

Impact of COVID-19 Pandemic on Plastic Grocery Bag Supply Chain, Usage, and Long-Term Effects

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Abstract

The ongoing COVID-19 pandemic has caused unprecedented global changes: altering consumer habits, straining global healthcare, and damaging economies. While some essential stores remain open, many banned customers from bringing reusable bags to protect their employees and minimize the spread of COVID-19 within the community. This caused a sudden increase in demand and resurgence for single-use plastic bags, sharply contrasting the established shift towards reusable bags, as evident by California's ban in 2016. As the pandemic continues, the single-use plastic bag supply chain has been forced to adapt to the sudden COVID-19 volatility. This paper aims to analyze the increase in single-use plastic bag usage and shed light on the short- and long-term ramifications on the supply chain and the environment. This analysis will also dive into a case study of a grocery store chain. This analysis will also consider if the current supply chain is sustainable or if more consideration is needed for a more robust alternative while still minimizing risks of COVID-19 transmission.

Keywords

COVID-19, Supply Chain, Sustainability, Grocery Bags, Single-Use Plastic.

1. Introduction

In late 2019, a few individuals in Wuhan, China, were infected with a novel coronavirus strain. By March 2020, the coronavirus disease, now called COVID-19, spread across the world and was declared a global pandemic by the World Health Organization (WHO) (Rabi et al., 2020). Many governments implemented new mandates to limit the spread of COVID-19, including stay-at-home orders and closing non-essential businesses. At essential businesses, like grocery stores, new policies were set in place to protect the employees and shoppers. One such policy is the reversion towards using single-use plastic bags (SUPB) to limit personal contact. This sudden increase in demand has created more strain on the plastic supply chain. As the pandemic continues, it is important to analyze the SUPB supply chain health and potential long-term impacts.

1.1 Objectives

This paper aims to analyze the SUPB supply chain and environmental impacts before and during the COVID-19 pandemic. Specifically, this involves understanding the SUPB supply chain, manufacturing process, and environmental trends. This research provides insight into the SUPB's supply chain stability and future environmental implications as the pandemic continues.

1.2 Paper Organization

This paper is organized into various key sections. These sections include a literature review, an overview of environmental and COVID-19 trends as they relate to plastic bags, an overview of the plastic bag supply chain, and an analysis of the impacts on the supply chain and environment resulting from COVID-19.

2. Literature Review

The SUPB was originally invented in the 1960s by Swedish engineer Sten Thulin. At the time, the SUPB offered a lighter, waterproof, and cheaper alternative to paper and cloth bags (Rosenwald, 2013) and was an instant success. By the early 1980s, Safeway and Kroger adopted the SUPB. By the end of the decade, the SUPB would own over 80% of the grocery market (Laskow, 2014), becoming a ubiquitous part of American life for decades to follow.

The SUPB manufacturing process remains largely unchanged, with most of its advancements being concerned with the bag material. Today, most SUPBs are constructed from high-density polyethylene (HDPE), a common thermoplastic. HDPE is made from petroleum and natural gas through a process known as "cracking" to create ethylene gas (Scranton Products, 2017). The ethylene gas undergoes further refinement and molding to create small ~5mm diameter HDPE beads. The plastic bag manufacturing receives raw HDPE beads and uses an extruder to compress and melt the beads. The molten HDPE then flows over a circular die in the blown film extrusion process to form a continuous tube with a 0.7-1.75 mil wall thickness. Finally, the tube is flattened and passed through rollers for printing, sealing the bottom, and cutting (Muthu & Li, 2014). This continuous production process allows manufacturers to make upwards of 70,000 bags per hour (A-Pac Manufacturing Co., 2020) and brings the unit cost to approximately \$0.01 per bag. Switching to a biodegradable or compostable plastic increases the unit cost to \$0.05-\$0.08 per bag (Conway, 2007). Images of the standard process are shown in Figure 1 and Figure 2 below.

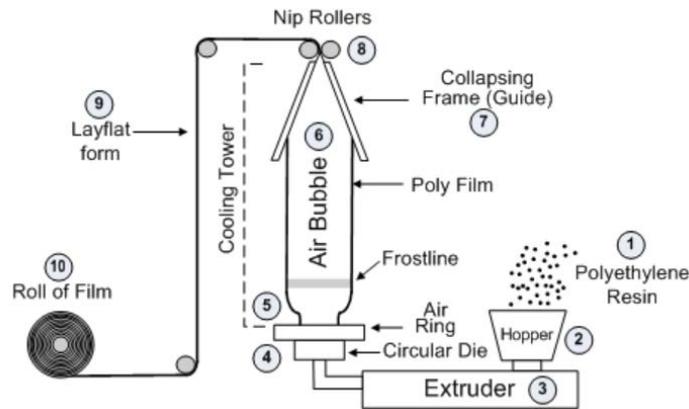


Figure 1. Blown film extrusion manufacturing process (Multi-Pak USA Inc., 2018)

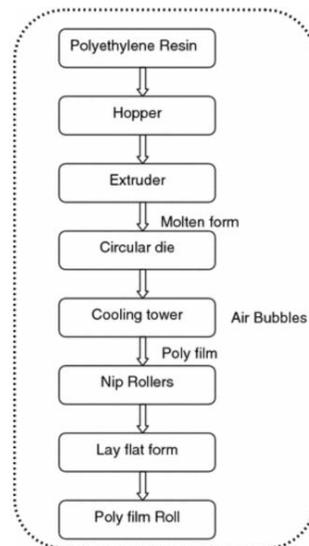


Figure 2. Plastic bags process flow diagram (Muthu & Li, 2014)

The SUPB has remained a ubiquitous part of the shopping experience for most consumers for decades. A 2016 U.S. International Trade Commission report estimated that Americans use over 100 billion SUPBs annually, although there has been a steady decline since 2010 (Scranton Products, 2017). The steady decline is largely due in part to taxes, fees, and shifting consumer sentiment towards using reusable bags instead.

3. Environmental Trends

It is important to understand the environmental effects that single-use plastic bags have and what a rise in the use of SUPBs can mean for our planet and ecosystems. Only about 1 percent of bags get recycled, leaving 99 percent that enters landfills or the environment to begin their pollution cycle (The Center for Biological Diversity, 2020). On average, it takes 500 years for an SUPB to photo-degrade into microplastics that absorb toxins and continue polluting the ocean and other water bodies. As a microplastic, the degraded bag can sit in the environment from anywhere for a couple hundred to thousands of years (National Geographic, 2020). This is a lengthy cycle of pollution for something that is used on average for 12 minutes (The Center for Biological Diversity, 2020). In 2005, the Wall Street Journal reported that 100 billion single-use plastic bags were used per year (Powers, 2008) 100 billion plastic bags are equivalent to 12 million oil barrels.

Since 2016, some states have begun to cut back or remove the SUPB from their stores due to environmental concerns. This switch still causes some concern as reusable bags have become a popular alternative to SUPBs. These reusable bags are much thicker and require much more material and processing to produce. The National Resource Defense Council (NRDC) reported that to bring the carbon footprint of one reusable bag below that of an SUPB, it would need to be used 52 times (Lindwall, 2019). After banning SUPBs, there was still an uptick in garbage bags' sales because SUPBs are often reused as garbage bags. Despite this uptick in sales, plastic usage still decreased by 70 percent.

In 2020, 8 states have active bans on SUPBs: California, Connecticut, Delaware, Hawaii, Maine, New York, Oregon, and Vermont (Maldonado et al., 2020). On the opposite side, there are 14 states with legislation that protect single-use plastics. In 2019 there were 95 anti-plastic bag-related bills, including fees, improved recycling measures, and outright bans. With the introduction of these bans, there has been a push back and lobbying from the plastic industry, because globally they net 22 billion, and U.S. sales make up about 1.4 billion of that. The map in Figure 3 shows states with more bag legislation in dark blue and states with no yellow legislation.

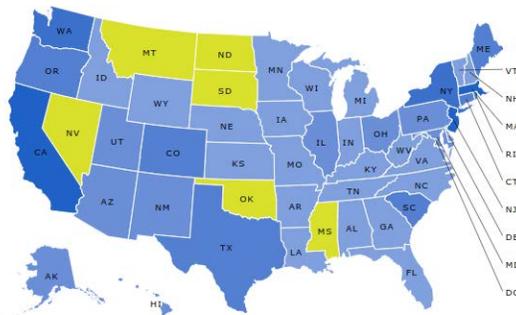


Figure 3. Map of U.S. Bag laws (S. Walter Packaging, 2020)

In California, SUPBs have been banned since 2016 with some strict constraints. Suppose a grocery store provides or sells plastic bags. In that case, they must be made of a minimum of 40% recycled material, have a thickness of 2.25mils or greater, be accepted by a majority of recycling programs in the state, and have the manufacturer's information printed on it (S. Walter Packaging, 2020). These are laws and trends generally accepted by politically liberal states. As of 2019, National Geographic reported that bag bans in the United States are limited in impact but are responsible for a net reduction of about 28 million pounds of plastic bags as of 2019.

4. COVID-19 Trends

4.1 U.S. Reactions to COVID-19

State and local ordinances, driven by fear and lack of information on the new virus, are likely the biggest factor in the increase of single-use plastic grocery bags in grocery stores. In March, the Plastic Industry Association wrote a letter to Health and Human Services Secretary Alex Azar, pointing to studies that reusable bags can harbor viruses and bacteria and said they could be spread through a grocery store. This was a strategic move to urge government officials to suspend bag bans and increase SUPB use (Toloken, 2020). In May of 2020, a conservative columnist John Tierney wrote in the *New York Post*, warning that 'sustainable' shopping bags would sustain the COVID-19 and flu viruses and therefore spread the viruses throughout the store (Griffith, 2020). However, the Plastic Industry Association's and Tierney's warnings do not necessarily match the CDC's guidelines. The CDC does not condemn the use of reusable bags; instead, it simply asks those who normally bring their own reusable shopping bags to make sure they are cleaned before each use. Despite this, it emphasizes that customers should check state, local, store, and market policies before bringing a reusable bag into a store as they might be banned. The CDC website also clearly states that the risk of infection by the virus from "food products, food packaging, or bags is thought to be very low" and even explains that no cases of COVID-19 have currently been identified where the infection was thought to have been caused by touching food, food packaging, or shopping bags (CDC, 2020).

Following the Plastic Industry Association warnings, Governor Gavin Newsom of California suspended the plastic bag ban for 60 days with an Apr. 23 executive order. This was also seen in other states like New York, Massachusetts, New Hampshire, and Maine (Penton Media Inc., 2020). Furthermore, the California Grocers Association (CGA) urged more than 150 cities and counties with their own local bag bans or restrictions to suspend their ordinances for at least 60-days or until health officials and the state government determine it is safe (Toloken, 2020). Environmental groups like Californians Against Waste (CAW) expressed their disapproval towards these actions. Mark Murray, Executive Director of CAW, argued in a statement that if customers bag their own groceries in reusable bags, there is no danger to workers. Murray brought attention to guidelines by the California Occupational Safety and Health Administration (OSHA) released in April on the use of reusable bags. He expressed his perception that incentivizing the use of SUPBs is a costly and unnecessary act for retailers and customers. Instead, Murray explained that grocers should follow the simple and safe solution recommended by Cal-OSHA of allowing customers to bag their own groceries in their own reusable bags (Toloken, 2020).

According to an article by *Plastics News*, on Jun. 22, Greenpeace released a letter from more than 100 doctors, public health specialists, and scientists. This letter stated that reusable packaging partnered with good hygiene can be used safely during the pandemic. The arguments in the letter were based on evidence that the virus spreads primarily from inhaling droplets rather than through surface contact. That same day, California revealed it would reinstate the bag ban it had suspended in April. Similarly, Vermont's state government announced it would start its ban on plastic bags on Jul. 1. In reaction to the ban's uplifting, CAW said consumers with reusable bags will still be obligated to bag their own groceries to limit exposure for store employees or other customers. It said, bringing back the plastic bag ban will "reduce an unnecessary source of plastic pollution" (Toloken, 2020). Meanwhile, Maine has suspended its plastic bag ban until January, and New Hampshire and New Jersey have suspended the ban indefinitely. The city of Minneapolis announced on Jun. 25 that it would delay a mandatory 5-cent-per-bag fee on single-use paper and plastic bags until Oct. 1, months after the original enforcement start date of Jul. 1.

While the Plastics Industry Association expressed the importance of the use of SUPBs back in March 2020, no research validating the idea that SUPBs are more hygienic than paper or cloth bags has emerged. According to an article published in the *Science of the Total Environment* in June of 2020, the coronavirus can survive on plastic surfaces for up to 3 days which is longer than its lifespan on paper or cloth, which is 3 hours and 2 days respectively (Vanapalli et al., 2020). Dr. Ben Locwin, a healthcare executive and consultant with the FDA and CDC, explained that bacteria's likelihood to transfer from a plastic bag and infect someone is very low. Switching from reusables to a disposable culture is, as Dr. Locwin notes, "pure scientific nonsense." (Griffith, 2020). Unbacked claims, mostly fueled by fear, that plastics are cleaner than other materials can dramatically affect consumer habits. As consumers become more adjusted to using single-use plastic bags, they become more likely to continue doing this even after states reinstall bag bans and stores begin allowing self-bagging once more.

4.2 Case Study: San Diego Grocery Stores Reaction to Reusables

To further understand the variability in grocery stores' COVID bagging policies per county, we looked at San Diego County in California as it is among the highest populated counties in the U.S. NBC7 San Diego's article describes the different store policies in San Diego back in mid-April, before the suspension of the bag ban. Before the bag ban suspension, the state required grocery stores to charge 10 cents for every plastic bag used by customers (Board, 2020). NBC7 reached out to local grocery stores to understand what the individual store policies were at this time.

Ralphs explained that as per the ordinance that had recently been passed by San Diego County, the store banned customers from bringing items such as bags, mugs, or other reusable items into the store. Ralphs also obeyed state laws directing them to charge a fee for multi-use plastic bags. Other stores like **Target** and **Trader Joe's** gave customers the option of bringing their own bags but also waived local bag fees for plastic and paper bags. On the other hand, grocery stores like **Food4Less** had a slightly different reaction as they have a Zero Hunger/Zero Waste commitment to end hunger and eliminate waste in communities by 2025. Food4Less continued to permit customers to use reusable shopping bags provided no state or local ordinance banned the use of bags. It encouraged customers to frequently clean and wipe down their reusable shopping bags to help maintain a safe shopping environment. Similarly, **Sprouts** customers were permitted to bring their own reusable bags while shopping as long as they kept them in their shopping cart. Sprouts team members would place the items in the customer's carts for them (Kjeldbaard, 2020).

Table 1 shows different store policies in San Diego County before suspending the C.A. bag ban, and after reinstating the bag ban on June 22 (Gomez, 2020). The chart also indicates whether stores provide paper bag options to customers or not. In states like California, customers would likely turn toward paper bags before plastic bags when not given the reusable bag option.

Table 1. San Diego Grocery Store Policies Pre-Bag Ban Suspension vs. Post-Bag Ban Suspension 2020

Store	Provides paper bags?	April (Pre-Bag Ban Suspension)		July (Post-Bag Ban Suspension)	
		Allowing reusable bags?	Charging for single-use?	Allowing reusable bags?	Charging for single-use?
Ralphs	N/A	No	Yes -10 cents apiece	No	No
Target	N/A	Yes, bag your own	? -Waiving local bag fees	Yes	Yes
Trader Joe's	Yes	No	No	No	Yes
Food 4 Less	N/A	Yes, provided no state/local ordinance bans use of reusable bags	N/A	No	No
Sprouts	N/A	Yes, bag your own	N/A	Yes	No

As shown in Table 1, many stores continued to waive single-use bag fees after the reinstalment of the bag ban. Very few stores allowed the use of reusable bags, although it is unclear if these stores permit customers to bag their own groceries outside of the store like at Sprouts. Ralphs, owned by Kroger, exemplifies a store that presents conflicting information about how the chain is handling reusable bags and single-use plastic bags. News articles like those by NBC7 San Diego claim that Ralphs has expressed they are not allowing the use of reusable bags. However, Ralph's COVID-19 website section claims it has a Zero Hunger | Zero Waste commitment, encouraging customers to continue using reusable shopping bags in a sanitary manner. This conflicting information makes it difficult to tell how exactly the supply chain has been affected by the stores.

5. Plastic Bag Supply Chain

The supply chain for producing plastic bags at grocery stores includes suppliers, manufacturers, distributors, transporters, warehouses, and customers. This combination of these stages allows for the needs of the customers to be fulfilled. There are a minimal number of raw materials required to produce a typical grocery bag. Polyethylene, typically high density, is the most crucial component. The polyethylene pellets are produced through the extraction and refining of crude oil that is then shipped to the companies for use. Therefore, the manufacturing process relies heavily on the quantity, quality, and price of crude oil. The pellets can be of various sizes and it is predicted that 4% of the global oil production each year can be attributed to polyethylene manufacturing alone (Global Market Insights, 2019).

The market for plastic bags is fragmented and includes numerous small and large manufacturers rather than a few manufacturers that dominate the industry (Global Market Insights, 2019). Mondi, Berry, AEP Industries, Alpha Poly, Emmbi Industries, Bischof & Klein, Schur Flexibles, Interplast, Ampac, Novolex, Goglio, Mayur Industries, Dangote, Pebal, Bag JSC, and Bag JSC are some of the most prevalent manufacturers in the industry. These manufacturers produce the bags which are then distributed to their customers that include various grocery and retail stores.

Since the SUPB is a functional product, the supply chain is an efficient rather than a responsive (Fisher, 1997). Functional goods typically have high competition due to their consistency as evident by the SUPB's fragmented market. Due to this competition, companies typically operate nearly at 100% capacity to meet demand and maximize profits. However, demand volatility, as seen with SUPB during COVID-19, can cause issues for companies that do not have higher production levels (Fisher, 1997).

6. Analysis

To understand the impact that COVID-19 had on the plastic bag supply chain, it is beneficial to break the supply chain down. We first examine how raw material demand and pricing changed by using market data. Then an analysis of transportation and labor availability and pricing is conducted. This brings us to what we know about plastic bag demand pre-COVID and during COVID. Lastly, we discuss how plastic bags relate to health, store and government policies, and the environment.

6.1 Supply Chain Impacts

What impact did the pandemic have on the various nodes of the supply chain network? One important component is how the price and availability of raw materials were impacted. From the bag manufacturers' perspective, the 2nd tier suppliers provide the materials that go into polyethylene. There was a decrease in the cost for polyethylene's feedstock which primarily consists of crude oil or natural gas (Cunningham, 2020). From 2019 to 2020, the price for West Texas Intermediate (WTI) crude oil decreased by about 40%, reaching an extreme low in March and April (Macrotrends, 2020). U.S. natural gas prices were also low but stable from January until the end of July (Clemente, 2020). Yet, unlike crude oil, these have mostly returned to a normal range. Low prices, coupled with plenty of crude oil and natural gas in storage, set favorable polyethylene manufacturing conditions by tier 1 suppliers. Months before the pandemic, the demand for polyethylene had been decreasing slightly (Cunningham, 2020). This would suggest, in typical times, that polyethylene value chains would find themselves with an oversupply. However, with unprecedented variability in demand came more stress on the supply chain

The pandemic brought a sudden increase in single-use plastic. This was due to spikes in demand for supplies such as plastic bags, masks, gloves, test kits, takeout containers, and delivery packaging (Bengali, 2020). In the third quarter of 2020, demand began to stabilize closer to pre-pandemic levels (Services, 2020). Despite this, the supply chain continued to experience difficulties with tightened supplies. According to Independent Commodity Intelligence

Services, the shortages were primarily caused by Hurricane Laura. Beginning around the end of August, Hurricane Laura forced plants along the Gulf Coast to shut down. This is one of the reasons the price of plastic bags did not decrease much during the summer.

Transportation is one of the largest expenses within a supply chain. In this case, it is especially significant because the cost per unit of product is extremely low. Domestically produced plastic bags would likely be transported by truck. Like many industries, the trucking industry experienced much volatility. The demand for shipping was down in March, April, and May (Wolf, 2020). After May, demand began rising and shifting from commercial/services to retail. Typically, trucking rates peak in June. This year the rates are continuing to increase. Ken Adamo, DAT chief of analytics, attributes some of the volatility to states' different reopening rates. Rates are expected to remain high along with high load volumes, increasing fuel prices, and decreased truck capacity. Labor costs had similar peaks and valleys with the unemployment peak in April. However, plastic bag manufacturing is highly automated, so labor costs would not have a huge impact.

California's SUPB ban, along with a 10-cent charge for paper or reusable plastic bags, reduced the yearly number of plastic bags distributed by approximately 13 billion (Board, 2020). In 2010, plastic bags composed about 7.4% of the trash collected from state beaches on Coastal Cleanup Day (TIDES, 2017). By 2017, the percentage had dropped to 3.1%. This was not a simple overnight transition; efforts began years before the ban. As the head of a recycling center in Berkeley stated, "it's taken us five years to really cement the behavior of bringing our own bags" (McCormick, 2020). Yet, the instantaneous transformation of decade-old behaviors was noticeable.

Fears of the virus spreading through reusable material temporarily shifted the anti-plastic movement to a pro-plastic movement. Guidance from the CDC, federal agencies, and the plastic industry encouraged disposable goods. In California, this resulted in the lifting of the plastic bag ban. Although the ban was reinstated after 60 days, habits and preferences had already shifted (McCormick, 2020). According to the director of Californians against Waste, about 500 million additional plastic bags have been handed out each month in California alone. This amounts to an increase of 6 billion bags per year. While it does not fully counteract the ban's benefits (a 13 billion yearly reduction), the increase is significant. Many states have not implemented any government regulation on SUPBs and are now even less likely. Single-use plastic was already being generated at environmentally unsustainable levels. Unfortunately, the problem is now even more extreme.

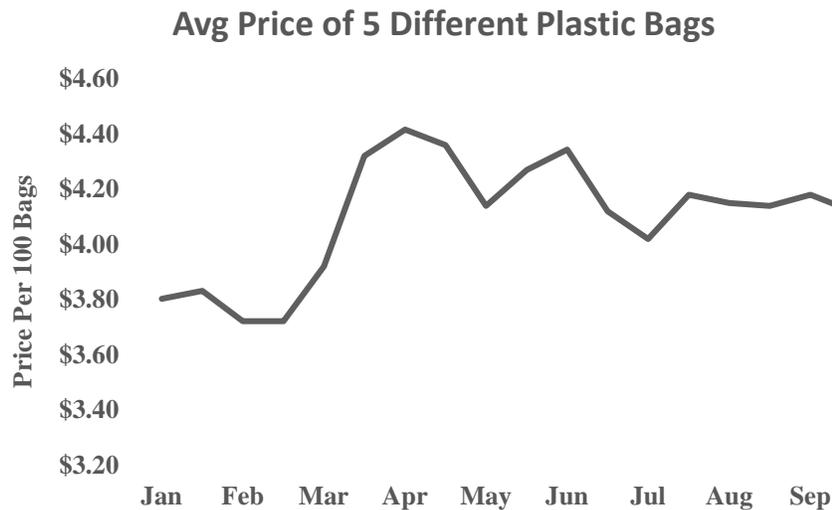


Figure 4. Average of 5 Different Plastic Grocery Bag Prices

Figure 4 above plots the average price for 5 different plastic bags (per 100 bags) sold by different companies. After analyzing the various supply chain components, this graph looks as expected. From February to March, the price jumps up. Because polyethylene and transportation costs remained low during these months, the jump can only be explained by a sudden increase in demand, which corresponds to the ban's temporary lifting. As demand began to

stabilize, the price remained elevated. This can be attributed to the shortages caused by the hurricane and continuously increasing shipping costs. Ultimately, what concerns us more than paying more for plastic grocery bags is how detrimental the increased demand will be to the environment.

6.2 Environmental Impacts

The resurgence in SUPB usage due to COVID-19 is in sharp contrast to recent environmental efforts to reduce SUPB usage. Even as local governments roll back initial COVID-19 reusable bag restrictions, many individual grocery stores and retailers have implemented their own policies to continue using SUPBs out of extreme caution. This increased demand means the plastic industry will continue to consume more resources and create localized pollution. On top of increased global production of single-use plastics by 40% to meet rising demand, the U.S. faces a shortage of resources to properly dispose of and recycle them (Greener Ideal, 2017). Many major cities have temporarily suspended recycling programs out of fear of contaminated waste in recycling centers and smaller municipalities have even dropped their collection services. These discrepancies in the recycling industry can draw waste toward incineration, which generates high greenhouse gas levels (Greener Ideal, 2017; Vanapalli et al., 2020).

Additionally, since only a small percentage of SUPBs are properly recycled, there's a clear expectation to see an increase in environmental damage to wildlife, waterways, and oceans. Although an SUPB's use is limited from the time the cashier bags up the user's groceries to the moment the user unloads groceries in their house, the bag's overall life cycle is far longer. The increase of plastic bag production and the lack of infrastructure to properly dispose of or recycle them means that the large increase in plastic bag production in 2020 will be shown in our landfills for over 1,000 years in the best-case scenario or will end up in the environment damaging already fragile ecosystems (Greener Ideal, 2017).

As the pandemic drags on, consumers may change their perspective on SUPBs. Consumers may prefer to use SUPBs out of fear against COVID-19, despite the environmental cost and scientific evidence. This change in mindset unravels the decades-long shift towards reusable bags and may deter future legislative actions from moving away from SUPBs. Looking at the greater environmental impact, this potential mindset change carries a greater environmental impact rather than a one-time increase in SUPB production. All these environmental risks grow as the pandemic continues. Even though the COVID-19 pandemic has altered many aspects of everyday life, the best way to mitigate the SUPB's environmental impacts is to implement clear communication that reusable bags remain a safe alternative.

7. Conclusions

As was expected, a temporary suspension of the plastic ban in California was the main driver for a surge in demand for plastic bags. This can be reflected in the increased price of plastic grocery bags from February to March. Although the price has stabilized and the plastic ban has been reinstated, the price remains much higher than what it was at the beginning of the year. This is an indicator that either grocery store policies or consumer habits have been dramatically affected by the fear of transmission through reusable bags. As people adjust to the COVID-19 pandemic, they continue to use SUPBs to prevent COVID-19 transmission. This surge is in sharp contrast to the recent social and political trends to reduce SUPB usage and pollution. Despite being a simple product, the sudden surge overwhelmed the SUPB supply chain, especially the transportation components, resulting in increased prices. As the COVID-19 pandemic drags on, progress towards reducing SUPB usage is slowed. Manufacturers will continue to produce SUPBs to meet demand, as there does not appear to be an end in sight to consumers' desire to use SUPBs. Inevitably, many of these new SUPBs will end up in the fragile ecosystems, contributing to the growing environmental crisis.

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Biographies

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Hannah Carlile is a fifth-year Industrial Engineering undergraduate in her last quarter at Cal Poly. She has a passion for continuous improvement and using her skills to help people. Hannah has experience in the entertainment, food, beverage, and retail industries. She is eager to continue to gain knowledge and experience as she enters the workforce and is hoping to go into consulting after she graduates.

Jack Maughan is a fifth-year Undergraduate Manufacturing Engineer. He is currently in his last quarter at Cal Poly and is very interested in robotic automation. He hopes to get a job in a field that will positively affect the earth. He has had, for the past 2 summers, an internship/consulting job for the Georgia Aquarium building ocean research equipment.

Madeleine Schmidhauser will be graduating in December 2020 with a Bachelor of Science in Industrial Engineering and a Minor in Dance. The past two summers, she interned with the global supply chain team at Amgen's biotechnology company. She enjoys the strategic nature of supply chain engineering and is excited to continue working in the healthcare industry.

Michael Wu is currently an Industrial Engineering graduate student with an undergraduate degree in Mechanical Engineering, both at Cal Poly. His current research is focused on implementing machine learning in additive manufacturing quality control. Professionally, he has experience with early prototyping, design, manufacturing, and testing in outdoor sports, commercial automotive, and consumer electronics industry.

Mohamed Awwad is an Assistant Professor in the Department of Industrial and Manufacturing Engineering at California Polytechnic State University (Cal Poly), San Luis Obispo, CA. He received his Ph.D. and M.S. degrees in Industrial Engineering from the University of Central Florida, Orlando, FL, USA. Additionally, he holds M.S. and B.S. degrees in Mechanical Engineering from Cairo University, Egypt. Before joining Cal Poly, San Luis Obispo, Dr. Awwad held several teaching and research positions at the State University of New York at Buffalo (SUNY Buffalo), the University of Missouri, Florida Polytechnic University, and the University of Central Florida. His research and teaching interests include applied operations research, logistics & supply chain, blockchain technology, distribution center design, unconventional logistics systems design, and OR applications in healthcare and the military.