Bryant University

HONORS THESIS

A Life Cycle Assessment Comparing End of Life Treatment for Paper and Plastic Bags

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ABSTRACT

This research focuses on the effects paper, plastic, and textile grocery bags have on our environment. This project aims to answer two questions: Based on an LCA approach of the disposal stage, which is better for the environment: plastic or paper? Which type of grocery bag, paper or plastic has a higher sustainability potential based on end of life data? LCA software and assessment tools identified the risks paper, plastic, and textile waste has on the environment in the disposal stage. OpenLCA was used as a platform to compile the life cycle data. To obtain the data needed, the European reference Life Cycle Database (ELCD) was used for raw data collection while the ReCiPie – Endpoint HA impact assessment method was used to analyze the results. The results indicate that despite common beliefs and the original hypothesis that stated paper and textile bags were better for the environment, paper, plastic, and textile waste have very similar impacts on the environment when disposed in a landfill. However, this analysis only looks at the disposal stage of these products. Therefore, these same conclusions about the effects each product have on the environment throughout their entire life cycle (e.g. during raw material extraction, production, and transportation stages) may not hold true.

INTRODUCTION

Plastic pollution has filled coastlines, landfills, and oceans for decades. It is found that approximately 100 billion plastic bags are used in the United States every year (Penn State). Over the last decade, government regulation, individual businesses, and conscientious shoppers have made the decision to stop using plastic bags due to their perceived impact on the environment; and instead, have switched to paper or reusable bags to carry goods. However, the question often arises what type of bag is better for the environment? The question of paper or plastic echoes in every checkout lane, as customers are forced to make a choice every day.

Although it may seem paper bags are better for the environment than plastic, a deeper analysis of each product is necessary due to the complex production and degradation process. It is known that plastic is a persistent material. That is, it does not break down easily due to its stable chemical structure which is created with the use of nonrenewable resources such as crude oil or other fossil fuels. Plastics do not easily break down by biodegradation. It takes up to 450 years for plastic in a landfill to break down by physical and chemical means. However, paper bags often include harsh chemicals that were added during the production stage which can leach into water and topsoil as they degrade after being thrown out. In addition, paper bags require millions of trees to be cut down to produce the product and high emissions are released into the atmosphere during production.

In addition to literature research, a Life Cycle Assessment and Environmental Impact Assessment will be conducted to aid in the comparison. An in depth analysis will provide evidence on which products have a higher sustainability potential and are more ecologically friendly when looking specifically at the disposal stage of their life cycles. Although there are similar studies, databases continuously add new information every year therefore, more current analysis was needed. To conclude, this thesis will look at two main questions: Based on an LCA approach of the disposal stage, which is better for the environment: plastic or paper? Which type of grocery bag, paper or plastic has a higher sustainability potential based on end of life data?

LITERATURE REVIEW

Paper or Plastic Debate

In 2013 a large debate emerged comparing paper and plastic grocery bags. The debate highlighted the positive and negative aspects on plastic bags and began to shift the focus of conscientious shoppers and researchers. Research shows that once plastic bags are disposed "this process can release toxins that contaminate soil and water, stunt plant growth, and make water undrinkable" (Should Plastic Bags Be Banned, 2018). Even though plastic bags can be recycled, PEW Research Center reports that only 13.5% of plastic bags were recycled in 2013. Studies also show that the average bag is used for 12 minutes while the chemicals that come from the plastic bags live in oceans for thousands of years (Plastic Bag Bans All the Rage).

As more information on plastic bags has been exposed to the public, there seems to have been a shift in people's opinions regarding plastic bags. As years progress, more and more shoppers are opting to utilize kraft paper grocery bags instead of plastic. With research confirming the facts about plastic bag pollution on coastlines and in oceans, countries like the United States, Argentina, UK, India, Bangladesh, Kenya, and Australia have all set some sort of plastic bag ban on the industry to reduce the amount of waste. Today, many more countries have joined this initiative. Focusing on just the U.S, states like California and Hawaii have banned plastic bags all together while states like Delaware, Maine, Rhode Island, and New York have created mandatory recycling programs. Statistics show that over 10 states have placed preemptive bans on banning plastic bags as well (Plastic Bags All the Rage). However, despite conscientious consumer's efforts to switch to kraft paper bags, research shows that paper bags still negatively affect our environment.

Despite the evidence that plastic bags are hurting the environment and have an overall negative effect on our planet, there are still people who believe that banning plastic bags is not the answer. "Because they are light weight, plastic bags only constitute a tiny percentage of the overall waste stream (less than 1%), but they tend to be in the spotlight because they are an icon of modern convenience culture and lifestyles. Plastic bags are popular with consumers and retailers because of all the practical advantages they offer; they are light, cheap, strong, and a hygienic way to transport food and products home" (Rujnic-Sokele).

According to the debate "Should Plastic Bags be Banned", some believe that "if we ban plastic bags, many people will switch to using paper ones. But to manufacture those, we must cut down millions of trees. Research supporting their viewpoint has shown that paper bags have a higher carbon footprint than plastic ones because it takes more energy to produce and transport them (Should Plastic Bags Be Banned).

Life Cycle of Polyethylene

Polyethylene is the most popular plastic in the world and makes up most plastic bags and plastic materials. This plastic was discovered by Reginald Gibson and Eric Fawcett in the 1930s. It is created in two ways: modifying natural gas, either methane, ethane, propane mix, or from the process of catalytic cracking of crude oil into gasoline (Rujnic-Sokele, 2014). The flow chart in Figure 1 below shows the complete production cycle of polyethylene from natural gas and oil extraction to the production of plastic film. There are different variations of plastic that change in toughness, flexibility and resistance depending on what the plastic is used for. Plastics produced can range from various food packaging to shopping bags, overwraps, lamination, and more (Rujnic-Sokele 2014).

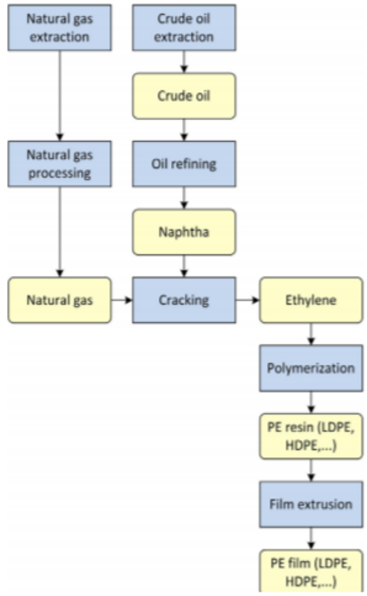

Figure 1

A flow chart displaying the production process of Polyethylene (Rujnic-Sokele, Maja, and Gordana Baric)

Eco-Impact of Plastic and Paper Shopping Bags

A Life Cycle Assessment titled "Eco-Impact of Plastic and Paper Shopping Bags" by Subramanian Senthilkannan Muthu published in 2012 was completed comparing paper and plastic bags. This study was examined to narrow the scope of this project, gain a better perspective on what information an LCA would provide, and what steps were necessary to complete the analysis.

The research works to discover which material is better for the environment based on guidelines such as ozone layer, land use, fossil fuels, climate change, etc. A life-cycle assessment (LCA) is a "tool which can help researchers to understand the environmental impact of a product from the acquisition of raw materials to final disposal" (Muthu, Subramanian Senthilkannan, 2012). The article begins with a general background about plastics. Plastic bags are made from non-renewable fossil fuel sources. The main sources to produce these bags are petroleum and natural gas, with the most popular form of plastic being made from polyethylene. As stated before, polyethylene is one of the most common materials used to produce plastic grocery bags specifically due to its ideal thickness and glossy finish. However, the bags often cause lots of plastic waste considering they are disposed quickly after their single use mission (Rujnic-Sokele, 2014).

According to the 2012 study by Muthu, the Environmental Protection Agency in Hong Kong reported that about 8 billion bags are disposed of every year. Similar statistics match what China and India are witnessing, and it was found that China could save up to 3 million metric tons of crude oil every year and cut 7.6 million metric tons of carbon dioxide emissions every year if limitations were introduced (Muthu Subramanian Senthilkannan, 2012). It is estimated that 100 billion to 1 trillion plastic bags are produced each year worldwide (Muthu, Subramanian Senthilkannan, 2012).

On the other hand, to produce paper bags in the quantity that is demanded, it is found that an estimated 4 billion trees, almost 35% of total trees around the world would need to be cut down to produce enough bags for the world. As of 2012 Americans use about 10 billion paper bags each year which totals about 400 per family (Penn State). To keep up with this demand, it is required to cut down approximately 14 million trees to produce 10 billion bags (Penn State). Both paper and plastic bags utilize enormous amounts of natural resources and it can only get worse if we were to look at current statistics, considering this data was released about 8 years ago. However, to gain a more accurate understanding, another analysis should be run to update the current published research.

The next step in Muthu's research was to conduct a Life Cycle Assessment, or LCA. There are 4 universal stages in an LCA and are as follows: 1) goal and scope; 2) inventory analysis; 3) impact assessment; 4) interpretation. Following these 4 phases allowed the team to conclude how each type of bag affected the environment. The study "Eco-Impact of Plastic and Paper Shopping Bags" completed in 2012 mentioned there was a hole in the research that had been complied on grocery bag research and the information that is published for the public to see.

EPA Waste Facts and Figures

To narrow the scope further, this project will be looking at just the effects plastic, paper, and textiles have on the environment after they are deposited into a landfill. Textile waste was taken into consideration to represent cloth reusable bags in a landfill once disposed. According to the EPA, the total generation of municipal solid waste (MSW) in 2018 was 292.4 million tons, 23.7 million tons more than the 2017 total. Although there was an approximate 30% recycling rate, high quantities of waste still end up in landfills. The EPA specifically defines "trash" as "as various items consumers throw away after they are used" (EPA). Figure 2 below shows a pie chart published by the EPA breaking down total MSW by percentage based on weight generated in 2018.

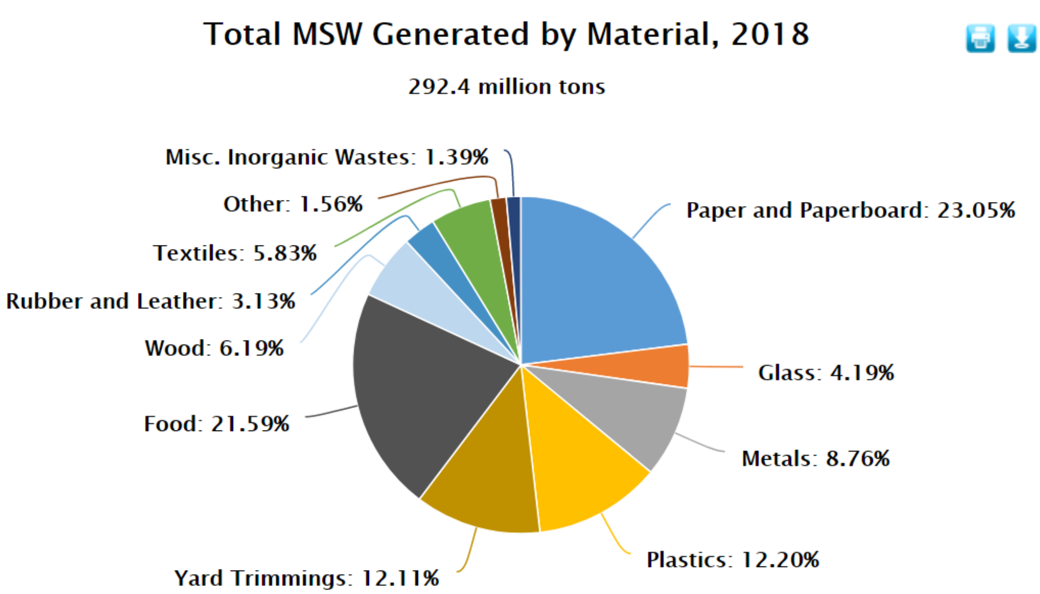

Figure 2

Total Municipal Solid Waste Reported for 2018 (U.S. Environmental Protection Agency)

After analyzing the graph, paper, and cardboard products, including paper bags, account for a total of 23.05% (wt.) of total MSW. Although paper and cardboard are recyclable, it should be noted that it does rank number one in disposable products. Plastic accounts for 12.02% (wt.) of total MSW and textiles come in third with 5.38% (wt.) of total MSW.

The graph in Figure 3 displays the overall tonnage of various waste categories over the time of 1960-2018. In general, all categories have increased in tonnage. However, plastic and textile waste have shown percentage growth while paper has remained steady in but just makes up a large portion of the waste stream throughout.

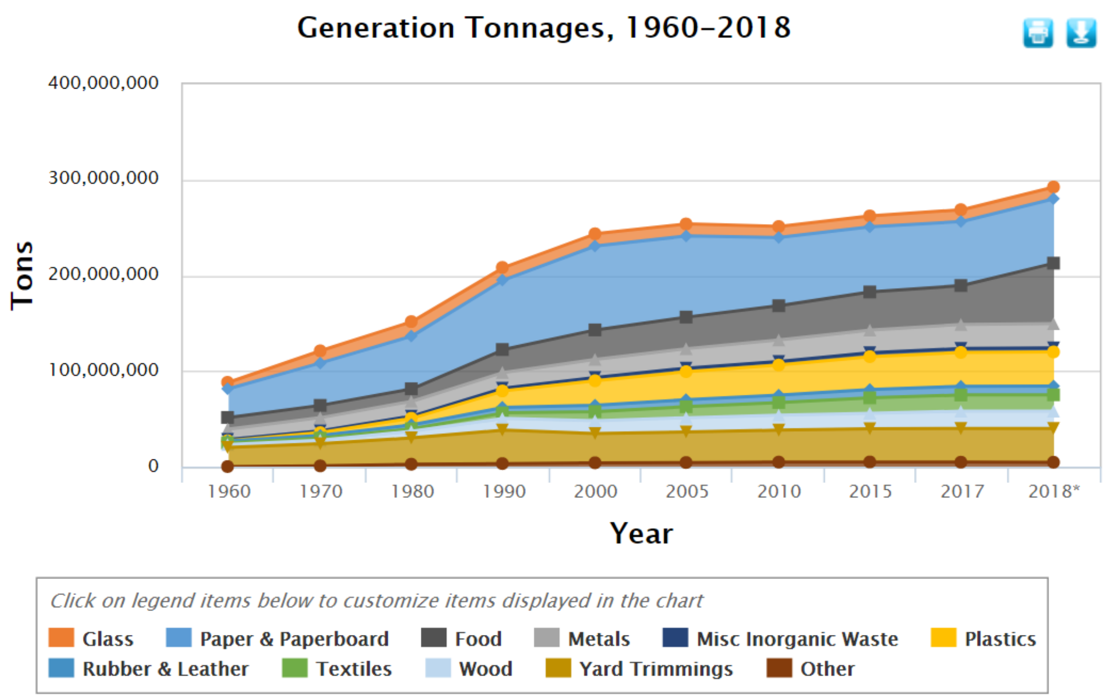

Figure 3

Overall tonnage of various waste categories from 1960-2018 (U.S. Environmental Protection Agency)

In addition to general waste data, the EPA highlights specific plastic waste data. According to the graph published by the EPA, plastic packaging, bags, and containers had the highest tonnage in the national waste stream at over 14.5 million tons in 2018 (EPA). “This category includes bags, sacks and wraps; other packaging; polyethylene terephthalate (PET) bottles and jars; high-density polyethylene (HDPE) natural bottles; and other containers” (EPA). A data table shown in Appendix A displays the total number of tons of plastic generated, recycled, composted, combusted, and landfilled from the years 1960 to 2018. As expected, the tonnage increased overtime as plastic production and single use product demand increase.

Life Cycle Assessment (LCA)

An LCA, is a factual analysis of a product's life cycle in terms of sustainability. It is an assessment that evaluates the impacts of a product (or service) from the beginning to the end of its life cycle. According to the standardized methodology, there are four main phases.

1. goal and scope
2. inventory analysis
3. impact assessment
4. interpretation

Often, an LCA assists individuals in deciding which product is the least impactful to the environment based on the product type, the process, and technology involved. ("Life Cycle Assessment: The Basics").

The first step in the assessment is establishing the goal and scope which focuses on the reason for completing the LCA and includes a description of the best way to deal with the situation or problem at hand. The second step in the assessment is the inventory analysis, which looks at the different environmental inputs and outputs associated with the product. The goal of this step is to identify what flows into the system and what flows out ("Life Cycle Assessment: The Basics"). Such inputs and outputs might include the use of the raw materials, emissions, various pollutants, and energy. The third step looks at the impact assessment where conclusions are evaluated and drawn in hopes to gain better business decisions. These impacts could then be shown through different themes such as global warming or health. The fourth and final step in the LCA is interpretation ("Life Cycle Assessment: The Basics"). During this stage, the conclusions formed during the previous stages can be evaluated and the results from the assessment can be shared.

The Product Life Cycle

Within a product life cycle, there are typically five phases: raw material extraction, manufacturing and processing, transportation, usage and retail, and finally waste disposal. This sequence of phases is often called "cradle to grave", meaning the assessment is all-encompassing, staring with the inception of the product and ending with the disposal of the product (Liebsch). When looking at the complete life cycle of a product there are different groupings of the phases, which can be configured to obtain a deeper understanding of the different stages of the product. Figure 2 below displays a diagram which compares the various phases side by side.

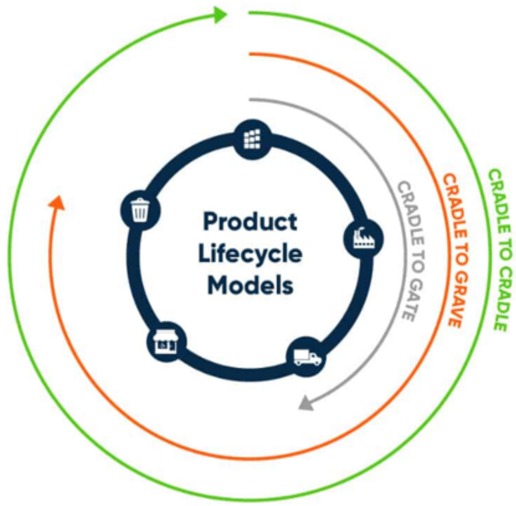

Figure 4

A diagram displaying the various phases in a Product Life Cycle (Liebsch)

LCA Limitations

Although Life Cycle Assessments provide key information in the assessment of a product, there are some limitations. The accuracy and dependability of the assessment depends on the availability of the data which can be difficult to collect or can be dated. In addition to data limitations, an LCA does not consider the cost of the product so an LCA should be combined with a cost analysis and evaluation to gain a better understanding if the product under consideration is a logical solution ("Life Cycle Assessment: The Basics").

Environmental Impact Assessment

In addition to a Life Cycle Assessment (LCA), another assessment tool called an Environmental Impact Assessment (EIA) can be used to determine more information about how a certain product impacts the environment. This additional step provides information to properly address our research questions and does not appear to be a part of LCAs conducted in the past, according to the literature search. According to the Convention on Biological Diversity, an EIA, is a process of evaluating the likely environmental impacts of a proposed project.

The fundamental components if an EIA are as follows:

1. screening
2. scoping
3. assessment and evaluation of impacts and development of alternatives
4. reporting the Environmental Impact Statement (EIS) or EIA report
5. reviewing the impact statement
6. decision making
7. monitoring compliance and enforcement

The screening process will determine what objects or materials require an impact assessment. Then, throughout the stages it is determined what impacts the product has on our environment. ("What is an Impact Assessment").

GOALS AND SCOPE

Goal:

The goals of this project are 1) determine the environmental impact for each product in the disposal stage, 2) determine the sustainability potential by looking at sustainability opportunities, and 3) compare the products to determine which product impact the environment less. The significance of this project is to address the debate regarding which grocery bag, paper, or plastic, impacts the environment less. In general, there is a stigma that paper grocery bags have a higher sustainability potential.

Scope:

A traditional Life Cycle Assessment takes multiple processes into consideration. However, to narrow the scope of this project the software will only look at the plastic and paper bags in their disposal stage once the products enter a landfill. Although an LCA can look at the entire life cycle of a product, cradle to grave, only one section will be examined due to time constraints and availability of data. The depth of this analysis relies heavily on the number of subprocesses, and number of flows entered in the life cycle calculation. However, the number of flows entered in the calculation will only be factors that provide a serious contribution to the life cycle impact.

Relevance:

The application of this project's findings may be useful to a variety of professionals. Policy makers and local governments can use this information to assess current business practices and establish various policies and regulations regarding plastic and paper bag consumption. In addition, corporations and conscientious customers can use this information to make private decisions regarding which bags to use in retail spaces. Although life cycle assessments of grocery bags have already been conducted, the findings here can fill gaps in the existing research or provide individuals with an up to date analysis.

METHODOLOGY

Life Cycle Assessment

To complete this research project a Life Cycle Assessment, or LCA, will be used to compare plastic bags to paper bags to determine their impact on the environment and sustainability potential. An LCA is an established process which can evaluate the environmental impacts of a product. As stated earlier, there are four main stages in an LCA: goal and scope, inventory analysis, impact assessment, and interpretation. ("Life Cycle Assessment: The Basics").

The first stage in an LCA is to determine the goal and scope of the project. This stage focuses on the reason for completing the research, the boundaries, and establishes what the research will focus on. The second stage in an LCA is considered inventory analysis. This stage looks at the various inputs and outputs for each product which can later be used to analyze the effects each product has on the environment ("Life Cycle Assessment: The Basics"). Examples of various inputs and outputs include but are not limited to raw materials, emissions, pollutants, chemicals, and energy. The third stage in an LCA considers the impact assessment where conclusions can be made about the product ("Life Cycle Assessment: The Basics"). The assessment looks at various categories such as human health impacts, marine and freshwater eutrophication, climate change, and ozone depletion. Through the program, this research will be able to complete a side by side comparison between plastic and paper grocery bags to see which product performs better throughout the various categories. The fourth and final stage in an LCA is interpretation where conclusions are formed from the previous stages and results from the assessment can be published ("Life Cycle Assessment: The Basics").

In addition to an LCA, an Environmental Impact Assessment (EIA) method will also be conducted. This process evaluates likely environmental impacts that would take place during each project or development ("What is an Impact Assessment"). This research will be looking at plastic and paper bags in their disposal stage, meaning the products will be assessed on degradation processes and their effects on the environment at that stage of life.

Data Collection

Due to a lack of public information regarding paper and plastic bag production and raw material use, the data for this project was supplied with databases available to import into the OpenLCA platform. The eligible databases considered were all free of charge due to the financial restrictions of this project. For this project, elcd_3_2_greendelta_v2_18 database was used provided by the European reference Life Cycle Database (ELCD) to analyze paper, plastic, and textile landfill waste. Since the creation of the database, ELCD has uploaded data from EU-level business associations and other sources regarding energy carriers, waste management and transport (OpenLCA). In addition to these products, metal and glass end of life data will be added to the analysis to show contrast in results.

<u>Life Cycle Impact Assessment</u>

A Life Cycle Impact Assessment, or LCIA is a method for transforming the inventory data into condensed sets of potential impacts. The LCIA Method utilized to analyze the impact categories in this project was ReCiPie Midpoint – (H), while ReCiPie – Endpoint (H-A) for damage categories by subtotal and total points.
Paper, plastic, and textile products were looked upon individually to decipher the top impact categories to determine the environmental impact for each product. Impact categories include but are not limited to natural land transformation, ozone depletion, human toxicology, climate change, and fossil depletion. Once landfill plastic, paper, and textile were looked at individually, all products were entered into a report where a side by side comparison can be conducted.

Within this method, ReCiPie will determine the various indicators at two different levels. After comparing various methods ReCiPie midpoint includes the most impact categories within its impact assessment method. ReCiPie endpoint is used to make comparisons using normalized points for damage categories and total point indexes. After the products were selected from the database each product was turned into a product system which could then be analyzed for their top impact category results. Paper, plastic, and textile products were looked upon individually to decipher the top impact categories to determine the environmental impact for each product. Impact categories include but are not limited to natural land transformation, ozone depletion, human toxicology, climate change, and fossil depletion. Once landfill plastic, paper, and textile were looked at individually, all products were entered into a report where a side by side comparison can be conducted.

It should also be noted that each method includes factors based on cultural perspectives. The individualist (I) perspective looks at products short term and has an overall optimistic look upon technology and its ability to avoid problems. The hierarchical (H) perspective is often encountered in scientific models as it is considered the default model. Finally, there is the egalitarian perspective which looks at situations long term. This project will be using the hierarchical model, therefore the LCIA methods used are ReCiPie –Midpoint (H) and Endpoint (H-A).

Inventory Analysis

Figure 5 below is a municipal landfill site flow chart which displays inputs and outputs within the system boundaries. It should be noted that although this project looks at three different products in their disposal stage, the software provided the same municipal landfill site flow chart for all products being examined even though the input and output amounts are different. Here, we can see various inputs that are entered into the landfill body as well as the leachate treatment and landfill gas collection which are converted into sludge treatment, waste fill deposit, and power, respectively. In addition to the broad flowchart displayed above, the LCA software looks at the inputs and outputs for each product individually to gain a better understanding of the specific impact paper, plastic, and cloth have on the environment.

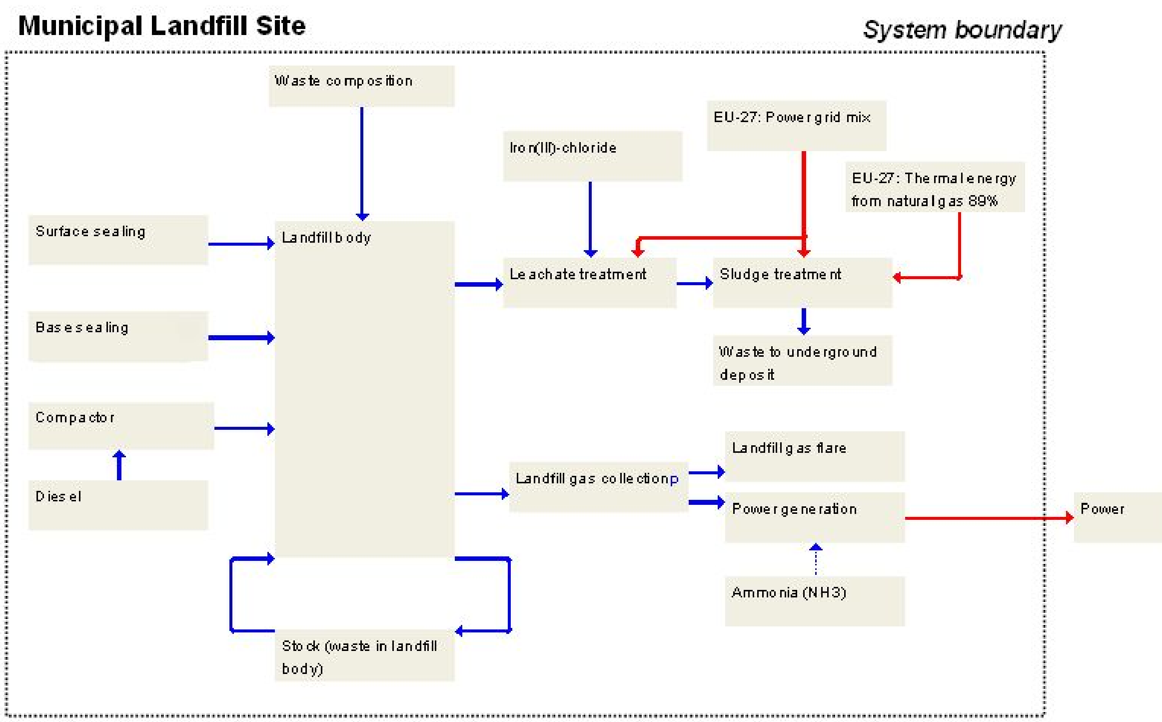

Figure 5 *Municipal Landfill Site flow chart inside the system boundary (OpenLCA)*

RESULTS AND DISCUSSION

Impact Analysis

The LCA software displays the finalized data in various ways. To gain a better understanding of the effects the plastic, paper, and textiles had on the environment once they entered the landfill, the products were compared to one another by looking at the top single impact categories. The analysis included 17 different impact categories (midpoint) and then compared plastic, paper, and textiles by analyzing the 3 different damage categories: ecosystems, human health, and resources (endpoint). It should be noted that the charts displayed below use a point system to normalize all the different units when comparing the 3 products. If one normalized point system were not used as an index, it would be impossible to compare the 3 products.

Figure 6 below compares all the relative indicator results. For each impact and damage category the maximum result is set to 100% and the results of the other materials are displayed on relation to this result. Impact categories that do not have any data indicate that the impact category is not affected by paper, plastic, or textile waste once disposed. For example, the impact category resources (fossil depletion) is not affected by paper, plastic, or textile waste because no resources are being used to create a product. Again, this LCA is only looking at the products once they enter a landfill. Ecosystem quality (terrestrial ecotoxicology) and ecosystem quality (freshwater ecotoxicology) appear to be the only impact categories where plastic waste effects the environment the most with points totaling 2.46 and 3.08, respectively. As shown in the chart, all other categories, plastic, paper, and textile waste are scored almost identically. A full list of the numerical indicator results data can be found in Appendix B.

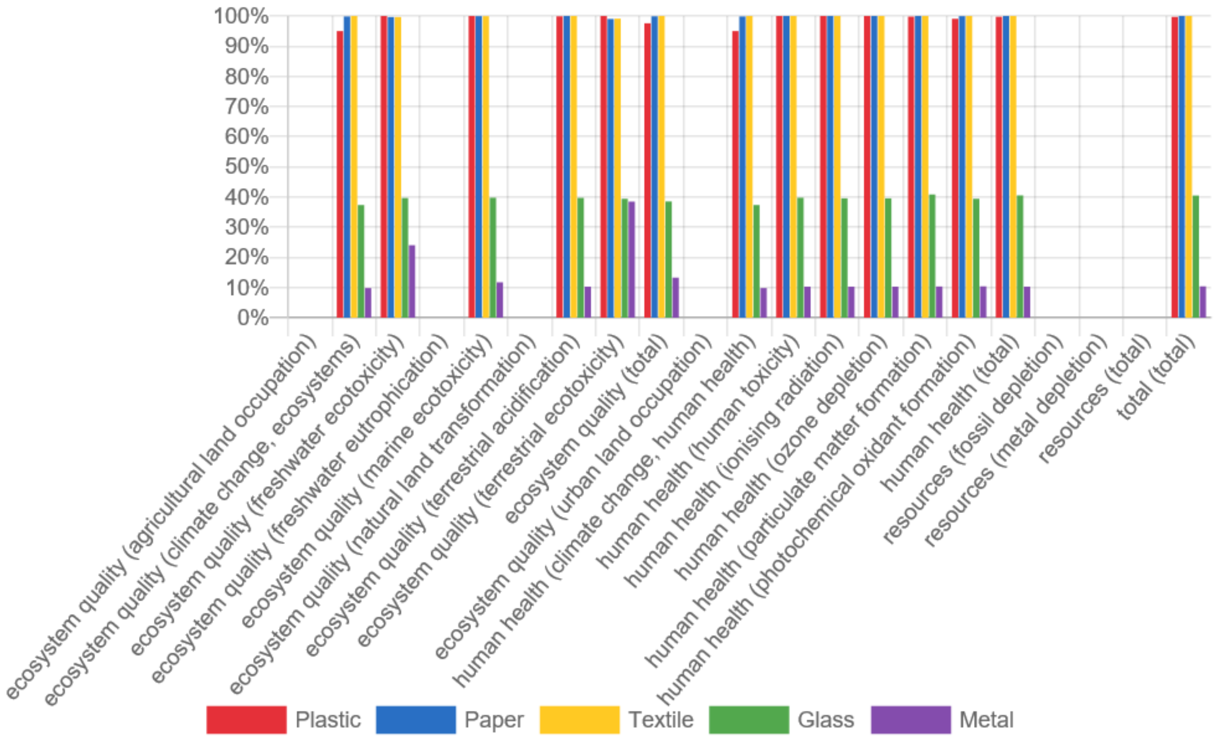

Figure 6 *Side by side comparison of all impact and damage categories (OpenLCA)*

Note: The following chart shows the relative indicator results of the respective project variants. For each indicator, the maximum result is set to 100% and the results of the other variants are displayed in relation to this result.

According to the data found in the ELCD database, the top 3 categories of paper, plastic, and textile waste have the greatest impact on human health and climate. The top 3 categories were determined by comparing the numerical data found in Appendix B. The largest numbers recorded in the table indicate the largest impacts the products have on the environment once disposed of in a landfill.

Figure 7 displays a graph that shows the impact category human health (particulate matter formation). In addition to the 3 products of focus, glass and metal products are included in the graph as a comparison between the products of interest and other materials that would be found in a landfill. As displayed in the graph, glass, and metal products both have a much smaller impact than plastic, paper, or textile waste. Here, the table shows that plastic, paper, and textile waste products all score much higher than glass or metal waste products. However, plastic, paper, and textile products scores were virtually identical to one another. According to the results, plastic scored 0.0217 points while paper and textile both scored 0.0222 points. Therefore, according to the report, paper and textile waste are 2.2% more impactful to human health (particulate matter).

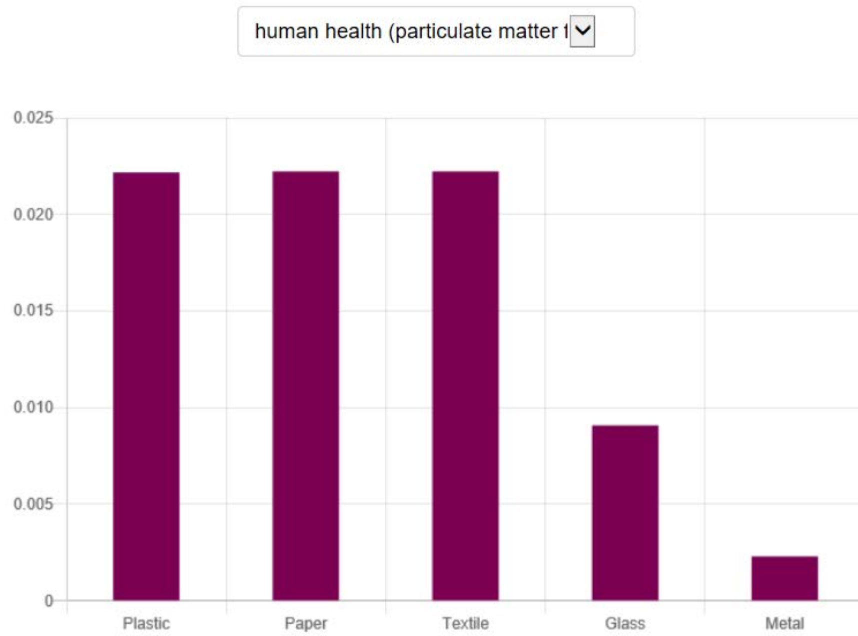

Figure 7 *Product comparison looking specifically at the impact category human health (particulate matter formation) (OpenLCA).*

Figure 8 below shows the impact category of human health (human toxicity). Like the human health (particulate matter formation), all three products are virtually identical when looking at their impact on the environment once disposed of. According to the numerical data found in Appendix B, all three products totaled 0.0057 points, significantly higher than the glass and metal products provided for comparison which totaled 0.0029 and 0.0005 points, respectively.

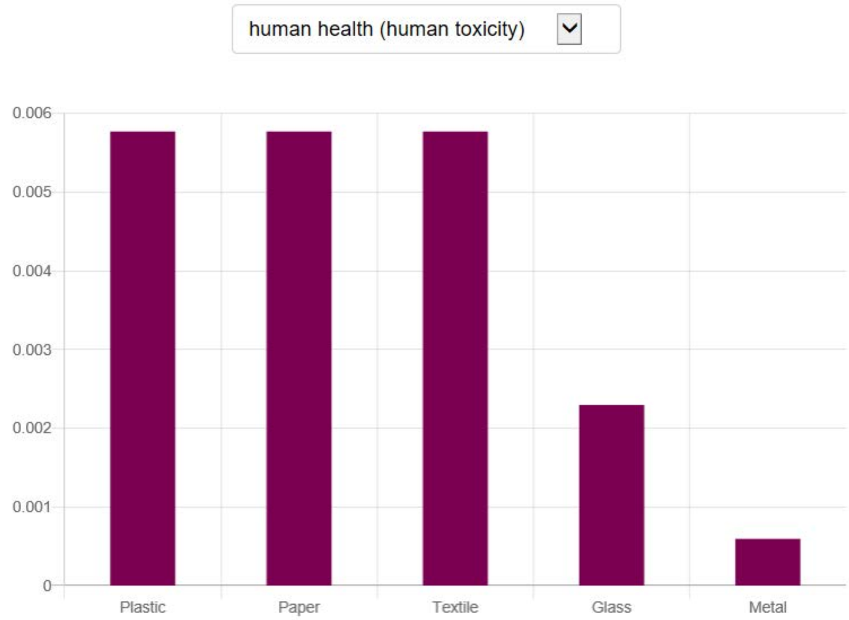

Figure 8 *Product comparison looking specifically at the impact category human health (human toxicity) (OpenLCA).*

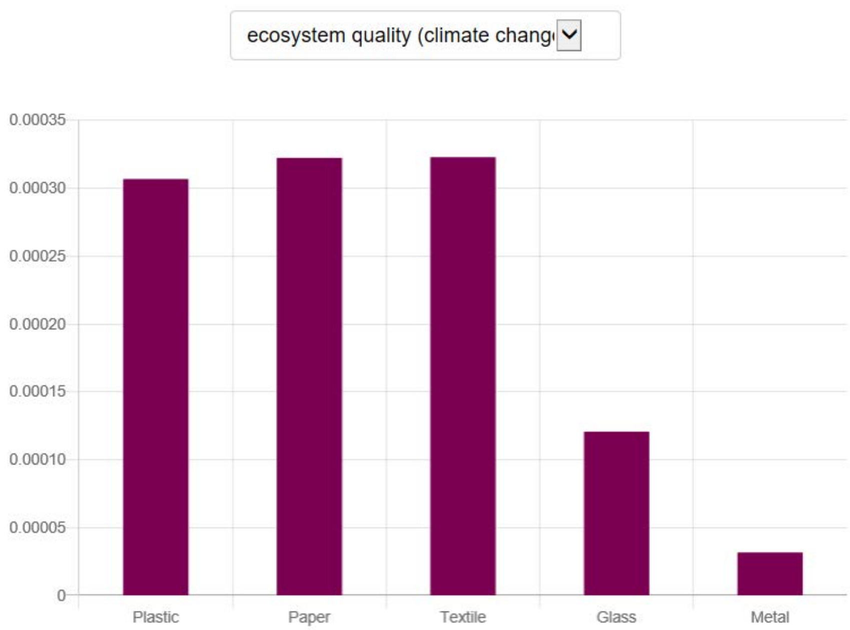

Figure 9 *Product comparison looking specifically at the impact category ecosystem quality (climate change, ecosystems) (OpenLCA).*

The third impact category examined was ecosystem quality (climate change, ecosystems). Out of the three impact categories examined in Figure 9, the chart displays the largest difference between plastic, paper, and textile products. Although the difference is extremely small, compared to the other results, it appears plastic waste has less of an impact on climate change within ecosystems compared to paper and textile waste. According to the data, plastic totaled 0.00036 points, and paper and textile totaled 0.00032 points. Therefore, according to the data, plastic waste has a little more than 10% less of an impact than paper or textile waste. These results can be explained when the inputs and outputs for paper and plastic products are looked at individually. For this particular impact category, paper bag waste releases more harmful gas emissions than plastic waste would release which helps explain the results this graph shows.

Figure 10 below displays a graph displaying the total (total) results when looking at paper, plastic, textile products in a side by side comparison regarding overall environmental impact once the product is entered into the landfill. For comparison purposes, glass and metal products are displayed on the graph as well.

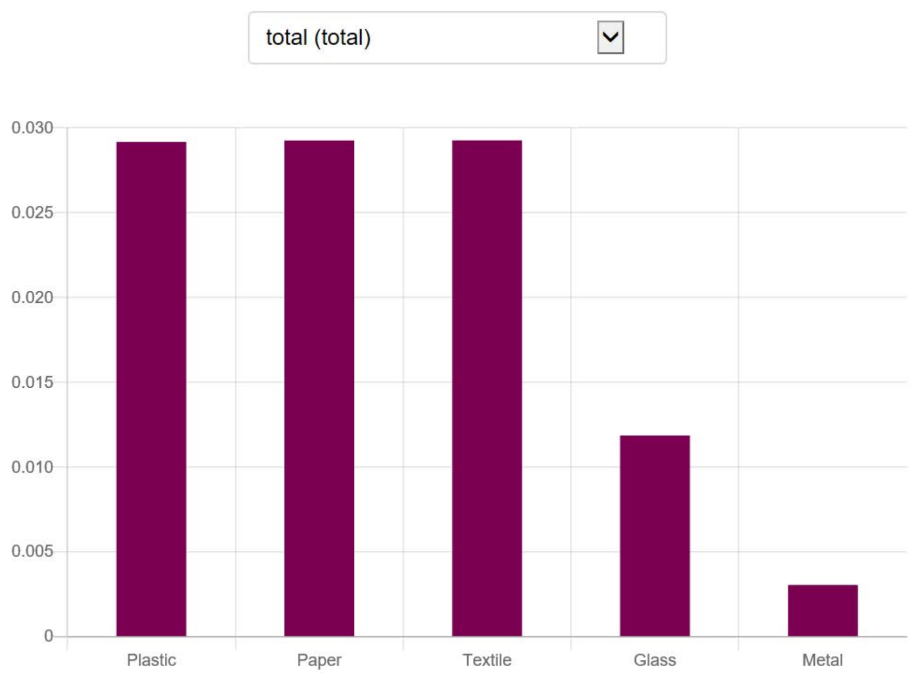

Figure 10 *Product comparison looking specifically at the total (total) damage indicator of all impact categories (OpenLCA).*

After running the LCA software, plastic total point value equaled 0.0291 points, paper equaled 0.0292 points, and textile equaled 0.0292 points. Glass and metal products disposed of in a landfill scored significantly lower. These results show that overall, plastic, paper, and textile all have a relatively large impact on the environment once disposed of in a landfill, especially when they are compared to glass and metal products. However, it appears that not one specific product is impacting the environment more than the others. Looking solely at the numerical values of all categories, plastic may have a slight edge with less impact on the environment when it comes to waste disposal.

Project limitations

Although this project aims to answer several important questions regarding the sustainability of paper and plastic, there are still limitations. Interestingly, Europe is further along using LCA that the United States. In fact, there have been few databases established for the U.S and they are primarily small databases for specialized products.

It should also be noted that the LCA could only be conducted with the data that was provided via a published database. A search was conducted to find the best match for both paper and plastic bags to get the most accurate results possible. Data could not be found to conduct a full cradle to grave LCA regarding paper and plastic bags so only end of life landfill data was utilized. It should also be noted that since the databases only provide a finite amount of information there could be more current and accurate data elsewhere that this LCA program did not have access to. If additional information about paper and plastic bags could be found within the database, a more holistic, cradle to grave analysis could be completed. Future studies will provide additional data on all facets of materials management and allow for more complete analysis.

CONCLUSION

Interpretation

For years, it has been assumed to us that plastic bags, and plastic materials in general are more detrimental to the environment than paper products. This problem has grown even more over the recent years with the explosion of microplastics and other plastic materials littering our oceans and effecting the entire food chain. However, after examining similar studies and running various reports using the OpenLCA software, the impact results on landfill waste has shown that paper may have significant negative environmental effects as well. When looking at the results, paper, plastic, and textile waste all scored very similar which was different than what was originally expected.

Due to various sustainability articles, one would expect that the plastic waste would have a much larger impact on the environment compared to paper or cloth waste due to its complex and durable chemical structure. However, the results from the software analysis show a different story. Once entering a landfill, paper, plastic, and cloth bags seem to rank very similarly to one another in terms of environmental impact. But again, this analysis was only conducted for the waste disposal stage of the life cycle. Plastic could very well have a much higher impact on the environment with the rest of its life cycle.

Since this analysis only looks at the waste disposal stage of the paper, plastic, and textile life span a more complete analysis is needed to gain a better idea of the effects each product has on the environment during raw material extraction, production, and transportation stages. It has been found that paper and textile production often add chemical and synthetic materials added to products which leach out into the environment once disposed of. In addition to the destructive practices that comes with the extraction of raw materials to produce all paper, plastic, and cloth bags, the products can also be destructive to multiple ecosystems when being produced or transported to various locations. Taking these steps of the life cycle into consideration may alter the results of this project.

If more time were permitted, additional research would have been conducted on the recycling and reuse of these products. For example, well developed recycling programs could significantly reduce the amount of paper and plastic waste from being entered into a landfill. If public sediment toward either of these products led to different recycling patterns, this could also reduce the overall environmental impacts. Although the LCA software utilized can take these factors into consideration, this additional step did not fit in the timeframe of the project. Along with the consideration of recycling, it would have been interesting to narrow the data to just plastic and paper bag waste within a landfill. The data provided looks at broader categories in which the products fit into, however looking at how bags specifically effect our waste stream would be helpful information. Finally, the report results may vary if a complete Life Cycle Assessment is conducted. This last step in this project would be to complete an analysis on raw material extraction, production, and transportation of the products to gain a clearer picture regarding which product has the highest impact on the environment.

APPENDICES

Appendix A – 1960 – 2018 Data on Plastics in MSW by Weight

1960-2018 Data on Plastics in MSW by Weight (in thousands of U.S. tons)

Management Pathway	1960	1970	1980	1990	2000	2005	2010	2015	2017	2018
Generation	390	2,900	6,830	17,130	25,550	29,380	31,400	34,480	35,410	35,680
Recycled	-	-	20	370	1,480	1,780	2,500	3,120	3,000	3,090
Composted	-	-	-	-	-	-	-	-	-	-
Combustion with Energy Recovery	-	-	140	2,980	4,120	4,330	4,530	5,330	5,590	5,620
Landfilled	390	2,900	6,670	13,780	19,950	23,270	24,370	26,030	26,820	26,970

Appendix B – LCA Indicator Results

Indicator	Plastic	Paper	Textile	Glass	Metal	Unit
ecosystem quality (agricultural land occupation)	0	0	0	0	0	points
ecosystem quality (climate change, ecosystems)	3.06814e-4	3.22443e-4	3.22886e-4	1.20646e-4	3.16418e-5	points
ecosystem quality (freshwater ecotoxicity)	3.08890e-7	3.07760e-7	3.07826e-7	1.22477e-7	7.42715e-8	points
ecosystem quality (freshwater eutrophication)	0	0	0	0	0	points
ecosystem quality (marine ecotoxicity)	3.60011e-7	3.59877e-7	3.59884e-7	1.43145e-7	4.21611e-8	points
ecosystem quality (natural land transformation)	0	0	0	0	0	points
ecosystem quality (terrestrial acidification)	2.46413e-4	2.46602e-4	2.46607e-4	9.79346e-5	2.53291e-5	points
ecosystem quality (terrestrial ecotoxicity)	7.35423e-5	7.28176e-5	7.29068e-5	2.89745e-5	2.82897e-5	points
ecosystem quality (total)	6.27438e-4	6.42530e-4	6.43068e-4	2.47821e-4	8.53771e-5	points
ecosystem quality (urban land occupation)	0	0	0	0	0	points
human health (climate change, human health)	4.85418e-4	5.10144e-4	5.10847e-4	1.90877e-4	5.00613e-5	points
human health (human toxicity)	5.77274e-3	5.77320e-3	5.77329e-3	2.29688e-3	5.93608e-4	points
human health (ionising radiation)	9.05917e-5	9.05917e-5	9.05917e-5	3.58440e-5	9.30364e-6	points
human health (ozone depletion)	1.19633e-5	1.19633e-5	1.19633e-5	4.73353e-6	1.22862e-6	points
human health (particulate matter formation)	2.21757e-2	2.22215e-2	2.22228e-2	9.07221e-3	2.29403e-3	points
human health (photochemical oxidant formation)	1.54008e-6	1.55389e-6	1.55477e-6	6.12483e-7	1.61761e-7	points
human health (total)	2.85380e-2	2.86090e-2	2.86111e-2	1.16012e-2	2.94839e-3	points
resources (fossil depletion)	0	0	0	0	0	points
resources (metal depletion)	0	0	0	0	0	points
resources (total)	0	0	0	0	0	points
total (total)	2.91654e-2	2.92515e-2	2.92541e-2	1.18490e-2	3.03377e-3	points

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