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

ESS 555: Life Cycle Assessment for Sustainability

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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.

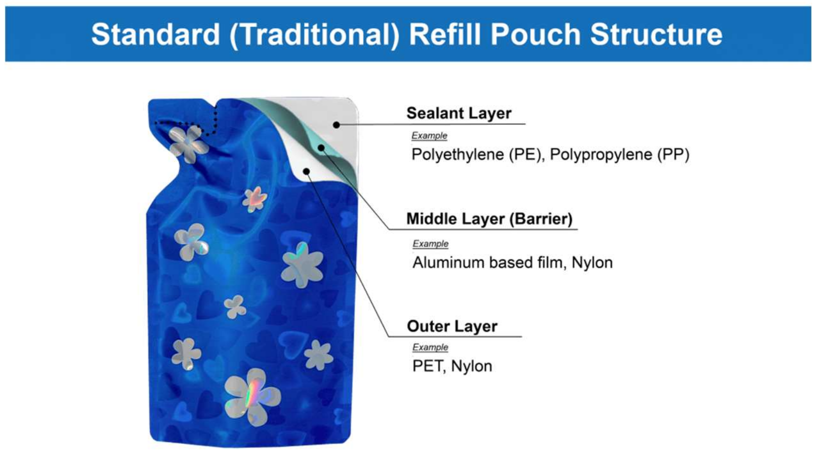

Figure 1: Example Hand Soap Refill Pouch Construction (Keane, 2022)

Inventory Analysis

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 pouches, 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. Target environmental impact categories include greenhouse gas (GHG) emissions as well as energy and water consumption will be considered during this inventory. Other impact categories are not the target of this study but may be included if results are notable. 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. That said, the pouch refills range from 28 to 67.6 fl oz with most holding ~32 fl oz. Bottle refills range from 24 fl oz to 64 fl oz with many holding ~50 fl oz. This analysis uses 30 fl oz pouches and 50 fl oz bottles due to local availability.

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 container altogether. While there may be some costs associated with the soap pumps, they are assumed to be zero in this context to reduce uncertainty. 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

The system boundary of this LCIA is limited to cradle to gate, to reduce scope, complexity and uncertainty. This boundary definition is helpful in comparing products fairly because many of the companies producing pouch refills are shipping direct to consumer rather than selling through retailers, which presents challenges when establishing market values for transportation costs.

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

The following assumptions involving the system boundary have been made to reduce confounding factors where possible:

- The average soap dispenser bottle is 12 fl oz.
- The average pouch refill size is 30 fl oz.
- The average bottle refill size is 50 fl oz.
- The liquid soap is the same between the package options.
- All raw materials used in the packaging are virgin.

Input and Output Flows

Inventory input flows will include consumption of energy (kg oil-eq) and water (m^3). The only output flow considered in the initial inventory is GHG emissions (kg CO_2e). While other flows are not the focus of this study, results will be available after completion of calculations and other flows that stand out will be mentioned.

Process-Flow Diagrams

The figures below illustrate the process-flows including inputs and outputs for plastic bottle and plastic pouch soap refill packaging. These products are somewhat similar in material composition such that the process-flows differ some in petrochemical compounds but primarily in input quantities and in the specific manufacturing processes, not detailed in the figures below. There are also differences in transportation outside of the system boundary as mentioned previously.

Figure 2: **Hand Soap Bottle Refill Process-Flow Diagram for LCIA**

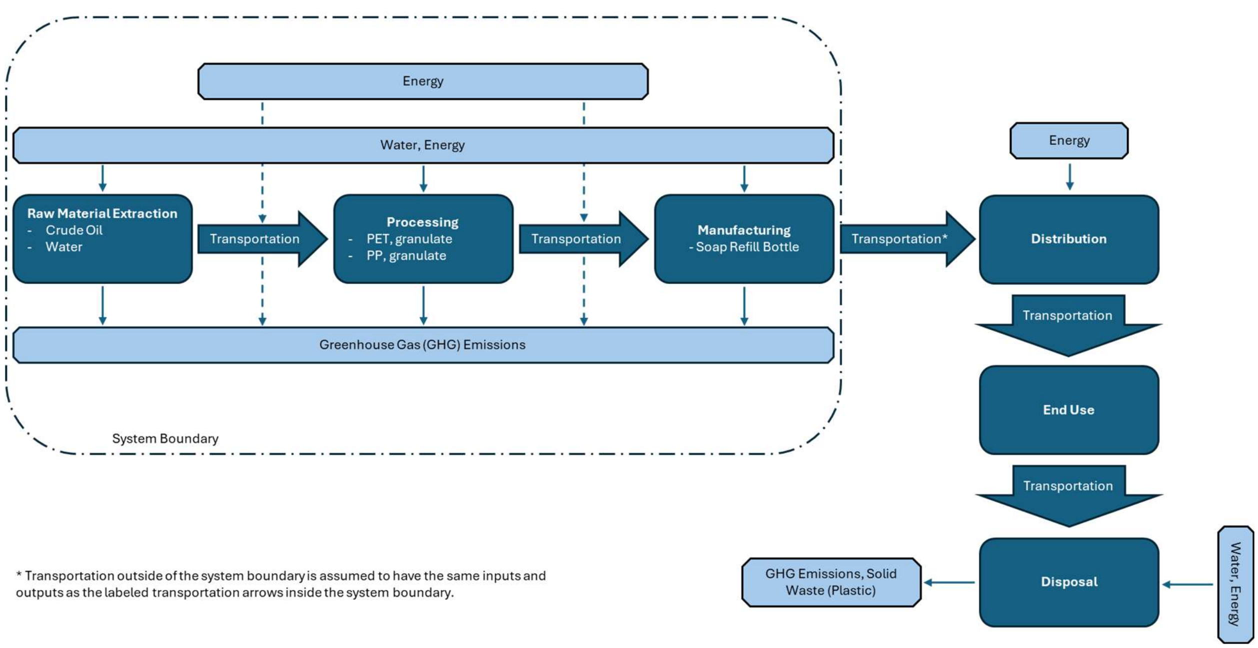
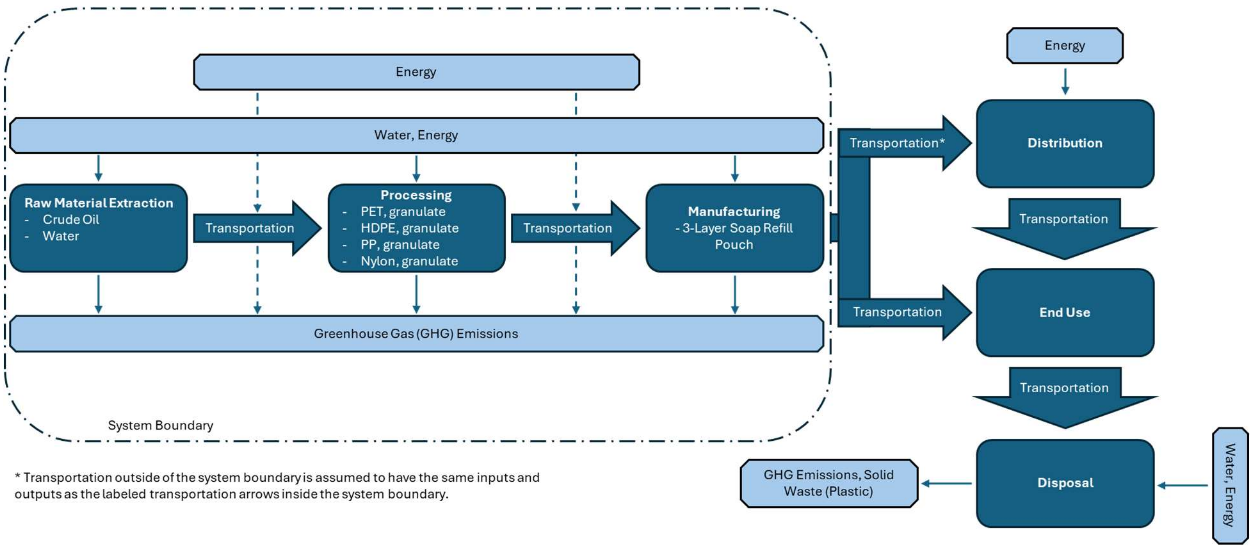


Figure 3: **Hand Soap Pouch Refill Process-Flow Diagram for LCIA**



* Transportation outside of the system boundary is assumed to have the same inputs and outputs as the labeled transportation arrows inside the system boundary.

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 (m^3) are the primary concerns. Energy consumption (kg oil-eq) 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 pouches 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

A sample product from each category was used weighed to determine mass scaling for each input flow. Input flows based on item quantity rather than mass were scaled based on a relatively large flat bed die cutting process detailed on an industry supplier website. The estimate for die cutting and sealing (see Table 2, stamping and thermocompression) the die cut pieces assumes 30 pouches are produced in each batch (Focus Digital Development, 2025). The output flows were scaled to the functional unit based on volume. The values listed in Table 1 were modified with conversion factors to

Table 1: Soap Refill Container Mass Composition

Product	Refill Bottle	Refill Pouch
Volume	50	30
Volume Unit	fl oz	
Mass Unit	g	
Lid/Cap Mass	4	4
Body Mass	62	17
PET Mass	62	4.25
PP Mass	4	4.25
PA (Nylon) Mass	-	8.5
HDPE Mass	-	4

account for loss in the manufacturing processes based on the flow description for each process.

Product systems for each product were modeled in OpenLCA using ecoinvent 3.11 without creating custom flows or processes. The database had "Allocation, cut-off by classification (Cutoff, U)" providers which were selected resulting in no additional allocation method be used during calculation to avoid double allocation. ReCiPe 2016 v1.03 was the model selected using the "midpoint (H), no LT" version to calculate midpoint impact on a 100-year timeframe excluding long-term emissions associated with disposal since use and disposal are not included in the scope of the project. Table 2 (below) identifies the manufacturing process flows from ecoinvent 3.11 used in each product system. Selection of stamping and thermos compression flows was based on melting and bonding temperatures of the component plastics.

Table 2: Manufacutring Processes for Soap Refill Containers

Product	Refill Bottle	Refill Pouch
Blow Moulding	X	-
Injection Moulding	X	X
Extrusion, plastic film	-	X
Stamping, electricity use, 50-150 t press, >200 °C	-	X
Thermocompression, electricity use, 50-150t press, 180 °C, 20 min. cycle	-	X

Uncertainty calculations used Monte Carlo Simulations with not additional cutoff and 1000 iterations and uncertainty matrices account for the small sample size of mass measurements and limited information about production practices.

Data Quality

This analysis uses data from ecoinvent 3.11, downloaded on January 31st, 2025. Preference was given to global (GLO) market providers to best capture the global economy and unknown origins of many plastics and raw materials for plastic production. To that end, most of the ecoinvent data used in the process comes from "Cutoff, U – GLO" providers. Nylon 6, data was unavailable with a global provider, so a "rest of world (RoW)" market provider was selected instead to best align with the global scope of the other data.

Other data sources include literature data found in the references section of this report, as well as product data collected through physical analysis of empty soap refill containers as detailed in the methods section. All literature data will be the most recent data available. The literature data used will exclude data produced prior to 2000, unless no other option is available.

This is intended as a preliminary assessment, the masses used in this assessment were measured from two example products from a large home good chain for convenience. Processes involved in the refill pouch production required quantity input rather than mass input. For those inputs it was assumed both processes operated in batches of 30 pouches making the itemized impact ~0.033. This assumption was made due to limitations in the plastics manufacturing processes listed in the ecoinvent 3.11 database and lack of publicly available information on manufacturing processes. If notable patterns are observed, a more rigorous assessment of both products to achieve a more wholistic understanding of average material input masses and manufacturing process quantities. This boundary excludes distribution, use and disposal of the produce.

Results

General Results

Table 3: ReCiPe 2016 v1.03 - midpoint (H), no LT Impact Analysis Results					
Name	Refill Pouch	Refill Bottle	Unit	Higher Impact Product	% Difference
Acidification: terrestrial no LT	0.00142	0.00092	kg SO2-Eq	Pouch	42.57%
Climate change no LT	0.44177	0.32314	kg CO2-Eq	Pouch	31.02%
Ecotoxicity: freshwater no LT	0.00014	0.00022	kg 1,4-DCB-Eq	Bottle	42.84%
Ecotoxicity: marine no LT	0.00054	0.00083	kg 1,4-DCB-Eq	Bottle	41.68%
Ecotoxicity: terrestrial no LT	0.59062	0.84307	kg 1,4-DCB-Eq	Bottle	35.22%
Energy resources: non-renewable, fossil no LT	0.12615	0.13687	kg oil-Eq	Bottle	8.16%
Eutrophication: freshwater no LT	0.00002	0.00001	kg P-Eq	Pouch	50.93%
Eutrophication: marine no LT	0.00001	0.00001	kg N-Eq	Pouch	28.59%
Human toxicity: carcinogenic no LT	0.00117	0.00120	kg 1,4-DCB-Eq	Bottle	2.53%
Human toxicity: non-carcinogenic no LT	0.06144	0.05362	kg 1,4-DCB-Eq	Pouch	13.60%
Ionising radiation no LT	0.00336	0.00177	kBq Co-60-Eq	Pouch	62.02%
Land use no LT	0.00675	0.01635	m2*a crop-Eq	Bottle	83.09%
Material resources: metals/minerals no LT	0.00315	0.00520	kg Cu-Eq	Bottle	49.09%
Ozone depletion no LT	0.00000	0.00000	kg CFC-11-Eq	Bottle	20.13%
Particulate matter formation no LT	0.00078	0.00046	kg PM2.5-Eq	Pouch	51.58%
Photochemical oxidant formation: human health no LT	0.00100	0.00072	kg NOx-Eq	Pouch	32.40%
Photochemical oxidant formation: terrestrial ecosystems no LT	0.00104	0.00079	kg NOx-Eq	Pouch	27.58%
Water use no LT	0.00351	0.00205	m3	Pouch	52.47%

In two of three impact categories, climate change and water use, the pouch refills have higher impact than the bottle refills. In energy use, the bottle refills have a greater impact, but the relative difference is smaller than the differences in climate change and water use.

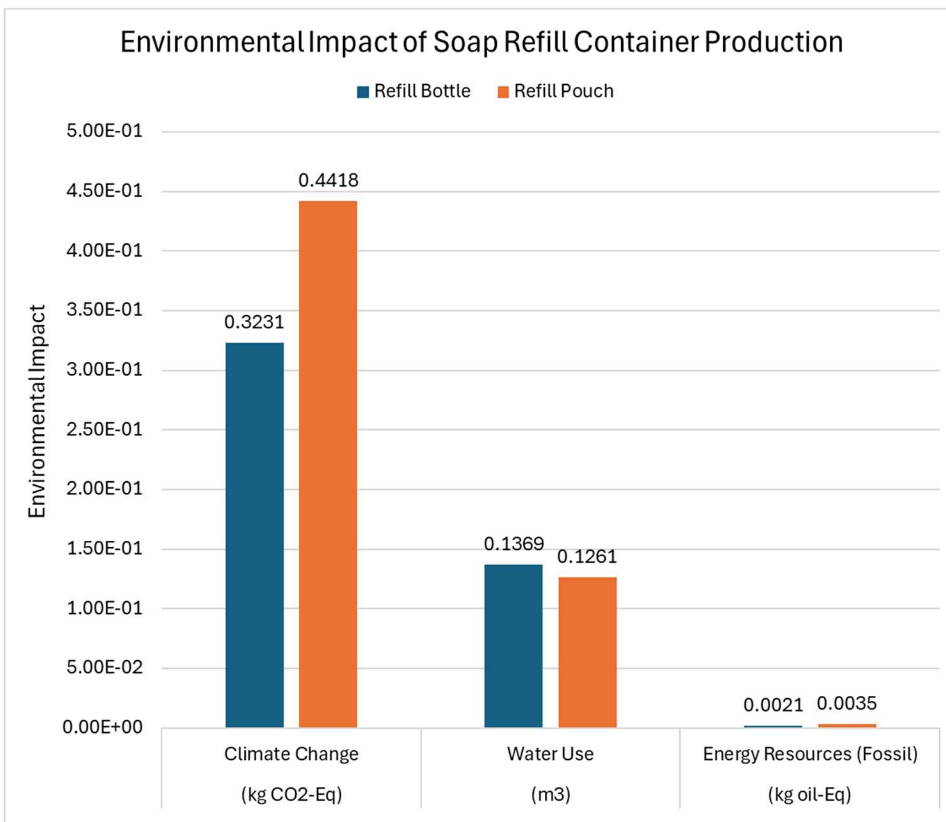


Figure 1: Environmental Impact of Soap Refill Container Product Systems

Uncertainty and Variability

Mass measurements, container volume assumptions, and assumptions regarding manufacturing processes almost certainly have a moderate level of uncertainty. A larger, more representative sample of container mass and volume as well as a better understanding of manufacturing processes would significantly reduce data uncertainty.

Table 4: Uncertainty Matrix Values

Refill Bottle Manufacturing	Reliability	Completeness	Temporal Correlation	Geographical Correlation	Further Technological Correlation	Base Uncertainty
blow moulding	3	2	2	2	1	1.0
injection moulding	3	2	2	2	1	
polyethylene terephthalate, granulate, bottle grade	3	2	2	2	1	
polypropylene, granulate	3	2	2	2	1	
Refill Pouch Manufacturing	**Reliability**	**Completeness**	**Temporal Correlation**	**Geographical Correlation**	**Further Technological Correlation**	**Base Uncertainty**
extrusion, plastic film	3	2	2	2	2	1.0
injection moulding	3	2	2	2	1	
nylon 6	3	2	2	2	2	
polyethylene terephthalate, granulate, bottle grade	3	2	2	2	1	
polyethylene, high density, granulate	3	2	2	2	1	
polypropylene, granulate	3	2	2	2	1	
stamping, electricity use...	4	2	2	3	3	
thermocompression, electricity use...	4	2	2	3	3	

To account for data inconsistencies, uncertainty was calculated with ecoinvent using the ecoinvent Data Quality System. The uncertainty matrix values are reflected in Table 4 for each flow with higher values accounting for low accuracy, small sample size measurements for mass and single source predictions for production quantities. When running the Monte Carlo simulation, the median was the reference value used to compare to the general results. Of the three target impact categories, climate change is much less affected by uncertainty than water use and energy resources for both products. Unfortunately, the small sample size and lack of industry inside information of manufacturing techniques limits the usability of the model for water use and energy resources but the model can still be used to assess climate change impact. The modeling of the other two impact categories would likely improve significantly with stronger industry sources behind the manufacturing process assumptions and more, higher precision mass measurements.

Table 5: Monte Carlo Simulation Results

openLCA Results	Climate Change	Water Use	Energy Resources
Units	kg CO2-Eq	m3	kg oil-Eq
Bottle	0.32314	0.13687	0.00205
Bottle w/ Uncertainty	0.32393	0.00205	0.13693
Bottle % Difference	0.244%	194.099%	194.096%
Pouch	0.44177	0.12615	0.00351
Pouch w/ Uncertainty	0.39734	0.00317	0.11445
Pouch % Difference	10.590%	190.199%	188.096%

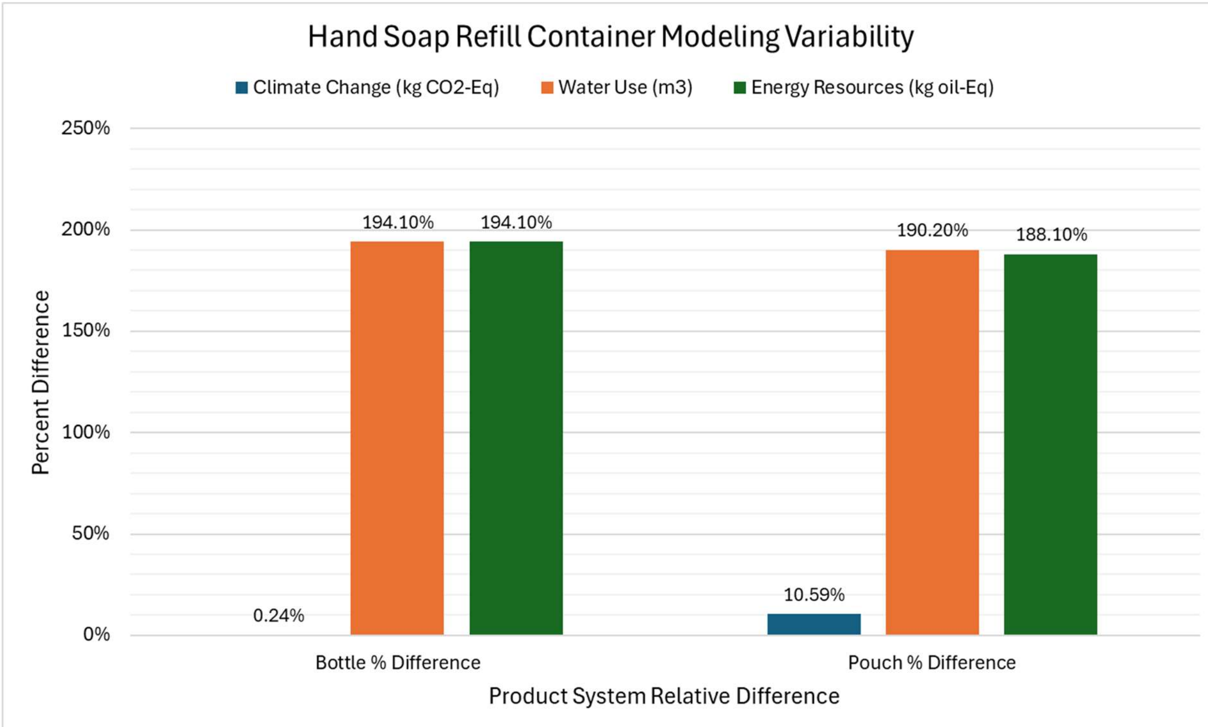


Figure 2: Variability from Uncertainty in Product Systems for Soap Refill Containers

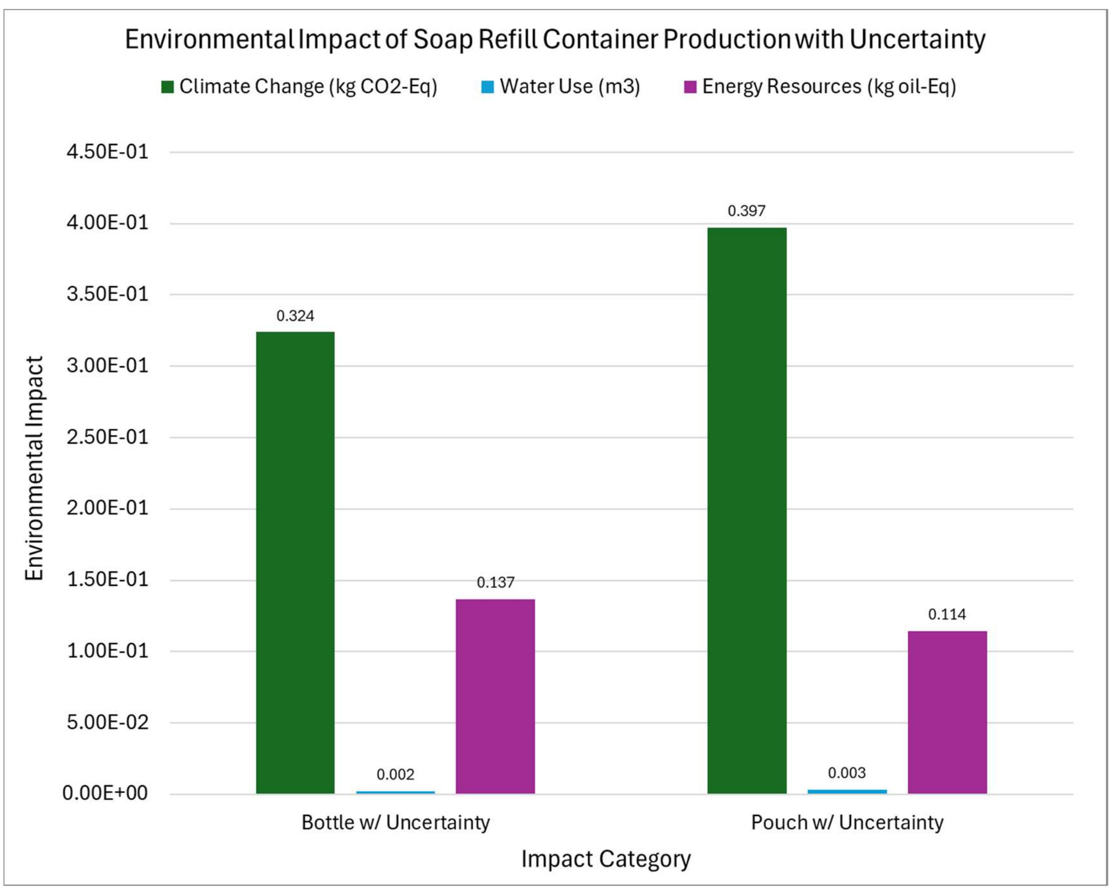


Figure 3: Environmental Impact of Soap Refill Container Product Systems Adjusted for Uncertainty

Sankey Diagrams

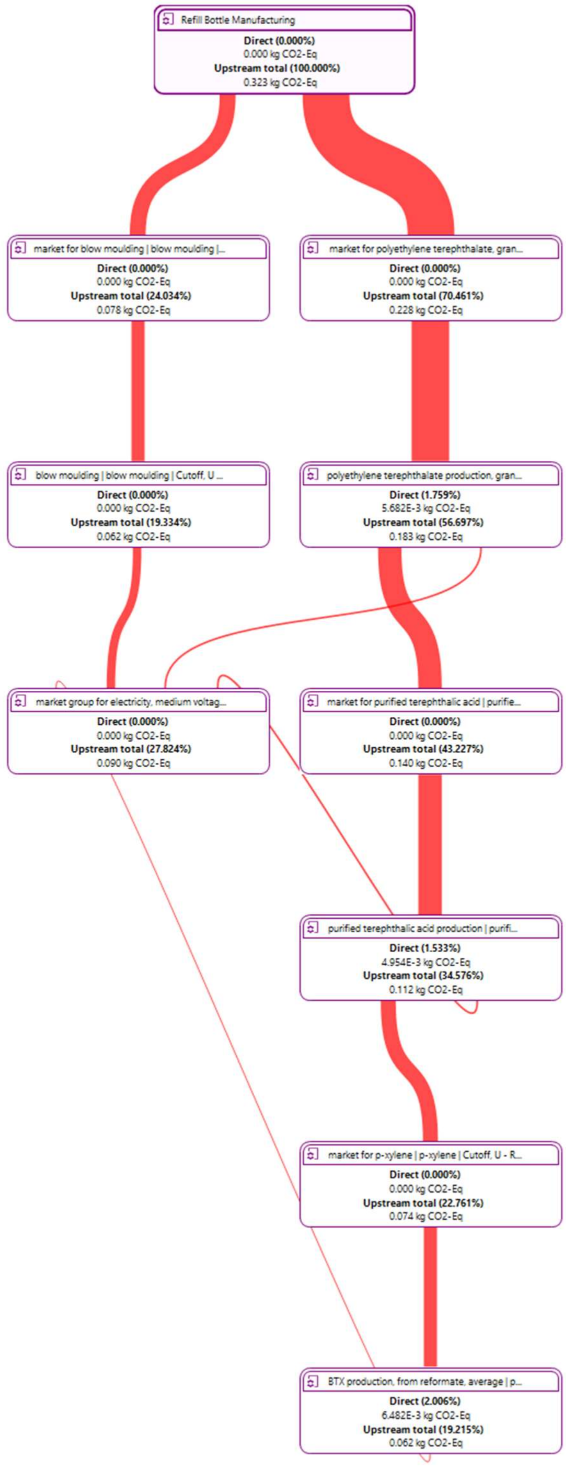


Figure 4: Sankey Diagram from Refill Bottle Manufacturing Climate Change Impacts

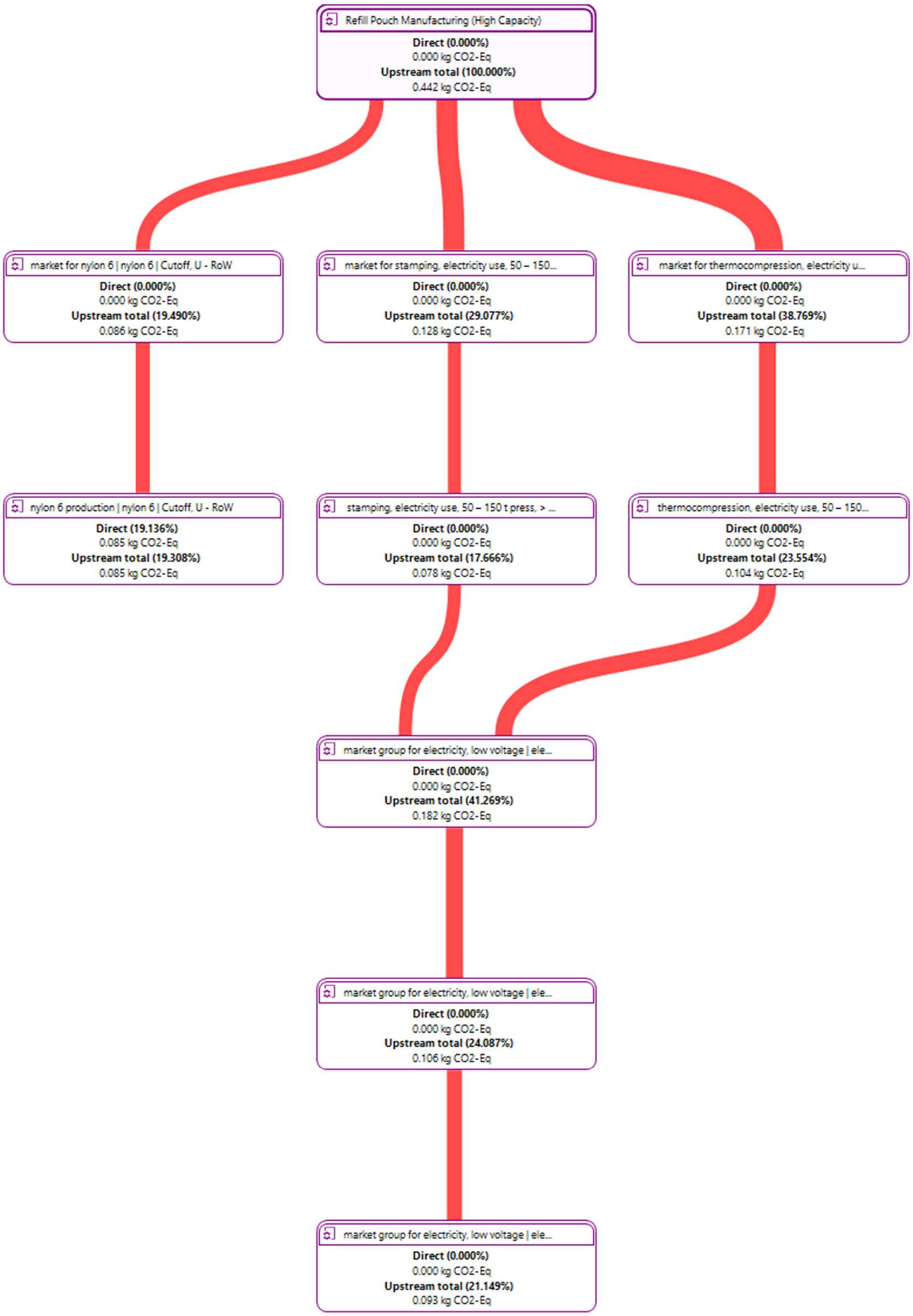


Figure 5: Sankey Diagram from Refill Pouch Manufacturing Climate Change Impacts

The Sankey diagrams show that much of the climate change impact (kg CO_2e) for the refill bottles stems from PET granulate production and the blow molding process. While the main climate change impact (kg CO_2e) for bottles is in the PET production and molding process for the refill pouches most of the impact stems form the stamping and thermocompression processes during manufacturing with nylon production as a tertiary factor.

Discussion

Data uncertainty has been a major problem in this report, primarily conflicting with scope and budget, preventing significant market research regarding average soap container sizes and component petrochemical masses. The easiest way to improve this for a future experiment would be to reach out to manufacturers and ask for specifications or samples, barring that commercially available soap refills could be purchased and measured. Alternatively, this research could be adapted to the container types in more general terms to examine a wider range of different multi-layer plastic pouches and different bottle materials from container manufacturers rather than needing to work directly with soap companies which are financially incentivized to put their product on a pedestal.

This LCIA looked exclusively at PET bottles with PP caps and PET/PA/PP laminate pouches with HDPE caps. As Figure 1 identifies, there are multiple petrochemical compounds used in laminate pouches including ethyl vinyl alcohol (EVOH), not mentioned in the ZACROS article. The environmental impact of each of these laminate combinations may be significantly different such that one or more combinations not discussed in this report can provide a more sustainable alternative. That said, this LCIA assumed virgin material and only considered cradle to gate, excluding distribution, use and disposal. Figures 2 and 3 highlight clear differences in distribution patterns with the pouches much more likely to be sold with a direct-to-consumer model, potentially reducing the environmental impact of post-production transportation. Even accounting for the smaller volume of the refill pouch tested in this report, the pouches are also lighter per fluid ounce than the bottles, potentially making transportation more efficient and reducing the environmental impact of transportation.

On the other hand, the plastic films required in the pouch refills usually require higher quality material than the bottles which may be able to use more recycled material were the virgin plastic assumption dropped. Finally, the pouches are harder to recycle both consisting of plastic film, a difficult material to recycle to begin with and a composite material requiring separation prior to recycling. Additionally, if there is a local source for the soap, reuse becomes a significant consideration. Similarly to plastic and paper shopping bags, if one product ends up being more durable therefore, it gets reused more times than it may have a significant edge in more wholistic cradle to grave LCAs (Gaudreault, 2020).

Without more technical knowledge it is difficult to say if there are more circular use opportunities with the bottle refills, but an easy next step is changing some or all of the material flows to the preexisting recycled material flows in the ecoinvent 3.11 database and testing again. Ideally this testing would include a larger, more representative sample of volume and mass data to refine the assumption made by this report. It seems that an additional report should combine the soap and packaging as more support for a cradle to grave analysis comes from Witlox et al (2015) identifying the use phase of soap as significantly higher impact than the manufacture of it, in large part due to heating water for handwashing.

The uncertainty adjusted results in Figure 5 suggest that soap refill pouches are roughly equivalent or even detrimental to the environmental impact of soap refill containers. While water use and energy use aren't directly comparable because of the data uncertainty there are no clear differences in either category. In combination with the significantly worse greenhouse gas emissions from the refill pouch product system it is safe to say that using these methods and metrics, the refill pouches have an equal or greater environmental impact than the refill bottles. Though somewhat inconclusive, the lack of a clear difference between the containers across multiple impact areas provides some degree of evidence against one option being substantially more sustainable.

Previous independent studies from Kim and Park (2020), Villota-Paz et al (2023) created significant suspicion of claims like those made by Keane and ZACROS (2022), a company trying to sell these refill pouches. Kim and Park found that despite requiring less identifiable plastic, laundry detergent pods used higher impact plastics that were just less identifiable as plastic to laypeople. The idea that much of the alternative packaging of soaps is a marketing ploy aligns with the results of this study. Witlox and Villota-Paz focused more on the use phase. Villota-Paz found similar to Kim and Park, some bio-detergents weren't much better than their synthetic counterparts and sometimes they were worse. Given the increasingly technical landscape of science and sustainability it's important to provide resources for the general population to educate themselves on science and develop more advanced critical thinking skills. Critical thinking skills and technical jargon aren't the only problem though, the need to pick a side and societal pressure for individuals to maximize their personal sustainability need reevaluation. While personal sustainability is important, corporate and industrial sustainability is higher impact with substantially more room for improvement.

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