Life Cycle Inventory of Liquid Hand Soap Refill Packaging for Home Use

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Introduction

In recent years consumers have demanded more sustainable products and practices from the companies they purchase from. This is most apparent in the household soap industry. There have been several innovations like detergent sheets claiming to make the soap more sustainable by reducing the impact of transportation. However, less change has occurred in the hand soap space. The changes that have occurred focus on the container rather than the soap product itself.

Similarly, multiple studies have been conducted on the sustainability differences between soap types including a comparison between liquid and bar soaps (Witlox et al., 2015) and different bio-detergents (Villota-Paz et al.). Comparative LCAs have been completed on different soap dispenser types (Coppini et al., 2017) and laundry detergent packaging methods (Kim & Park, 2020). The publicly available information on soap refill packaging is limited to companies with a vested interest in selling their product like Zacros, a company offering refill pouches which claim to be the most sustainable option (Keane & Petlack, 2022). Given the lack of publicly available information on the sustainability of liquid hand soap packaging this assessment seeks to provide consumers with a life cycle inventory (LCI) from a source unaffiliated with the industry.

Goal & Scope

The goal of this life cycle inventory is to compare the environmental sustainability of liquid soap refills packaged in plastic bottles versus soap refill bags, which are marketed as a more sustainable alternative. This assessment aims to provide household consumers with information on the environmental impacts of these liquid soap packaging options, helping environmentally conscious shoppers make informed purchasing decisions. Environmental impact categories such as greenhouse gas (GHG) emissions as well as energy and water consumption will be considered during this inventory. The results of this comparative inventory will be publicly disclosed.

Function and Functional Unit

This inventory focuses on the packaging rather than the soap product contained within and will strive to compare identical or similar liquid soaps to focus on the packaging. The function of the product is to refill a soap dispenser rather than to clean hands. The scope of the project, as defined above, assumes that the soap liquid contained by the different packaging is comparable. However, the capacity (volume) of the packaging is a factor in the inventory. Most soap refill packaging supports more than one refill of an average 12[1] fl oz liquid soap dispenser but there is little consistency between brands and packaging materials.

The functional unit of this inventory is a soap refill container that holds 24 fl oz of liquid soap. 24 fl oz was selected as the functional capacity because for liquid soap refills to make sense, the refill needs to be more efficient or sustainable materially than purchasing a new dispenser altogether. While there may be some costs associated with the dispenser pumps, they are minimal at scale. As such, a package capable of holding at least two refills of the average soap dispenser is necessary to maintain the value of the soap refill product.

System Boundary

When conducting an LCI the system boundary is restricted to cradle to gate by the structure of the data as well as the models and tools used in data manipulation. This boundary excluding distribution, use and disposal of the produce. This is helpful in comparing products fairly because many of the companies producing bag refills are shipping direct to consumer rather than selling through retailers which presents challenges for assessing transportation costs.

While the LCI is limited to a strict cradle to gate structure, many of the claims by bag refill companies allude to reduced waste and transportation costs, a cradle to grave assessment would be useful in the future to further explore the subject. To create a reasonable scope for the funding and time available to the assessment that will follow this inventory, the system boundary for the LCA is also cradle to gate but slightly modified. To briefly explore the idea that transportation costs and impacts are a major factor, this study will assume that the manufacturer of each packaging option controls a pre-distribution warehouse facility separate from the production facility. The production facility is 50 miles via highway from the pre-distribution warehouse, goods are transported between these locations with tractor-trailers.

The following assumptions have been made to reduce confounding factors where possible:

- The average soap bottle is 12 fl oz.
- The liquid soap is the same between the package options.
- The packaging as well as the soap are manufactured the United States.
- All raw materials used in the packaging are virgin.

[1] Among a wide range of sizes, 12 fl oz soap dispensers emerge as a common standard size in the U.S. market.

- The soap manufacturer also manufactures their own containers (there is no distributor markup).

Input and Output Flows

Inventory input flows will include consumption of energy (MJ) and water (kg). The only output flow considered in the initial inventory is GHG emissions (kg CO_2e). That said, while not detailed in the primary results, the summary table includes other air quality indicators including respiratory effects, hazardous air pollutants, smog formation potential and ozone depletion. These effects were excluded from the detailed inventory to keep the scope reasonable but added to the summary for additional comparison. Additional inputs such as manufacturing materials and outputs such as solid or hazardous waste, environmental toxicity, etc. were excluded from this assessment to keep the scope reasonable. These categories were selected for exclusion because of the similar material inputs and manufacturing processes involved in the production of both refill containers.

Process-Flow Diagrams

The figures below illustrate the process-flows including inputs and outputs for plastic bottle and plastic bag soap refill packaging. As these products are compositionally similar, the process-flows differ only in raw material inputs and, at a more detailed level, the transportation impact per unit will differ because of the different materials.

Figure 1: **Bottled Soap Refill Process-Flow Diagram for LCI**
NAICS 326160 (Plastics Bottle Manufacturing)

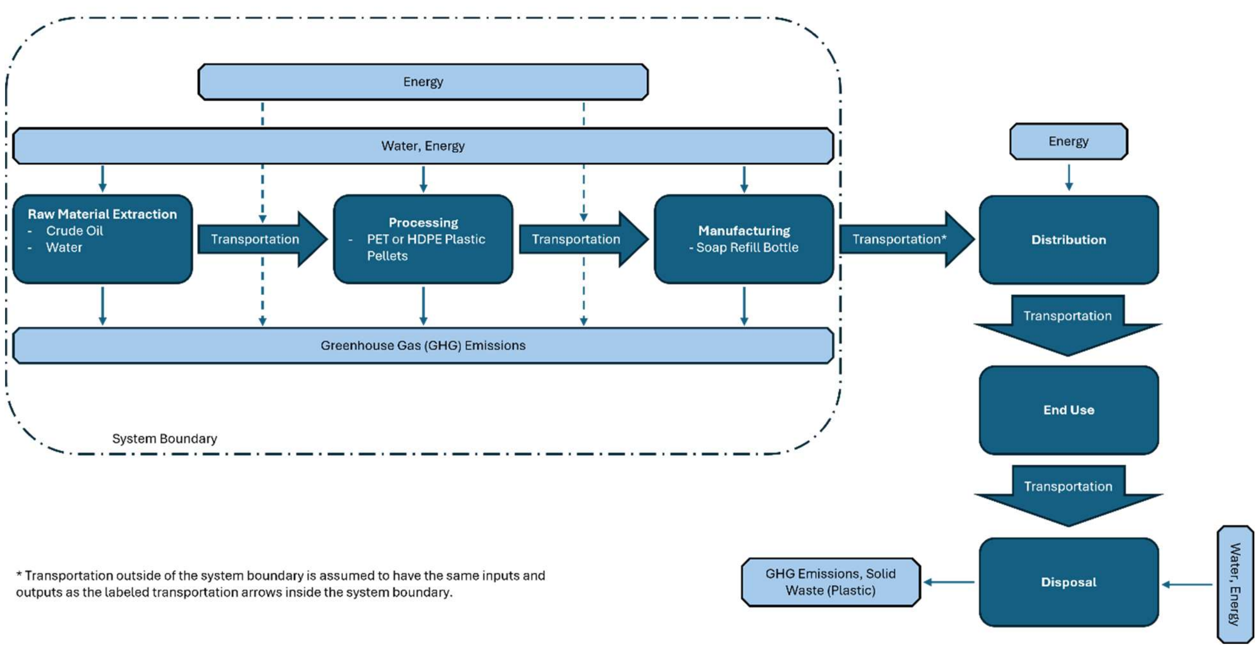
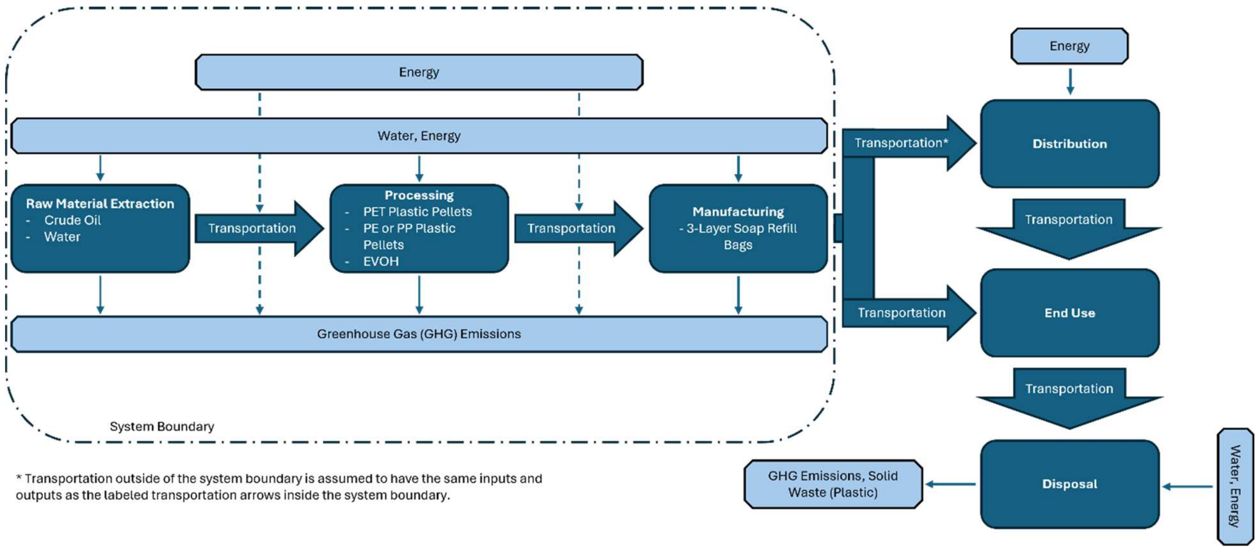


Figure 2: **Bagged Hand Soap Refill Process-Flow Diagram for LCI**
NAICS 326112 (Plastics Packaging Film and Sheet Manufacturing)



Environmental Impacts

Global warming potential and resource depletion are the two primary environmental impact areas of interest. Of those impact categories, greenhouse gas emissions (kg CO_2e) and water usage (kg) are the primary concerns. Energy consumption (MJ) is a secondary impact of concern that will be assessed if data are available and time allows. Both product flows are very similar, differing primarily in the additional raw material types required for the soap refill bags and the transportation impacts resulting from the different packaging. The assumptions detailed in this report will guide the focus of the environmental impacts and some of the secondary concerns may be excluded from the LCA report to follow if they end up beyond the scope of this project

Methods

Data Quality

This study is using an environmentally extended input-output model to calculate the life cycle inventory. Specifically, it will use the USEEIO v2.0.1-411 framework created by Li et al. This model represents the 50 US states using data from the US Bureau of Economic Analysis (BEA) which has been extended by the US Environmental Protection Agency's (EPA) Office of Research and Development to tie economic data for industry sectors to environmental data on resource use and waste production. The v2.0.1-411 model uses 2012 as the US dollar (USD) year for the model data where USD is used (Li et al.)

The assessment to follow will use secondary and tertiary data from the ecoinvent V3.11 database as well as literature data found in the references section of this report. There will be a preference for data from sources domestic to the United States of America as that is the author's country of origin and the location of the products which inspired this LCI. All literature data will be the most recent data available. The literature data used will be no data used prior to 2000. Given the limited resources and time, the scope may be narrowed to one environmental impact, likely global warming potential, if there is insufficient data to assess multiple impacts. The ecoinvent database will be accessed through OpenLCA the software tool used to model the assessment.

Functional Unit Economic Value

Refill Bottle:

In November 2023, the cost of producing a 500 ml PET bottle was $0.30 – 0.50 (2023 USD) (*Plastic Bottles Procurement & Cost Intelligence Report, 2024-2030*, n.d.). A quick look at bulk retailers shows the differences between 500 ml (~16 fl oz) bottles and the 24 fl oz containers needed for this study are minimal with prices leaning towards the high end of that range and decreasing for high-volume purchases. We will assume that each bottle costs $0.40 (2023 USD) given the likelihood of very high quantities. We are assuming that the markups which would normally increase the distributor and retail prices by ~20% and ~20% and ~30-40% respectively do not exist so it makes sense that it would be slightly cheaper than distributors are listing it for. The US Bureau of Labor Statistics lists 0.40 USD-2023 as having equivalent purchasing power to 0.30 USD-2012, a 33% inflation rate. For the 24 fl oz refill bottle functional unit in 2012 dollars, the estimated cost is $0.30 USD each.

Refill Bag:

As these bags are relatively new to the market, it is challenging to find research-validated sources for them. The cost may also decrease as they become more common and production lines shift to producing more of the bags. Today, in 2025, ULINE (an industrial distributor) sells bags like those used for 24 fl oz soap refills in 300 packs for $160 (USD-2025). That comes out to ~$0.53 per bag in current (2025) dollars, if we assume a 15% distributor markup increasing the cost we end up with ~$0.45 current dollars per bag. The US Bureau of Labor Statistics suggests that the 2012 value of $0.45 is $0.33. For the 24 fl oz laminated plastic pouch the estimated unit cost in 2012 dollars used in this report is $0.33 USD each

NAICS Sector Selection

The NAICS Association Code Search was used with keywords to find the best fitting sector for each product. Based on the descriptions for each sector, the NAICS sector used in this LCI for plastic refill bottles is Plastics Bottle Manufacturing (NAICS 326160). This sector is included in the 2012 USEEIO version used. The laminated plastic refill bags best fit Plastics Packaging Film and Sheet (including Laminated) Manufacturing (NAICS 326112). However, the USEEIO v2 model only included NAICS 326110, Plastic bags, films and sheets. Given that 326112 is a subsector of 326110, 326110 was used for the plastic bag refills.

Table 1: Summary of LCI Variables

Categoties	Bottle	Pouch/Bag	Units
Functional Unit	1	1	24 fl oz container
Production Price/Unit	$ 0.30	$ 0.33	$/ea
$ Value of Functional Unit	$ 0.30	$ 0.33	USD (2012)
NAICS Sector #	326160	326110	

Results

These results were calculated using the USEEIO v.2.0.1-411 model created by Li et al. and transposed to Microsoft Excel for easier modeling by Gwen DiPietro. All monetary values in this section are assumed to be USD 2012 unless otherwise specified. This model has been used to compare the two products discussed so far, and the results of the LCI have been summarized and adapted to display only the relevant categories.

Table 2: USEEIO v2.0 LCI Results

Inventory Impact Categories	Flow	Bottle	Pouch/Bag	Units
Biomass/resource/biotic	Input	6.819E-01	8.356E-01	MJ
Coal/resource/ground	Input	2.584E+00	2.644E+00	
Crude oil/resource/water	Input	6.617E+00	6.897E+00	
Energy, geothermal/resource/ground	Input	5.308E-02	4.754E-02	
Energy, hydro/resource/water	Input	1.322E-01	1.188E-01	
Energy, solar/resource/air	Input	9.051E-02	8.116E-02	
Energy, wind/resource/air	Input	3.216E-01	2.881E-01	
Natural gas/resource/air	Input	1.098E+01	1.144E+01	
Uranium/resource/ground	Input	1.136E+00	1.017E+00	
Water, fresh/resource/water/fresh water body	Input	2.779E+01	2.595E+01	kg
Water, fresh/resource/water/fresh water body	Input	7.566E+00	7.390E+00	

Table 2 Cont.: USEEIO v2.0 LCI Results

Inventory Impact Categories	Flow	Bottle	Pouch/Bag	Units
1,1,1-Trichloroethane/emission/air	Output	6.420E-06	6.553E-06	kg CO_2e
Carbon dioxide/emission/air	Output	8.144E-01	8.244E-01	
Carbon tetrachloride/emission/air	Output	2.384E-04	2.412E-04	
Carbon tetrafluoride/emission/air	Output	2.652E-04	5.359E-04	
CFC-11/emission/air	Output	3.443E-05	3.764E-05	
CFC-113/emission/air	Output	7.058E-04	6.892E-04	
CFC-114/emission/air	Output	5.658E-04	5.418E-04	
CFC-115/emission/air	Output	1.915E-05	2.464E-05	
CFC-12/emission/air	Output	2.210E-04	2.356E-04	
CFC-13/emission/air	Output	1.170E-05	1.114E-05	
Chloroform/emission/air	Output	1.208E-05	1.269E-05	
Chloromethane/emission/air	Output	3.387E-06	3.678E-06	
Dibromomethane/emission/air	Output	1.875E-10	2.382E-10	
Halon 1211/emission/air	Output	4.553E-07	5.824E-07	
Halon 1301/emission/air	Output	5.480E-06	7.025E-06	
HCFC-123/emission/air	Output	2.308E-06	2.424E-06	
HCFC-124/emission/air	Output	6.412E-06	8.111E-06	
HCFC-142b/emission/air	Output	3.175E-05	3.835E-05	
HCFC-21/emission/air	Output	2.199E-08	2.830E-08	
HCFC-22/emission/air	Output	1.295E-03	1.415E-03	
Hexafluoroethane/emission/air	Output	1.665E-04	3.478E-04	
HFC-125/emission/air	Output	1.455E-03	1.422E-03	
HFC-134a/emission/air	Output	1.638E-03	1.605E-03	
HFC-143a/emission/air	Output	8.015E-04	7.830E-04	
HFC-23/emission/air	Output	8.586E-04	1.131E-03	
HFC-236fa/emission/air	Output	3.339E-05	3.263E-05	
HFC-32/emission/air	Output	1.558E-04	1.523E-04	

Table 2 Cont.: USEEIO v2.0 LCI Results

Inventory Impact Categories	Flow	Bottle	Pouch/Bag	Units
Methane/emission/air	Output	9.531E-02	9.943E-02	kg CO_2e
Methyl bromide/emission/air	Output	1.328E-06	1.366E-06	
Methyl bromide/emission/air/troposphere/rural/ground-level	Output	8.564E-09	8.833E-09	
Methylene chloride/emission/air	Output	5.743E-06	6.231E-06	
Nitrogen trifluoride/emission/air	Output	5.469E-05	1.234E-04	
Nitrous oxide/emission/air	Output	6.833E-02	6.575E-02	
Perfluorocyclobutane/emission/air	Output	9.841E-06	2.220E-05	
Perfluoropropane/emission/air	Output	9.043E-06	2.040E-05	
Sulfur hexafluoride/emission/air	Output	7.750E-04	8.483E-04	

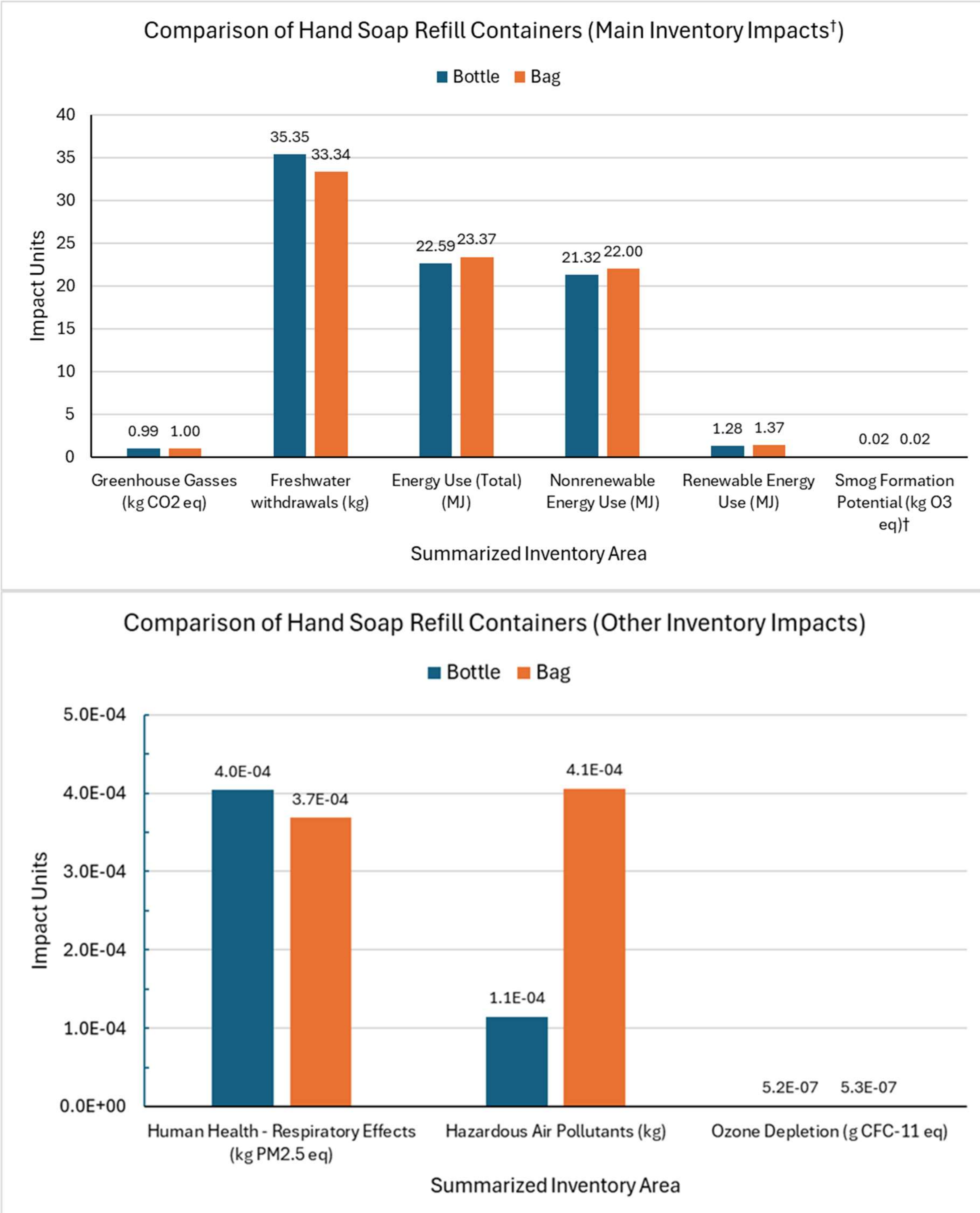
The following table contains data outside the main scope of the project, summarized and included for additional comparison given the similarities between the main LCI results.

Table 3: USEEIO v2.0 LCI Expanded and Summarized Results

Categoties	Flow	Bottle	Pouch/Bag	% Diff.*	Units
Main Invetory Impacts					
Greenhouse Gasses	Output	0.987	1.000	1.256	kg CO_2 eq
Freshwater withdrawals	Input	35.355	33.340	-5.698	kg
Energy Use (Total)	Input	22.595	23.374	3.448	MJ
Nonrenewable Energy Use	Input	21.315	22.002	3.224	MJ
Renewable Energy Use	Input	1.279	1.371	7.174	MJ
Other Inventory Impacts (Air Quality)					
Human Health - Respiratory Effects	Output	4.039E-04	3.689E-04	-8.673	kg PM2.5 eq
Hazardous Air Pollutants	Output	1.147E-04	4.058E-04	253.710	kg
Smog Formation Potential	Output	0.0222	0.0231	4.279	kg O_3 eq
Ozone Depletion	Output	5.24003E-07	5.347E-07	2.041	kg CFC-11 eq

*Calculated relative to the bottle refills to normalize the data.

Figure 3: Comparison of Hand Soap Reill Container USEEIO v2.0 Results



† Smog formation potential is not included in the main inventory impacts but is displayed with the main inventory impacts due to numerical magnitude relative to the remaining Other Inventory Impacts.

Discussion

These data show the breakdown between renewable and non-renewable sources as well as other impacts to air quality. Given the similarity between the two products, comparisons were made in Table 3 using percent difference to reflect the relative change from bottle refill containers to bag refill containers. Of the summarized categories included in the main inventory, only freshwater withdrawals and renewable energy use reflect major differences (> 5% difference) between the products. The additional impacts included in Table 3 show two more categories with major differences, albeit at a much smaller magnitude. The impact of producing refill bags on respiratory effects is lower than for refill bottles. Additionally, there is over 250% difference in Hazardous Air Pollutants released between bottle and bag refills, strongly favoring bottles.

Other than the few categories listed above the remainder of the inventory reflects less than a five percent difference in values. With similar values, the bottle refills seem to be slightly more sustainable in most areas. However, the differences are so minor that forming a definitive statement is difficult if not impossible. Freshwater withdrawals and respiratory effects are the only areas where there is a major difference in favor of the bag refills. Hazardous air pollutants is the category with the greatest percent difference by far and favors bottle refills as the more sustainable option. However, without the impact assessment that will follow this LCI, it is difficult to determine the weight of each impact category. If the magnitude of the difference matters, it may be worth including the category in the main inventory impacts going forward. If the magnitude of the impact has any bearing, hazardous air pollutants are among the smallest values in the inventory for both containers.

While much of this LCI remains similar, clear differences may be related to comparing products from two different NAICS Sectors, creating areas with impact categories with more significant differences. While there are no significant differences in the use of the product, the different distribution pathways reflected in Figures 1 & 2 may be significant when calculating transportation impacts. Transportation impacts may also be affected by the weight or shape of the container making one option more efficient. Given the soap contamination, recycling is likely difficult if not impossible. Assuming neither container is getting recycled, the only real difference in the waste management phase is again the weight and size of the empty refill containers which may favor the bags as they take up less space.

Any number of the assumptions made in the Goal & Scope or Methods Sections of this report may affect the data if they are incorrect. The average refill size and financial value of the functional unit are the estimations most likely to have a large impact on the data. The assumptions that the containers only contain virgin plastic and are produced cradle to gate exclusively domestically are unlikely conditions, set to simplify the system.

Foreign production and some use of recycled plastic in manufacturing are likely scenarios that could have any number of impacts on the LCI. These scenarios need much more detailed process flow analysis to begin to predict the impact on the LCI. This study represents a comparison of more similar products than previously assessed. While historic studies have found more substantial differences between liquid and bar hand soaps (Witlox et al, 2015) as well as different laundry detergent materials and packaging formats (Kim & Park, 2020) there has been little research comparing such similar items. Beyond the life cycle impact assessment to come, more research on the efficiency of conventional liquid vs foaming liquid hand soaps could add more nuance to the topic.

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