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Life Cycle Assessment of Banned Single-Use Plastic Products and Their Alternatives

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Abstract: Plastic and microplastic contamination continue to be growing problems across the globe for both ecosystems and human health. Canada has banned single-use plastic products such as bags, cutlery, and foodservice ware (containers) to address and mitigate plastics and microplastic contamination. This study evaluates the life cycle of banned plastic products and their alternatives to determine whether environmental impacts can be mitigated. The environmental impacts of bags (plastic, paper, cotton), cutlery (plastic, wooden, biodegradable), and containers (plastic, styrofoam, biodegradable) were determined considering both domestic and imported products. The bag study saw paper bags having the highest environmental impacts and cotton bags with the lowest due to their reusability. For the cutlery study, plastic cutlery was the most impactful across all categories except for eutrophication and ozone depletion, where biodegradable cutlery was the most impactful by 25% and 35%, respectively. In the case of foodservice ware (containers), styrofoam was found to be the least impactful. Similar to cutlery, the plastic containers had the greatest impact except where the biodegradable container contributed more to ozone depletion and eutrophication by 25% and 45%, respectively. Local production reduced impacts across all categories. Furthermore, on a local scale, biodegradable cutlery had a greater impact on the smog and respiratory effects categories than plastic by 10% and 30%, respectively. The results of this study indicate that future regulations should focus on promoting and educating consumers on the use of reusable products over single-use products, funding research to mitigate challenges associated with waste management, and consider an informed ban on all single-use products and not just those made of plastic material to mitigate environmental impacts.

Keywords: single-use plastic products; reusable products; domestic products; imported products; life cycle assessment; environmental impacts

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1. Introduction

Plastic products became ubiquitous in all facets of the economy and human activity because of their light weight and convenience [1]. The packaging sector is the main contributor to total global plastic waste [2]. Globally, approximately 8.3 billion tons of plastic have been produced since 1950, as it is a highly successful product material due to its low cost, versatility, and durability [3]. Canada uses 1.4% of global plastic, which equates to 4.6 million tons each year, an amount that continues to increase [4]. The largest end-use market for plastics is packaging, such as bags and food containers, which account for over 40% of total plastic use [5]. Each year, single-use packaging generates millions of tonnes of plastic waste [6]. Around 50% of this plastic is immediately disposed of after its first use [7]. Such plastic products grew in popularity quickly due to their wide availability. For example, single-use grocery bags became widely available in grocery stores at an unlimited amount for little or no cost, and restaurants no longer offered metal cutlery and plates, but instead gave out plastic to be easily discarded after use [5].

In the plastic life cycle, greenhouse gases are emitted at all stages, which include extraction of raw materials, refining and manufacturing, and the management of waste, overall causing an impact on the environment [8]. This environmental impact is ongoing as the majority of these plastics then end up in landfills or the wider environment because of improper disposal and recycling. In Canada, only 9% of plastic is recycled each year [9]. The major consequence is that plastics do not break down but instead break into small fragments known as microplastics when exposed to sun, wind, water, or microbes [3,5]. These microplastics negatively impact the environment, wildlife, and human health. For wildlife especially, they easily accumulate in the body when eaten and cause serious intestinal blockages [3]. This is made worse as most plastic waste ends up in the water. Only ten rivers carry 93% of the global waste plastic that ends up in the ocean each year through rivers [3]. Petroleum-derived plastics are made of a combination of over 10,000 chemical substances such as additives, processing aids, and unintentionally added substances [10]. Most of these chemicals that are added to plastic are endocrine disruptors, and as such, exposure to microplastics has been shown to harm human health, including causing infertility and cancer [3]. Alternative options to petroleum-based plastics include bioplastics which are produced from renewable biomass sources, such as corn, sugars, wood, recycled food waste, etc. [11].

As the concern regarding plastic pollution and its consequences grows, many countries have implemented full or partial bans on single-use plastics. In Canada, this ban has been placed on grocery bags, cutlery, foodservice ware (containers), straws, stir sticks, and ring carriers [12]. Gradually they are being replaced with reusable or more sustainable options. Grocery stores no longer offer plastic bags, but instead sell cotton bags, paper bags, or biodegradable bags. In restaurants, plastic cutlery and plastic food containers are being replaced with compostable options. With the growing concerns about plastic contamination and the environmental impact of single-use plastic products, several LCA studies were conducted regarding the use of plastic products. A study on single-use cutlery, cotton buds, joss-stick and cloth wick wrappers, pesticide bottles, grocery bags, straws, and water bottles and their more sustainable alternatives, which included biodegradable and steel options, revealed that single-use plastics had a substantial contribution in every life-cycle stage in terms of global warming potential (GWP) and endpoint impact categories. It also demonstrated that biodegradable options contribute to both the mid- and endpoint impact categories, while energy use in the conversion process emerged as the main environmental hotspot [13]. Another study on the life cycle of cotton buds, cutlery, straws, and plates revealed that single-use items are harmful to the environment irrespective of their origin (either plastic or non-plastic) [14]. The authors noted that all single-use items, regardless of their composition, would be harmful to the environment, and non-plastic ones were thus only a partial solution to global plastic pollution.

A cradle-to-grave LCA of 16 shopping bag types in South Africa revealed that HDPE and non-woven polyester bags had low environmental impact but were high in persistence, whereas paper and biodegradable bags had a lower persistence and were thus determined preferable for reducing plastic accumulation [15]. The reusable bags needed to be used only 3–10 times to render a lower impact than any single-use bag [15]. The HDPE and LDPE durable carrier bags are environmentally better than cotton or paper bags, and the reuse of shopping bags as bin liners has led to a reduction in their environmental burden [16]. Reusable packaging for fresh food distribution is reported to be environmentally beneficial compared to single-use packaging [17]. Herweyers et al. (2023) noted that consumers' attitudes and subjective norms toward the alternatives to single-use plastic led consumers to avoid single-use plastic, and thus the design as well as the marketing can play an important role [18]. The environmental impact of single-use or reusable food containers has also depended on consumer behavior, such as excess washing at home and consumers trips to returns the containers resulting in higher GHG emissions and energy consumption [6].

There have been several LCA studies conducted to implement a waste reduction strategy and replace single-use plastic products such as tableware [19], reusable restaurant

takeout containers [6,20], plates, [21], cutlery sets [22], and bags [16,23,24] in different jurisdictions. Most of these studies have focused on a single product and did not discuss the impact of policy changes on the life-cycle environmental impacts of single-use plastic products and their alternatives, and domestic vs. imported products. However, policy changes often lead to unintended consequences [25]. In 2023, Canada enacted the regulation SOR/2022-138 to prohibit single-use plastic products, focusing on grocery bags, cutlery, and foodservice containers [26]. It is thus important to evaluate the effect of such policy changes on the environmental impacts of the life cycle of single-use plastic products. Therefore, this study evaluated the life cycle of single-use plastic bags, cutlery, and food containers and compared them with their counterparts, both domestic and imported, to determine whether the environmental impacts from these products can be mitigated in Canada.

2. Methodology

2.1. Goal and Scope

Canada has introduced "Single-use Plastics Prohibition Regulations" to address the impacts of plastic pollution and to aid in reducing greenhouse gas (GHG) emissions in an attempt to meet a target of zero plastic waste by 2030 [12]. These regulations involve prohibiting the manufacturing, import, and sale of single-use plastic products such as checkout bags, cutlery, and foodservice ware [12]. This study aims to compare the products listed to the common reusable or "environmentally friendly" alternatives that are currently available to Canadians. These products include cotton and paper bags, wooden and biodegradable cutlery, and biodegradable containers as alternatives to plastic bags, plastic cutlery, and plastic and styrofoam containers, respectively. Both local and imported products (cutlery) are considered to demonstrate realistic scenarios and allow an evaluation of their environmental impacts, which can facilitate the decision-making process in selecting reusable or single-use products.

2.2. Data Acquisition and Requirements

Both the literature and estimated data were used in this study. The chosen sources of data were reputable and published recently, to ensure accuracy and relevancy. Assumptions were made when considering the exact origin of the manufactured single-use products. Manufacturing inputs were generalized based on research conducted on common origins of Canadian single-use products and their respective alternatives.

2.3. Functional Unit and Reference Flow

The functional unit for this report is an individual use of a chosen product. In this report, three different aspects of the single-use plastic ban are targeted: grocery bags, cutlery, and foodservice ware/containers. The number of uses per single product within a product's lifetime was used to determine the reference flow value. The calculations used to determine this value for each product are shown in Table 1 below. These values were used to scale each product to the same function of 1 single use.

Table 1. Study scenarios and reference flow calculations with associated reference values.

Product Type	Scaled Reference Flow Unit Calculation	Reference Value
Checkout bags		
Plastic bag	1 use/2 uses = 0.5 *	0.5
Paper bag	1 use/1 use = 1	1
Cotton bag	1 uses/416 uses = 0.0024 **	0.0024
Cutlery		
Plastic cutlery	1 use/1 use = 1	1
Compostable cutlery	1 use/1 use = 1	1
Wooden cutlery	1 use/1 use = 1	1

Table 1. *Cont.*

Product Type	Scaled Reference Flow Unit Calculation	Reference Value
Foodservice ware		
Styrofoam container	1 use/1 use = 1	1
Plastic container	1 use/1 use = 1	1
Compostable container	1 use/1 use = 1	1

* assumes an initial first-time use and second use for household purposes; ** assumes a use of twice a week for 4 years.

2.4. Project Boundary and Boundary Limitations

2.4.1. Boundary

This study is a cradle-to-grave study and includes material production, product packaging, distribution, use, and disposal. Figure 1 displays the key life-cycle stages within this system's boundary that were evaluated for each product. The details of each stage vary between product types, especially during material production. It is critical that the system boundary of this study encompasses all stages, because all processes involved in the life cycle of single-use plastics and any other consumable products hold an environmental impact. This report is comparative and evaluates the environmental impacts of several products of a similar nature at all stages. These products and associated processes were evaluated against several primary-impact categories including ozone depletion, climate change, acidification, eutrophication, smog formation, human health impacts, and ecotoxicity.

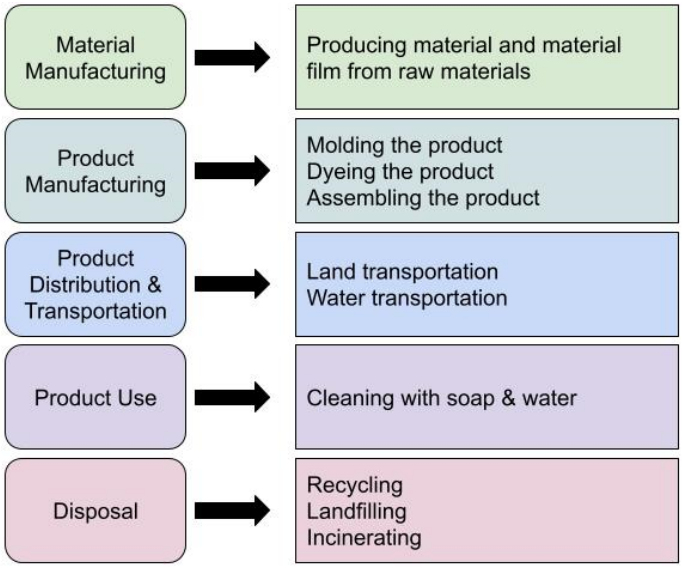


Figure 1. Proposed system boundary and process details.

2.4.2. System Phases

This involves the extraction of raw materials and manufacturing of the products. The inputs include the amount of raw material required (plastic, wood, corn, etc.), as well as any resources and materials needed in the life cycle of the products. The location of the production and manufacturing varies between each item and includes international locations such as China and India as well as local facilities in Southern Ontario, Canada. The locations were chosen based on the availability of products, cost, and distribution capabilities (Tables S1–S9 in the supporting information define the location of each product).

- Product Packaging

Packaging includes any cardboard or plastic film that is required to contain the products during transportation to their final retail location.

- Product Distribution

In product distribution, any transportation required to ship the products from their production site to their final retail location is considered.

- Use

Consumer use is considered when the product is reusable and requires washing. There is no requirement for cleaning of single-use products. To evaluate this, any required water and detergent (soap) are considered.

- Disposal

This phase is considered the end of life for the products and involves the disposal of the products and any packaging for transport to either landfill, recycling, or compost.

2.4.3. Limitations

The products chosen for this study are generalized and based on the common or most standard alternatives to single-use plastic products. Any components or materials that are not typically made to be a part of these products are not considered. Some examples include products made of partially recycled plastic, insulating materials (found in some reusable bags), and zippers. It was assumed that these products were being transported to a local Guelph business. Although it is understood that single-use products can be reused, under the usage stage, it was assumed that the usage is based on the most common usage trends. For example, single-use plastic bags are often reused or replace the need for garbage bags, and therefore the number of uses for this product is two. In this study, the midpoint environmental impact categories were determined.

2.5. Life-Cycle Inventory

Figure 2 below displays a generalized inventory for the study. The primary inputs required for the processes involved in producing a product include the raw material (plastic, stainless steel), energy (i.e., fuel, electricity), water, and solvents (i.e., dyes, soap). These inputs will vary between each scenario and product.

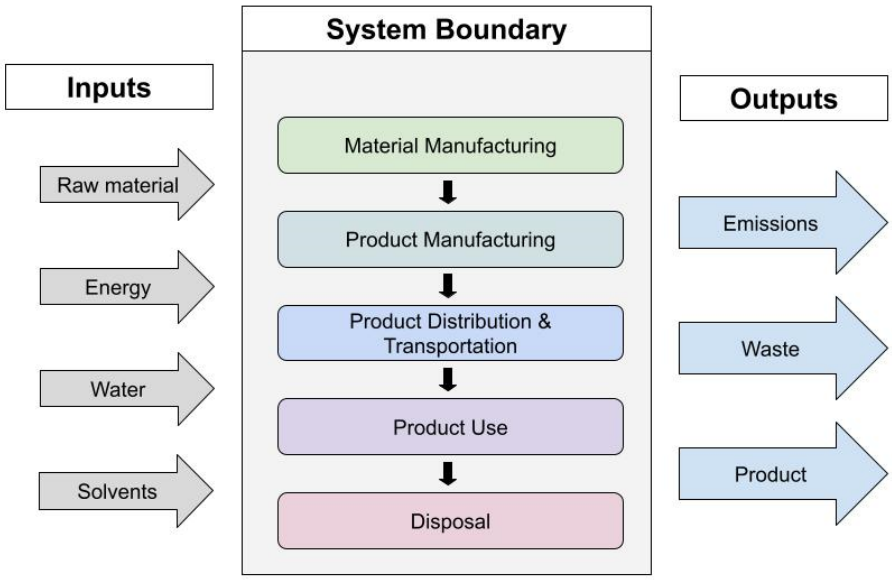


Figure 2. Product system and life-cycle inventory details.

2.5.1. Grocery Bags

Table 2 displays the inventory parameters and values used for the life-cycle analysis of bags (plastic, cotton, paper). In material production, the estimation of electricity used was based on the country of production for the material, as was that of product distribution. For plastic and paper bags, the production occurred within Ontario, and thus no transportation

via boat was required. For cotton bags, the production was assumed to occur in India, followed by shipment to Canada, and then road transportation was required to reach the final retail location. Cotton grocery bags have an assumed use of 416 times, thus consumer use through washing was required. Tables S1–S3 include detailed SimaPro input parameters used in this study.

Table 2. LCA parameters and values used for grocery bag analysis.

Parameter	Unit	Plastic	Cotton	Paper	Reference
			Material Production		
HDPE	kg	0.00535	-	-	[27]
Ethanol	kg	0.0010716	-	-	[27]
Ethyl Acetate	kg	0.0002265	-	-	[27]
1-Propanol	kg	0.00093765	-	-	[27]
Toluene	kg	0.0003215	-	-	[27]
Kraft Paper	kg	-	-	0.06	[28]
Glue	kg	-	-	0.0015	[28]
Cotton	kg	-	0.000480769	-	Assumed based on the average weight of a cotton bag
Electricity	kWh	0.0040553 (Ontario)	2.8846×10^{-5} (India)	0.00258915 (Ontario)	[28,29]
			Product Packaging		
Cardboard	kg	0.000195	4.8077×10^{-5}	0.0031	[28]
Polypropylene	kg	-	8.1731×10^{-7}	-	[28]
			Product Distribution		
Boat	tkm	-	0.015889 (India to Vancouver)	-	[30]
Truck	tkm	0.0004436 (Mississauga to Guelph)	0.002119 (Vancouver to Guelph)	0.006137 (Toronto to Guelph)	Estimated
			Use		
Water	L	-	0.509615	-	Assumed based on a single load of laundry
Soap	L		0.000144	-	Assumed based on a single load of laundry
			Disposal		
Recycling	kg	0.00195	4.8077×10^{-5}	0.0646	Estimated
Landfill	kg	0.00525	0.0004816		Estimated

2.5.2. Cutlery

Table 3 displays the inventory parameters and values used for the life-cycle analysis of the three cutlery types (plastic, wood, biodegradable) and the associated literature references. Again, the estimation of electricity and transportation used were based on the country of production for the material. In this case, it was assumed that all cutlery was produced in China. Further, as each piece of cutlery was only used once, no consumer use process was required. Tables S4–S6 include detailed SimaPro input parameters used in this study.

Table 3. LCA parameters and values used for cutlery analysis.

Parameter	Unit	Plastic	Wood	Biodegradable	Reference
			Material Production		
Polystyrene	kg	0.0035	-	-	[31]
Wood	kg	-	0.0026	-	[31]
Corn	kg	-	-	0.00714286	[32]

Table 3. *Cont.*

Parameter	Unit	Plastic	Wood	Biodegradable	Reference
Electricity	kWh	0.0003559	0.0052	0.0090079	[31–33]
Product Packaging					
Cardboard	kg	-	0.0000545	-	[31]
Polypropylene	kg	0.00035559	-	0.00035668	[34]
Product Distribution					
Boat	tkm	0.1465254 (China to Vancouver)	0.100871 (China to Vancouver)	0.165554 (China to Vancouver)	Estimated
Truck	tkm	0.0154237 (Vancouver to Toronto)	0.010618 (Vancouver to Toronto)	0.017427 (Vancouver to Toronto)	Estimated
Disposal					
Recycling	kg	-	0.0000545	-	Estimated
Landfill	kg	0.0038559	-	0.00035668	Estimated
Compost	kg	-	0.0026	0.004	[31]

2.5.3. Foodservice Ware (Containers)

Table 4 displays the inventory parameters used for the life-cycle analysis of the three types of containers (plastic, styrofoam, biodegradable). Based on the literature, styrofoam was produced in Germany, plastic was produced in China, and biodegradable containers were produced in Nebraska (U.S.). Again, as each container was only used once, no consumer use process was required. Tables S7–S9 include detailed SimaPro input parameters used in this study.

Table 4. LCA parameters and values used for foodservice ware (container) analysis.

Parameter	Unit	Plastic	Styrofoam	Biodegradable	Reference
Material Production					
Polystyrene	kg	-	0.024	-	[6,35]
Polypropylene	kg	0.0315	-	-	[36]
Corn	kg	-	-	0.052857	[32]
Electricity	MJ	1.345365 (China)	0.0072 (Germany)	0.239971 (Nebraska, U.S.)	[6,35]
Water	L	1.28331	1.8768	1.11	[6]
Product Packaging					
Cardboard	kg	0.012083	0.012083	0.003708	[6]
Product Distribution					
Boat	tkm	1.66192 (China to Vancouver)	0.254405 (Germany to Brockville)	-	[37,38]
Truck	tkm	0.17433 (Vancouver to Guelph)	0.015588 (Brockville to Guelph)	0.061161 (Nebraska to Guelph)	Estimated
Disposal					
Recycling	kg	0.043583	0.012083	0.003708	Estimated
Landfill	kg	-	0.024	-	Estimated
Compost	kg	-	-	0.0296	Estimated

2.6. Life-Cycle Impact Assessment

The SimaPro (Classroom 8.0.4.26 Multi-user) and the U.S. EPA impact assessment method (TRACI 2.1, v. 1.01; the U.S. and Canada, 2008) were used to analyze data and determine environmental impacts. Ten impact categories (ozone depletion, global warming, smog, acidification, eutrophication, carcinogens, non-carcinogens, respiratory effects, ecotoxicity, and fossil fuel depletion) were considered in this study.

3. Results

3.1. Grocery Bags

In the life cycle of a single plastic bag for its one use, the production process makes up over 90% of the environmental impact for all impact categories. Production includes materials and production processes which contribute major environmental impacts compared to the other stages of the life cycle. In terms of fossil fuel depletion and global warming, production accounts for nearly 100% of the environmental impacts. This is owing to the fact that the plastic used is sourced from fossil fuels, which are the largest contributor to global warming [39]. The environmental impacts arising from cotton bags occur at various stages, especially production, transportation, and consumer use. Transportation has less of an impact on eutrophication, but a large impact in terms of ozone depletion and smog. As the cotton bags are initially produced in India and then transported via boat and truck to their destination, the transportation process is much more impactful than those of paper and plastic, which could be produced more locally. The production of cotton bags plays a large role in eutrophication and non-carcinogens. Due to the laundering process of the cotton bags, which involves detergent containing carcinogens, consumer use makes up 45% of the total environmental impact in terms of carcinogens. It is evident that paper bags have the greatest impact across all categories (Figure 3), with cotton bags having an environmental impact of approximately one-tenth that of paper. Figure 4 breaks down the environmental impact for each stage of the life cycle of the paper bag. Paper bag production is the most impactful across the board, making up over 90% of all categories. The production of paper involves pulping and processing of wood or recycled paper that generates dust and particulates which can cause irritation when inhaled [40]. Hence, the production process is responsible for nearly 100% of the impact in respiratory effects. As paper bags can be recycled after their use and can then be reprocessed into other paper products, the disposal process has only negative values for the environmental impact, signifying that this stage of its life cycle does not negatively harm the environment. Based on this, paper bags have the greatest environmental impacts, largely arising from their production, and thus are not the best alternative to single-use plastic bags. Production is the leading cause or one of the leading causes of the negative environmental impacts for each bag type. Therefore, while cotton bags are the best alternative, it is the production process that should be investigated and evaluated to determine more sustainable production processes.

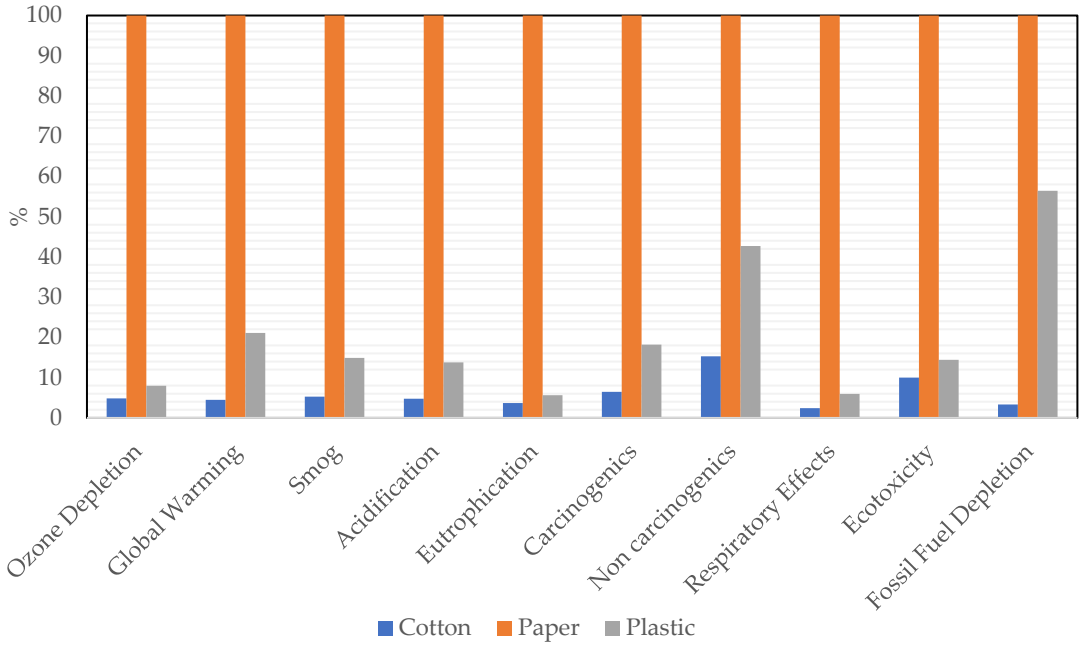


Figure 3. Comparison of environmental impacts for various impact categories for the single use of a plastic, paper, and cotton grocery bag.

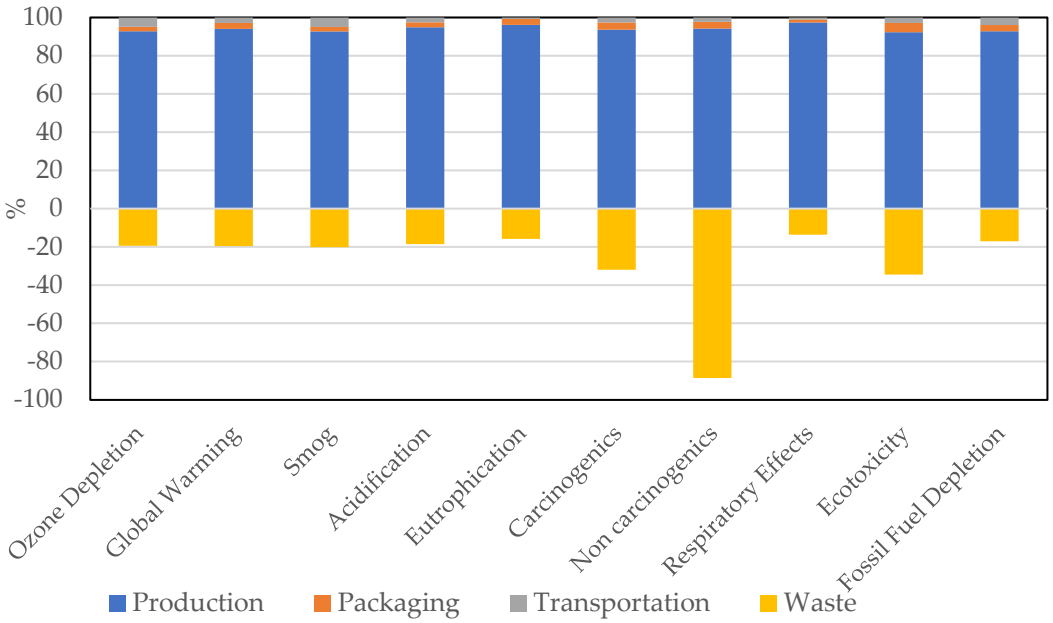


Figure 4. Environmental impacts for various stages in the life cycle of a single use of a paper bag.

3.2. Cutlery

For both wooden and biodegradable cutlery, the disposal process is the most impactful, followed closely by transportation. In both scenarios, the production process has little impact, indicating that this is a more environmentally sustainable process. The composting of wooden and biodegradable cutlery contributes a minimum of 35% and up to 85% of the total environmental impacts, with a significant contribution to eutrophication. For each piece of cutlery, the production occurred in China. For wooden and biodegradable cutlery, Canadian land transportation via truck contributed greatly to the environmental impact, especially regarding smog and fossil fuel depletion. Land transportation, especially by truck, emits many pollutants including nitrogen oxides, particulates, and volatile organic compounds during the combustion of fossil fuels [39,41]. These pollutants are precursors to smog as they undergo reactions in the atmosphere contributing to ground-level ozone [42–44]. Moreover, trucks consume large amounts of fuel, depleting non-renewable energy sources and releasing excess carbon dioxide into the environment. The production process of these alternative cutlery types has an impact of up to 30% in terms of smog, acidification, and respiratory effects. Similar to paper bags, the production of wooden cutlery can release particulates that irritate the respiratory system when inhaled [40]. Similarly, the production of PLA can cause volatile organic compounds to be released into the environment which cause irritation [42]. Figure 5 depicts the total environmental impacts of plastic, wood, and biodegradable cutlery. Here it can be seen that plastic has the greatest impact, except in ozone depletion and eutrophication, for which biodegradable cutlery has a higher impact by 35% and 25%, respectively. Wooden cutlery has a significantly smaller environmental impact than both plastic and biodegradable cutlery, except in ozone depletion, with a 15% higher impact than plastic. Breaking down the life cycle of plastic cutlery in Figure 6, it is evident that plastic production has the greatest impact across each category, with contributions greater than 70%. Through further analysis, it was revealed that the electricity consumed during production contributed the most to the negative impacts. The electricity consumed during production leads to resource depletion and to air and water pollution through the combustion of fossil fuels which releases carbon dioxide and other pollutants [45]. Overall, these results indicate that wooden cutlery is the best alternative to single-use plastic, as the production of plastic cutlery has a great effect on all environmental impact categories.

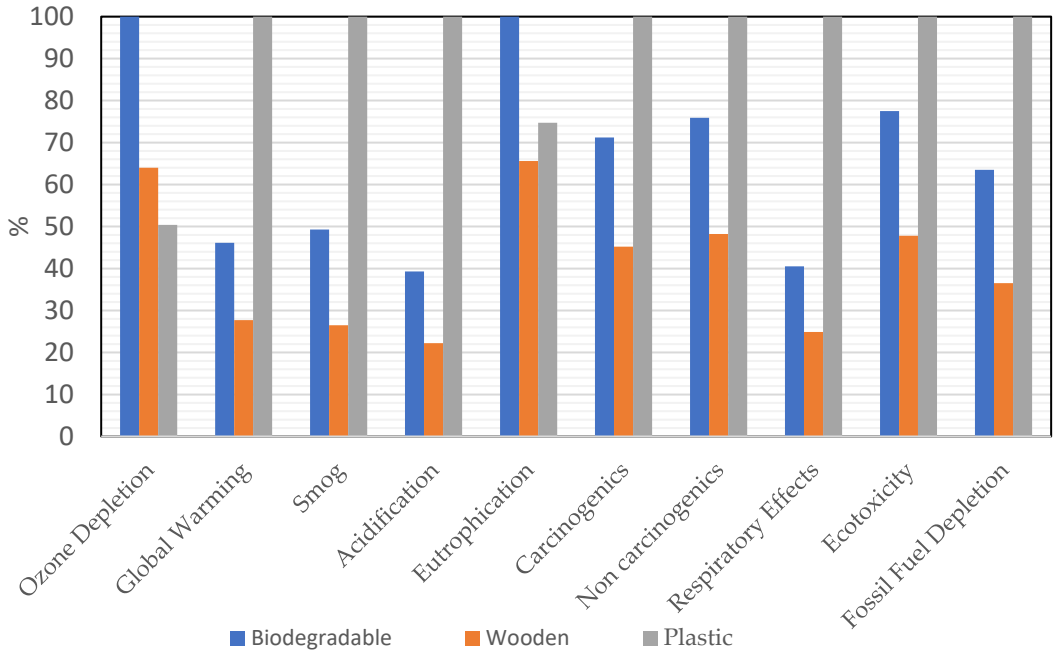


Figure 5. Comparison of environmental impacts for various impact categories for the single use of plastic, wooden, and biodegradable cutlery.

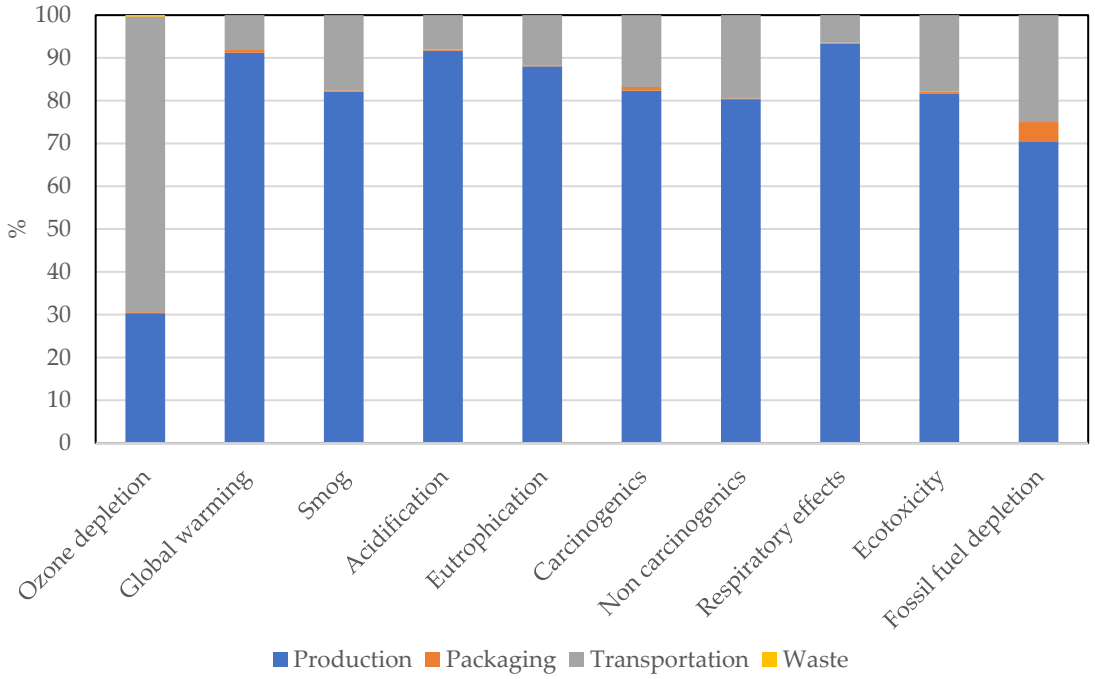


Figure 6. Environmental impacts for various stages in the life cycle of a single use of plastic cutlery.

3.3. Foodservice Ware (Containers)

Biodegradable containers are composted after use. This composting process contributes greatly to the environmental impact, with the disposal stage being responsible for 55–80% of the overall contribution. The production of this type of container has the greatest impact of 35% for smog, which is likely contributed by raw material extraction and energy consumption [46]. The low contribution to the environmental effects from biodegradable container production indicates that the production process is more environmentally sustainable, and that it is important rather that these containers are disposed of correctly to further minimize their impacts. Conversely, the production of styrofoam

containers is the greatest contributor for each impact category except non-carcinogenic. Over 85% of the effects of fossil fuel depletion in this case come from the production stage, whereas for other categories it can contribute anywhere from 35 to 80%. The manufacturing of polystyrene is the leading contributor to these negative effects. Polystyrene is a commonly used plastic is derived from petroleum, the extraction and processing of which into polystyrene consumes non-renewable sources and contributes to resource depletion and ecosystem degradation [47,48]. Moreover, its manufacture requires significant amounts of energy and releases greenhouse gases and various chemicals which are all harmful to the environment and public health [48]. As shown in Figure 7, comparing plastic, styrofoam, and biodegradable containers, styrofoam has less of an impact across all categories except fossil fuel depletion, where each container type has an impact of over 90%. Overall, the plastic container has the greatest impact on the environment, with the exception of ozone depletion and eutrophication, for which biodegradable containers contribute more by 25% and 45%, respectively, as was similarly seen with cutlery. Looking at the breakdown of plastic containers in Figure 8, it is evident that plastic production is the most impactful, making up over 55% of the impacts in each category excluding ozone depletion. Upon further analysis of the production process, the manufacturing of polypropylene played the largest role in fossil fuel depletion, due to polypropylene being derived from fossil fuels. However, contrary to styrofoam production, the electricity consumed during container production was the largest contributor, not the manufacturing of the plastic material itself. Further, the impact resulting from the disposal of plastic containers and their packaging has negative contributions to the environment, owing to the fact that both can be recycled. In conclusion, single-use plastic containers manufactured from polypropylene have significant environmental impacts. However, biodegradable containers are not the best alternative, as they have more negative impacts compared to other single-use containers such as styrofoam. Styrofoam is also included in the single-use plastic ban. As such, these results conclude that single-use alternatives do not necessarily have the lowest environmental impacts.

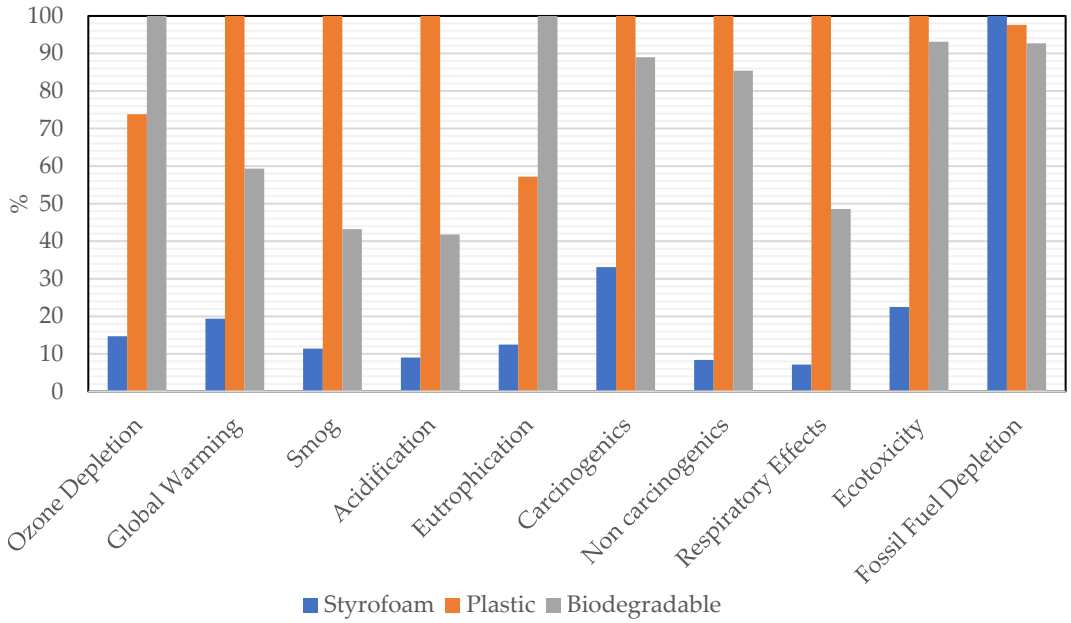


Figure 7. Comparison of environmental impacts for various impact categories for the single use of plastic, styrofoam, and biodegradable containers.

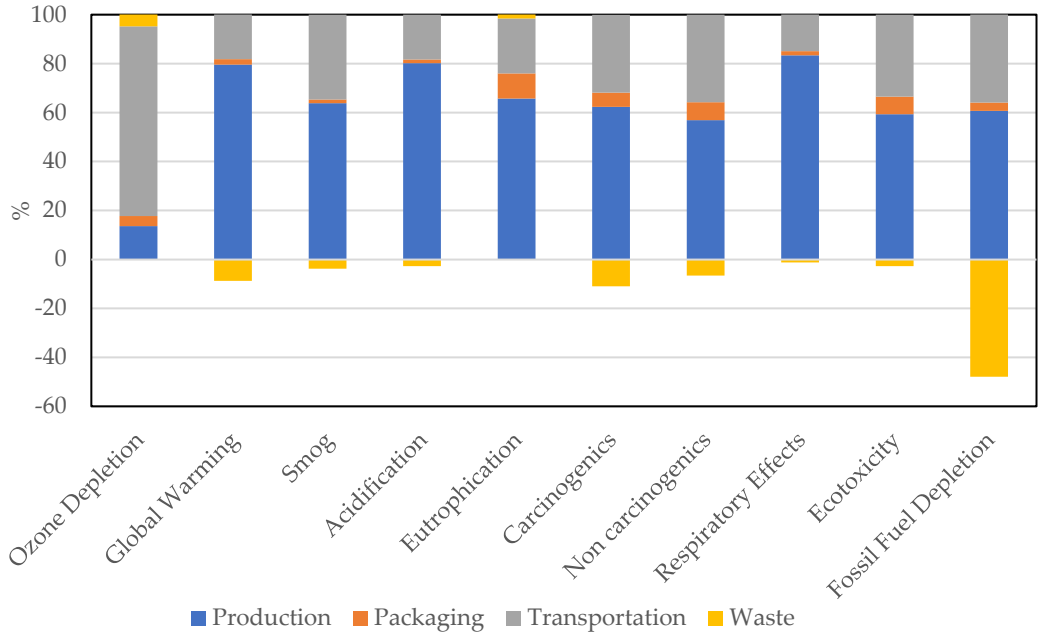


Figure 8. Environmental impacts for various stages in the life cycle of a single use of a plastic container.

3.4. International vs. Local Production of Cutlery

A comparative study was also conducted for the three cutlery products in which the effect of production location was assessed. In this study, each cutlery type was assumed to be produced within China and then transported to its retail destination in Guelph, Ontario, Canada. In the following section, we investigate the effects of producing the cutlery locally within Mississauga, Ontario, Canada. Figure 9a depicts the environmental impacts of plastic cutlery with local versus international production. These results indicate that local production has less of an impact overall. For ozone depletion, global warming, smog, acidification, and respiratory effects, this difference is significant, with local production only half as impactful as international production. There is a 5% difference in the impact on eutrophication between the two productions, with local production having a greater impact. Similar to international production, it is the production process of plastic cutlery that is the greatest contributor to the environment. In the case of locally produced plastic cutlery, the production process contributes over 90% to each impact category, compared to the 70% contributed by international production (Figure S1). This is largely because transportation has much less of an impact when local, especially on ozone depletion, as the product is not being transported via shipping or truck cross-country but is instead transported within Southern Ontario.

Comparing international and local production of wooden cutlery (Figure 9b), it is evident that locally producing the cutlery has less of an environmental impact across all categories. International production is 10–60% more impactful, with the smallest difference seen for eutrophication and the greatest difference in smog. With international production, the disposal process through composting is the most impactful. This result was also seen for local production but with a much greater percentage for all categories, at a contribution of over 85% (Figure S2). Similar to local plastic cutlery production, transportation has very little impact. This contribution is significantly less compared to international wooden cutlery production, where transportation was the greatest contributor to both smog and fossil fuel depletion. When produced internationally, the final product must be shipped from China to Vancouver, British Columbia, where it must then be transported cross-country to Guelph, Ontario via truck. However, when produced locally, it must only travel from Mississauga, Ontario. With this vast reduction in transportation distance, there is much less contribution to smog formation from the combustion and burning of fossil fuels.

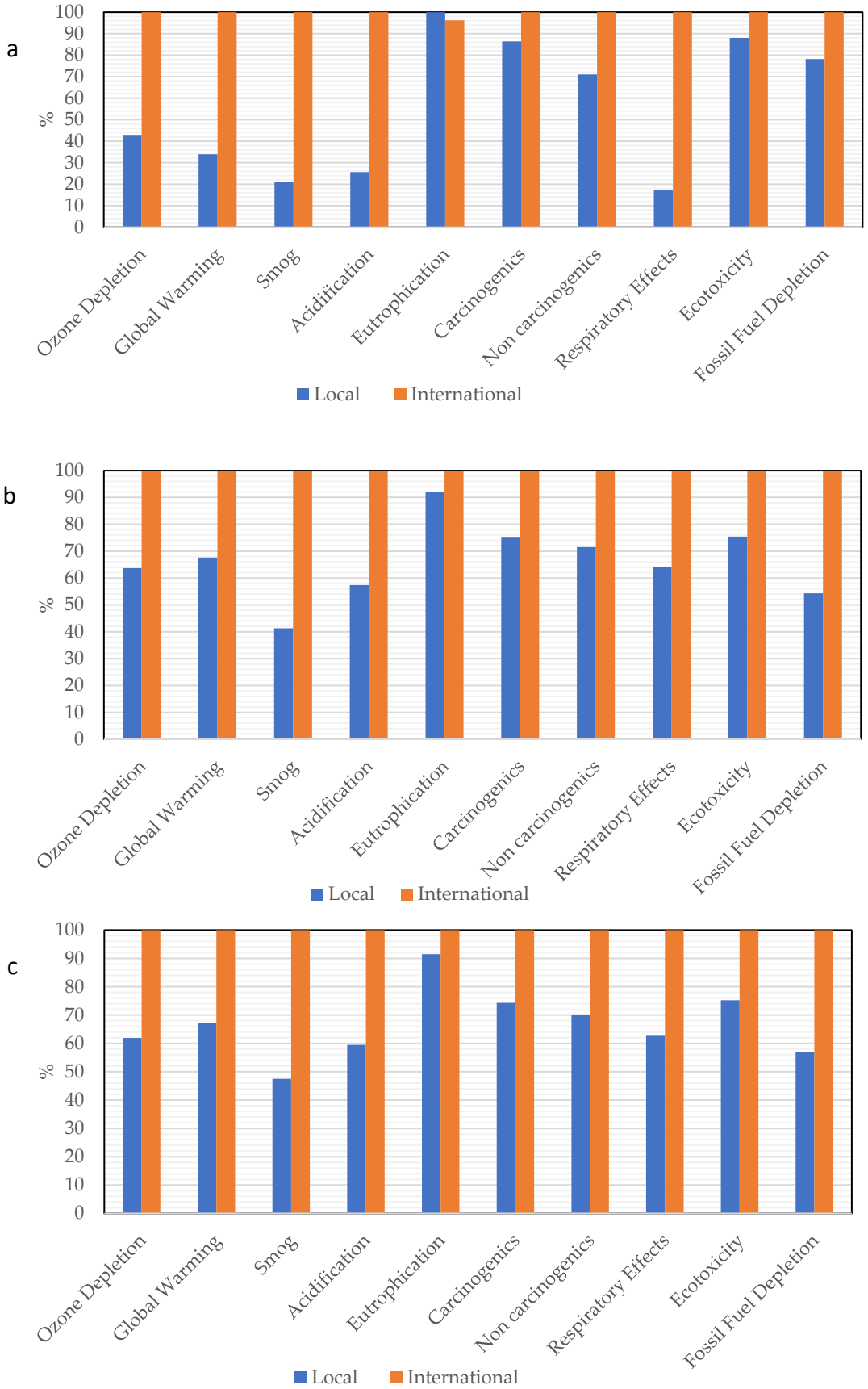


Figure 9. Comparison of environmental impacts with local versus international production for (**a**) plastic cutlery, (**b**) wooden cutlery, and (**c**) biodegradable cutlery.

From Figure 9c, it is evident that, as for wooden cutlery, international production has the greatest impact on each environmental impact category, with differences ranging from 10 to 50%. As for wood, the smallest difference in impact is on eutrophication and the greatest difference is for smog. The transportation process contributes no more than 2% to the environment (Figure S3). Similar to both wooden and plastic cutlery, this is due to the reduction in transportation compared to international production. With international production, disposal contributed 30–85%. With local production, the disposal process is the greatest contributor (65%+) for all categories, with production contributing less than 65% for all categories.

Comparing plastic, wooden, and biodegradable cutlery when each is produced locally (Figure 10), it is evident that wooden cutlery has the smallest environmental impact. This result was consistent with the initial scenario where the cutlery was produced internationally. Just as with international production, plastic cutlery remains the most impactful on the environment when produced within Canada. With international production of plastic cutlery, plastic had the greatest impact on all categories excluding ozone depletion and eutrophication, for which biodegradable products had a larger impact. Similarly, with Canadian production, biodegradable cutlery had the largest impact on these categories, being more impactful in terms of smog and respiratory effects than plastic cutlery by 10% and 30%, respectively. Overall, the results indicate that when produced within Canada instead of internationally, single-use plastic cutlery remains the most impactful on the environment. These impacts can be greatly reduced through the use of wooden alternatives.

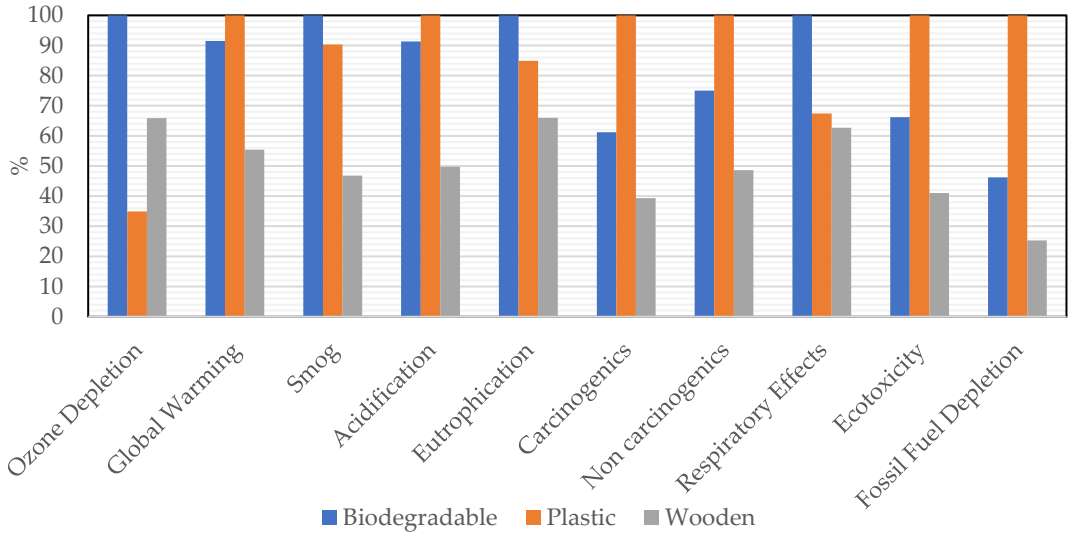


Figure 10. Comparison of environmental impacts for various impact categories for the single use of plastic, wooden, and biodegradable cutlery when produced locally within Canada.

4. Discussion

4.1. Summary

Based on the results related to bags, it was identified that paper bags have the highest environmental impact across all categories. The unit process of production (specifically the paper material) made up the majority of the paper bag impacts. In contrast, reusable cotton bags have the lowest environmental impact of all three products. For cutlery, plastic is the most impactful across all categories except for eutrophication and ozone depletion, for which biodegradable cutlery has a higher impact, due to its waste unit process (composting). However, foodservice ware (containers) saw styrofoam as the least impactful. Plastic foodservice ware is the most impactful across most categories, with some impact categories (ozone depletion, eutrophication) being dominated by the biodegradable alternative. When considering the products produced locally compared to internationally, it is evident that the local product sees a reduction in impacts across all categories in

comparison to the international. This is likely due to a significant change in transportation requirements and energy sources for production and manufacturing. Probing the cutlery types, data show that in both scenarios, wooden cutlery is the least impactful, and plastic cutlery continues to be the most impactful to the environment. The local scenario differs due to an increased impact of biodegradable cutlery in the smog and respiratory effects categories, which was not as significant in the international scenarios.

The results of this study are in agreement with previous studies. This is exemplified in both the cutlery study and the bag study. As mentioned, wooden cutlery has the overall lowest environmental impact in comparison to single-use plastic and biodegradable alternatives. Although the biodegradable plastic alternative does prove to be overall less impactful than the single-use plastic cutlery, it dominates in the ozone depletion and eutrophication impact categories. When comparing these data to a previous study conducted for the UN Environment Programme, the findings do align. The previous study saw that in some cases, bioplastic and cellulose-based tableware products have the greatest environmental impacts, while those made of wood-based fibers have a lower impact (compared to plastic) [34]. Furthermore, the previous study also noted that cellulose pulp has the highest eutrophication potential, followed by PLA [34]. This justifies the results that show the high impact of biodegradable alternatives in the eutrophication impact category, seen both in the cutlery and foodservice ware studies.

As mentioned, the results show that reusable cotton bags have the lowest environmental impact. In contrast, paper bags have the greatest impact in comparison to plastic bags, due to a greater number of uses associated with the plastic bag. These findings confirmed that reusable alternatives have the lowest impact across all categories [34]. Another study on single-use and reusable kitchen products conducted by Fetner and Miller concluded that, depending on the number of uses, washing, and consumer behavior, reusable alternatives have the ability to pay back their environmental impacts [49]. Gomez and Escobar also confirm the results regarding plastic bags and paper bags. They discuss that when a plastic bag is reused, it is projected to have less of an impact on the environment, specifically contributing approximately 60% less in environmental impacts than a single-use paper bag [5].

Based on the results of this study, it is evident that non-plastic alternatives do not guarantee lower environmental impacts. This impact is the result of the material used for paper bag production. Unlike paper bags, plastic bags typically have two uses and require less material, and therefore the overall impacts of the plastic bag are reduced. The next key finding is that, specifically for plastic products, the production unit process is the driving force of environmental impacts. This is seen in all three studies for plastic bags, plastic cutlery, and plastic containers. It is noted that products that enter composting streams have their environmental impacts driven by the waste unit process. This is evident with both wooden products and biodegradable (PLA) products used in the cutlery and container studies. The last key finding from the results is that reusable products showed the greatest success (lowest environmental impact) across all categories. Cotton bags (in the bag study) are less impactful than both the paper bag (non-plastic single-use product) and the plastic bag, and this result is attributed to the fact that the cotton bag usage is higher (416 uses vs. 1 use vs. 2 uses, respectively).

4.2. Reduce and Reuse

It is known that all products that are produced and consumed have an environmental impact on both local and global scales. Governing bodies and agencies have been placing great importance on mitigating the impacts of plastics and microplastics due to concerns surrounding health and the environment [12]. However, although plastics do play a role in the contamination of aquatic, terrestrial, and food systems, it is also necessary to acknowledge contamination and pollution through other sources and materials. Non-plastic products, and especially single-use products, have negative implications for the environment as well. Eliminating and reducing the production and consumption of plastics does have many

benefits, but it also has limitations when considered in terms of the environment, economy, and society. As Canadians are experiencing now, moving towards a future with less plastic being produced and consumed will see a reliance on non-plastic alternatives (both single-use and non-single-use) as a stepping stone for a smoother adjustment. Given the results of this report, it is evident that single-use alternatives continue to pose challenges and threats to the environment. Therefore, to successfully transition society away from plastics and reduce overall environmental impacts, it is suggested that Canada and Canadians move towards alternatives that are reusable over non-plastic single-use products.

Reusable alternatives have the potential to reduce consumer reliance on single-use products. Since reusable products have a longer life span and have several uses, they eliminate potential reoccurring impacts from material extraction, production, packaging, transportation, and waste. Although usage may require inputs such as water, soap, and energy to upkeep and maintain the product, based on the results of this study, these do not equate to the environmental impacts of the processes associated with production, distribution, and disposal. Reusable products often have a high upfront cost in comparison to their single-use or disposal counterparts, but over time (depending on the product), reusable products become less expensive as cost per use decreases [50]. It must be acknowledged that more research must be conducted to understand the environmental, social, and economic impacts to determine the best strategies for implementing and promoting reusable products in Canada. For example, it is understood and accepted that not all single-use plastics and non-plastic products can be replaced with reusable alternatives, such as those used in the medical field [51].

4.3. Suggestions for Future Regulations

To complement the results and discussion related to this study, the following suggestions are outlined for future regulations that would be beneficial to Canadians.

(i) Promote the use of reusable products over single-use products that use alternative materials to plastic.

(ii) Educate Canadians on the impacts of production, consumption, and waste management of common products that are used and purchased.
- Education should be implemented in schools through environmental science courses starting from early childhood through to secondary school.
- Local education programs should be implemented to teach Canadians about sorting waste and how waste facilities are operated (so that Canadians understand their role in waste production and management).
- Campaigns should be run as public service announcements, to inform consumers about greenwashing marketing strategies and the importance of informed decision-making.

(iii) Fund research projects in the waste management sector to further mitigate impacts and challenges surrounding composting and recycling.
- Improvements should focus on increasing the number of products truly being recycled through technological advancements in sorting, identifying non-recyclables, etc.
- Run programs in coordination with education to promote consumer understanding of waste management.

(iv) Introduce regulations surrounding the labelling of biodegradable and compostable products.
- Test and ensure biodegradable products' breakdown at compost facilities.
- Develop a certification system specific to Canadian municipalities.

(v) Consider an informed ban on unnecessary single-use products, not just single-use plastics.
- Evaluate social and economic implications prior to implementation.

- Advertise the importance of reduction and reuse over recycling and composting.

4.4. Recommendations for Future Research and Questions

This report covered a variety of topics surrounding plastics, plastic alternatives, and waste, but research must continue in these areas to ensure consistent progress and the mitigation of environmental impacts. Below are some research areas and questions that should be considered as the next steps toward a more sustainable and informed Canada:

- Evaluate the environmental impact of reusable alternatives made with different materials (including hard plastics).
- Conduct an economic analysis of the impact of reusable products on small businesses. Will businesses be able to cut costs? Would a rebate or incentive be economical to promote the purchase of reusable products?
- Perform a survey or study of Canadians and their thoughts on eliminating single-use products altogether and their willingness to purchase and use reusable products.

5. Conclusions and Recommendations

Plastic and microplastic contamination continue to be growing problems across the globe for both ecosystems and human health. To address and mitigate issues related to plastics and microplastics, countries around the globe have begun to implement regulations and policies surrounding the production and use of plastics, specifically single-use plastic. Canada has introduced a single-use plastic ban. The goal of this report was to conduct an LCA on a series of plastic products that have been banned in Canada as well as currently available alternatives. Studies were conducted analyzing the environmental impacts of bags (plastic, paper, cotton), cutlery (plastic, wooden, biodegradable), and foodservice ware (plastic, styrofoam, biodegradable). Results showed overall that reusable products have less of an impact on the environment than both non-plastic and plastic single-use products. Furthermore, not all non-plastic alternatives have lower impacts than plastics. Both paper bags and compostable containers have higher environmental impacts than plastic bags and styrofoam containers, respectively. Plastic product production heavily plays a role in the environmental impact of plastic products.

Given the results, it is recommended that future regulations focus on promoting and educating consumers on the use of reusable products over single-use products, and the materials for reusable products and plastic alternatives should also be selected carefully to reduce their environmental impacts. Funding of projects to mitigate challenges associated with recycling and composting is also recommended. Lastly, an informed and well-researched ban should be considered on all single-use products, not just those made of plastic material. Conducting the studies for this project provides a background for potential future regulations and policies, but to effectively create change to mitigate the impacts of both plastics and other forms of waste on the environment, it is necessary that research continues in this area.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/microplastics3040038/s1, Figure S1: Environmental impacts for various stages of the life cycle of the single use of plastic cutlery when produced locally within Mississauga Ontario, Canada. Values are normalized; Figure S2: Environmental impacts for various stages of the life cycle of the single use of wooden cutlery when produced locally within Mississauga Ontario, Canada. Values are normalized; Figure S3: Environmental impacts for various stages of the life cycle of the single use of biodegradable cutlery (manufactured from PLA) when produced locally within Mississauga Ontario, Canada. Values are normalized; Table S1: SimaPro input parameters and associated units, values, and notes for plastic grocery bags; Table S2: SimaPro input parameters and associated units, values, and notes for cotton grocery bags; Table S3: SimaPro input parameters and associated units, values, and notes for paper grocery bags; Table S4: SimaPro input parameters and associated units, values, and notes for plastic cutlery; Table S5: SimaPro input parameters and associated units, values, and notes for wooden cutlery; Table S6: SimaPro input parameters and associated units, values, and notes for biodegradable cutlery manufactured from PLA; Table S7:

SimaPro input parameters and associated units, values, and notes for plastic containers; Table S8: SimaPro input parameters and associated units, values, and notes for Styrofoam containers; Table S9: SimaPro input parameters and associated units, values, and notes for biodegradable containers manufactured from PLA.

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