Comparison of Plastics Bags and It's Most Common Alternatives

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Plastics have become an essential part of modern-day society. With the increased use of plastics as carrier bags (bags used to transport shopped goods), research has suggested that reusable and degradable materials such as paper and cotton bags are more environmentally friendly. However, this previous research has not explored the full life cycle of carrier bags, specifically the different environmental impacts during production, emissions, transportation, and degradation. We utilized data from the Environmental Protection Agency and the English Environment Agency to analyze the different types of carrier bags and the extent of their environmental impacts. With the goal to identify which carrier bags have the least environmental impacts and thus should be used more. Contrary to what has often been assumed, the most common carrier bags such as HDPE and LDPE bags result in lower environmental impacts when compared to materials like cotton and paper. Generally, our findings indicate that the best way to reduce the environmental impact of all carrier bags is to reuse them as many times as possible. If reuse for shopping is not practical, contributing to secondary reuse applications such as bin liners are extremely beneficial in reduction of environmental damage. The following 8 types of carrier bags were studied:

- a conventional, durable carrier bag made from high-density polyethylene (HDPE)
- a conventional, lightweight carrier made from low-density polyethylene (LDPE)
- a recycled LDPE carrier made using recycled plastic
- a polypropylene carrier (PP)
- a woven polypropylene carrier (PP)
- a paper carrier
- a conventional cotton bag
- a organic cotton bag, made from organically farmed cotton.

Keywords: Plastics, Polypropylene, Polymers, Carrier Bags, Climate Change

Introduction

Humans have benefited from the use of Polymers ever since approximately 1600BC when ancient tribes first discovered how to process natural rubber for medicines, rituals, and to paint[1]. Since then, polymers have emerged as a diverse material with applications in countless fields. Polymers represent an extremely broad category. Simply put, a polymer is a large molecule composed of many smaller molecules of the same kind called monomers. These monomers form an extended network of molecules which is the basis of many minerals and man-made materials. Polymers are also found in nature, making up many materials found in living organisms such as silk, wool, and DNA[2].

Due to their variety of properties, artificial and natural polymers play essential and ubiquitous roles in our daily lives. This extensive reliance on polymers has proliferated due to the invention of plastics. From grocery bags to our phones and laptops, humans all over the world have become reliant on the material.

Research Question

What are the environmental impacts from the life cycle of high-density polyethylene (HDPE) plastic bags in comparison to their 8 most common alternatives?

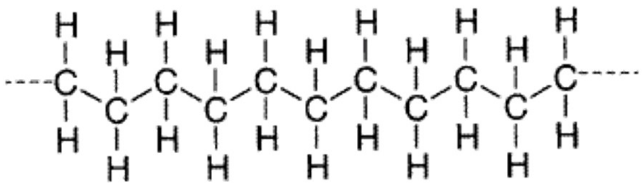


Fig. 1 Is an example of a polymer chain, specifically a polyethylene chain. Different chains form different types of plastics which have their own unique properties. Some examples of these properties can be increased strength or flexibility.

The Plastics Problem - Greenhouse Gases and the Garbage Patch

Studies show that an estimated 583 billion plastic bottles were produced in 2021 alone, a 100 billion increase from the amount produced five years ago[3]. Worldwide usage of single-use plastics continues to grow exponentially every year. The unfortunate reality is that our planet cannot keep up; an accumulation of the energy used to produce them, the carbon emissions released during their transport, and the issues involved with disposing of them have all contributed to deteriorating our planet's ecosystems and harming our environment.

After their intended purpose as a single-use item is fulfilled, plastics often end up in oceans or landfills, where they leak harmful gases into the air. A chemical reaction with sunlight and heat called solar radiation causes plastic to release powerful greenhouse gases. These gases are then released into the atmosphere, where they become trapped, effectively creating a greenhouse, hence the name. This decreases the planet's ability to reflect incoming sunlight back into space, causing the planet's temperatures to continue rising. Carbon dioxide emissions make up the most significant portion of gas released into the atmosphere. Most of these emissions stem from fuel combustion activities, industrial processes, and natural gas processing[4].

More recent research has dived into the gases that are released during plastic degradation. The research found that the two main gases released during the plastics' degradation process are methane and ethylene. In comparison, methane is a far more potent gas, shown to be at least 21 times more potent than carbon dioxide[5]. Though ethylene is a far less potent greenhouse gas, the production amounts of ethylene are much higher than methane, contributing significantly to the overall gas emissions from plastics. The effect of the constant release of harmful greenhouse gases not only causes the planet to warm but also leads to damaged ecosystems.

Over the last century, burning fossil fuels like coal and oil has increased atmospheric carbon dioxide concentration. Since 1970, rapid development has led C02 emissions to increase by about 90%, with fuel combustion and industrial processes making up about 78% of total emissions[6]. With increasing global temperatures, ice has significantly deteriorated, resulting in less solar energy being reflected into space. This means that more carbon dioxide is being trapped inside our atmosphere. In a study conducted by NASA, scientists found that our planet's arctic sea ice coverage is shrinking by an average of 12.6% every decade[7]. If nothing is done to halt this, our sea levels will rise, devastating much of our cities and environment.

Plastics Problem – Origins and Effects of Plastics

In its early years, plastic was used to imitate precious natural materials like ivory, tortoiseshell, and linen[8]. Nevertheless, plastic was often seen as a cheap and worthless material. Over time, with chemical modification and technological improvements, plastic became its own diverse material. The ability to mold plastics into any shape required, combined with the cheap production and transportation costs, made it easy for factories to transition into using the new material. Quickly, the production of plastic became more and more efficient, replacing expensive materials like wood, glass, and fabrics. Eventually, these technologies opened new avenues for packaging. The introduction of high-density ethylene made it easier to keep food and products fresh for more extended periods. The new polymer protected valuable products from contamination, improved shelf-life of products substantially, and allowed for transportation for longer distances.

Suddenly, there were plastic garbage bags, plastic wraps, squeezable plastic bottles, plastic takeaway cartons, and plastic containers for fruit, vegetables, and meat. Factories began adopting plastics and transitioning away from glass and ceramics. Unbeknownst to the general population of the world, plastics came with a dark drawback. The degradation time as compared to that of paper, which can fully degrade in around 6-8 weeks[9], is substantially longer. Plastics can take up to 500 years or more to degrade[10], lasting for extensive periods without damage. Today, plastic consumption continues to damage the planet, and the negative effects of a century of plastic waste is already seen.

The sheer amount of plastic on the planet has led to much of it littered in the oceans. The great pacific garbage patch, also known as the Pacific trash vortex spans waters from the west coast of North America all the way to Japan. Comprised of two sections: The Western Garbage Patch located near Japan, and the Eastern Garbage Patch located between the U.S. states Hawaii and California, the patch is a collection of plastic debris linked together by the North Pacific subtropical convergence zone. This convergence zone is where warm water from the south pacific converges with cooler water from the arctic. The zone acts like a highway that moves debris from one patch to another[11]. A study by The Ocean Cleanup[12] found that 75%-86% of the plastic debris in the Great Pacific Garbage Patch originates from fishing activities at sea.

The plastics in the oceans have had a serious impact on marine life. Yearly, thousands of seabirds, sea turtles, seals and other marine mammals are killed after ingesting plastic (often mistaking plastics for food) or getting entangled in them, leading to continued deterioration of marine ecosystems. Furthermore, marine life isn't the only thing that is affected by plastics, humans also consume plastics. Another study investigated the contents of the patch and found that 94% of the patch is made up of microplastics[12]. Microplastics are classified as plastic smaller than 5mm in length. Microplastics are formed mainly during the degradation process, as larger plastics are corroded by the ocean's currents, they begin to break down into smaller pieces. These pieces pose a threat not only to sea life but also to humans. Fish can easily ingest microplastics without even noticing, getting trapped inside their stomachs. Some of these fish are caught by fishermen and sold in markets, where humans then consume the fish, hence transferring the microplastics into our stomachs. Studies published from 2010-2013 found that an average of 15 percent of the fish sampled contained plastic; in studies published from 2017-2019, that share rose to 33 percent[13]. Humans consume an average of 70,000 particles of microplastics per year. Per week, humans consume about 0.1 to 5grams of plastic[14]. For context, 5grams is the typical weight of a credit card.

Methodology

Overall, we found that HDPE carrier bags are the most common type of carrier bag and the carrier bag type that can always be found in supermarkets. Therefore, this carrier bag can act as a baseline to compare how many times the other carrier bags should be reused in order to reach a similar environmental performance. Additionally, carrier bags have substantial differences in weight, so bags with larger weight are likely to have a higher environmental impact due to the increased amount of material required to produce the carrier bag. Each type of bag has different characteristics and cannot all cover the same functionality and criteria. Hence, conducting a comprehensive comparison is difficult.

With plastic packaging littering every corner of the planet, this study investigates which type of packaging has the least environmental impact on the planet. We read through the data sourced from the England Environment Agency[15] and the Danish Environmental Protection Agency[16] to discuss the pros and cons of each carrier bag in comparison to a standard HDPE bag.

Results

Production

The common rhetoric is that plastic bags are the most detrimental towards our environment and that we should try to use other alternatives like paper and cotton bags. However, the production of some of these alternatives is often also detrimental to the environment. Though cotton and paper bags degrade much faster than plastic bags, the gases that are emitted in their production can be more harmful than the plastic bag itself. Moreover, studies have showed that in comparison to its most common alternatives, plastic bags may be the carrier bag with the least environmental impact.

The process of making plastic bags starts from the extraction of fossil fuels from the earth. Fossil fuels like crude oil and natural gas are extracted through drilling and mining operations creating hydrocarbons. These hydrocarbons go through a process called cracking, where large hydrocarbon molecules are broken down into smaller ones. This produces monomers which are then chemically bonded together to form polymer chains, which then form a polymer resin[25]. During this process, significant amounts of greenhouse gases are released into the atmosphere. In fact, a U.S geological survey reported that 24% of all U.S carbon emissions come from fossil fuel extraction[26]. The polymer resin is then melted and extruded through a die to form a long tube of plastic. The continuous tube of plastic is then cut to form different bag lengths, and one end of the tube is sealed off to form the bottom of the bag. Handles, if required, are then added to the bags. The process of creating these single-use plastics requires heavy energy consumption. Plastic production accounts for 3% of total U.S energy consumption[27]. Non-woven Polypropylene and Woven polypropylene have similar production processes as HDPE and LDPE bags. With the exception that they use a different monomer.

Paper bags are made from a renewable resource and are biodegradable. In the U.S alone, around 10 billion paper bags are used each year, resulting in the felling of around 13 million trees per year[28]. Once the trees are cut down, they are then transported to mills where they sit for up to 3 years before they can be used. From there, the trunks are broken up into 1-inch cubes which are then subjected to high heat and pressure. Then they are mixed with a combination of limestone and sulfuric acid to become pulp. This pulp is then washed and pressed into new paper. As a result of the heavy use of toxic chemicals in the process, paper is responsible for 70 times more air pollution and 50 times more water pollution than plastic bag production[29]. This results in a higher toxicity rate to humans and the environment compared to HDPE plastic bags. In addition, paper bags are 6 to 10 times heavier than plastic bags[29]. Thus, transportation and distribution demand more fuel and higher costs resulting in further pollution of the environment.

Another common alternative to plastic bags is cotton tote bags. Like paper bags, the environmental impacts during the production of cotton bags are devastating. Multiple studies have found that in terms of environmental impacts, cotton bags have the worst impact on the environment. Large areas of land, huge quantities of water, chemical fertilizers and pesticides

Plastic Type	Common Uses
HDPE (High-density polyethylene)	Bottles, containers, plastic bags
LDPE (Low-density polyethylene)	Plastic bags, shrink wrap, squeeze bottles
LDPE recycled (Recycled Low-density polyethylene)	Trash bags
PP non-woven (Polypropylene non-woven fabric)	Tote bags, disposable clothing
PP woven (Polypropylene woven fabric)	Shopping bags, sacks, agricultural covers

Table 1 Type of Plastics and Common uses

are essential parts required to grow the cotton for bags. The cotton then must be picked and moved to mills where they are then processed and turned into cotton bags. Enormous amounts of energy are used in cotton production, processing, and transportation. Additionally, cotton totes are more expensive to ship because of their weight and bulk. As a result, a cotton bag needs to be used 7,100 times to equal the environmental profile of a plastic bag[29].

Moreover, the use of organic cotton for production actually yields 30% less cotton compared to conventional cotton. Additionally, organic cotton requires 30% more water and 30% more land to produce the same volume. Compared to a conventional cotton bag, organic cotton bags need to be reused a total of 20,000 times to equal the environmental impact of plastic bags[29].

As mentioned in the prior section, the uncontrolled disposal of plastics has had a devastating impact on marine life. However, for cotton and paper bags, the materials are less harmful to marine life when digested. This is mainly because cotton and paper are biodegradable, allowing them to break down at a faster rate than plastics.

Transportation

Cotton and paper bags tend to be heavier than plastic bags, however, for long-distance shipments, particularly when transported by larger cargo vessels which emit less greenhouse gases, their transportation is more efficient. On the other hand, though plastic bags are generally compact and can be stacked easily which reduces the amount of space needed during transportation, they are often shipped via train or truck, which emit more greenhouse gases when compared to cargo vessels. When comparing the relationship between average weight and average weight holding capacity, HDPE is the most efficient and cotton is the least efficient.

Degradation

Recycling any type of material is a better alternative than sending it to a landfill or incineration where it will sit and continue to emit greenhouse gases. The common end-of-life process with ridding of plastic bags involves mainly recycling or dumping them in landfills. However, though the large portion of plastics are recyclable, recycling is often expensive and requires a much more intricate process in comparison to the alternate landfill. It was found that in 2015 about 730,000 tons of plastic bags, sacks and wraps were generated (including PS, PP, HDPE, PVC LDPE) in the United States, but more than 87% of those items are never recycled, winding up in landfills and the ocean[30].

Recycling is an energy-intensive process that becomes more expensive as additional steps are added. Plastics can be split into two groups of plastics: thermoset and thermoplastics. Thermoplastics are plastics that can be re-melted and re-molded into new products, which hence means they can be recycled. On the other hand, thermoset plastics comprise of polymers that link to form a permanent chemical bond, meaning that no matter how much heat you apply, they cannot be remelted into new material and hence are non-recyclable. Thermoplastics make up about 75% of all plastics with the remaining comprising of thermoset[31].

Although plastics are predominantly recyclable, one of the biggest reasons' plastics are hard to recycle is due to the myriad of different types of plastics. Plastics are composed of several different polymer types each with corresponding melting points depending on the manufacturing process. Chemical additives give plastics unique characteristics, they can be used to make a plastic more flexible or rigid. Consequently, plastics need to be sorted by type before they can be recycled and re-used. Furthermore, plastics that are dirty or contain food residue are unrecyclable. This means that much of the plastic thrown into public recycling bins still end up in landfills (because they are either too troublesome to clean, or not capable of generating income). Some recycling centers do wash plastics multiple times before they are recycled. But this process is often expensive and inefficient. The simpler alternative being to send the plastic to the landfills or incineration plants. One thing to note is that as mentioned before, landfills release large concentrations of methane gas. These gases combined with flammable waste can be easily ignited, making landfills prone to fires which can cause further environmental and safety issues.

Moreover, one environmental impact that is rarely taken into account is the presence of "forever chemicals" in plastics. "Forever chemicals" otherwise known as PFAS or per- and polyfluoroalkyl substances are a toxic class of fluorine compounds used in many consumer products[32]. PFAS are detrimental to the environment as they do not break down, can move through soils

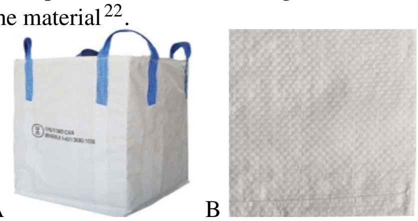
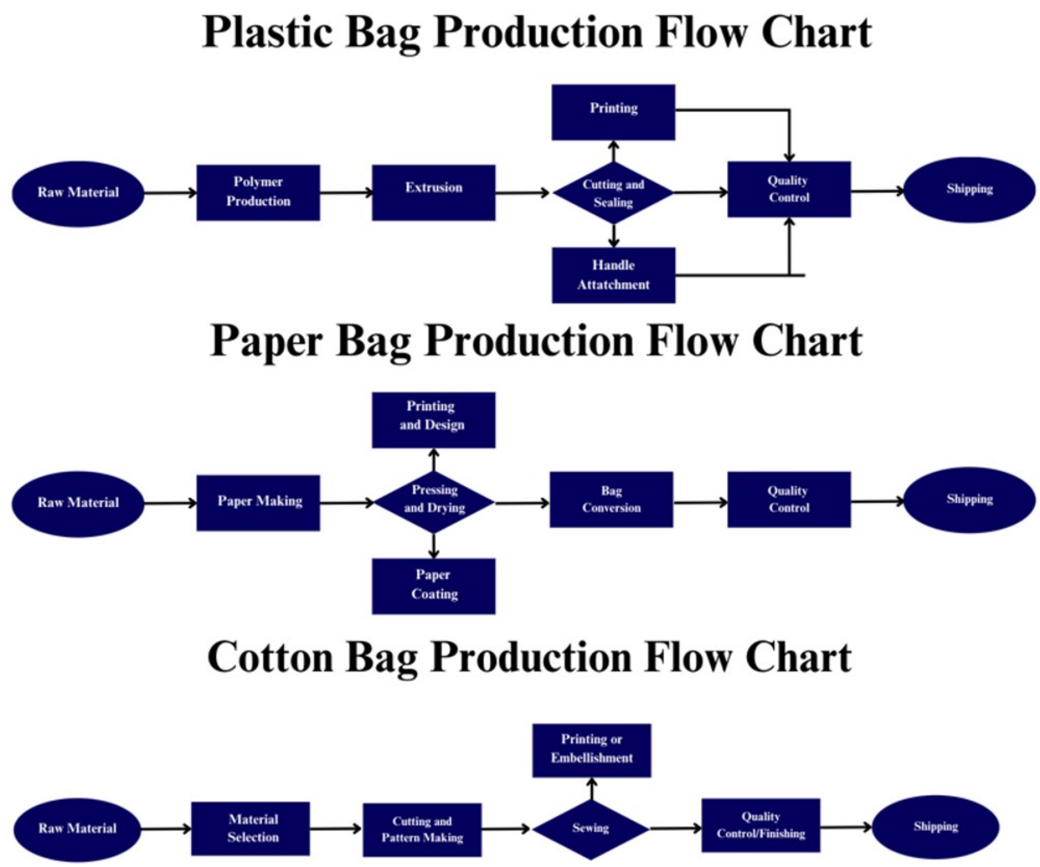
Bag Type	**Production Process**	**Figure**
High-density polyethylene (HDPE)	HDPE plastic bags are formed from an HDPE plastic melt, which is blown and sealed to form a bag. Figure 2 provides an example of HDPE bag with a handle.	Example of HDPE bag with handle[17] 
Low-density polyethylene (LDPE)	LDPE plastic bags and LDPE recycled bags are formed from an LDPE plastic melt, which is blown and sealed to form a bag. Figure 3 provides an example of LDPE bag with a simple handle.	(A) An example of LDPE bag with a simple handle[18] and (B) recycled LDPE bag[19].  A B
Non-woven polypropylene (PP)	Bags are spun bonded and formed from a molten filament of PP. Non-woven PP bags are stronger and more durable. They are generally larger in volume in comparison to LDPE carrier bags and are intended to be reused many times. This figure provides an example of A) non-woven PP bags and of the fabric type and (B) detail of the nonwoven PP fabric.	Example of A) non-woven PP bags and of the fabric type[20] and (B) detail of the nonwoven PP fabric[21].  A B
Woven polypropylene (PP)	Plastic bags obtained from weaving PP fibers. Similarly, to non-woven PP bags, these bags are tougher and more durable than LDPE carrier bags. Figure 5 provides an example of A) a woven PP bag and B) a close up of the material.	Example of A) a woven PP bag[20] and B) a close up of the material[22].  A B
Paper bags	Carrier bags obtained from craft paper, which is glued together to form the bag. This type of carrier bag has decreased in usage, mainly because of how easily they tear when wet. An example is provided in figure.	Example of a paper bag[23]. 
Cotton Bags	made of woven cotton, intended to be reused many times and to carry heavier items. Textile bags can be made of either organic or conventional textiles. Figure 7 provides an example of a cotton bag.	Example of a cotton bag[24]. 

Table 2 Carrier Bag Breakdown



Material	Type	Average Weight (g)	Average Volume (L)
Plastic	HDPE (Baseline)	12.6	21.8
Plastic	LDPE	24.2	22.4
Plastic	LDPE recycled	24.9	21.7
Plastic	PP non-woven	137.0	29.0
Plastic	PP woven	118.7	36.7
Paper	Paper	44.7	23.0
Textile	Cotton conventional	232.0	27.0
Textile	Cotton organic	252.0	20.0

Table 3 Carrier Bags and Their Average Capacity (Weight and Volume)

and drinking water, and bioaccumulate in fish and wildlife. This is significant as they can affect reproduction, thyroid function, the immune system, and injure the liver[33]. Hence, PFAS need to be accounted for when considering the environmental impact of HDPE bags.

As the disposal of plastics is often overlooked and collection requires extensive logistical processes, some European countries such as Norway, Germany, and Sweden have implemented alternative systems for plastic waste collection. In Germany and Norway for example, consumers can pay a small deposit on plastic bottles and other beverage containers during purchase. When they return used bottles to designated collection points, they can receive a refund of the deposit. This incentive helps to centralize waste collection and make the recycling process more efficient and ultimately more cost effective[34]. Similarly, in Sweden, they have implemented a recycling program called "Pantamera" that offers financial rewards for recycling plastic bottles and cans. Consumers can return these items to specially marked machines at supermarkets to receive a refund[35]. These systems show that cost-effective measures can be deployed on a large scale, however, it still requires extensive effort which some countries are unable to provide. Making landfills the easier alternative.

Lastly, plastic can be converted to resources like oil, but it is extremely energy-intensive and expensive. Plastic pyrolysis involves heating plastic waste in the absence of oxygen to produce a mixture of hydrocarbon gases, vapors, and liquid products, which can include oil like substances[36]. Plastic can also be transformed into other objects due to its high malleability. Which opens avenues into processes like injection molding and thermoforming. On the contrary, cotton and paper can only be repurposed, but their advantage is that processes like upcycling are accessible to everyone and can be easily done at home. Upcycling is the process of transforming waste materials into new items of higher value or quantity. Unlike recycling, which requires the breaking down of products into raw materials for reproduction, upcycling involves creatively reusing or repurposing materials. Upcycling is especially useful when linked to cotton and paper textiles as they can be easily made into new product or materials such as clothing, artworks, and even new packaging materials.

Paper is the only carrier bag that is suitable for composting. Making it the most well rounded in terms of end-of-life processes. Composting is significant as organic waste in landfills generates, methane, a potent greenhouse gas. By composting wasted food and other organics, methane emissions are significantly reduced. Furthermore, compost can help aid reforestation, wetlands restoration, and habitat revitalization efforts by improving contaminated, compacted, and marginal soils[37]. Both organic and conventional cotton are the least environmentally friendly as they cannot be recycled or composted.

Discussion

The production of the baseline HDPE bag required the extraction of fossil fuels like crude oil and natural gas which makes emissions of greenhouse gases high. The HDPE bag was on average the lightest of all bags, making it the easiest to transport in bulk. The average volume of the bag came in 6th between both LDPE bags. The degradation process was especially concerning as HDPE bags were not only non-biodegradable, but they also contained the presence of forever chemicals which can be harmful to the environment and our health.

Similarly, to the baseline HDPE bag, the production of the LDPE and LDPE recycled bags involved the extraction of fossil fuels like crude oil and natural gas from the earth making the bags emissions high. Additionally, the LDPE bag LDPE recycled bag came in 7th and 5th in terms of average volume and 2nd and 3rd in terms of average weight respectively. Highlighting how both LDPE bags are relatively easy to transport due to their light weight. The degradation process of the bag was similar to the HDPE and PP woven/non-woven bags, with them all being non-biodegradable but recyclable, however, it is important to note that the recycling process is tedious and involves the cleaning and breaking down of the bags before they can be recycled.

The PP-Woven and Non-Woven bags again had similar production processes to the HDPE and LDPE bag types, making the emissions of greenhouse gases high. Additionally, the PP woven and PP non-woven came in 1st and 2nd in terms of average volume. However, they were also the 5th and 6th heaviest of the carriers. Hence, the transportation of these bags was more difficult as the bags were generally heavier. The degradation process was again concerning as the bags were non-biodegradable and required tedious processes to recycle.

Although the paper used for the paper bag is renewable, the production process still includes the heavy use of toxic chemicals. As a result, paper is responsible for 70 times more air pollution and 50 times more water pollution than plastic bag production[29], making the environmental impact of the production and emissions extremely high. Additionally, paper bags came 4th in weight, making transportation difficult. The main strength of the paper bag came in the degradation process as it is not only biodegradable but was the only bag that could be composted (avoiding the release of greenhouse gases). Moreover, paper can be recycled and upcycled for new uses.

Lastly, the production processes of both the standard cotton and organic cotton had a detrimental impact on the environment. Large areas of land, huge quantities of water, chemical fertilizers and pesticides are essential parts required to grow the cotton for bags, making the production of them extremely harmful to the environment. Additionally, the cotton and organic cotton bags came in 7th and 8th in weight as well as 3rd and 8th in volume, however, as they are usually transported by large cargo vessels which emit less greenhouse gases, the impact of their transportation was lower. Lastly, the degradation of both cotton bags was the worst out of all bags as they cannot be recycled or composted.

Conclusion

Overall, the environmental impact of carrier bags is dominated by resource use and production. Transport, secondary packaging, and end-of-life processing generally have a smaller influence on the environmental performance of the various carrier bags. Accordingly, the best way to reduce the environmental impact of all carrier bags is to reuse them as much as possible. If reuse for shopping is not practical, secondary reuse applications such as bin liners are more beneficial. The secondary reuse of conventional HDPE and other lightweight carrier bags for shopping and/or as bin-liners can substantially improve their environmental performance. Reusing lightweight carrier bags as bin liners produces greater benefits than recycling bags due to the benefits of avoiding the production of the bin liners they replace. Recycling or composting generally produces only a small reduction in global warming potential. The reduction is greatest for the biodegradable material paper. The results combine previous

Material	Type	Landfill	Incineration	Mechanical Recycling	Composting
Plastic	HDPE (Baseline)	✓	✓	✓	
Plastic	LDPE	✓	✓	✓	
Plastic	LDPE recycled	✓	✓	✓	
Plastic	PP non-woven	✓	✓	✓	
Plastic	PP woven	✓	✓	✓	
Paper	Paper	✓	✓	✓	✓
Textile	Cotton conventional	✓	✓		
Textile	Cotton organic	✓	✓		

Table 4 Carrier Bags and According Disposal Methods — Methods of recycling were chosen using the EPA's Waste Management and Hierarchy[?] .

research on various carrier bags to cover the entire life cycle of carrier bags, explicitly identifying the different environmental impacts during production, emissions, transportation, and degradation, identifying what bag is most environmentally friendly based on the performance of the bags during different stages in their life cycles. Ultimately highlighting which carrier is best suited for daily use and other possible alternative uses that can help decrease the overall environmental impact of carrier bags.

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