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The Impacts of Single-use Plastics - A Life Cycle Assessment

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ABSTRACT The objective of this study is to compare some examples of plastic and compostable single-use eating and drinking utensils in terms of their environmental degradation. I used Life Cycle Assessment (LCA) to quantitatively compare these products' impacts on the environment throughout their life cycle. Specifically, I quantifed and compared the global warming potential (GWP) of each single-use item that was assessed in this study. The results of this study were influenced by the products weight, and the material that items were composed of. Both these attributes contribute to how significant of an impact on GWP these products had. This research has been outlined by similar studies that have been conducted on this topic to better understand the environmental effects of single-use products, and efforts to minimize their impacts as their use continues to grow.

INTRODUCTION

Modern plastic wasn't used extensively until the start of World War II, where the military discovered how versatile of a material it was. Its low production cost and flexible nature made it more valuable compared to its metal and glass counterparts. Post-World War II, plastic or "the material of a thousand uses" (Meikle 1997), became much more prevalent in the consumption driven America. Plastics manufacturing companies shifted the production of their plastic products toward creating products that could be used by the public. This is how widespread plastic consumption started, continuing to the present use of plastics today. The history of plastics is vividly outlined in Jeffrey Meikle's novel "American Plastic: A Cultural History" (Meikle 1997). In the last 50 years, global plastic production has risen from 1.7 million tons in the 1950s to 335 million tons in 2016 (Karbalei et al. 2018).

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All plastic garbage must end up somewhere, so where does it go? Some of it accumlates into a landfill, some is incinerated, and some ends up in the ocean (Geyer et al. 2017). Recently, large amounts of waste has accumulated to island sized masses in our oceans. The most known example of this anthropogenic phenomenon is the Great Pacific Garbage Patch. According to NOAA's Office of Response and Restoration the "Great Pacific Garbage Patch" has many garbage patches that congregate around numerous points in the Pacific where currents and winds converge. (NOAA 2013). Estimates of the areal extent of the Pacific Garbage Patch range from 700,000 to 15,000,000 square kilometers. The plastic in the ocean not only affects marine life (Franeker and Law 2015); (Wilcox 2016), but also humans (Karbalaei et al. 2018). Due to plastics synthetic nature, it is very difficult for plastic to decompose. Although plastics iself may not readily decompose in the environment, parts of plastic known as microplatics, can leak into the environment over time (Karbalei 2018). These microplastics along with chemical additves dissociate from the plastic and persist in the environment until they are ingested by organisms (Karbalei 2018); (Groh et al. 2018). The presence of these microplastics in smaller organisms is especially common in aquatic ecosystems (Wilcox 2016). Microplastics containing additves including nonylphenol (NP) and BPA (bisphenol A) leach from plastics and are ingested by marine organisms (Groh et al. 2018). Large concerntrations of these microplastics and chemical addvites can bioaccumlate in larger organisms that humans eat (Karbalei 2018). BPA has also received considerable press and scientific attention in relation to its impact on human health (Karbalei 2018).

A 2017 research article looking at the end of life fate of plastics, estimated that 8.3 billion tons of virgin plastic (plastic resin that is produced from petrochemical crude oil) has been produced to date. The study also estimated in 2015 that out of the 6.3 billion tons of plastic waste produced only 9% of it was recycled, 12% was incinerated, and 79% accumulated in landfills or was found in the natural environments (Geyer et al. 2017). A large percent of virgin plastics produced today is used for single-use applications such as bags, utensils, cups, and cutlery. A European study estimated that 88–100 million tons of food waste are generated every year (Fieschi and Pretato 2018). Whereas the waste does not include cutlery, this food waste is often associated with disposable single-use tableware. Around 12% of this food waste comes from the food hospitality sector. Much of the hospitality sector utilizes single-use plastic products for convenience to accommodate the consumer. Because these products are only used once, it can be predicted that these products' greatest impact is on the disposal period of their lifecycles. However, if these single-use products did not have to be discarded traditionally and could be composted with food waste, would that help mitigate their impact during the disposal period of their lifecycle? A Life Cycle Assessment (LCA) study on compostable tableware conducted by Fieschi and Pretato found that compostable tableware had less than half the global warming impact of a traditional tableware (109 kg CO_2 eq. vs. 221 kg CO_2 eq.). If single-use items could be switched over to a compostable substitute this study suggests that the environmental impact of single-use items could be lessened. Compostable single-use items may not be the only opportunity for improvement. Investigating which to-go products have the highest impact can provide information relevant for reducing the impact of single-use items.

The objectives of this study are to:

(1) Utilize LCA, to identify the impacts of single-use products made from plastics, bioplastics, and compostable materials on the environment within the impact catergory of Global Warming Potential (GWP), measured in kg CO_2 equivalents. This measurments includes all emissions that contribute to global warming, such as methane, carbon dioxide etc.

(2) Compare published LCA data for various single-use products to highlight potential differences in impacts among the materials used in single-use products. With the hopes that consumers, businesses, and production companies will be informed on the impacts of single-use plastics to be inspired to shift toward a sustainability future.

METHODS

Collection of Goods

The materials obatined for my research entailed acquiring discarded single-use plastics from around the DePaul University Lincoln Park campus. I obtained these items with sterilized gloves and placed them into sealed bag to bring back to the laboratory to be massed. I obtained additonal multi-use products from my home or from family and friends who did not wish to use these products anymore.

The Items

The products that were collected for the single-use products were: 1 large soup container, 1 Styrofoam take-out container, and 1 small water cup. The product that was collected for the single-use alternative compostable products was: 1 compostable pizza box from Whole Foods Market located 959 W Fullerton Ave, Chicago, IL 60614.

Massing the items

After obtaining these items I brought them back to the laboratory to be massed using a scale. The items were massed and logged into an excel spreadsheet along with information on physical features, where they were obtained, the size of the item, and the materialLife Cycle Assessment

In Appendix A, a table was created that contains information on each item measured regarding; plastic resin type or number, which is identified by the resin number located on every plastic item. A descriptive common name for the item, an image of the item and, the mass of the item (grams) are also included. Appendix A also illustrates how I matched the material of the item (i.e. compostable cardboard) with the appropriate production process that exisited from databases such as EcoInvent and Gabi (i.e. corrugated board box). The process data from these databases were then converted from inputs to impacts using TRACI 2.1, a tool that combines input data and mass and converts it into values of impacts. We used the conversion from TRACI 2.1 to go from inputs to impacts by creating comparable units. This allows for items processes to be directly compared as an “apples to oranges comparison.” Where it takes the emissions produced by an item at various parts of the it being created (methane, sulfur dioxide etc.) and alters them into a comparable unit (kg CO_2 eq.). This process acts as a currency converter of sorts by altering different currencies to the same unit of comparison. For example, this is like comparing a yen and a rupee, and asking which one is better? The answer to the question cannot be answered by directly comparing the two currencies because they aren’t the same. “Therefore, a universal unit of comparison is needed so that they can be directly compared, so converting the yen and rupee into USD will allow them to be compared readily. The universal unit of comparison for greenhouse gas (GHG) emissions is one kilogram of carbon dioxide equivalent (kg CO_2 eq.). However, not all emissions that products create during their life cycle are nicely quantified as a kilogram of carbon dioxide (kg CO_2). Other greenhouse gases need to be converted into the comparable unit and are done so through a conversion factor which TRACI 2.1 possess. A common GHG some products emit is methane (CH_4), methane is known for contributing a greater impact on global warming compared to carbon dioxide. This means that for everyone kilogram of methane a product emits it is converted using TRACI 2.1 into 25 kg CO_2 eq. This is because methane is 25 times more impactful toward global warming than carbon dioxide is. This methodology of using TRACI 2.1 was performed using the EPA's Standard Operating Procedure: SOP NO. S-10637-OP-1-0. Along with the "Life Cycle Assessment: Principles and Practice" released by the Environmental Protection Agency (2006). OpenLCA software was used for these calculations. The corrugated board box was used for the compostable pizza box in the LCA. Although this was not the exact material of the compostable pizza box, the board box data set was utilized to represent the pizza box material due to its similar composition and production methods.

RESULTS

The masses of the items measured in this LCA include:

Plastic water cup: 6.5 g

Clam shell take-out container: 12.0 g

Pizza box: 32.2 g

Large take-out soup container: 30.1g

LCA results (*Figure 2)* show a direct relationship with increased weight of a single-use item corresponding with increased impact on Global Warming Potential (GWP) measured in kg CO_2 eq. The only exception is the pizza box which had a higher mass than the large take-out soup container, but a lower impact. All the impacts in GWP were placed into a table along with the masses (g) of the items, and the name of the material used in LCA (*Table 1)*. The corrugated board produced a GWP of 0.046 (kg CO_2 eq), whereas the Clamshell take out container produced a GWP of 0.039 (kg CO_2 eq) and the Small plastic water cup produced 0.027 (kg CO_2 eq) GWP. The two plastic items alone would be significantly less than the corrugated board box, but the plastic items require an additional process called "Injection moulding (of) plastic" that increases the products GWP overall. This process is shown in Figure 1, which displays a process flow-diagram for the plastics products measured in this study. The largest measured impact of GWP was from large take out soup container. This soup container had the second greatest weight of all the products measured (30.1 g), behind the compostable pizza box (32.2 g). All the weights measured, along with the products common name, material name used in the LCA, and a photograph of the products are listed in Appendix A. The large take out soup container produced a GWP impact of 0.116 (kg CO_2 eq). These results focused primarily on the production aspect of each of these products and did not contain tabulated data for end of life impacts, or distribution impacts.

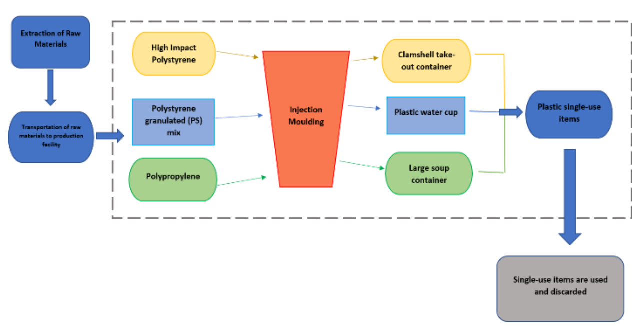

Figure 1. Process Flow Diagram for all plastic materials in this study. Exchanges (shapes) within the

4

dashed line indicate those processes that were included in this study. Exchanges outside the dashed line were not part of this study.

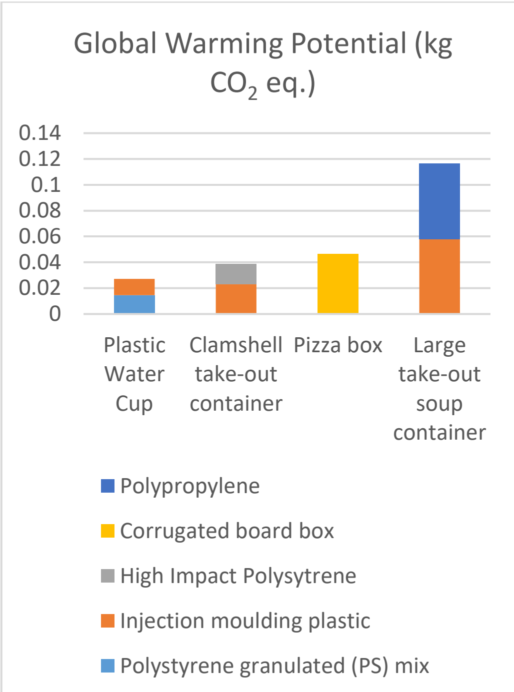

Figure 2. A Stacked bar graph displaying the single-use items and their calculated global warming potential (GWP) (kg CO_2 eq.).

Item	Materia	Mass (g)	Global Warming Potential (kg CO_2 eq.)
Plastic Water Cup	Polystyrene granulated (PS) mix	6.5	0.014686
Clamshell Container	High impact Polystyrene	12.0	0.015801
Pizza Box	Corrugated board box	32.2	0.046429
Large soup Container	Polypropylene	30.1	0.057894

Table 1. A table displaying the item, material used in LCA, mass of the item (g), and the global warming potential (kg CO_2 eq.)

DISCUSSION

The results from the LCA of the single-use products illustrated the importance of mass in relation to product GWP. The compostable product (pizza box) had the second greatest impact on GWP behind the large plastic soup container. This highlights the relatively low GWP per gram of the corrugated board box. In comparison to the two polystyrene items, the plastic water cup, and the clamshell take-out container, which have relatively high GWP per gram. It is clear that these items had less of an impact compared to both the compostable pizza box, although they had masses of 6.5 and 12.0 grams. The difference is most obvious when comparing the large soup container and the pizza box. These items had roughly similar weights, although the impact of the pizza box was less than half of the soup container.

Limitations in impact data for compostable and bioplastics items are because of how new these materials are. With more data on these materials, future studies should focus on the production process of compostable items which may result in a lower impact on GWP than what was found in this study. Although limited studies have been conducted on the impacts of biodegradable and compostable single-use products, some studies for example, Ciriminna and Pagilaro (2019) have discussed a critical shift in the use of bioplastics in replacing traditional plastics. Ciriminna and Pagilaro (2019) suggests that bioplastics can help achieve a circular sustainable economy due to bioplastics' extensive ability for use after primary consumption. The study demonstrates the multitude of secondary uses for bioplastics, such as, organic recycling for the creation of biofuel or fertilizers (Ciriminna and Pagliaro 2019). Bioplastics would not only aid in steps toward a circular economy, but also could mitigate the extreme wastefulness that single-use items produce. A study by CJ Rhodes (2019) found that 90% of all plastic waste is used once and then discarded, which corresponds to around 50% of the total plastic manufactured. Although bioplastics would not mitigate the amount single-use items are used and discarded, they could reduce the amount of fossil fuel used to create traditional plastics and lower the overall impact on single-use items. However, further studies are needed to better understand the impacts of alternative single-use items, as they become more prevelant in the future.

This study focused on comparing the impacts of various single-use plastic products with, one compostable product. Some related research by Blanca-Alcubilla et al. (2020) written in the journal of Science and the Total Environment, conducted a life cycle approach study that looked at the impacts of resuable tableware in the avaitaion catering sector. The study compared different tableware products impacts on greenhouse gases (GHG), which were made from different materials. Some of the materials they focused on were metals, plastics, and various paper products. The study also investigated if some of these materials impacts on GHG would be altered if they were reused. The study found that from reusing items (steel cutlery was used as an example in the study) the impact on GHG during the production phase of its life cycle was greatly affected over multiple reuses. In table 6 of the article by Blanca-Alcubilla et al. (2020), the table displays the total kg of CO_2 eq. for steel cutlery for different number of reuses. Which showed that the resues went from 10, 20, 50, 100, with total kg CO_2 eq trend of 110.0, 103.3, 97.6, 96.1, respectively. This indicates that, as reuse occurred more the kg CO_2 eq. of the items decreased, since less cutlery was being produced (Blanca-Alcubilla et al. 2020).

This study omitted end of life disposal of these products (i.e., whether they were recycled or disposed of in a landfill etc.). This means that based on these results alone, there is still a gap in understanding the full impact of these single-use products on the environment. A major assumption behind single-use items lies in the name itself. These products are used once, maybe twice and then discarded. Much of the research conducted on single-use items, plastics specficially, focused on the end of life status of these items, and how these items would affect the environment and potentially impact human health.

A European study on how plastics can migrate into food by Gelbke et al. (2019) found significant amounts of plastic toxins from the consumption of fish and fish products. They found that the highest exposure to styrene oligomers (a plastic toxin) was in the consumption of fish and fish products. The study also found that over 95% of UK children were exposed to styrene oligomers through consumption of fish and fish products (Gelbke 2019).

As the world continues to grow to utilize the convience of single-use items, a greater understanding of what impacts, and how these impacts occur is greatly needed. Investigating safer, more sustainable alternatives to tradtional single-use items (plastics), will aid humanity toward a projected future in which humans live with consideration of future generations, and the well-being of the Earth.

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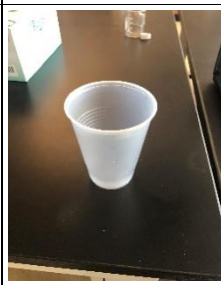
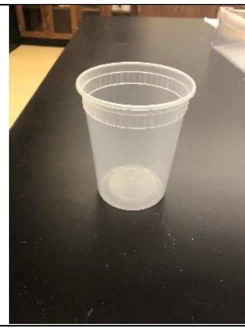
APPENDIX A. Table of items assessed in the study, including common name, material, image of the product, weight (g), what database the data was accessed from, and the label in the OpenLCA program.

Item	**Material**	**Photograph**	**Weight (g)**	**Database**	**Label in OpenLCA**
Small plastic water cup	Polystyrene		6.5	Gabii Professionals	Polystyrene granulated (PS) mix
Clamshell take out container	Polystyrene		12.0	Gabii Professionals	High Impact Polystyrene
Whole Foods Pizza Container	Compostable cardboard		32.2	EcoInvent	Corrugated board box

Large Soup Container	Polypropylene		30.1	Gabii Professionals	Polypropylene