 $/sac (0,001 £/sac en 2010)	0,0018 $/sac (0,001 £/sac en 2010)	0,0018 $/sac (0,001 £/sac en 2010)	Source : DEFRA (2010)

7.4 Interpretation

The LCCA interpretation phase includes a comparison of the systems described in the previous sections. This includes in particular:

- Contribution analysis according to the payors;
- Scenario analysis: Expensive and economic scenarios are used to calculate the minimum and maximum equivalent numbers for each bag type.

After having explained the LCCA method, the results are presented in the following chapter.

8 LCCA Results and Discussion

This chapter covers the last two phases of LCCA, i. e. assessing the life cycle costs of the shopping bags studied and interpreting the results. It presents the cost profile of the bags under study, a comparison of the number of uses required for a bag to achieve a life cycle cost equal to that of a conventional plastic bag.

The gross cost results are available in Appendix E.

8.1 Life Cycle Cost Profile of Shopping Bags

The following figures illustrate the profile of each shopping bag as a percentage contribution to the costs borne by the various life-cycle payers (retailer, consumer, municipality and sorter). The results presented in Figure 8-1 (Economic Scenario) and Figure 8-2 (Expensive Scenario) are valid for both the small and large shopping scenarios. It is recalled that the two price scenarios (economic and expensive) are used to reflect the variability of the identified prices.

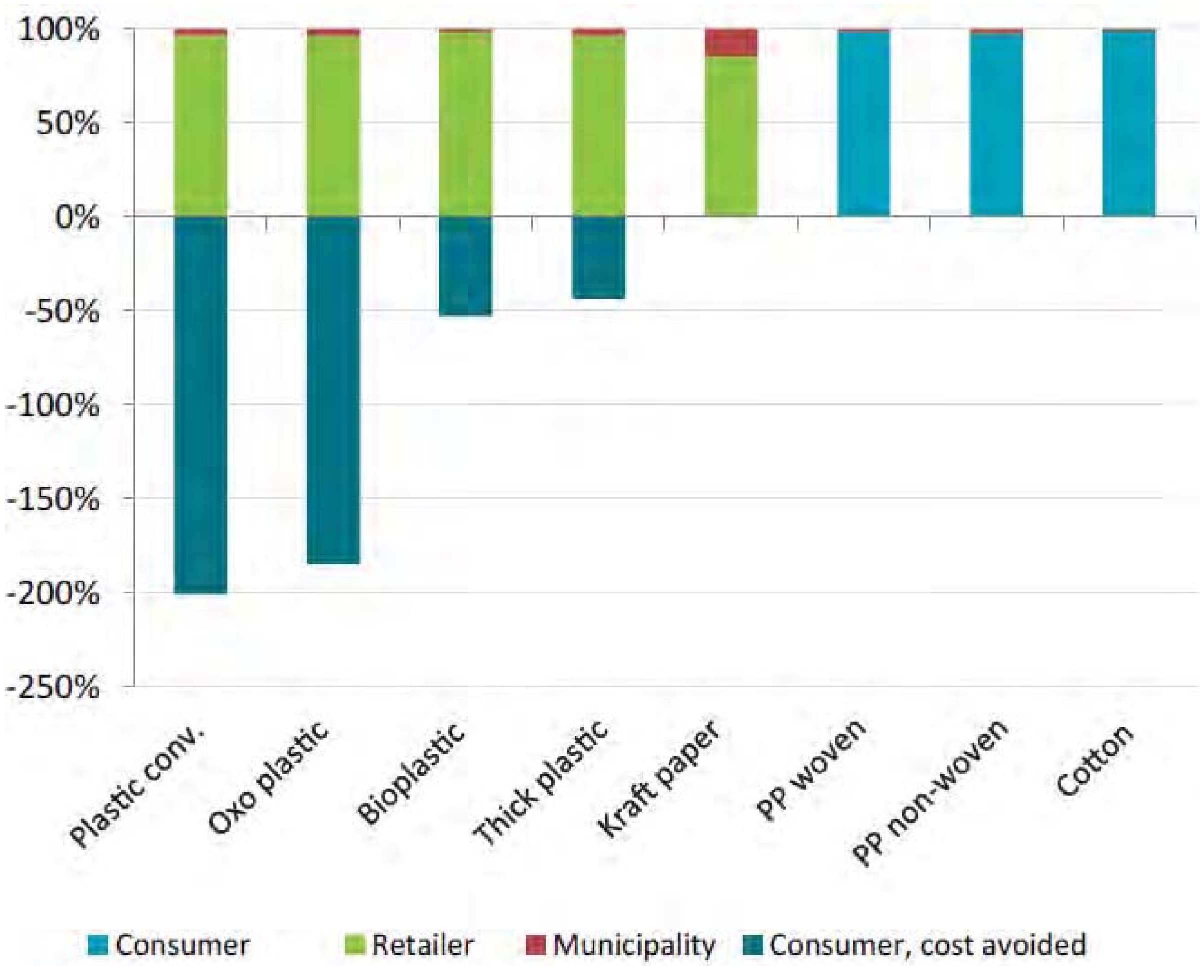


Figure 8-1 : Contribution of life-cycle payers of shopping bags to the economic scenario. Each column represents a bag.

The preceding figure (economic scenario) highlights the following elements:

- Avoided garbage bag costs for plastic bags (dark blue) can outweigh other bag lifecycle costs, resulting in a net gain. The consumer is the stakeholder benefiting from this gain.
- Excluding avoided garbage bag costs, the acquisition of the shopping bag by the retailer or consumer is the primary component of life cycle costs.
- End-of-life management costs (estimated from municipal compensation plan data) are low relative to the total life cycle cost, except for the paper bag. For the latter, end-of-life management costs (landfill and recycling) account for about 15% of life-cycle costs due to its high mass and low acquisition cost for this scenario.

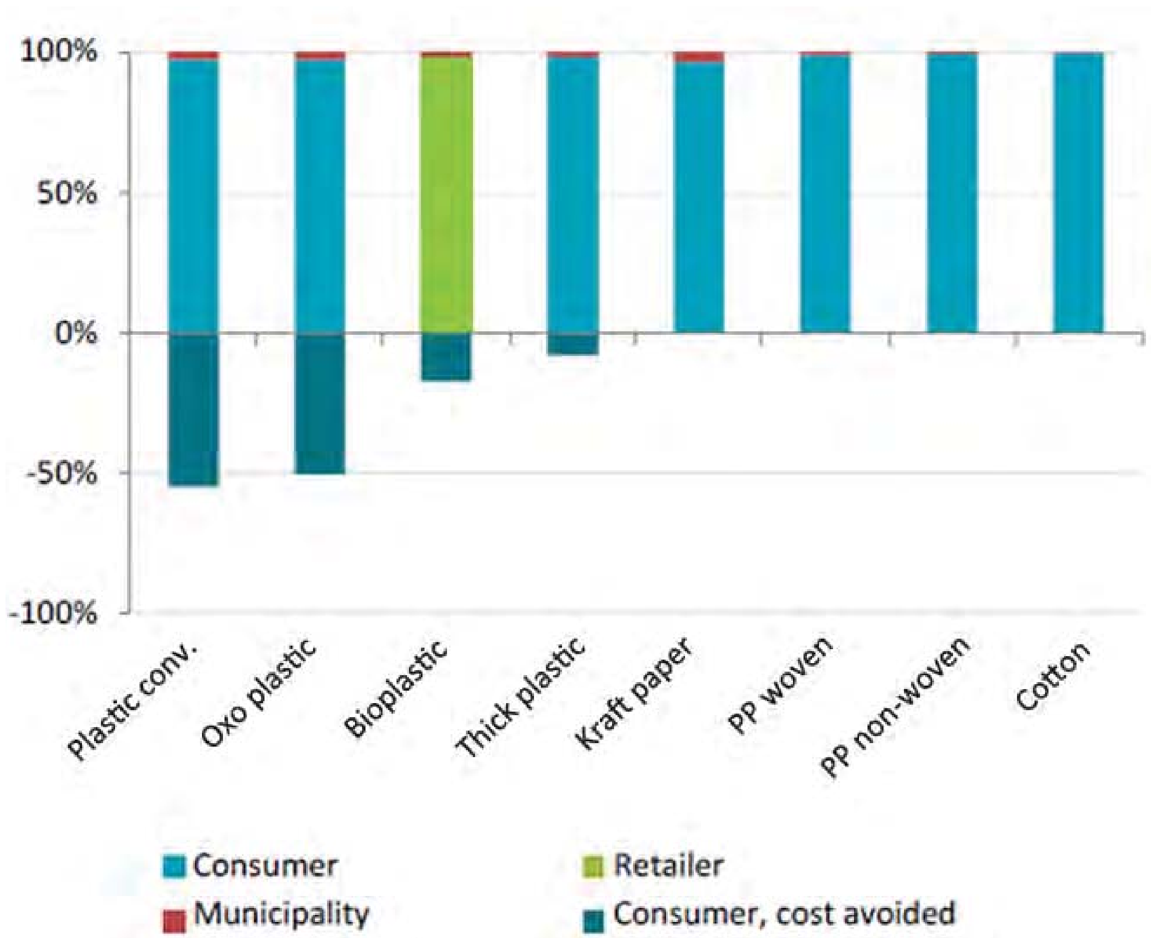


Figure 8-2: Lifecycle Payor Contribution of Shopping Bags for the Expensive Scenario. Each column represents a bag.

With respect to the maximum cost scenario, most bags are sold at a higher price that matches the price paid by consumers (light blue in the previous figure), who bear the majority of life cycle costs despite the avoided cost of garbage bags. The latter is less important because of the lower cost of shopping bags and the higher cost of garbage bags in this scenario.

Finally, it is assumed that the acquisition cost of the bioplastic bag made of starch and polyester is paid by the retailer (green in the previous figure), but this hypothesis could not be supported by a field observation because this type of bag is rare.

Overall, we note that...

- The savings to the consumer through reuse of plastic bags as garbage bags exceed the life cycle costs in the most favourable case (economic scenario).
- Excluding avoided garbage bag costs for conventional and oxodegradable plastic bags, the retailer's or consumer's acquisition of the shopping bag is the primary component of life cycle costs.
- End-of-life treatment costs are low compared to the total life cycle cost of bags.

8.2 Equivalent number of uses

After identifying the key life cycle costs of each type of bag, this section compares the main life cycle costs of each type of bag with the number of uses required for a bag to have a life cycle cost equal to the reference bag, the conventional plastic bag.

As with the environmental component, a use means the use of a bag in its main function, i. e. the transport of purchases during a shopping trip. Table 8-1 presents the minimum and maximum values obtained for both shopping scenarios. Both scenerios take into account all the costs illustrated in the previous section, including avoided costs. The minimum value of the equivalent number of uses is calculated using the economic scenario for the replacement bag and the expensive scenario for the conventional plastic bag. The maximum value of the equivilant number of uses is calculated using the expensive scenario for the replacement bag and the economic scenario for the reference bag.

Table 8-1: Equivalent Number of Uses for Shopping Scenarios

Bag	SMALL SHOPPING SCENERIO		LARGE SHOPPING SCENERIO	
	MIN	MAX	MIN	MAX
Oxodegradable plastic	more expensive		always more expensive	
Bioplastic	3	Conventional plastic bag always less expensive	3	Conventional plastic bag always less expensive
Thick plastic	3		3	
Kraft Paper	3		1.8	
Woven PP	33	reusable always more expensive	25	reusable always more expensive
Non woven PP	11		7	
Cotton	88		71	

Overall, we note that...

- Among disposable bags, excluding the oxodegradable bag, conventional plastic bags are the cheapest in the life cycle.
- The lifecycle costs of the oxodegradable bag are equivalent to those of the conventional plastic bag.
- For reusable bags :
    - In the most favourable case to the conventional plastic bag, reusable bags are always more expensive than the latter.
    - In the unfavourable case to a conventional plastic bag, the reusable bags must be used between 7 and 11 times for the non-woven PP bag, between 25 and 33 times for the woven PP bag and between 71 and 88 times for the cotton bag to make them profitable.

9 Economic Conclusion

Lifecycle costing analysis has yielded a number of findings. The cost of bag acquisition by the retailer or consumer, which includes the upstream costs of use (e. g. bag production and distribution to the point of sale), is the primary life cycle cost. For conventional and oxodegradable plastic bags, the costs avoided at the end of life when the bag is reused as a garbage bag are also significant and may even exceed the life cycle costs. End-of-life treatment costs are low compared to bag life cycle costs.

When consumer savings from the reuse of conventional plastic bags as garbage bags exceed life- cycle costs, other types of bags, disposable and reusable, have a higher life-cycle cost, regardless of their number of uses. Even in the case of less favourable use of conventional plastic bags, other disposable bags remain more expensive, with the exception of the oxodegradable bag. While reusable bags must be used 7 to 88 times to be less expensive, depending on the type and shopping scenario. If the thick plastic bag is considered a reusable bag, it must be used three times when shopping to be cheaper than the conventional bag.

COMPONENT III: CONSEQUENTIAL LCA OF A BAG BAN

10 Consequential Study Model

10.1 Objectives of the study and its intended application

Previous components have assessed potential environmental impacts and life cycle costs of different types of shopping bags by modelling their life cycle and the use of production resources. This approach, the most common in the field of LCA, is known as attribution-based analysis, i. e. product systems are studied on the assumption of a static market economy. In a context of large-scale change, particularly through the adoption of a new public policy, effects can be expected on different sectors of the economy, and consequently on the means of production mobilized. In order to assess the environmental impacts of a large-scale ban on (thin) disposable plastic bags in Quebec, the consequential ELCA was used. This type of LCA seeksto describe the consequences of a decision on related markets and, consequently, on the lifecycles of the systems studied, for example on the supply chain and end-of-life management of disposable and reusable bags. It makes it possible to compare different strategies for managing shopping bags while considering the rebound effects of these strategies, and to identify the positive or negative effects of a ban. The consequential effects can be multiple. In the face of actions taken to reduce the use of disposable plastic bags, they are necessarily linked to consumer behaviour.

In the following section, a bibliographic review of the social acceptability of a plastic bag ban is presented in order to gather the information needed to define ban scenarios. To date, only a few studies have attempted to quantify the consequences of banning disposable plastic bags. The methodology of the consequential approach used in this study is then presented.

10.2 Social acceptability of banning conventional plastic bags

The literature review on the social acceptability of banning conventional plastic bags is based on analysis of 15 cases that are currently in place, pending or have been revoked. It is based mainly on the Chamard (2015) study, stakeholder reports, official documents and scientific articles. The impact of the voluntary ban on the SAQ (Société des Alcools du Québec) is reviewed. The following points were discussed:

- Experiences of other cities and states where the ban is in effect;
- The reactions and behaviour of the various stakeholders before and after the ban.

Information gathering is focused on the views of three stakeholders:

- Consumers or citizens, users of bags for their shopping;
- Retailers from various sectors, main suppliers of bags to consumers;
- Players in the plastics industry.

This review made it possible to draw up an inventory of the reactions of the three selected stakeholders, the obstacles and levers linked to the implementation of a ban and to identify differences, depending on the jurisdiction, regarding social acceptability and consumer behaviour.

The objective of this section is to provide an overview of the possible multiple and varied reactions which provide guidance for the development of hypotheses. .

10.2.1 Bag Ban Cases studied

A total of 15 case studies are analysed. They include:

- Three Canadian cases (Toronto, ON (population 2.81 million), Sainte-Martine (population 4,500) and Huntingdon, QC) (population 2,400) (Chamard, 2015),
- Citizen consultation carried out by the City of Montreal (Permanent Commission on Water, Environment, Sustainable Development and Major Parks of Montreal, 2015),
- The cases of the American cities of Austin (TX), San Francisco (CA), Los Angeles (CA), Long Beach (CA), Seattle (WA), Brookline (MA) and Portland (OR),
- A case in Australia, including the Australian Capital Territory (ACT),
- A case in Italy,
- A case in the United Kingdom,
- A case in Taiwan.

Of course, there may be other bag ban cases that have not been evaluated because of lack of information or because they are too recent.

In all the jurisdictions analysed, two types of bans were applied:

- A ban on conventional plastic bags combined with the pricing of other single-use bags;
- A ban on conventional plastic bags without pricing applied to other single-use bags.

10.2.2 Stakeholder opinion

Consumer reactions regarding the reduction of plastic bags are usually negative before the measures are applied:

- In Toronto, a large proportion of citizens (46%) were against bag bans while 19% of citizens were in favour (Chamard, 2015).
- In California in Austin, Brookline and Portland, citizens opposed plastic bag pricing because the proposed pricing was considered too high, especially for low-income families who would have difficulty purchasing shopping bags. In addition, this pricing would have limited access to free plastic bags for dog owners (Chamard, 2015; Waters, 2015).
- In the other cities or states investigated, the opposition reported before the project appeared to be weak.
- None of the cases investigated in the Chamard Report referred to a rescindment after the bags were banned except for Toronto, and the City of Chicago which ended in 2017, its ban on thin plastic bags and replaced it with a plastic bag tax.[5]

Consumers who favour bans do so for mainly environmental reasons; plastic waste abandoned in the environment. (European BIO Intelligence Service, 2011). The reduction of visual pollution is one of the goals found in the vast majority of reduction measures (Chamard, 2015). Bags left in the wild are considered unpleasant, reducing the quality of life and image of rural and urban areas (BIO Intelligence Service, 2011). After a ban, the number of bags present in nature seems to be reduced:

- Residents of the city of Austin, Texas, have noticed a significant decrease in this type of waste after the ban was introduced.
- The Austin Parks Foundation, responsible for park maintenance, noted a 90% decrease in the number of thin plastic bags six months after the measurement (Waters, 2015).
- In Long Beach, Environmental Services reports that plastic bags are less present in waste found in streams and shorelines (Charmard, 2015).
- The other jurisdictions investigated did not report any improvement in the situation; either by omission or because there was no significant improvement.

Bag ban opponents offer a number of reasons, but most cite the impossibility of continuing to reuse conventional plastic bags as garbage bags, or to collect dog droppings. A ban on this type of bag forces consumers to buy new bags for these uses, which represents an additional expense and increases the amount of plastic consumed. (Chamard, 2015). The loss of freedom of choice is also of concern. (BIO Intelligence Service, 2011).

Once the ban is implemented, opposition can soften or lead to rescindment.

- In Australia, six months after the ban was introduced, 58 per cent of Australia's residents support the legislation and 33 per cent are against it (ACT government, environment and sustainable development, 2012).
- In Toronto, the ban by-law was set aside, partly because of the legal difficulties raised by such a ban and partly because of the above-mentioned citizen's opposition.

Citizens' reactions therefore depend on the efforts, information and awareness-raising campaigns carried out by decision-makers and stakeholders, the popular culture of the city or region concerned, actions carried out by neighbouring cities and countries, and the opinions of political parties (Chamard, 2015).

Retailers are generally opposed to bans, particularly in the case of the City of Toronto, where opposition from merchants and the plastics industry led the city to reverse its decision. Retailers are willing to cooperate as long as the measures taken do not impose excessive costs or are time-consuming (AECOM, 2010). Merchants, particularly those in small businesses, fear that they will have to use more expensive alternatives and that a ban will negatively effect their sales if they do not offer the bags to their customers (Charmard, 2015).

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[5] http://chicago.cbslocal.com/2016/12/29/chicago-plastic-bag-ban-ends-in-2017-new-bag-tax-delayed-until-february/

Retailers most concerned by the changes in bag policies are those with the smallest shops (AECOM, 2010). A ban on free plastic bags results in a high use of paper bags as a replacement. Because paper bags are 7 times heavier they require more trucks to transport them and larger spaces to store them. This increases costs for merchants facing higher transport and storage costs (AECOM, 2010). In addition, paper bags would take longer to fill than plastic bags, so in the case of a no-fee ban, where paper bags are widely used, there would be an impact on employment because of either the longer time it takes to fill bags or the need to hire new employees. In the case of a ban pricing the substitute bags, the number of paper bags used is generally lower than the number of conventional plastic bags, which generally reduces transportation and storage costs and bagging problems (AECOM, 2010). In California, retailers can charge consumers for the use of single-use or reusable bags. This measure is considered advantageous, as the revenue generated by the sale of bags is passed on to the merchants. Regardless of the measure, retailers usually ask for a year or two to adapt to the regulatory change and for politicans to clearly announce to citizens the imposition of new measures. (Chamard, 2015, AECOM 2010).

Efforts by the plastics industry to oppose bag bans focus on higher costs to consumers, the potential loss of employment and bacterial contamination of reusable bags (ACIP, 2016b), with consumers rarely washing these types of bags (CROP, 2015). As an alternative, the industry proposes a greater commitment by all stakeholders to voluntary reduction strategies, product stewardship, the 3R's hierarchy, individual responsibility and consumer choice.

10.2.3 Quebec case

Quebeckers are sensitive to the issues related to the management of single-use shopping bags. When the Province of Quebec introduced its Voluntary Code of Good Practice on the Use of Shopping Bags to reduce the amount of bags being distributed by 50%, the number of bags distributed in the province decreased by 52% in two years, even though the program was to run for four years. (RECYC-QUÉBEC et al., 2012)

[6] http://www.allaboutbags.ca/

The initiative by the small communities of Sainte-Martine and Huntingdon to ban single-use plastic bags found little opposition from consumers or citizens. The only complaints came from the industry and retailers. Consumer complaints about the ban related to the loss of the use of plastic bags for dog droppings. Some retailers in Huntingdon were reluctant to implement a ban, but no particular problems were encountered (Chamard, 2015).

The SAQ in Quebec completely removed single-use bags (plastic and paper) in 2009, and encourages customers to bring reusable bags. It estimates that this measure avoids the use of 80 million single-use bags (SAQ, 2016b). The Crown Corporation has seen no impact on sales, but then it is in a monopoly situation.

The public consultation on the issues and impacts of the City of Montreal's ban of thin conventional plastic shopping bags, showed that citizens are equally divided between support for the ban and opposition related to the removal of free access to plastic bags for disposing of garbage (Permanent Commission on Water, the Environment, Sustainable Development and Major Parks of Montreal, 2015). 55% of Montrealers prefer to be made aware of this problem rather than having the bags banned; they believe that the best solution to reduce the number of plastic bags in the City of Montreal is to raise awareness about recycling and reusing plastic bags. Retailers fear a flight of customers to the municipalities on the outskirts of Montreal, not subject to the bag ban, which would result in a loss of revenue. The plastics industry and manufacturers of single-use plastic bags advocate the loss of jobs and plant closures that can result from such a measure, but exact figures are not available (ACIP, 2016b).

10.2.4 Consumer behaviour

After the ban, with or without pricing on other disposable options, consumers generally turn to three alternatives: paper bags, reusable bags and thick plastic bags that are not subject to the ban to transport their purchases (Chamard, 2015; Morris and Seasholes, 2014).

According to available information, when single-use bags are banned without charging for the alternatives, consumers tend to use paper bags (Chamard, 2015). For example, the City of Portland reported a 304% increase in the use of reusable bags and a 491% increase in the use of paper bags one year after a ban (without specifying the rate of use of these bags before banishment). Although this is piecemeal information, the application of a mandatory fee of five cents per disposable plastic or paper bag in April 2015 in Portland resulted in an increase in the use of reusable bags from 10% to 80% in a local supermarket chain (Pols, 2015).

A ban with fees: A study conducted by Equinox-Center (2013) in the cities of San Jose, Santa Moncia and Los Angeles County, showed when there are fees on the alternatives and conventional plastic bags are banned, reusable bags are preferred (Chamard, 2015), as well as other packaging alternatives (no bags, backpacks, reused cardboard boxes, etc.).

With a tariffed ban, 45% of purchases are transported with reusable bags, 39% without bags and 16% with paper bags (Equinox-Center, 2013).

A study in Australia compared the use of other means of transporting goods from store to home. It found that consumer adoption of options other than conventional plastic bags ranged from 17% when there is no ban and no pricing or fees on other single-use alternatives to 40% with fees only and no ban showing that fees are effective at reducing bag usage. (Chamard, 2015).

The use of thick plastic bags is problematic because their thickness meets the criteria for being recognized as reusable and they use more plastic to make than single-use plastic bags. And it is not clear whether consumers will be able to reuse these types of bags or if they meet satisfactory resistance criteria. In cases where the appearance of this type of bags was problematic following a ban on thin plastic bags, regulations were adapted to exclude these bags according to a thickness criterion (Portland) or by imposing resistance tests (San Francisco) according to Chamard (2015).

Consumer reuse single-use plastic bags for many purposes; as garbage bags; as lunch bags; for storage; to pick up after pets and many other uses.

- In Australia, 85% of consumers reuse plastic bags and 75% of the population reuses them for garbage disposal (ACT government, environment and sustainable development, 2012).
- In the United Kingdom, 76% of single-use bags are reused including 40.3% to contain waste.

In Montreal, according to a CROP survey, 87% of Montrealers reuse their plastic bags, mainly to replace garbage bags (CROP, 2016).

Depending on the main use of the plastic bag, its end of life is different. Supermarket bags destined for the home seem to be more likely to be reused, while "take-out" quick service bags are more likely to be thrown in garbage or left in the wild (Nolan ITU, 2002). According to data from the United States and the United Kingdom, the LCA study by Kimmel et al (2014) assumes that 40% of plastic bags and 22.1% of paper bags are reused. In Quebec, 77.7% of plastic shopping bags are reused. (EEQ)

The Nolan-ITU study (2002) estimates that a ban on single-use plastic bags is followed by a 70% increase in garbage bag sales. In Australia, an increase of 31% was observed following a ban (ACT government, environment and sustainable development, 2012). Bio Intelligence Services (2011) reports that the increase in the purchase of garbage bags, in the case of a ban, is very small compared to the reduction in single-use plastic bags. In Austin, where the number of single-use bags used decreased by 75%, the actual amount of plastic consumed increased 52%. (Waters, 2015).

10.2.5 Conclusion

Following a review of the case studies described in the preceding paragraphs, some trends can be observed. First, with regard to the acceptability of a ban, the type of legislation, i. e. a ban with or without tariffs, does not seem to influence the views of stakeholders. Prior to a ban, the main concerns of citizens concern the re-use of plastic bags for kitchen waste and for pets.

However, citizens' objections vary widely. Small businesses feel more concerned and fear that these changes will have a negative impact on their sales or that plastic bag alternatives will be expensive. The plastics industry is generally opposed to bans. It mainly refers to the loss of employment and issues of bacterial contamination of reusable bags. (Chamard 2015)

Once the ban is in place, consumers turn to three types of bags: single-use paper bags, thick plastic bags, and reusable bags. When thick plastic bags are available, the consumer can more easily turn to these bags (Chamard, 2015), which do not necessarily meet the criteria for resistance and run counter to measures taken to reduce the use of plastic and conventional plastic bags. The loss of plastic bags for reuse as garbage bags is offset by the increase in sales of garbage bags and is generally thought to be offset by the decrease in the use of plastic bags. In the case of a no-fee ban, the consumer prefers paper bags, whereas in the case of a fee-based ban, the consumer prefers reusable bags.

These trends help to define the direct and indirect consequences of a ban on thin conventional plastic shopping bags in Quebec. The following section assesses the environmental consequences.

10.3 Main function and functional unit

Like the attribution-based LCA, the systems studied are evaluated on the basis of their main function: "to package for transport products purchased by individuals while shopping".

The large-shop scenario was selected for the consequential analysis. Given that between 75% and 80% of shopping bags are used for grocery purchases (RECYC-QUÉBEC, 2007; ÉEQ, 2016a), this scenario is considered more representative of all uses than the small- shop scenario. Its functional unit is formulated slightly differently to fit the context of a ban: "to pack for the transportation of 100L of products purchased by an individual when shopping in a municipality in Quebec in 2016 where certain types of shopping bags are banned".

The products selected to meet this function differ from the attribution analysis. They depend on the ban scenario studied. The latter corresponds to that adopted by the City of Montreal in August 2016, which prohibits plastic bags with a thickness of less than 50 microns, as well as oxodegradable, biodegradable and oxobiodegradable plastic bags of any thickness starting in 2018. In order to determine the consequences that may result, the following question must first be answered:"What are the changes in behaviour if the supply of banned plastic bags to the consumer is stopped? ». The next question is:"What are the changes in the production of goods if demand for such plastic bags decreases?"

Oxodegradable plastic and bioplastic bags made of starch and polyester are not considered in the consequential analysis, as the life cycle of the oxodegradable plastic bag is very similar to the conventional bag and the bioplastic bag is rare.

10.4 Development of consequence scenarios following a ban on single-use plastic bags

A major difference between attribution-based and consequential LCAs is the establishment of system boundaries. Although the same life cycle stages are included, the consequential approach considers only those production technologies affected by change, also known as marginal technologies. A marginal technology is that which would ensure the production of additional demand for a product, or conversely, which would no longer be used following a decrease in demand for a product.

The most obvious consequence of a ban on plastic bags is that they are not available to the consumer. First, if they are no longer in circulation, a portion of them no longer find their way into the environment. In addition, since consumers can no longer carry their purchases with these bags, they can no longer use them as a substitute for PE garbage bags. Consumers then have to buy more PE garbage bags, which would result in an increase in the production of garbage bags.

Without banned plastic bags, consumers face a choice where they have to:

- Shop at other businesses where the ban of such bags is not in force, which increases the amount of energy consumed (electricity, fuel, food) to make such purchases;
- Use an alternative bag to carry their shopping.

The first situation does not seem to have materialized in Brossard Quebec, according to the officials of the City of Brossard, as consumers just traded up to thicker plastic bags. (Fournier, 2016):

In the second situation, consumers can choose to substitute from a number of alternatives that could or could not be offered following a ban on conventional thin plastic shopping bags. The alternatives considered are

- Thick plastic bag (LDPE, 50 microns, with cut-out handles)
- Paper bag (recycled unbleached kraft paper)
- Woven PP bag
- Non woven PP bag
- Cotton bag
- Bagless purchase

Other alternatives were observed in Brossard, but were not evaluated in this study.
Warning: the previous working hypothesis outlined above is based on very limited information about the consequences of banning single-use plastic bags in Quebec. This analysis is based on a very small sample, and will not necessarily be representative of the consequences of a ban across the province or in other jurisdictions.

As specified in the literature review, the City of Portland reported a 304% increase in the use of reusable bags and a 491% increase in paper bags one year after the ban. As for the City of Brossard, it reported an increase in the supply of bags by retailers: 33% offer paper bags, 18% of thick plastic bags conforming to the by-law, 19% reusable bags, while 22% no longer offer bags (Rabeau and Arteau, 2016). As cotton bags were not significantly offered by retailers in both Portland and Brossard following a ban on (thin) single-use plastic shopping bags, this alternative was not considered in this consequential LCA. Each of the remaining options is therefore evaluated as a potential alternative.

What happens then with plastic that is no longer used to produce banned plastic bags? Two different possibilities were considered.

The first alternative, which could be described as a better case, assumes that a ban would lead to a reduction in the production of plastic. The material used to manufacture banned bags would simply no longer be produced and would not be used to make other plastic products. In such a case, the entire life cycle of the banned plastic bag (including abandonment in the environment and avoidance of garbage bags) is affected by a negative sign indicating that it would no longer occur following a ban, conversely the complete life cycle of replacement bags is affected by a positive sign as their consumption will increase. This scenario is illustrated in Figure 10-1.

Figure 10-1: Best Case Scenario: Decreased plastic production.

In the second worst case scenario considered, the plastic used to make banned bags is still produced and used to make other plastic products. In this worst case scenario, garbage bags ar e excluded from these "other plastic products" (otherwise, the plastic made available would b e used to make the garbage bags purchased as a result of a ban, which would reduce the amou nt of extra plastic to be produced). Then, for the purposes of the worst case analysis, it is postulated that these "other plastic products" are manufactured according to identical processes, are then distributed and used in Quebec, and have the same recovery rate as the banned plastic bag. The latter will be assessed in a sensitivity analysis. Finally, new plastic products are considered not to be reused at the end of their useful life as garbage bags or discarded in the environment. So in the end, following the ban, the result of this scenario is: more replacement bags, fewer banned bags and more other plastic products made with the same amount of plastic as the banned bags. Since the life cycles of banned bags and new plastic products are almost identical, the only difference between the two is: less abandonment in the environment and more garbage bags. This scenario is illustrated in Figure 10-2.

For the consequential analysis, the number of uses for reusable bags was set at 50. This value is based on SAQ statistics, which estimate that less than 2% of transactions include the purchase of a reusable bag. Considering that this data is of primary importance for reusable bags, two other use scenarios were evaluated: 1 and 100 uses.

Figure 10-2: Worst-case scenario: Re-appropriation of plastic production for other purposes.

10.5 Processing Secondary Functions

Like the attribution approach, the consequential approach takes secondary functions into account. Only the secondary function of recycling plastic bags into garbage bags is considered in this component. As a ban on conventional plastic bags deprives users of this source of bags to use for household garbage, additional production of conventional garbage bags has been included within the system's boundaries, as illustrated in the previous section.

10.6 Sources, Assumptions and Life Cycle Inventory Data

The data collection provisions and key assumptions for the attribution stream of this study presented in Section 3.7 are applicable to this stream.

10.7 Environmental Impact Assessment (EIA)

The environmental indicators used for this component are the same as for the attribution-based LCA (see section 3.7.1).

10.8 Interpretation

The reader is referred to Component I for the following elements of the attribution-based LCA interpretation which is applicable to consequential analysis and looks at:

- Evaluation of data quality;
- Analysis of coherence and completeness;
- Uncertainty analyses.

In addition, the following section provides sensitivity analyses on the number of uses, as well as the recovery rate of the "new" plastic product from the worst-case scenario.

11 Consequential Results and Discussion

Figures 11-1 to 11-4 present the results of the consequential analysis for Human Health, Ecosystem Quality, Fossil Resource Utilization and Abandonment in the Environment indicators, respectively.

The indicator results presented are the result of the following calculations:

Best case: Ban conventional plastic bags and increase garbage bags.

$$\text{Result} \quad \frac{1}{nb.use} \times \text{Replacement bag life cycle}$$
$$-.Life.cycle.of.banned.bags$$
$$+.Production.of.PE.garbage.bags$$

Worst case: Ban conventional plastic bags, increase garbage bags and reuse plastic in other plastic objects.

$$\text{Result} = \frac{1}{nb.use} \times \text{Replacement bag life cycle}$$
$$-Life.cycle.of.banned.bags$$
$$+Production\ of\ PE\ garbage\ bags$$
$$+Life\ cycle\ of\ plastic\ products$$

Therefore, on these graphs, a negative indicator result means that the ban results in fewer potential environmental impacts. A positive indicator result means that ban generates more potential impacts. A value of 0 indicates an equivalence: there is no advantage or disadvantage to a ban.

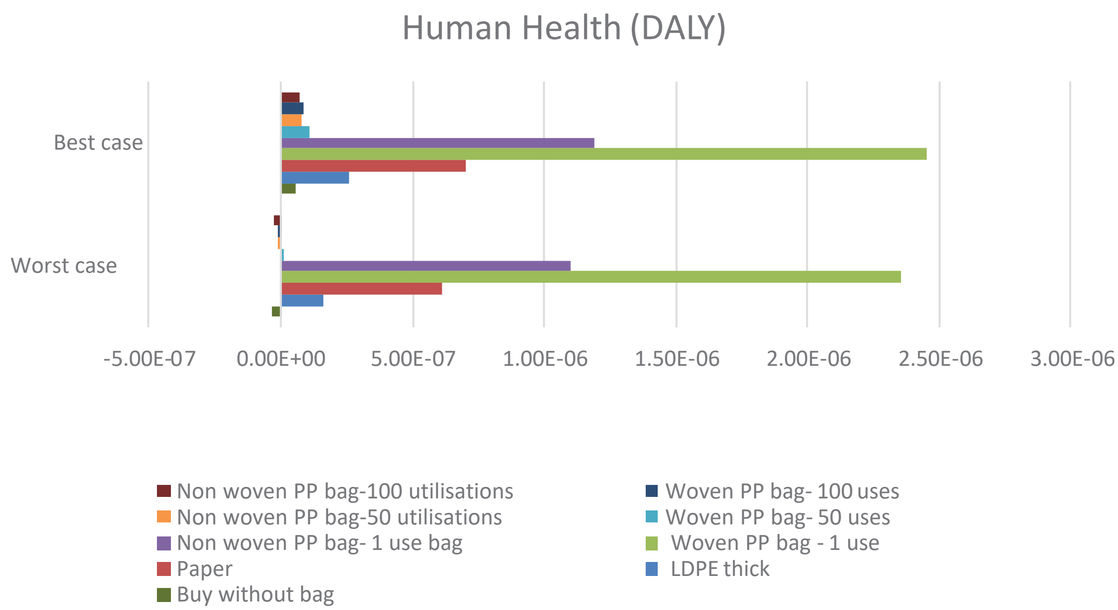

Figure 11-1: Result of consequential LCA, Human Health

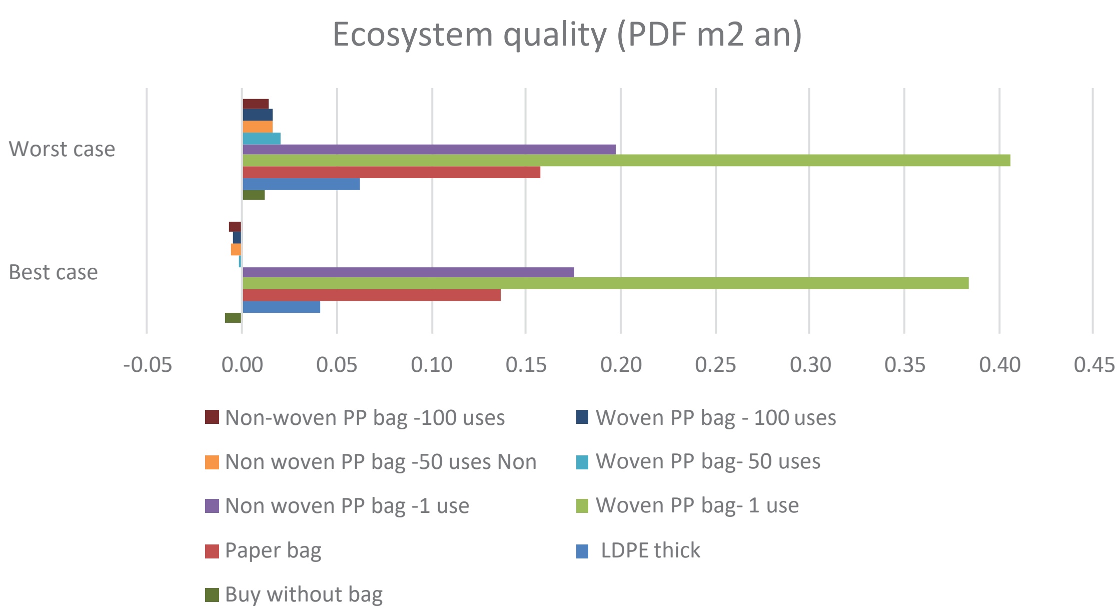

Figure 11-2: Consequential LCA result, Ecosystem Quality

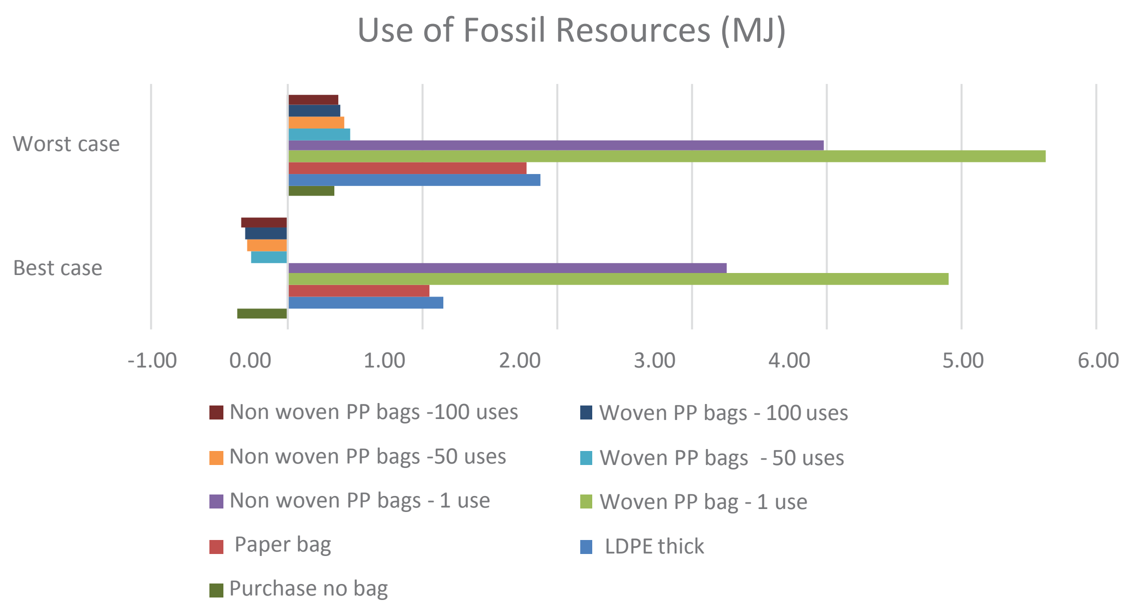

Figure 11-3: Consequential LCA result, Fossil Resource Utilization.

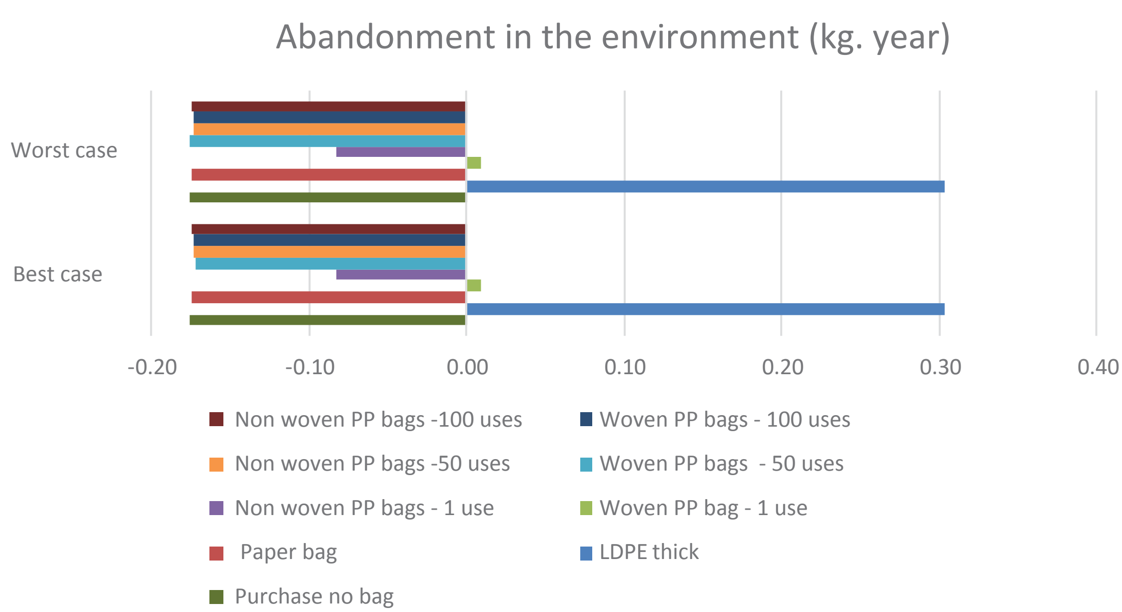

Figure 11-4: Consequential LCA result, Abandonment in the environment

The results show that for Human Health, Ecosystem Quality and the Use of Fossil Resources:

- For the best case scenario ::
    - The reusable bags of woven and non-woven PP are an advantageous substitution, the more bags are used. The 100-use scenario is preferable to the 50-use scenario. However, one use of these bags alone is not sufficient to replace the banned bag. Equivalence would be achieved, depending on the indicators considered, between 14 and 67 uses for the woven PP bag and between 10 and 32 uses for the non-woven PP bag.
    - Bagless shopping is also an advantage over banned plastic bags.
- For the worst-case scenario :
    - No replacement option following the ban on plastic bags offers an environmental benefit
    - Although shopping without bags or using reusable bags at a high level of reuse (more than 50 uses) would be unfavourable options following a ban on conventional plastic bags, these are the options with the lowest consequences.
    - For this scenario, an infinite number of bag uses would push the reusable bag life cycle impacts to zero. However, since the released plastic is still being used for other purposes, there would be no environmental credit as a result of the ban.
    - Banning could be favourable only by changing certain analytical assumptions :
        - It is possible that the other plastic products may have a higher recovery rate than the banned plastic bag considering that the banned bag has one of the lowest recovery rates of all plastics according to Residential Residual Materials Characterization 2012-2013 (QEC and RECYC-QUÉBEC, 2015).
        - The variation in the recovery rate of the other plastic products relative to that of the banned bag required to ensure that the ban scenario is not harmful is presented in Table 11-1.
        - Under these conditions, bagless purchases as well as reusable PP woven and non-woven PP bags with more than 50 uses are most likely to make the ban scenario preferable. Indeed, it would be sufficient to recycle this new plastic product at a rate of more than 20% (in addition to the recycling rate of the conventional plastic bag under consideration) to make the systems equivalent. At this stage, however, it is impossible to characterize this probability because the "other plastic product" could not be identified, so it is impossible to determine if the product is actually more (or less) recycled than conventional plastic bags.

Table 11-1: Variations in the recovery rate of the other plastic product compared to conventional plastic bag for a beneficial ban in the worst-case

	No bag	Thick plastic	Paper	PP bag			Non PP bags		
Nb util.	1	1	1	1	50	100	1	50	100
Human health	> 100 %	> 100 %	> 100 %	> 100 %	70.2%	26.9%	> 100 %	53.0%	22.8%
Quality of ecosystems	> 100 %	> 100 %	> 100 %	> 100 %	58.1%	23.1%	> 100 %	45.6%	20.2%
Fossil resources	> 100 %	> 100 %	> 100 %	> 100 %	29.4%	12.8%	> 100 %	26.9%	12.3%

For Abandonment in the environment:

- There is no difference between the best case and worst-case scenarios, since the consequences of the ban on abandonment in the environment are the same.
- Since conventional plastic bags are considered to be more often abandoned in the environment than other plastic products, the ban is favourable for most of the alternatives evaluated.
- With the exception of the thick plastic bag and reusable bags used only once, all other bags tend towards the same indicator result.
- The only option that would prove unfavourable following a ban is the thick plastic bag, unless it is considered to be a reusable bag. In this case, the thick plastic bag should be reused at least three times.
- The woven PP bag used only once would also prove unfavourable after banning if it were used only once (equivalence: 1.05 use).

12 Conclusion of the consequential ELCA

Based on the hypotheses and data considered, the results of the consequential part of the LCA indicate an improvement in the issue of abandonment in the environment following a ban on conventional plastic bags and without pricing of non-banned disposable options, since there would be fewer abandoned bags in most of the cases studied.

However, it is unclear whether this ban would lead to improvements in other indicators, such as human health, ecosystem quality and the use of fossil resources. This situation arises because it is difficult to assess the likelihood of occurrence of a scenario for the production of plastic products following a ban on conventional plastic bags. Two cases had to be evaluated representing a worse and a better case.

- In the best case, plastic no longer used to make banned bags is not used to make other plastic products, resulting in a reduction in the production of hydrocarbons that were used to make these bags. Under these conditions, several positive alternatives exist, the most efficient being the non-woven PP bag with a large number of uses (equivalent to 32 uses). Single-use bags (including reusable bags used only once) are not a favourable alternative to these indicators.
- In the worst case scenario, this plastic is used to make other plastic products, so its life cycle is added to the replacement bag (thick plastic bag, paper, woven PP or non-woven PP), as well as to the additional garbage bags that consumers will have to use for lack of conventional plastic bags banned. As a result, no alternative option leads to an improvement in the indicators evaluated. In this context, banning would not be advantageous. However, if the other plastic product has a higher recovery rate than that considered for conventional banned plastic bags, it may be possible that banning is a favourable option for reusable bags (50 uses or more) or for bagless purchases.

Since no probability of occurrence of the scenarios has been estimated, the consequential analysis is not able to definitively conclude on the absolute justification of banning conventional plastic bags without pricing the disposable options not banned according to the various indicators evaluated. The pricing of disposable options not covered by the ban has not been evaluated in this study, and are not part of the legislative tools currently provided to Quebec municipalities. However, it would help to reduce the harmful effects of a ban by discouraging the use of non-banned disposable bags, which are problematic according to the results, and encourage the use of reusable bags.

13 General conclusions

As part of this study, various reusable disposable shopping bags were compared in a Quebec context with respect to their potential impacts on the environment and their life cycle costs.

Conventional plastic bags have several environmental and economic advantages. Because of its thinness and lightness, being designed for a single use, its life cycle requires little material and energy. In addition, it avoids the production of garbage bags since it is commonly used for this function as well. Most environmental indicators and life cycle costs are low compared to disposable thick plastic bags[7], paper or bioplastic starch-polyester-type disposable bags.

The weak point of this type of bag is its abandonment in the environment. The non-biodegradability of the bag's polyethylene composition makes this bag a bad choice for litter with a score of 425 and 537 times, and 277 to 388 times for the Abandonment in the Environment indicator. However, this indicator does not assess the consequences of this abandonment, but represents the mass of the abandoned bag multiplied by the period of persistence of the material in years. *Further scientific research is needed to determine whether it is worse to abandon plastic in the environment than to emit other pollutants during the life cycle of the biosourced disposable bags studied (e. g. GHG emissions).*

The oxodegradable bag, on the other hand, would not offer significant environmental or economic benefits compared to its non-degradable equivalent, since its life cycle is almost identical. As for its so-called biodegradability benefits, its accelerated fragmentation into polyethylene particles makes it invisible to the naked eye, but these particles are also persistent in the environment for a long time, are more likely to integrate easily into the food chain, and eventually cause increased, albeit partially identified, effects.

For reusable bags, they are sturdier than disposable bags, but their manufacture generates more impact and is more expensive. They have the potential to offer the lowest environmental indicator results provided they reach the equivalent numbers of uses obtained (50+ uses). However, it was not possible to determine whether these numbers are realistic in the Quebec context. The values obtained vary greatly from one type of bag to another. Among the most commonly used reusable bags, PP woven and PP non-woven bags require 16 to 98 and 11 to 59 uses, respectively, so that their potential impacts are equivalent to conventional plastic bags, depending on the indicator and shopping scenario. The cotton bag studied requires much more, from 100 to 3,657 uses. Like bio-sourced disposable bags, cotton bags score on the Abandonment indicator in the environment lower than conventional plastic bags, between 599 and 741 times lower, but more work is needed to determine the magnitude of this benefit on the Human Health and Ecosystem Quality indicators.

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[7] If the thick plastic bag is considered to be a reusable bag, it must be used four to six times; as well as three times when shopping if the thick plastic bag is to match the environmental impacts and life cycle cost of a conventional plastic bag, respectively.

Regarding the costs of reusable bags, they must be used 7 to 88 times to be less expensive, depending on the type and scenario of shopping than the conventional plastic bag. Reusable bags are never cheaper in any scenario. The consumer savings achieved by reusing conventional plastic bags as garbage bags outweigh the life-cycle costs of the conventional plastic bag.

Finally, with regard to the banning of conventional plastic bags without charging for disposable options that are not banned, this would generally reduce abandonment in the environment. However, the results showed that for the other three environmental indicators, the benefits of a bag ban depended not only on the replacement bag and its number of uses, but also on the impact on the plastics industry, i. e. the extent to which the plastic used to manufacture the banned bags continued to be produced for other purposes. Pricing of disposable options not covered by the ban would help to reduce these undesirable effects and should be studied.

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APPENDIX

	English	French
A **Life Cycle Assessment (LCA) Methodology**	Click here	
B **UI* Mathematical Expressions**	Click here	Included in French LCA Report
C **Data and Assumptions**	Available in French Only	Click here
D **Evaluation of the Quality of Inventory Data**	Click here	Included in French LCA Report
E **Gross Results**	Available in French Only	Click here
F **Critical Review Report**	Available in French Only	Click Here Click here
G **Stakeholder Comments**	Available in French Only	Click here
H **ELCA of an Eco-Designed Shopping Bag**	Click here	Included in French LCA Report
I **Critical Review Report on the Eco-Designed Bag**	Available in French Only	Click here Click here

ADDENDA

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NORTH AMERICAN LITTER DATA

April 20, 2017

Summary of Litter Audits

Dear Mr. Hruska

Enclosed is our summary report on litter audits that our company has conducted over the past 15 years.

Our firm has developed a statistically rigorous methodology of auditing large and small litter items. This was done after working with one of North America's leading pioneers of litter audit, Mr. Dan Syrek, from

California. Mr. Syreks' methodology was deemed to be the "gold standard" of litter auditing in the 1990's; but it was very complicated and difficult to explain to clients.

MGM Management revised the litter auditing methodology to be less complicated. Our methodology was peer reviewed as statistically acceptable during a legal action in California some years ago.

CPIA asked us to:

- List the studies MGM Management has done in Canada & the USA
- Comment on how these studies quantify the retail bag litter rates
- Discuss key litter audits done in Canada
- Discuss our methodology to indicate it is statistically valid

Our analysis shows that during the 44 litter audits that our firm has conducted plastic retail bag litter represents 0.4% of the total large litter observed.

Mark McKenney
President

Litter Audits in Canada & USA

MGM Management has conducted 489 litter audits, since 1990 to the present time: These include, major and medium sized Canadian cities, Regional Municipalities, and municipalities the USA.

All the litter audits we have completed have been conducted using the same methodology, so that the results are comparable between different years, and comparable from one municipality to another.

The major cities audited for litter in Canada include:
• City or Toronto (1990, 1994, 2002, 2003, 2004, 2005, 2006)
• Regional Municipality of Peel (2003)
• Regional Municipality of York (2003)
• Regional Municipality of Durham (2003)
• City of Edmonton (2009, 2010, 2011, 2012, 2013, 2014, 2015)
• City of Winnipeg (2010, 2012, 2014, 2014, 2015)
• City of Brandon (2010, 2012, 2014, 2014, 2015)
• Regional Municipality of Wood Buffalo (2015) (Ft. MacMurray

The major cities audited for litter in the USA include:
• City of San Francisco (USA) - Streets Litter Audit (2007, 2008, & 2009)
• City of San Jose (USA) – Streets Litter Audit 2008 (August 2008)

Using the same methods, has allowed us to assemble a substantial data base of large litter observations. In total, we have documented nearly 103,000 large litter data observations from the cumulative data. We believe this is the largest litter data set currently available in Canada.

NORTH AMERICAN LITTER DATA (cont'd)

Of this bag litter plastic retail bags account for 431 bag litter observations, or 0.04% of total large litter observed. The table below illustrates the observations of plastic retail bags for all audits conducted since 2002.

Plastic Retail Bag Litter - MGM Management Audits - 2002 - 2016							
	1990's	2002	2003	2003	2003	2004	2004
	Ontario Litter (no data)	Toronto	York Region	Peel Region	Durham Region	Toronto	Toronto Parks
Total litter counted		6,304	8,678	4,362	5,698	5,265	5,551
Plastic retail bags	0	38	34	3	6	11	43
% plastic retail bags		0.6%	0.4%	0.1%	0.1%	0.2%	0.8%
	2005	2006	2007	2007	2007	2008	2008
	Toronto	Toronto	San Francisco	RCO Charact.	Edmonton Streets	San Francisco	San Jose
	6,309	4,323	3,813	1,391	2,650	3,973	3,928
Plastic retail bags	17	5	23	28	10	25	17
% plastic retail bags	0.3%	0.1%	0.6%	2.0%	0.4%	0.6%	0.4%
	2009	2009	2009	2010	2010	2010	2011
	San Francisco	Edmonton	Alberta Highways	Edmonton	Winnipeg	Brandon	Edmonton
	4,488	3,361	3,407	2,378	2,300	1,260	2,134
Plastic retail bags	69	9	2	12.5	10.5	6	23.5
% plastic retail bags	1.5%	0.3%	0.1%	0.5%	0.5%	0.5%	1.1%
	2012	2012	2012	2013	2013	2013	2013
	Edmonton	Winnipeg	Brandon	Winnipeg	Brandon	Steinbach	Edmonton
Total litter counted	1,933	1,922	996	1,442	842	185	1,957
Plastic retail bags	5.5	3	3.5	5.5	3	1.5	6.5
% plastic retail bags	0.3%	0.2%	0.4%	0.4%	0.4%	0.8%	0.3%
	2014	2014	2014	2014	2014	2014	2015
	Winnipeg	Brandon	Steinbach	Flin Flon	Thompson	Edmonton	Ft. McMurray
Total litter counted	1,400	731	121	303	514	1,895	1,855
Plastic retail bags	3	2		1		1	2.5
% plastic retail bags	0.2%	0.3%	0.0%	0.3%	0.0%	0.1%	0.1%
	2015	2015	2015	2015	2015	2016	2016
	Brandon	Flin Flon	Thompson	Winnipeg	Steinbach	Steinbach	Winnipeg
Total litter counted	732	296	469	1,221	96	116	1,189
Plastic retail bags	2.0	1.5	1.0	2.0	0.0	0.0	3.5
% plastic retail bags	0.3%	0.5%	0.2%	0.2%	0.0%	0.0%	0.3%
	2016	2016	2016				
	Brandon	Flin Flon	Thompson				
Total litter counted	502	244	420				
Plastic retail bags	3.0	0.0	1.0				
% plastic retail bags	0.6%	0.0%	0.2%				
Total plastic retail bags:	431	% plastic retail bags		0.4%	Total large litter		102,951

Page 96 – SAQ Reusable Bag Sales
"The SAQ in Quebec completely removed single-use bags (plastic and paper) in 2009, and encourages customers to bring reusable bags. It estimates that this measure avoids the use of 80 million single-use bags (SAQ, 2016b). The Crown Corporation has seen no impact on sales, but then it is in a monopoly situation."

Rebuttal: While the measure avoids the use of 80 million single-use bags, it has little impact on reducing the sale of reusable bag sales according to SAQ data from a Freedom of Information Request. According to the SAQ: In 2012-2013, the SAQ sold 2,324,184 reusable bags; followed by the sale of an additional 2,097,438 reusable bags in 2013-2014; and the following year, in 2014 -2015, SAQ sold 2,075,438 reusable bags. (FOI Request).