Food Service Ware LCA Harmonization

Submitted to: City of Portland Bureau of Planning and Sustainability (BPS)
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Table of Contents

Executive Summary

Many businesses and individuals are seeking to reduce the environmental impact of single-use food service ware items, such as cups, clamshells, and cutlery. Purchasing products that feature attributes such as "compostable" or "biobased" is a very common strategy. However, recently published research by the Oregon Department of Environmental Quality suggests that these attributes do not necessarily correlate with low-impact food service ware items. In response, the City of Portland asked DEQ if there is some other simple way of identifying lower-impact food service ware items. Specifically, the City asked if items made of certain materials can be shown to reliably and consistently result in lower impacts when compared against items made of different materials.

To evaluate that question, DEQ used the same methods as its previous research: a review of previously published life cycle assessment literature. For simplicity and due to inconsistency across studies, this new assessment considers only one type of environmental impact: climate change. Forty-seven data points were found representing food service ware that is "all or mostly landfilled," which is representative of waste management practices for food service ware in the Portland area. Considering all types of end-of-life methods, a total of 78 data points were found. The relatively small sample size representative of Portland-area waste management resulted in fewer statistically meaningful findings.

Across the larger sample, the following key findings emerge:

- Reusable dishware is often found to result in a lower carbon footprint than several different types of single-use items.
- Other than that, the type of material (e.g., PET vs. paperboard) is not a consistent or reliable predictor of reduced impact. There does not appear to be a clear "best" material among single-use options, at least from the perspective of climate change. Paperboard items frequently were found to have a lower carbon impact than items made from molded pulp or a number of different plastic resins (including bio plastics), but the distinction was not statistically significant.
- With the exception of reusable items, where washing dominates impacts, production-related impacts are typically many times larger than impacts at end of life.
- Different end-of-life treatments (e.g., landfilling, composting, recycling, or incineration) can result in different levels of emissions (or in some cases, emissions reductions). Recycling was found to consistently reduce emissions, while composting was found to consistently increase emissions. However, the number of data points evaluating recycling and composting were limited. The impacts of landfilling and incineration vary by material type – both sometimes result in net emissions and sometimes result in net emission reductions, depending in part on the material.
- Food service ware is a relatively small contributor to climate change. If every Oregonian used a single-use hot cup, cold cup, clamshell, dish, and cutlery set every day of the year, and happened to always choose the material and formulation with the highest carbon footprint, the resulting greenhouse gas emissions would equate to approximately 0.6 percent of Oregon's total consumption-based greenhouse gas emissions. In contrast, food and beverages represent 13 percent of emissions. Preventing the wasting of food may be a more important area to focus.
- That said, food service ware (FSW) items should not be ignored, as they are highly visible and sometimes unessential. The best approach is to avoid them when unnecessary, then to identify better choices by screening options using life cycle assessment to accurately understand environmental trade-offs.

1. Overview

Oregon DEQ's Materials Management program recently completed an analysis of published life cycle assessment (LCA) literature to answer the question, "Do material attributes correlate with reduced environmental impacts?" The study examined four attributes – recycled content, recyclable, compostable, and bio-based, along with two product categories – packaging and food service ware (FSW). Many of the study findings run contrary to popular wisdom and generally suggest (with exceptions) that, taken alone, a given attribute is not a consistent predictor of reduced environmental impacts.[1]

The results of DEQ's analysis are potentially disruptive, since purchasers, producers, and policy-makers have commonly used these attributes to make decisions. Furthermore, the results have limited potential for immediate action: they suggest what *not* to do—rely exclusively on attributes—but do not explicitly suggest an actionable alternative, other than to make decisions based on actual environmental impacts. However, information on actual impacts, especially for food service ware, is rarely available to purchasers in today's marketplace. Reflecting on that dynamic and in response to DEQ's analysis, the City of Portland asked DEQ the following questions (paraphrased): Since attributes are not a reliable predictor of reduced impact for food service ware, is there other, similarly simple guidance that the City could provide to businesses instead? Specifically, are certain materials or classes of materials consistently associated with reduced impacts?

This report documents DEQ's effort to answer that question. The following analysis is an extension of the original attributes study in which we seek to determine the preferred material for each of five FSW categories. As with the original study, the methodology here involves evaluating existing life cycle assessment literature, as opposed to conducting original modeling of environmental impacts. In this case, **Global Warming Potential (GWP)** is the environmental impact against which each product category and material type is evaluated. GWP was the most reported impact category across the literature, though it should be acknowledged that there are other impact categories and trade-offs that occur, those are omitted here since only GWP is considered. All GWP values within this report have the unit of "kilograms of carbon dioxide equivalents" **(kg CO_2 eq.)** unless otherwise noted.

[1] See https://www.oregon.gov/deq/mm/production/Pages/Materials-Attributes.aspx.

2. Methodology

To determine the preferred material – in terms of GWP – for each product category, we started with the literature from the original attributes study. The original attributes research contained 11 studies for FSW, however, four were deemed unsuitable for harmonization and so were excluded. DEQ contacted the authors of these four studies in an attempt to resolve data gaps, but was unable to obtain the necessary information. As an example, two of these four studies published normalized results, as opposed to absolute Life Cycle Impact Assessment results, meaning that the values could not be harmonized.

We ended up with 78 data points across seven studies. This represents a small sample size for FSW, particularly when compared to the number of studies found for packaging as a general category. A table of the original FSW studies can be found below, with key details related to their scope, and an indication of whether they were included in this report (Table 1). A decision flowchart illustrates our data exclusion process (Figure 1).

Table 1 - Summary of Literature Used for Harmonization

						Generic Material				Boundary			
Author	**Year**	**FSW Product**	**Functional Unit**	**Geography**	**LCIA Method**	Fossil-based Plastic Resins	Bio-based Plastic Resins	Paperboard	Composite/Other	Cradle-to-Gate	Product Use	End of Life	Included in Harmonization?
Pro.Mo	2015	Dishes and cups	1,000 meals/drinks	Italy	ILCD 2011 midpoint	x	x	x		x	x	x	x
Potting and van der Harst	2015	Cups	Serving of one hot beverage from vending machine	The Netherlands	CML 2001 baseline, Ecoinvent CED	x	x	x		x		x	x
Broca	2008	Plates	Dishwasher load, 2,960 plates	United States	Inventory based, EcoIndicator 99		x		x	x	x	x	
Pladerer et al.	2008	Cups	0.5 L drink	Germany, Austria, Switzerland	UBA (German Ministry of the Environment) Method	x	x	x		x	x	x	
PE Americas	2009	Drinking cups and flat lids	16-ounce single use cold beverage cup with flat lid	United States	CML	x	x			x		x	x
Franklin Associates	2011	Hot and cold cups, plates, clamshells	10,000 items of each FSW product	United States	IPCC 2007	x	x			x		x	x
Hakkinen and Vares	2010	Cups	100,000 cups	Europe	Not specified	x		x		x	x	x	
Fieschi and Pretato	2017	Tableware	1,000 single use tableware	Italy	Impact 2002+	x	x	x		x		x	x
Vercalsteren et al.	2010	Cups	100 L of beverage	Belgium	Eco-Indicator 99	x	x	x		x	x	x	
Razza et al.	2009	Cutlery	Serving 1000 meals	Italy	Impact 2002+	x	x			x		x	x
Harnoto	2013	Clamshells	360 uses	United States	Inventory based	x	x			x	x	x	x
						91%	91%	55%	9%	100%	55%	100%	64%

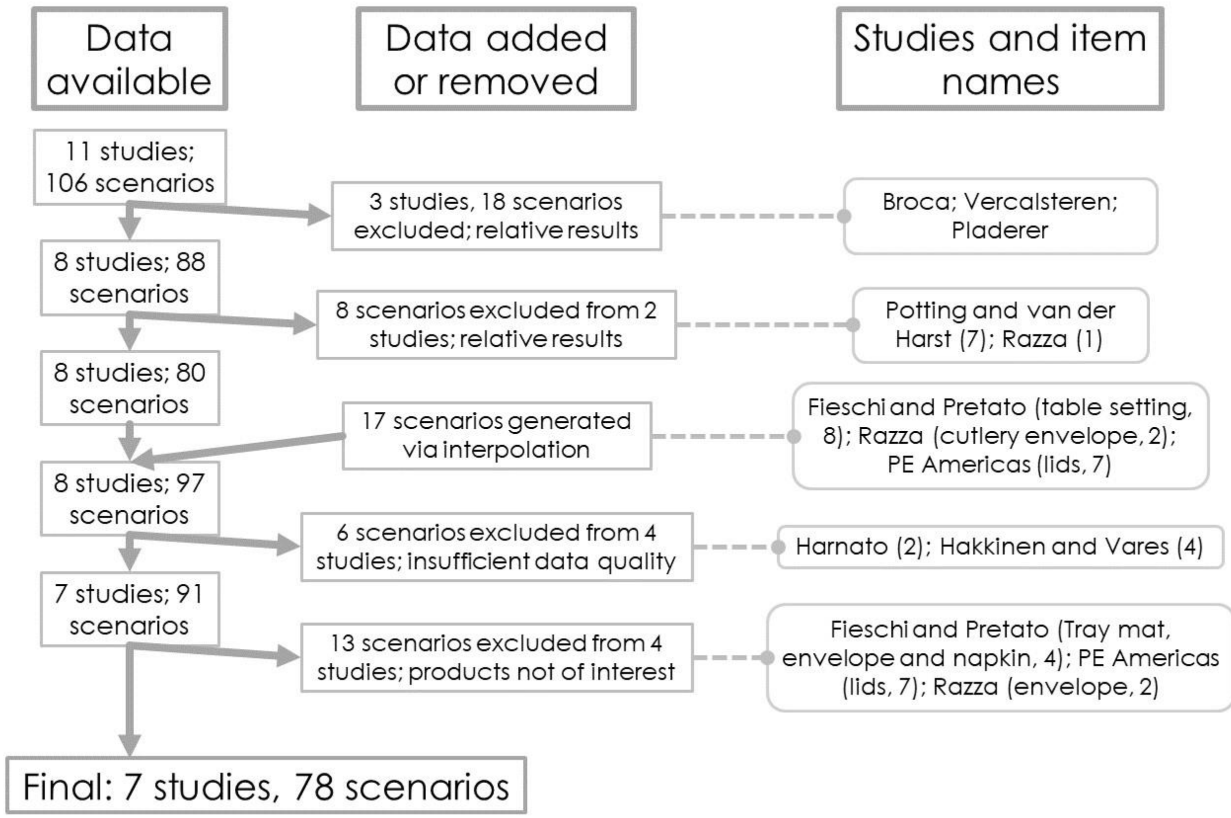

Figure 1 - A data exclusion flowchart illustrating data that was added or removed, the motivation for exclusion, and the originating source.

2.1 Data categorization

From the studies suitable for harmonization we identified five major FSW *Product Categories*:

- Clamshells
- Cups (cold)
- Cups (hot)
- Cutlery sets (consisting of a fork and knife)
- Dishes

The results of the original studies were harmonized to **10,000 units** of the specified product category to ensure functional equivalence. Cups were additionally harmonized to a volume of 16 oz.

For clarity, we grouped the materials from the data into eight main *Material Types*. These categories are **Pulp, PET, PLA, PS, PP, Mater-Bi, Paperboard and Reusables**.

Polyethylene terephthalate (PET or PETE), polypropylene (PP) and polystyrene (in a rigid form referred to as PS and an expanded foam version referred to as EPS) are petroleum-derived polymers. **PET** is lightweight and can be transparent, and has a wide variety of uses such as textiles, water bottles, and plastic film. **PP** is a durable, flexible polymer that holds up to repeated deformation and can be found in applications such as ropes, lid hinges, yogurt tubs and planter pots. **PS** is especially rigid, which makes it suitable for uses like disposable cutlery or clear clamshells. It can also be manufactured as expanded foam (EPS) used to make cups, plates, bowls, and foam clamshells.

Polylactic acid (PLA) is a bio-based plastic that is manufactured from sources of starch such as corn or sugarcane and can have properties similar to PET and PS. **Mater-Bi** is a compostable bioplastic made from a proprietary mix of starches, cellulose, and vegetable oils. **Pulp** denotes different types of molded wood fibers or cellulose, typically with a barrier material infused into the pulp before the product is formed. **Paperboard** refers to cardboard or paper products coated with a separate material to provide a barrier to moisture and grease. Barrier materials in the data included petroleum-based plastics, bio-based plastics, and wax.

Finally, **reusables** refers to durable dishware items, such as ceramic plates, durable cold drink cups, or durable clamshells made of rigid plastic, which are designed and intended to be washed and reused multiple times.

This analysis also considered three main *stages of the life cycle*. **Production** refers to all steps leading up to consumer use of the item. **End of Life (EOL)** refers to how the material was handled after use. The **Use** phase was excluded from the harmonization except in the case of materials that were reused and thus required washing.

2.2 Statistical Tests

A mixed-effect model was selected to determine how well materials predicted GWP. This allowed us to draw conclusions in spite of the unbalanced data structure. We were also able to control for the effect of the specific studies on the reported global warming potential. We expect values from a given study to be similar to each other in a meaningful way that explains some of the variation we see in the data. The mixed-effects model approach replaced a more traditional analysis of variance (ANOVA) that would compare means between our groups of interest.

We were specifically interested in net GWP as explained by material type within each product category. The post hoc tests of the main model indicated that product category, and the interactions between product category and material type were not significant predictors of GWP from the total life cycle. We retained this level of analysis to limit conclusions about material types that may not apply universally to our products of interest. The interaction between material type and product category was significant for the model that only considered GWP from production.

Models were fit using the “lme4” package in R. A Wald Type II Chi Square Analysis of Deviance indicated which explanatory variables in the model were significant. Estimated marginal means were estimated from the model using the “emmeans” package. A pairwise comparison identified differences between material means within product categories based on a 95 percent confidence interval.

3. Global Warming Potential Results

3.1 Mean Net GWP

This first plot displays the average total (Production + End of Life + Use, if applicable) amount of GWP within each product category, broken down by material (Figure 2).

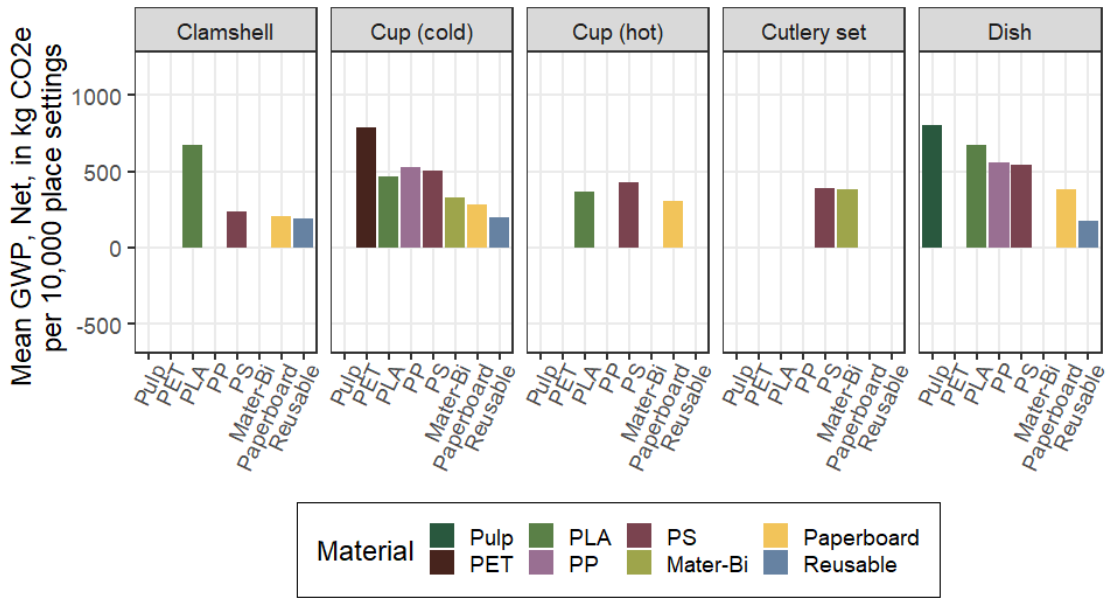

Figure 2 - The mean net GWP for each material separated by the five product categories. Net GWP was calculated by combining the GWP values for the different life cycle stages: production, end of life, and use, in the case of reusable items.

Interpretation

The results suggest, that on average, paperboard leads to marginally lower impacts than the other materials across all product types where it was evaluated. Differences between the averages for all other materials, which include fossil-based (PET, PS, PP) and bio-based (PLA, Mater-Bi), vary depending on the product category though no clear trend emerges to definitively rank the materials. Some materials stand out as the highest in given categories: PLA clamshells, PET cold cups and Pulp dishes.

Interestingly, results clustered between approximately 300-600 kg CO_2e per 10,000 servings when comparing the magnitude of GWP across different product categories, by taking the average of all results for all materials in a given product category. This suggests (and is further evaluated in Figure 3) an overall inability to clearly differentiate one product category being inherently more or less impactful than another.

3.2 Net GWP, Boxplot

Below, a boxplot shows the range of net GWP results for all scenarios in a given product category and for a given material type (Figure 3). The dots show the individual observations; the upper end of the box represents the upper quartile, while the lower end of the box represents the lower quartile. The horizontal line within the box shows the median value. The “whiskers” (vertical lines) extending beyond the box denote approximately two standard deviations. Dots beyond the end of the whiskers fall outside of this range and are often considered outliers.

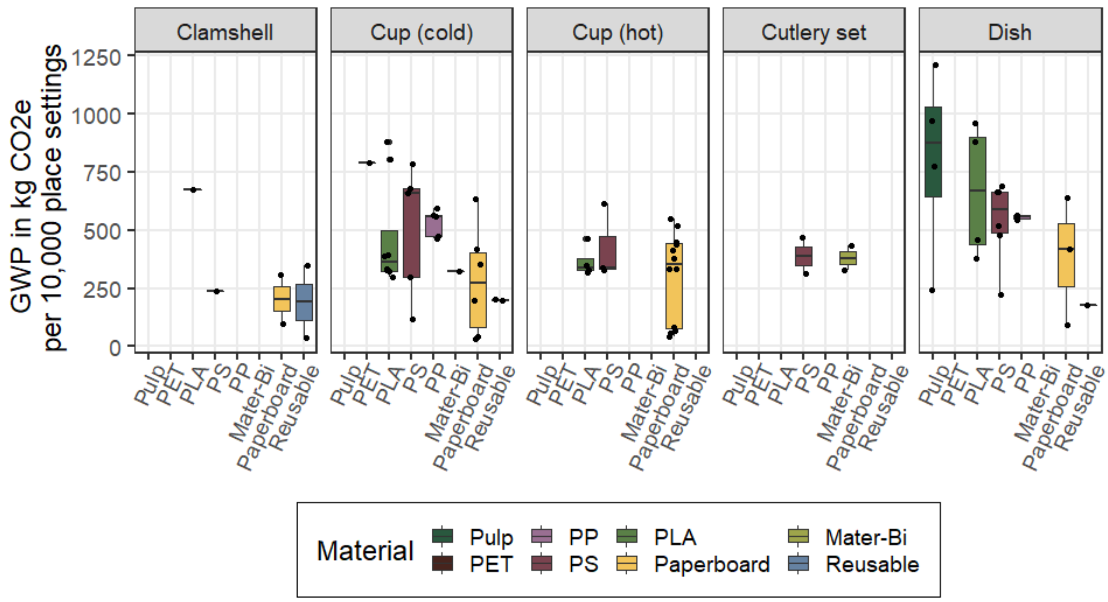

Figure 3 - Net GWP boxplot for a given material, within a product category. Dots show the GWP for individual observations. The top and bottom end of the boxes represent the upper and lower quartiles, respectively. The middle line in the boxes indicate the median. In contrast to Figure 2, this plot demonstrates the range and overlap of the values.

Interpretation

Here we get a better sense of the variation in GWP between different material types. In most cases, this shows that there is a good degree of overlap between material types in a given product category even when the medians appear to be different.

Using the mixed-effect model with pairwise comparisons, we identified four differences that were statistically significant (all $p < 0.05$). In the cold cups category, there was a difference between **PET and reusables** and **PLA and reusables**. In the dish category, there was a difference between **pulp and reusables** and **PLA and reusables**. The small number of observations for some groupings made it difficult to statistically detect differences.

3.3 GWP by Life Cycle Stage

On the next page, the contributions of life stages are represented (Figure 4Figure 5). This is the same data used to generate the net results. A variety of EOL treatments are included in this dataset; different treatments are compared against each other in a later section. Some EOL treatments result in negative values (a credit) for GWP, indicated by the bars dipping below zero. This is a function of the chemical composition of that material and its potential to either generate recoverable GHGs or sequester carbon when landfilled, incinerated, or recycled. It should be noted that the carbon sequestration of landfilled PLA, while modeled by papers included in the literature scan, is not a universally accepted fact. Laboratory tests of PLA intended to simulate landfill conditions have demonstrated that PLA will remain largely inert (sequestering biogenic carbon and not releasing methane) in landfills at lower temperatures, while at higher temperatures commonly found inside some landfills, the PLA can degrade into methane and carbon dioxide, resulting in minimal carbon sequestration.[2]

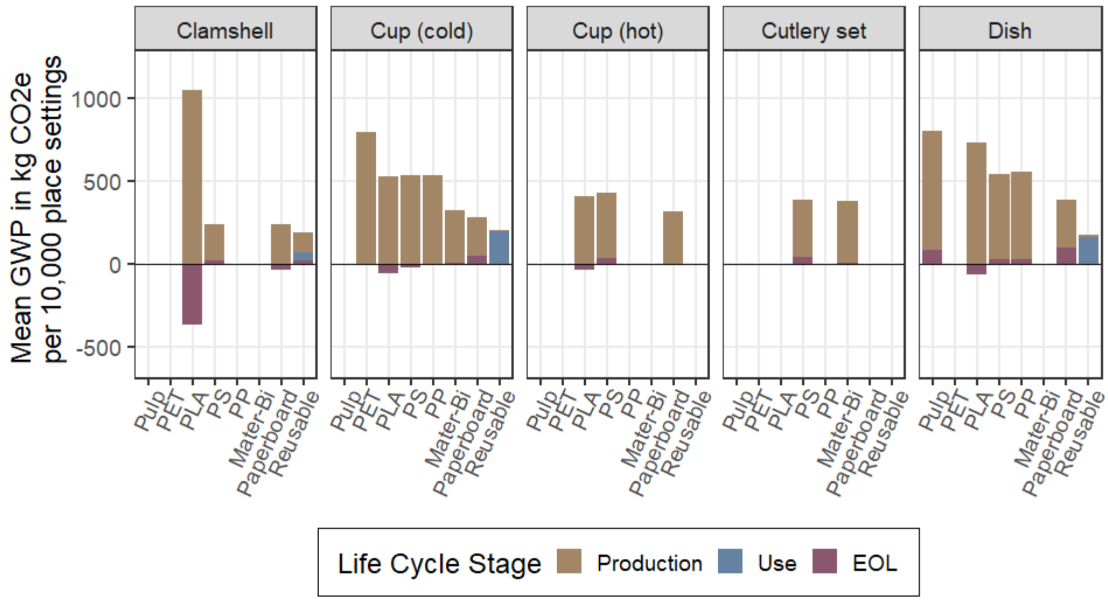

Figure 4 - A stacked bar plot illustrating the mean GWP contribution of the individual life cycle stages within each material, separated by product category. Values below zero indicate a GWP savings. Where there are multiple life stages all with positive GWP, the total height of the bar represents the sum of the mean life cycle contributions. Across all categories, production is the largest contributor to GWP.

Interpretation
The biggest takeaway from this chart is that, on average, the EOL contribution is a small fraction of the overall impact. The EOL contribution can vary widely depending on the method of EOL treatment and the assumptions from the original study. However, what this also means is that Production dominates the life cycle.

3.4 Production-only plot

For this reason, the next plot visualizes the range of GWP results for production only (Figure 5). This indicates the extent of variation in impacts from production by filtering out EOL treatments.

[2] See for example Krause, Max J. and Townsend, Timothy G. "Life-Cycle Assumptions of Landfilled Polylactic Acid Underpredict Methane Generation" Environmental Science & Technology Letters, 2016, 3 (4), Pages 166-169. https://pubs.acs.org/doi/abs/10.1021/acs.estlett.6b00068

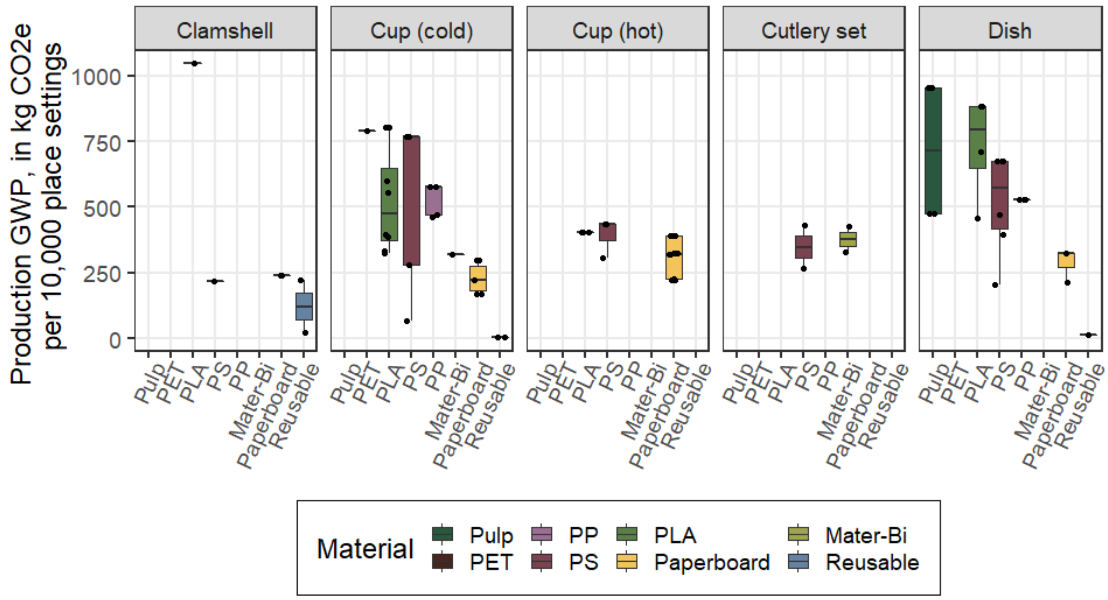

Figure 5 - A boxplot of GWP generated from the production stage. The differences in distribution from Figure 2 suggest that differences in impact between categories are sensitive to assumptions about EOL treatment, despite their small relative contributions to GWP.

Interpretation

Here again we still see lots of overlap between the middle quartiles of different material types. For example, in the product category "Cup (cold)" three material categories (PP, PS, PLA) completely overlap, where the range of impacts for paperboard production seem to be meaningfully lower.

A mixed-effect model identified more differences than for GWP across the whole life cycle (all $p < 0.05$). Findings for reusables are confounded by the fact that a number of reusables appeared to have low estimates for GWP from the production stage.

Within clamshells, differences were found between **PLA and Paperboard**, **PLA and PS**, and **PLA and reusables**. Within cold cups, **PET** (the highest value in the category) and **reusables** (the lowest) were found to be different from each of the other material categories. Differences were also found between **Paperboard and PLA**, **Paperboard and PP** and **Paperboard and PS**. No differences were found between materials in the hot cups or cutlery categories.

Within dishes, differences were identified between **reusables** and each other category. In addition, **Paperboard and PLA**, **Paperboard and Pulp**, **PLA and PP**, **PLA and PS**, and **PP and Pulp** were different from each other.

The increase in statistical findings suggests that comparisons are sensitive to assumptions about the EOL treatment. The same general trends in the net GWP were evident here, when there was a detectable difference, with Pulp, PET, and PLA tending to be higher impact, and paperboard and reusables tending to be lower impact.

3.5 End of Life Contributions

3.5.1 EOL Overview

There were fourteen distinct EOL categories in the original data. These were simplified into five *EOL Treatments*: **50% or greater energy recovery (ER)**, **All or mostly landfilled**, **Composted**, **Mixed Disposal,** and **Recycled.**

The category **50% or greater ER** aggregates EOL treatments such as, 100% incineration with ER and a blend of 50% incineration with ER and 50% composting or recycling. **All or mostly landfilled** includes any scenarios where materials were landfilled at a rate of 79% or greater.

Composted refers to items that were composted at a rate of 100%, as well as items that were 100% anaerobically digested. **Mixed disposal** combined scenarios that had a blend of recycling, incineration, and landfilling, or a split of 55% landfilling and 45% incineration. **Recycled** refers to items that were recycled at a rate of 100%.

3.5.2 GWP from EOL Treatment

The plot below illustrates the mean individual contributions to the EOL, with additional detail illustrating the contribution of each end of life treatment to the mean EOL for a given product category and material type (Figure 6). In some cases, the contributions of a type of treatment exceed the overall mean for EOL. For example, for the product category “Cup (hot)” and material type “PS” three of the five EOL treatments were found in the literature. The mean impacts of those three treatments are represented. This gives a sense of the trade-offs for different types of EOL treatments and the relative magnitude of GWP of the EOL treatment for a given material and product category. Unlike previous figures, the different components of these stacked bars are not additive but rather represent the net emissions for each EOL method for any given product type/material combination.

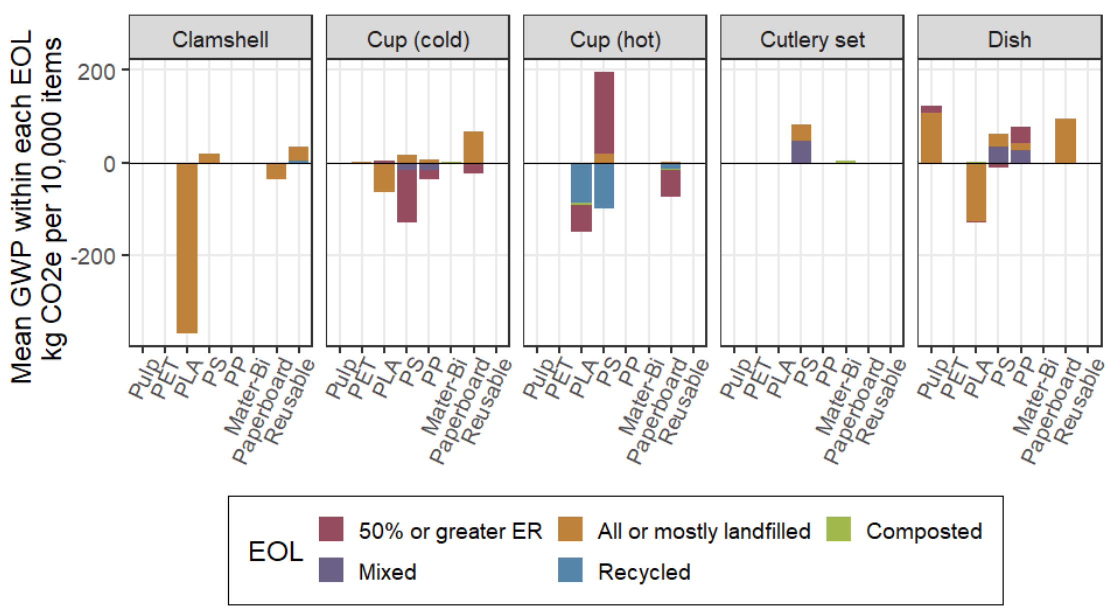

Figure 6 - This stacked bar plot shows the mean individual contributions of the different EOL treatments within the material categories for each product type. Some of the values are generated from only one data point, for example, Cup (cold) - PS - 50% or greater ER. This means the values are especially sensitive to the assumptions of the study from which they originate. As in Figure 4, the net contributions from EOL overall are low.

Interpretation

Credits (negative GWP) or burdens (positive GWP) can occur at end of life, dependent on a few key factors – the method of EOL disposition, assumptions regarding what is displaced, and the composition of the material itself. As shown above, the magnitude of the EOL stage is relatively small compared to production. In addition, when all EOL dispositions are averaged for all materials across each product category the results cluster around zero.

4. Data Overview

We had 78 data points across seven studies. The following plots indicate the amount of data available within the categories to provide supplemental details on the scope of the studies and observations behind the GWP results above.

4.1 Data available by Product Category

Cold cups, hot cups and dishes were the most prevalent product categories (Figure 7). For this analysis, we excluded data from lids and tableware envelopes due to their special use case and small sample sizes.

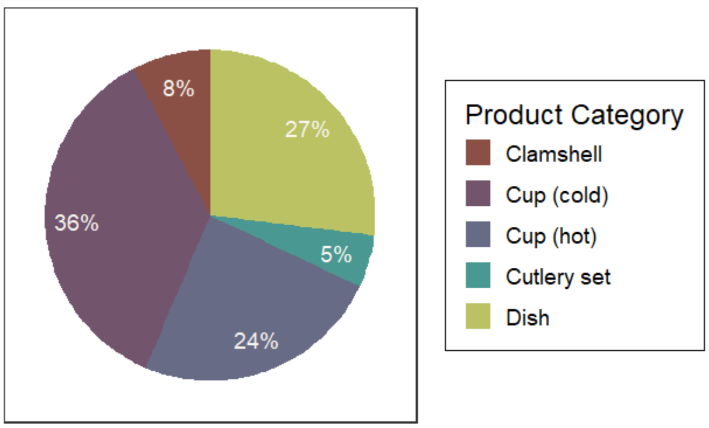

Figure 7 - The percentages of data available for each product category. Cold cups were the most well represented item in the data.

4.2 Data available by Material Type

Paperboard was the most frequently evaluated material type in the literature (Figure 8). The paperboard category includes a variety of coating materials. Pulp, Mater-Bi, PET and reusables had relatively few observations.

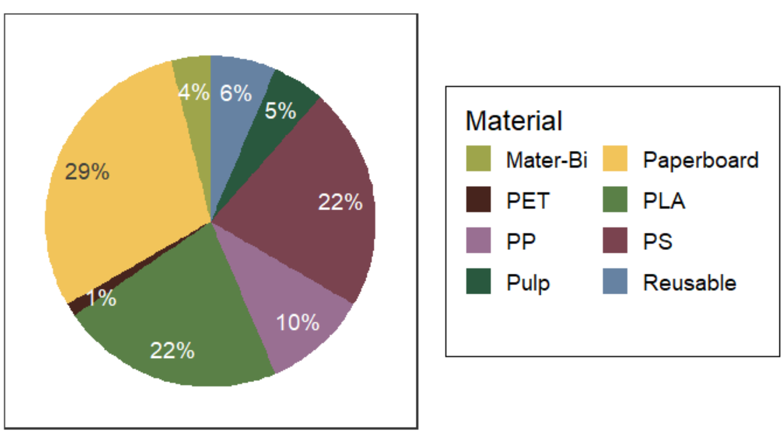

Figure 8 - Proportions of material types in the data. Paperboard included any paper or cardboard that was coated with any kind of barrier, such as wax or PLA. PS combined polystyrene subtypes.

4.3 Count of data within Product Category, across Material Type

The plot below indicates the number of observations available for each Material Type within each product category (Figure 9). Having fewer data points makes the GWP values reported more sensitive to the assumptions and boundaries of the original study.

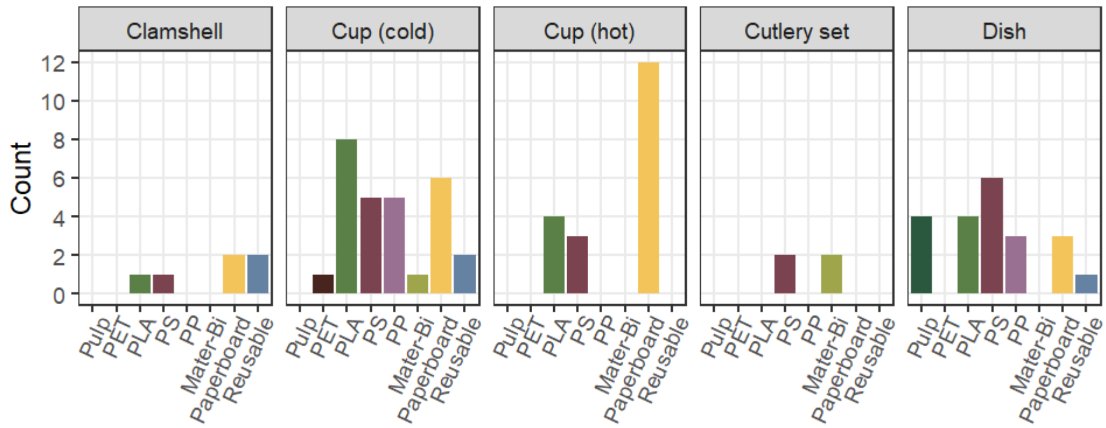

Figure 9 - A bar plot of the number of observations of each material within each product category.

4.4 Data available by EOL Treatment

Most of the values in the data were based on Landfilling (at a rate of 79% or greater) as an EOL treatment (Figure 10). This is likely an advantage when considering decisions for Portland, since food service ware is most likely to be landfilled. For that reason, it is possible for the energy recovery or other treatments to give a skewed indication of GWP in practice here in Oregon, although EOL tended to be a small contributor to the net GWP.

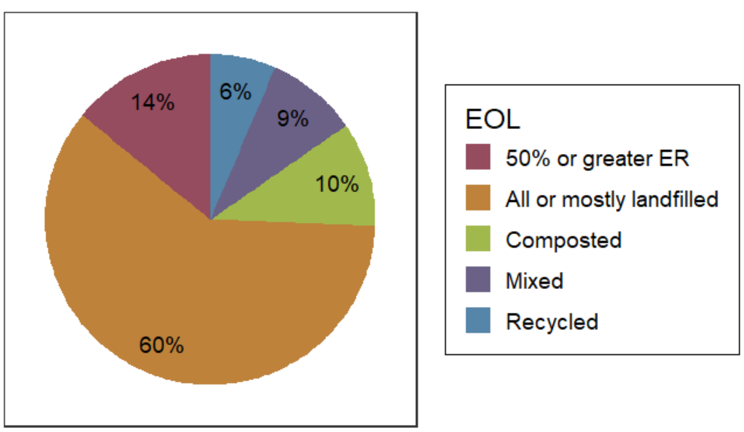

Figure 10 - Landfilling (at a rate of 79% or greater) was the most common type of EOL treatment, covering 60% of observations.

4.5 Data available by Study

Altogether, 75% of the data came from the private companies Pro.Mo, Franklin Associates, and PE Americas (Figure 11). The other 25% came from three academic studies.

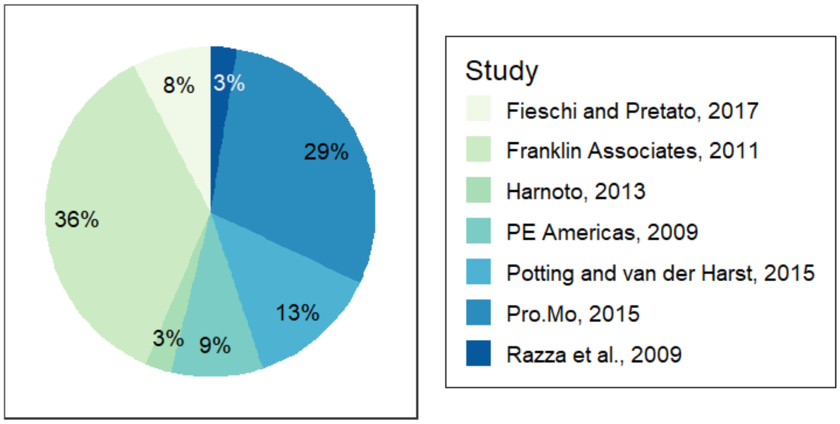

Figure 11 - A pie chart of percentage of data derived from each of the original data sources

4.6 Data available by Region

The data was fairly evenly split between the U.S. and Europe (Figure 12).

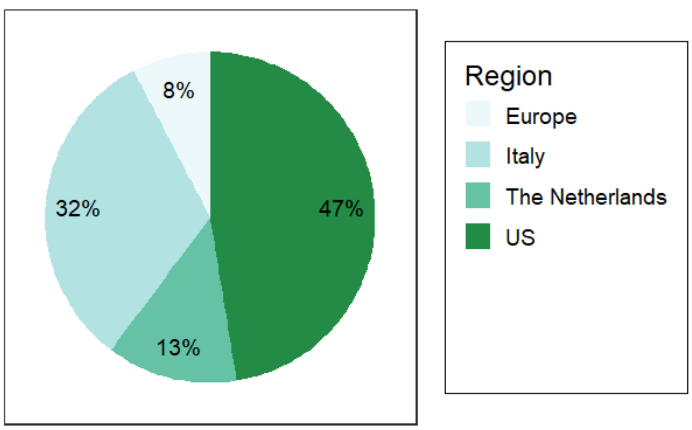

Figure 12 - A pie chart of the percentage of data from the originating geographical regions of the studies.

5. Portland Scenario

In Oregon, FSW is not readily recycled and has a limited potential for incineration (with only a fraction of total municipal solid waste going to one incinerator in Marion Country). FSW is also not accepted in residential or commercial composting in the Portland Metro region. This means that the vast majority of FSW will end up being landfilled, as such the charts below are filtered to EOL treatments that better represent regional conditions.

5.1 Net GWP, Portland Scenario

In the plot below, we removed all observations (cases) that had an EOL scenario other than “All or mostly landfilled” to reflect the expected conditions in Portland. There were 47 data points available. The chart below reflects the net GWP based on this data subset (Figure 13).

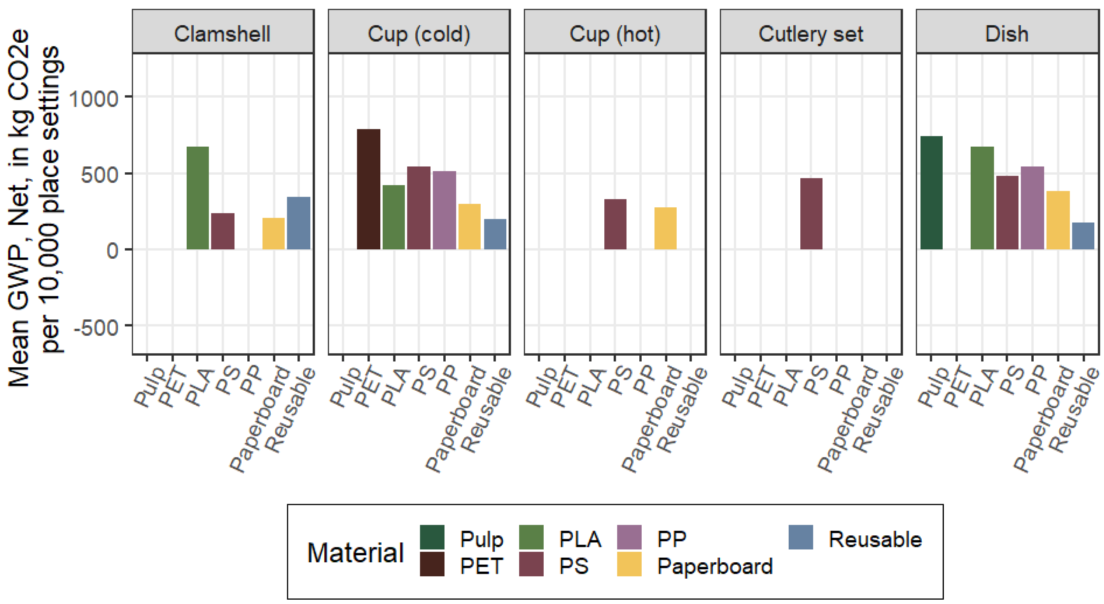

Figure 13 - A bar plot showing the mean net GWP for each material type within each product category, for a scenario representing Portland’s current end of life treatment. Only data that was all or mostly landfilled at end of life was included.

Interpretation
First, this filtered result reinforces the findings above (Figure 4) that the EOL treatment is a *de minimis* contributor to the overall impacts of FSW. On average, there appears to be some difference between individual material types within a given product category, which is a similar conclusion one might have drawn for the full set of results. Here it appears paperboard leads to lower impacts across different product categories. The same materials standout for having the highest impacts in a given product category: PLA clamshells, PET cold cups, and pulp dishes. However, it is difficult to determine if these differences are statistically significant when comparing means.

5.2 Boxplot of Net GWP for Portland Scenario

The plot below (Figure 14) is a boxplot showing the range of net GWP results for all Portland scenarios in a given product category and for a given material type. It uses the same data as used above, but instead of being summarized as a mean, the full spread of results is shown. The dots show the individual observations; the upper end of the box represents the upper quartile, while the lower end of the box represents the lower quartile. The horizontal line within the box shows the median value and the whiskers extending beyond the box denote the highest and lowest observation.

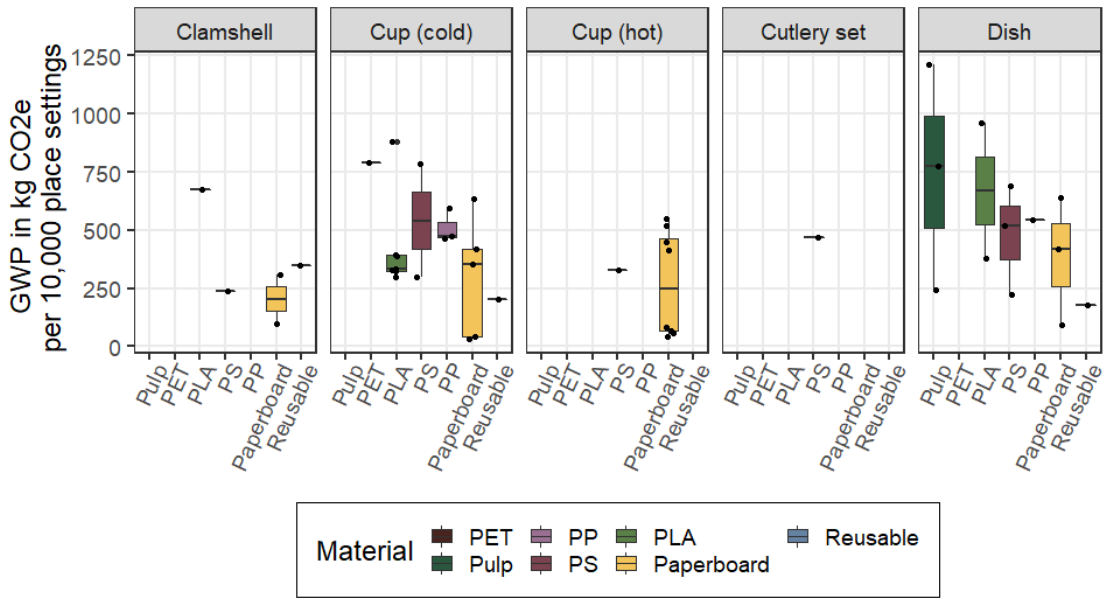

Figure 14 - A boxplot of data for a scenario that reflects the likely end-of-life treatment in Portland, Oregon. Data was subset to include only observations whose end-of-life was modeled as all or mostly landfilled.

Interpretation

Although some trends are visible in this data, the statistical tests were unable to detect differences between almost all materials, probably in part due to the small sample sizes. The exception was a difference between **Pulp** and **reusable** in the dish category. Many of the general trends in the data were consistent with the overall dataset (Figure 3), with the GWP of paper and reusables tending to be lower.

5.3 Portland Scenario, GWP by Life Cycle Stage

Here again we show the breakdown of each life cycle stage to the overall impacts, using the same data as above for the Portland scenario.

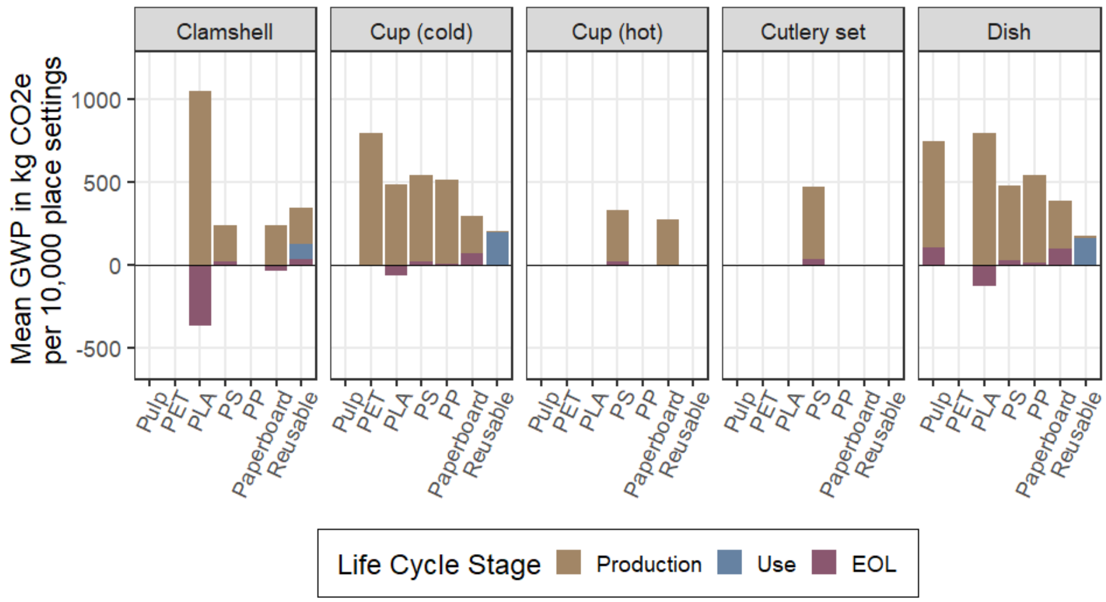

Figure 15 - A stacked bar plot that illustrates the mean contributions of each life cycle step (production, EOL, and use, if applicable) to GWP.

Interpretation
What is obvious here is the EOL contribution to the life cycle GWP of each material type is small. For reusables the use phase is often the most important contributor to GWP, except for clamshells where production of the reusable clamshells was the dominant contributor in one study. Finally, recalling that the Portland scenario filtered EOL dispositions to only include the 47 instances where the materials were "All or mostly landfilled" we see a decline in the number of EOL results that lead to a net GWP credit. The can be explained by the elimination of all scenarios associated with recycling or incineration with energy recovery.

6. Conclusions and Limitations

DEQ's original attributes study defined rigorous inclusion criteria for the literature it used, the same literature that formed the basis for this analysis. To the best of our knowledge, these data represent the universe of available published LCA research from the past 18 years.

Based on the limited available observations (cases), it is not possible to conclude with any meaningful certainty whether a given material type for a specific product category leads to reduced GWP. Paperboard consistently looked to have a lower mean GWP than other materials, however, further examination of the spread and variance of results for paperboard showed significant overlap between it and other material types. Unlike paperboard, there was no material that had higher impacts across product categories, though individual materials appear to stand out within a given product category. For example, PET cold cups have the highest mean GWP at ~750 kg of CO2e, however, this result comes from only one observation.

A few limitations hindered the ability to draw conclusions from this analysis. First, the relatively small sample size (n=78) spread across multiple product categories and material types is a limiting factor. As noted above, some instances of a given product category may only have a single observation for a material type, or none at all. Second, not all possible combinations of FSW products and material types on the market were studied in this literature. The geographical coverage of the studies (and their background data) may have introduced some uncertainty, as about half of the studies are based on European boundary conditions and thus do not represent the specific supply chains and production pathways for FSW products here in Oregon.

A fourth limitation has to do with possible production technology changes since the studies were published. In particular, this could be relevant for the 2009 PE Americas study of PLA, where the primary producer of PLA in the US (Natureworks) updated their production processes that same year. Those changes are not reflected in the study.

Finally, and most importantly, here we evaluate only GWP. Other environmental impact categories (e.g. acidification, human toxicity, smog formation, etc.) are excluded from this analysis partially for clarity but also due to the limited and inconsistent inclusion of these other categories in the original studies.

7. Context

A vast degree of effort is devoted to environmental actions around single-use packaging materials, likely because they are highly visible and, at least in the case of FSW, generally unessential to daily life. Yet, how relevant are these FSW items to overall environmental impacts? When placed in context these findings provide an important sense of scale.

Using the GWP data from this analysis we were able to derive a worst-case scenario for FSW consumption in Oregon. To do so we selected the highest-impact FSW item from each of the five product categories and multiplied it by the population (4.017 million) of Oregon in 2015 (thus assuming that each Oregonian used a cold cup, hot cup, dish, utensils, and a clamshell of the material and formulation with the highest carbon impact). The sum of this product was then multiplied by 365, assuming each Oregonian did this every day for a year, to arrive at an estimate for total annual demand and carbon impact for FSW.

Oregon DEQ's 2015 Consumption Based Emissions Inventory (CBEI) shows total emissions for all goods and services demanded in Oregon to be 88.7 MMT CO2e. The worst-case estimate for FSW described above, arrived at 0.56 MMT CO2e, or about 0.64 percent of total emissions in Oregon. In reality, the demand for FSW packaging is likely significantly lower than this worst-case estimate since not everyone in Oregon uses all or even some of these FSW items once every day of the year, and when they do, they do not always use the highest-carbon option available.

CBEI also provides a breakdown by sector and shows emissions associated with food and beverages at 11.8 MMT CO2e. We compared the worst-case FSW estimate (0.56 MMT CO2e) to this category of goods and services, since FSW is made to contain food and beverages (Figure 16). Here we find that under the worst-case assumption, FSW packaging constitutes just 4.7 percent of emissions relative to the food and beverages contained within it. To reiterate, this result is based on a highly unlikely overestimate of demand for FSW.

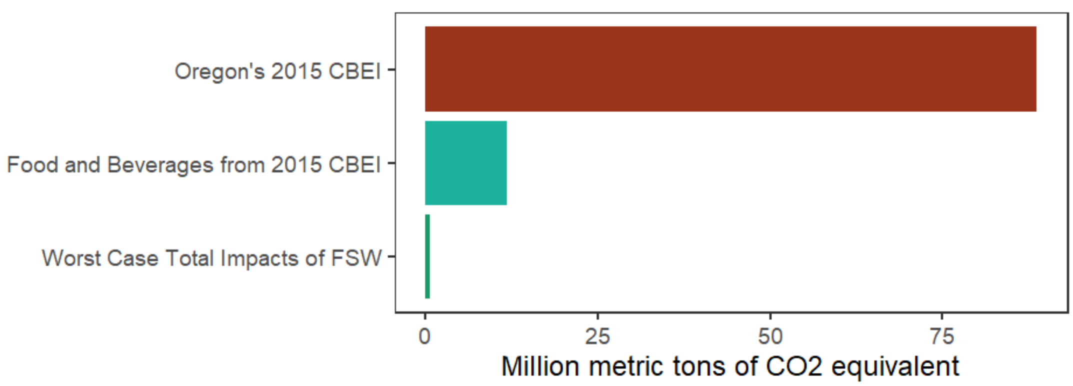

Figure 16 - A bar plot providing context for a worst-case scenario of every individual in Oregon using the worst (highest carbon) of each of the five FSW products every day for a year, compared against the 2015 Consumption Based Emissions Inventory for the whole state. Food and beverages represent about 13% of the CBEI for 2015. The impact from FSW in the worst-case scenario is only 4.7% of the GWP impact from food and beverages, and approximately 0.6% of the overall amount of CO2 equivalent.

What this implies is that the decisions regarding which type of FSW material to select are likely to have very little effect on overall emissions, even in the worst-case scenario. Alternatively, a small reduction in food waste is likely to have a multifold greater reduction in emissions.

8. Recommendations

No clear material demonstrated meaningfully lower net GWP across a given product category based on the harmonization of literature in this analysis. As such, the decision on which single-use FSW product or material to purchase comes down to factors beyond carbon emissions.

The inconclusive results of this analysis could be resolved through primary analysis. A comparative LCA of actual packages from specific suppliers for a given business would yield more specific and representative results.

When selecting FSW:

- If possible, do not offer any superfluous FSW items to begin with. Not purchasing or offering single-use items is the best way to reduce environmental impacts.

- Where feasible, seek a reusable item that is durable enough to stand-up in your given application. Reuse it as long as is possible. Wash it with an efficient appliance.

- If a reusable item is not an option, use other criteria that are important to and align with the values of your business and consumer.

    - **Are you worried about land or marine litter?** Consider how many of your FSW items are likely to end up as litter. If you are providing customers with materials that likely will be littered, invest in litter prevention and control projects. Also, use something that readily breaks down or is otherwise innocuous in a marine environment such as non-coated paper or untreated wood.

    - **Are you concerned about potential exposure to toxics?** Consider selecting materials that do not contain toxicants and have no potential mechanisms for transfer. Use resources such as Clean Production Action's Plastics Scorecard, Safer Made's Safer Materials in Food Packaging Report, or the Center for Environmental Health's Guide to Safer Foodware to evaluate the chemical footprint of various choices.

    - **Are you disturbed by the thought of waste entering landfills?** Know that most food service ware is landfilled. Also know that what happens to the FSW item after its use contributes a very small fraction to total life cycle GWP impacts. Therefore, selecting a FSW item on its potential EOL disposition – compostability, for example – provides limited benefits (or costs) in terms of life cycle GWP. More importantly, understand your jurisdictions' rules for handling FSW items. Often, used compostable or recyclable FSW items will not be accepted for recovery or composting.

- Place your decision in context. FSW is a *de minimis* contributor to GWP here in Oregon. Therefore, feel empowered that whatever choice you make is not likely to have drastic implications in either direction.

    - That is not to suggest FSW items necessarily should be ignored; after all, they represent a highly visible and sometimes unessential use of materials.

- Should you want to identify better choices, the best approach is to screen FSW options using life cycle assessment to accurately understand the environmental trade-offs. This can be done using tools like COMPASS, PIQET, or PackageSmart.

Finally, and most importantly, the inherent function of FSW is to contain food and beverages, the environmental impacts of which are vastly greater than the FSW items themselves. Estimates suggest that globally 30-40% of food that is produced is never eaten. A marginal reduction in the amount of food and beverages that are wasted would have a meaningful reduction in GWP emissions. Prioritizing efforts on reducing food waste would achieve the best outcomes for the environment in a food service setting.

9. Citations

Bates, Douglas, Martin Maechler, Ben Bolker, Steve Walker (2015). Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1-48.doi:10.18637/jss.v067.i01.

Broca, Mita. 2008. “A Comparative Analysis of the Environmental Impacts of Ceramic Plates and Biodegradable Plates (Made of Corn Starch) Using the Life Cycle Assessment Tool.” Masters, New Delhi, India: TERI School of Advanced Studies. http://sustainability.tufts.edu/wp-content/uploads/LifeCycleAnalysisPlasticPlatevsCeramic.pdf.

Fieschi, Maurizio, and Ugo Pretato. 2018. “Role of Compostable Tableware in Food Service and Waste Management. A Life Cycle Assessment Study.” Waste Management 73 (March): 14–25. https://doi.org/10.1016/j.wasman.2017.11.036.

Franklin Associates. (2011). Life cycle inventory of foam polystyrene, paper-based, and PLA foodservice products. Prepared for the Plastic Foodservice Packaging Group. Retrieved from https://www.plasticfoodservicefacts.com/wp-content/uploads/2017/12/Peer_Reviewed_Foodservice_LCA_Study-2011.pdf.

Harnoto, Monica. (2013). A Comparative Life Cycle Assessment of Compostable and Reusable Takeout Clamshells at the University of California, Berkeley. Retrieved from https://nature.berkeley.edu/classes/es196/projects/2013final/HarnotoM_2013.pdf.

Russell Lenth (2018). emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.3.1. https://CRAN.R-project.org/package=emmeans

Madival, Santosh, Rafael Auras, Sher Paul Singh, and Ramani Narayan. 2009. “Assessment of the Environmental Profile of PLA, PET and PS Clamshell Containers Using LCA Methodology.” Journal of Cleaner Production 17 (13): 1183–94. https://doi.org/10.1016/j.jclepro.2009.03.015.

Oregon’s Greenhouse Gas Emissions through 2015: An assessment of Oregon’s sector-based and consumption-based greenhouse gas emissions. May 2018. Retrieved from https://www.oregon.gov/deq/FilterDocs/OregonGHGreport.pdf.

Pladerer, Christian, Markus Meissner, Fredy Dinkel, Mischa Zschokke, Günter Dehoust, and Schüler, Doris. 2008. “Comparative Life Cycle Assessment of Various Cup Systems for the Selling of Drinks at Events.” Prepared for Austrian Federal Ministry of Agriculture and Forestry, Environment and Water Management; Swiss Federeal Environment Authority. http://www.meucopoeco.com.br/environmental_study.pdf.

PE Americas. (2009). Comparative Life Cycle Assessment IngeoTM Biopolymer, PET, and PP Drinking Cups. Prepared for Starbucks Coffee Company Seattle, WA & NatureWorks LLC. Joint Venture of Five Winds and PE International. http://www.ingeo.natureworksllc.com/~/media/The_Ingeo_Journey/EcoProfile_LCA/LCA/PEA_Cup_Lid_LCA_FullReport_ReviewStatement_121209_pdf.pdf.

Potting, José, and Eugenie van der Harst. 2015. “Facility Arrangements and the Environmental Performance of Disposable and Reusable Cups.” The International Journal of Life Cycle Assessment 20 (8): 1143–54. https://doi.org/10.1007/s11367-015-0914-7.

Pro.mo/Unionplast. 2015. "Comparative Life Cycle Assessment Study of Tableware for Alimentary Use." Milan, Italy. http://www.pro-mo.it/data/uploads/report-lca-eng.pdf.

Razza, Francesco, Maurizio Fieschi, Francesco Degli Innocenti, Catia Bastioli. (2009). Compostable cutlery and waste management: An LCA approach. Waste Management, Volume 29, Issue 4. Pages 1424-1433. https://doi.org/10.1016/j.wasman.2008.08.021.

Vercalsteren, An, Carolin Spirinckx, and Theo Geerken. (2010). Life Cycle Assessment and Eco-Efficiency Analysis of Drinking Cups Used at Public Events. The International Journal of Life Cycle Assessment 15 (2): 221–230. https://doi.org/10.1007/s11367-009-0143-z.