Facility arrangements, food safety, and the environmental performance of disposable and reusable cups

José Potting[1,2,*], Eugenie van der Harst[2]

[1] KTH Royal Institute of Technology, fms Environmental Strategies Research division, Stockholm Sweden
[2] Wageningen University, Environmental Systems Analysis group, the Netherlands
[*] Corresponding author. E-mail: *Josepha.Potting@abe.kth.se*

ABSTRACT

Conventional disposable cups, made of fossil-based plastic or paper with inner lining of fossil-based plastic, are typically associated with an unnecessary use of scarce resources and a superfluous production of waste. An alternative has become available in disposable cups from bio-based and biodegradable materials, so-called biocups, made from bioplastic or paper with inner lining of bioplastic. Many stakeholders consider disposable biocups as more environmental friendly than fossil-based disposable cups, though other stakeholders prefer reusable cups over disposable cups. Existing LCA studies show inconsistent and sometimes conflicting results, due to differences in used data and modeling choices, for LCA studies comparing different disposable cups and/or comparing disposable with reusable cups. This paper summarizes an LCA deliberately applying multiple inventory data sets and crediting principles for recycling in comparing disposable PolyStyrene (PS) cups with (1) disposable biocups of PolyLactic Acid (PLA) and paper lined with bioplastic, (2) handwashed and dishwashed reusable cups.

Keywords: Facility arrangements & food safety, Environmental LCA, Disposable and reusable cups, Multiple inventory data sets and modeling choices, Scenarios

1. Introduction

Public provision of drinking water was in the start of the previous century usually facilitated with a “common drinking cup” (as they were referred to in that time). Such “common drinking cup” could be found near water vessels and fontains in public places as parks, trains and railroad stations, department stores, schools, theatres and offices. Even hospitals made use of the “common drinking cup”, despite public awareness and scientific evidence about their role in distributing contagious diseases. Alvin Davison, professor of biology in Lafayette College (Easton, Pennsylvania, United States of America), published in 1908 an influential study “Death in school drinking cups”. This study documents the human cells and pathogens on a cup having been used nine days in row on a school, and contributed to the introduction of a disposable paper cup to curb pathogens growth and spread by the “common drinking cup”. Kansas was in 1909 the first American state to abolish by law the “common drinking cup”, and was eventually followed by all other American states putting into force similar laws (Anonymous 1995; Davidson 1991; Montreal Gazette 1908; Reading Eagle 1909).

A “common drinking cup” has meanwhile become an antiquity, and the use of disposable cups penetrated all sectors in society. Official numbers are not publicly available, but Wikiversity (2014) claims a worldwide use of 300 billion disposable cups per year (i.e. 300E9 disposable cups/year). Many restaurants and kiosks sell beverages in disposable cups for on-the-go consumption (e.g. by commuters, shopping public, or beach visitors). Disposable cups are also typically employed where absence of cleaning facilities and large numbers of customers in short time intervals make reusable cup service practically impossible. This is not only at stake for large public events like festivals and manifestations, but as well in medium and large organizations as schools and universities with peak-consumption during breaks. Disposable cups are also increasingly used in office-type organizations, typically in combination with vending-machines, to save time and money and to streamline their hot beverage facilities. Conventional disposable cup are made from fossil-based plastic (e.g. polystyrene, polypropylene, polyethylene terephthalate), or from paper with an inner lining of fossil-based plastic (e.g. polyethylene) or wax.

Whereas disposable cups were in the first half of the last century praised for their contribution to public health, the first commercial ones were even named ‘health cups’, they became in the second half of previous century increasingly associated with an unnecessary use of scarce resources and a superfluous production of waste (Butijn et al. 2014; Reinink et al. 1991). The debate about disposable cups already goes on for decennia, though the proposed solutions have slightly shifted over the years, also given changing facility arrangements for providing beverages. Reusable cups were often put forward as the obvious alternative for disposable cups in the nearby past when organizations typically had restaurant facilities or a room-to-room-service by a ‘coffee-lady’

(Reinink et al. 1991). Restaurant facilities and 'coffee-ladies' will not be easily found anymore, however, as many organizations nowadays make use of vending machines for providing hot and cold beverages. Reusable cups are also not practical, or simply infeasible, in situations where many customers need to be served in a short time. An alternative for the conventional disposable cups, however, has recently become available with the introduction of the so-called biocups. Disposable biocups are made from materials that are renewable and have the compostability label (EN 13432). The most common disposable bioplastic cups are made from PolyLactic Acid (PLA), typically produced from corn. Disposable biopaper cups are obviously from paper, but lined with a bioplastic instead of a fossil-based plastic.

The renewable and compostable characteristics make biocups in the eyes of many stakeholders more environmental friendly than the conventional disposable cups from fossil-based plastic or paper lined with fossil-based plastic (Jager 2008). Many restaurant facilities and catering services, or organizations buying these facilities or services, therefore consider a transition from conventional disposable cups to disposable biocups. Wageningen University & Research (Wageningen UR) already (partly) made this transition by replacing conventional disposable cups by disposable biopaper cups in their office-buildings having vending machines for hot beverages without automatic cup supply. The education buildings of Wageningen UR have hot beverage vending machines with automatic cup supply. Disposable biopaper cups tend to disrupt the vending machines with automatic cup supply (Butijn et al. 2014). Technology has just become available for producing disposable bioplastic cups for hot beverages, i.e. from thermo-resistant PLA, but these thermo-resistant disposable cups are not yet taken into commercial production. Cup producers wait for a sufficient large market demand, whereas potential customers wait for an actual market supply (a clumsy impasse; Potting 2013). Disposable PLA cups for cold beverages are already longer on the market.

The transition to disposable biopaper cups for vending machines with hot beverages in their office-buildings was first decided by Wageningen UR after careful consideration of the pros and cons of the earlier used disposable PS cup in comparison with disposable biocups from PLA and from biopaper (i.e. paper lined with bioplastic). The pros and cons of the three disposable cups were investigated by research employees and students of Wageningen UR in a comprehensive internal research project looking into environmental, economic as well as social aspects. It goes too far to describe the whole research project here (see therefore Potting 2013; in Dutch), but the in-depth comparative LCA study for the three disposable cups is summarized in this paper (see for details Van der Harst and Potting 2013; Van der Harst and Potting 2014; Van der Harst et al. 2014). A survey under employees and students of Wageningen UR turned out that over half of the office-building inhabitants for environmental reasons is using an own reusable cup (Butijn et al. 2014). The LCA results for the disposable PS cup were therefore also compared with the results of an additional (screening) LCA study for reusable cups washed by hand and washed in an energy-efficient dishwasher. The comparisons are summarized in this paper and their results are discussed in relation to environmental beneficial facility arrangements.

2. Methods and means

Existing LCA studies show inconsistent, sometimes conflicting results for comparisons of different disposable cups (Van der Harst and Potting 2013), and also for comparisons between disposable and reusable cups. This can be traced back to differences across LCA studies in data used, and modeling choices made. Van der Harst and Potting (2014) and Van der Harst et al. (2014) therefore deliberately applied multiple inventory data sets and crediting principles for recycling, i.e. a modeling choice, in an LCA study comparing disposable fossil-based PS cups with disposable biocups from the bioplastic PLA and from biopaper (i.e. paper lined with bioplastic). The additional LCA study comparing the disposable PS cup with handwashed and dishwashed reusable cups, in Potting (2013), refrained from using multiple inventory data sets and modeling choices for the reusable cup LCAs. The LCAs for the handwashed and dishwashed reusable cups took a screening approach. Both comparative LCA studies thus followed on this point different methodological approaches in their inventory phase, that therefore are separately described in more detail (i.e. Section 2.1 and 2.2). Both LCA studies basically took a similar methodological approach in the other LCA phases than the inventory phase (Potting 2013; Van der Harst and Potting 2014; Van der Harst et al. 2104):

Functional unit: Both LCA studies used the same functional unit of facilitating the serving of one hot beverage from a vending machine as frequently used in the Netherlands in big organizations. This functional unit puts constraints on the disposable cups, as most hot beverage vending machines with automatic cup supply in the

Netherlands use disposable cups with a volume of 180 ml (see 2.1 and 2.2 for details about the cups weights used in our LCA comparisons).

Impact assessment: Results from the inventory phase were translated into environmental impact by means of the CML Baseline 2001 methodology (Guinée et al. 2002), supplemented with the Cumulated Energy Demand (CED) from Frischknecht et al. (2003). Both comparisons therewith covered all together eleven environmental impact categories (see Table 2). Impact results were not normalized and neither weighted. ISO 14044 (2006) rejects normalization and weighting in comparative LCAs which results are to be disclosed to the public.

Interpretation: The results for the in-depth LCA study of the disposable cups were carefully evaluated against the background of the methodological approach used, quality of data obtained, and relevance of the results in the context of Dutch environmental policies. The screening LCAs of the handwashed and dishwashed reusable cups provided indicative impact results that were compared with average impact results of the in-depth LCA for the disposable PS cup. The results of both comparative LCA studies were evaluated with regard to their relevance for environmental beneficial management options.

Software: All LCAs for the disposable and reusable cups were performed in SimaPro 7.3, but impact results for the disposable cups were imported in Microsoft Excel 2010 for calculating average impact results and spread related to the applied multiple inventory data sets and crediting principles for recycling in the cup life cycles. Microsoft Excel 2010 was used in both comparative LCA studies for making the appropriate graphical representations of results.

2.1. Comparison of disposable PS cups and disposable biocups from PLA and biopaper

Van der Harst and Potting (2013) recently made a critical comparison of ten existing LCA studies comparing disposable beverage cups. These ten LCA studies only shared climate change as a common impact category. The variation in climate change results across LCA studies for each disposable cup material was quantitatively explored by Van der Harst and Potting (2013). They calculated the ratio between the highest and lowest climate change value, and found a ratio of 1.7 for PLA cups, 3.4 for petro-plastic cups, and 20 for paper cups. Since there was also no consistency among the LCAs about the cup with the smallest climate change impact, Van der Harst and Potting (2013) next qualitatively compared the data used and methodological approach followed in each of the selected ten LCA studies. Identified possible sources for the variation in outcomes were differences in the properties of the disposable cups (e.g., material choice and weight), differences in the data used, and different choices made in modeling production processes, energy production (e.g., fossil or renewable sources), and waste treatment (e.g. different allocation/crediting principles and waste treatment processes applied).

The critical comparison of the ten LCA studies was the basis for a new in-depth comparative LCA study of disposable cups. Van der Harst and Potting (2014) and Van der Harst et al. (2014) deliberately applied multiple inventory data sets and crediting principles for recycling, a modeling choice, in their LCA study comparing disposable fossil-based PS cups with disposable biobased cups from PLA and biopaper (i.e. paper lined with bioplastic). Their use of multiple inventory data sets and crediting principles for recycling involved two LCA iterations according to the following procedure (Van der Harst and Potting 2014; Van der Harst et al. 2014):

1. Initial LCAs with one inventory data set for each process in the life cycle of the disposable cups from the three selected materials (these initial LCAs used incineration as waste treatment process)
2. Contribution and sensitivity analysis to identify processes with major influence on the initial LCA results
3. Collecting additional multiple inventory data sets for all processes with an influential contribution
4. Applying multiple data sets, multiple modelling choices:
    - Applying the collected multiple inventory data sets in next LCAs,
    - Combined with one waste treatment processes (i.e. incineration, recycling, composting, or anaerobic digestion), and with
    - Applying multiple crediting principles for the disposable cup life cycles with recycling (e.g. multiple crediting principles for recycled material)
5. Calculating and presenting average impact results and their spread (highest and lowest value) for each life cycle process based on the multiple inventory data sets and crediting principles for recycling
6. Calculating and presenting average impact results and their spread (highest and lowest value) for each of ten disposable cup life cycles

Steps 1 to 6 were gone through for each of ten disposable cup life cycles. These ten disposable cup life cycles resulted from three disposable materials (i.e. fossil-based PS, biobased PLA, and paper lined with PLA), and four waste treatment processes (i.e. incineration, recycling, composting and anaerobic digestion; the latter two not being relevant for PS). This led to ten disposable cup life cycles for which multiple inventory data sets were collected, whereof three disposable cup life cycles with recycling for which multiple crediting principles were applied (see Table 1). The applied multiple inventory data sets and crediting principles for recycling are related to disposable cups as commonly used in hot beverage vending machines in the Netherlands (i.e. not necessarily for similar disposable cups used abroad). These disposable cups typically have a volume of 180 ml. Representative cup weights related to this volume were used in the analysis (see Table 1).

Table 1. Overview of the disposable cup materials, cup-weight for each material, life cycle processes and number of inventory data sets and crediting principles included in the in-depth LCA study comparing disposable cups. The LCA study covers altogether ten disposable cup life cycles, indicated by the grey-shaded cells, resulting from three disposable cup materials and four waste treatment processes (composting and anaerobic digesting are not relevant for PS). The dark grey-shaded cells indicate the three initial LCAs, each having incineration as waste treatment process and covering the rest of the life cycle for only one disposable cup material. All processes for which only one inventory data set was used, showed to be of minor importance in the contribution and sensitivity analysis.

Life cycle processes	**PS** 4.2 gram	**PLA** 4.2 gram	**Biopaper** 5.6 gram
Cradle to disposable cup material production	**3**	**5**	**5**
Transport of disposable cup material to cup manufacturer	1	3	1
Disposable cup manufacturing	**5**	**5**	**3**
Cradle to grave for the packaging of disposable cups	1	1	1
Transport of disposable cup to customer	1	1	1
Transport of used disposable cups to waste treatment	1	1	1
Waste treatment:			
- Incineration	**4**	**4**	**5**
- Recycling (recycling process/crediting principle)	**5/4**	**5/4**	**3**
- Composting		**4**	**4**
- Anaerobic digestion		**3**	**4**

2.2. Comparison of disposable PS cups with handwashed and dishwashed reusable cups (Potting et al. 2013; Van der Harst and Potting 2014; Van der Harst 2014)

The average impact results for the disposable PS cup life cycle with incineration from the in-depth LCA study was used for comparison with two reusable cup life cycles, one with handwashing and one with dishwashing of the reusable cup after use. The comparison took a one-time use of the disposable cup before disposing it, but looked into an increasing number of reuses of the reusable cup before dishwashing or handwashing. Screening LCAs were performed, i.e. screening inventory data were used, to calculate the impact results for the two reusable cup life cycles. The weight of the reusable cup was in both LCAs taken to be 370 grams, based on a random sample of reusable cups used in the Netherlands. The composition of the reusable cup was taken from Bramberg et al. (2011). The reusable cup was assumed to endure on average 1750 consumptions before breaking, and just like the disposable PS cup to go to the incinerator as waste (Hoeboer 2012).

Dishwashing: The composition of the dishwasher was taken from Kok et al. (1996), the energy use for assembling the dishwasher from Boustani et al. (2010), who also gave basis to the assumption of 2150 dishwashing-turns before disposing the dishwasher. Waste treatment for the dishwasher was ignored, which is a worst case approach as large parts of the dishwasher are probably recycled (leading to lower impact results for the dishwasher sub-life cycle). Based on currently common dishwashers from AEG and Bosch (Hoeboer 212), the dishwasher was taken to use 9.25 liters of water, 1 kWh electricity, and 1 gram of salt per washing turn. The composition and use of soap, 9.8 grams per washing-turn, was based on Bramberg et al. (2011).

Handwashing: Handwashing of the cups was assumed to be a single item-washing (as common for people using an own reusable instead of disposable cup). The use of hot water for handwashing was set on 1 liter, and the energy use for heating the water was set at 0.222MJ (heat from natural gas) as based on Eclectsite (2013). A use of 1 gram of soap per handwashing was assumed. The soap composition is based on data from the Dutch association of detergent manufacturers (2012). We assumed the use of two towels for drying one cleaned cup (Tork 2006, Jacobs 2006).

All cradle to product and electricity data in both reusable cup life cycles were taken from EcoInvent Centre (2010).

3. Results and discussion

The two LCA studies provided a wealth of information that is summarized in a number of subsections below. Detailed results and discussions can be found in the earlier publications for both LCA studies. The LCA study comparing disposable cups is addressed in Potting (2013), Van der Harst and Potting (2014), and Van der Harst et al. (2014). The LCA study comparing the PS disposable cup with dishwashed and handwashed reusable cups can be found in Potting (2013).

3.1. Disposable PS cups not better or worse than biocups from PLA and biopaper (Potting 2013; Van der Harst and Potting 2014; Van der Harst et al. 2014)

Table 2 summarizes the comparison of, i.e. the ratio between, the average impact results for all ten disposable cup life cycles with the average impact results for the disposable PS cup life cycle with incineration. The other nine disposable cup life cycles consist of one for PS with recycling, and eight for the two biocup materials (i.e. PLA and biopaper (i.e. paper lined with bioplastic) with one of the four waste treatment processes (i.e. incineration, recycling, composting and anaerobic digestion). The comparison in Table 2 may mistakenly lead to the wrong conclusion that the disposable PS cup life cycle with incineration tends to perform better than the other nine disposable cup life cycles, i.e. for PS with recycling and the two biocup materials regardless their waste treatment process. The table does not indicate, however, the considerable and overlapping spread around the average impact result for all ten cup life cycles in most impact categories as caused by applying multiple inventory data sets (and crediting principles for recycling). This large and overlapping spread in impact results prevents any conclusion about a preferable disposable cup material. The disposable PS cup life cycles do thus not perform better, but also not worse than the disposable biocup life cycles for PLA and biopaper (i.e. paper lined with bioplastic).

The large spread in our results were already presaged by the inconsistent and sometimes even conflicting results of the ten LCA studies in Van der Harst and Potting (2013). Each of these ten LCA studies always differed on more than one inventory data set and/or modeling choice with each of the other LCA studies. The influence and therewith importance of potential individual sources for spread in LCA results were therefore impossible to trace. Applying multiple inventory data sets for all major life cycle processes and multiple crediting principles for recycling allowed systematic quantification of their influence on the impact results for each of the ten cup life cycles. That is a major achievement of applying multiple inventory data sets and crediting principles for recycling, which in this LCA study generated a wealth of additional valuable scientific insights that are summarized here:

- The large spread in impact results, i.e. from applying multiple inventory data sets and crediting principles for recycling, hampers drawing decisive conclusions about the preferred disposable cup material. Such outcome in based on more robust impact results, however, than for those from LCAs based on single inventory data sets per life cycle process
- Despite their large spread, impact results consistently point to the same dominant processes in the life cycles for each disposable cup material. These dominant processes turned out to be the same as identified in the contribution analysis (i.e. none of the used inventory data sets made a given process into a minor contributor in the impact results for the cup life cycles)
- Particularly cradle to PLA production dominated the impact results for the four PLA cup life cycles. It should also be noted that PLA production was based on ‘cold’ PLA, since thermo-resistant PLA is not yet commercially produced
- The crediting of recycled material also considerably influenced the impact results for the recycling life cycles across all three disposable cup materials
- Across disposable cup materials, spread in impact results for energy related impact categories tend to be clearly smaller than in non-energy related impact categories (in the toxicity categories particularly)

- Average impact results for Abiotic Depletion and Global Warming are (obviously) better for the disposable biocups than PS cups, because PLA and paper are renewable materials and PS is not
- Production of all three disposable cup materials can environmentally improve, but this potential is probably largest for the relative new material PLA (presently produced from economically valuable sugar and starch instead of from lignocellulose in arable crops)
- Correlations between inventory data within one data set, e.g. between energy use and carbon dioxide emissions, are maintained by calculating spread on the basis of impact result. Mainstream LCA studies first calculate spread in inventory data, before performing impact assessment, which often violates existing correlations between inventory data within one data set

Table 2. Summary of the potentially misleading comparison of the average impact results for the disposable PS cup life cycle with incineration to the average impact results for the disposable PS cup life cycle with the recycling, and for the eight disposable biocup life cycles (i.e. PLA or biopaper in combination with one the four waste treatment processes; incineration = I, recycling = R, composting = C, anaerobic digestion = D). The results are potentially misleading because the spread around the average results is large and overlapping across all three materials in all impact categories. This is not reflected in the below indication whether average impact results for each of the other nine life cycles are higher than (>, darker grey shading), lower than (< , lighter grey shading) or similar as (1, similar grey shading) the average results of the disposable PS cups that is incinerated after use.

Impact category indicators	**PS**		**PLA**				**Biopaper**			
	I	**R**	**I**	**R**	**C**	**D**	**I**	**R**	**C**	**D**
Abiotic Depletion Potential (ADP)	1	<	<	<	<	<	<	<	<	<
Cumulative Energy Demand (CED)	1	<	>	<	>	>	>	<	>	>
Global Warming Potential (GDP	1	<	<	<	<	<	<	<	<	<
stratospheric Ozone Depletion Potential (ODP)	1	>	>	>	>	>	>	>	>	>
Acidification Potential (AP)	1	<	>	>	>	>	>	>	>	>
Eutrophication Potential (EP)	1	>	>	>	>	>	>	>	>	>
ground-level PhotoChemical Oxidation Potential (PCOP)	1	<	>	>	>	>	<	1	<	<
Human Toxicity Potential (HTP)	1	>	>	>	>	>	>	>	>	>
Terrestrial EcoToxicity Potenital (TETP)	1	>	>	>	>	>	>	>	>	>
Fresh-water Aquatic EcoToxicity Potential (FAETP)	1	>	>	>	>	>	>	>	>	>
Marine aquatic EcoToxicity Potential (MAETP)	1	>	>	>	>	>	>	>	>	>

3.2. Recycling slightly preferable over incinerating disposable cups
(Potting 2013; Van der Harst and Potting 2014; Van der Harst et al. 2014)

Table 3 shows the ranking of cup life cycles, within on disposable cup material, according to the average impact results for the used waste treatment process. Within one disposable cup material, the spread in impact results is identical from cradle to waste treatment entrance-gate, which allows focusing on the waste treatment processes only. There is also a large, but only partly overlapping spread in average impact results for the waste treatment processes within each cup material. Some cautious preferences are therefore possible to express on the basis of average results for the waste treatment process (i.e. not necessarily supported by the range in impact results for these processes.

Composting of the biocups is less good than the other three waste treatment processes as result of the absence of useful products derived from composting (e.g. both biocups do not contain nutrients). Composting therefore does not get credits, in contrast to the other three waste treatment processes, for the avoided production of products they replace. For the PLA cup, anaerobic digestion performs on average on almost all impact categories better than incineration for the PLA cup (i.e. avoided impact by energy production from biogas is larger than from incineration with energy recovery). There is no similar trend for the biopaper cup. The average impact results suggest a slight preference of recycling over incineration for the PLA cup and biopaper cup, i.e. the avoided impact of recycling is larger than for incineration, but not for the PS cups which average impact results are better in five and worse in six impact categories for recycling as compared to incineration. The comparison of recycling and incineration, however, revealed an interesting drawback of crediting processes with avoided production caused by their co-products.

The cup life cycles with incineration as waste treatment process got relative large credits for avoided electricity production from energy recovery by incineration, and these credits for incineration became more dominant when inventory data for improved disposable cup material production were used (i.e. credits for recycling became less). This may mistakenly suggests incineration to become preferable when disposable cup material production improves, whereas the appropriate policy recommendation would be to improve the relatively "dirty" Dutch electricity production. Dutch policies aim to improve the environmental performance of Dutch energy supply, amongst others by increasing the share of renewables (Government of the Netherlands 2014). Compared to other countries, Dutch electricity production uses little renewable sources, and predominantly relies on fossil fuels (CBS 2012; European Commission 2012; Eurostat 2012). A sensitivity analysis with hydro-dominated Norwegian instead of Dutch electricity production showed better impact results for recycling than for incineration of disposable PS cups in most impact categories.

The relatively large credits for avoided Dutch electricity production affected the comparison of cup life cycles with incineration and recycling as waste treatment process for all three disposable cup materials, but this particularly shows for the disposable PS cup in Table 3. Against this background, there is a slight preference for recycling over incinerating disposable cups. Other reflections worth to be mentioned here (Potting 2013):

- Pilot experiments suggest that efficiency and contamination of separate collection of disposable cups depends on the way of collecting (e.g. in stacks or loose in bins or containers). Contamination of the collected disposable cups was roughly 40%, 20% of beverage-remainders, and 20% others (e.g. plastic stirrer, plastic bread bags, metal staples, clock houses etc.)
- PLA is not compostable in a back-garden compost-heap, but disposable PLA and biopaper cups both composts well in (semi-) industrial compost facilities as a composting experiments showed ('cold' instead of thermo-resistant disposable cups were used in these experiments). Incomplete composted PLA cups remains visible as white traces, however, which makes the compost unfit for commercial sales
- Disposable biocups are in practice not composted in Dutch commercial composting facilities as biodegradable and non-degradable cups are difficult to distinguish, and also because incomplete composting of PLA cups leave white traces in the compost

Table 3. Ranking according to average impact results of waste treatment processes within disposable cup materials. Lowest impact results are indicated by 1, highest impact results are indicated by 4 (incineration = I, recycling = R, composting = C, anaerobic digestion = D).

Impact categories	**PS**		**PLA**				**Biopaper**			
	I	**R**	**I**	**R**	**C**	**D**	**I**	**R**	**C**	**D**
Abiotic Depletion Potential (ADP)	2	1	3	1	4	1	1	3	4	2
Cumulative Energy Demand (CED)	2	1	3	1	4	2	2	1	4	2
Global Warming Potential (GDP	2	1	3	1	4	2	1	3	4	1
stratospheric Ozone Depletion Potential (ODP)	1	2	1	3	4	2	1	2	4	3
Acidification Potential (AP)	2	1	3	1	4	2	2	1	4	3
Eutrophication Potential (EP)	1	2	3	1	4	2	3	1	4	2
ground-level PhotoChemical Oxidation Potential (PCOP)	2	1	3	1	4	2	2	1	4	3
Human Toxicity Potential (HTP)	1	2	3	2	4	1	3	1	4	2
Terrestrial EcoToxicity Potenital (TETP)	1	2	2	1	4	2	1	2	4	3
Fresh-water Aquatic EcoToxicity Potential (FAEP)	1	2	3	1	4	2	3	2	4	1
Marine aquatic EcoToxicity Potential (MAEP)	1	2	3	2	4	1	3	2	3	1

3.3. Dishwashing not convincing better than handwashing for reusable cups (Potting 2013)

Figure 1 shows the impact results of the screening LCAs of the reusable cup life cycles. The impact results are expressed as ratio with the average impact results for the disposable PS cup life cycle with incineration (for which the number of hot beverage consumptions is kept at a one). The reusable cup life cycle with dishwashing performs slightly better than the reusable cup life cycle with handwashing. The impact results for handwashing are strongly influenced, however, by the user-dependent amount of hot water, soap and paper towels applied in the screening LCA. These amounts were set on reasonable worst case amounts, but may in practice be considerably higher as well as lower. It is thus difficult to express a preference for either dishwashing or handwashing of reusable cups on the basis of these results.

As also can be seen from Figure 1, the impact results for both reusable cups roughly halves with two hot beverage consumptions before washing. The environmental gain declines with every next consumption before washing, however, and more than two or three consumptions does hardly lead anymore to a decrease of impact results. The disposable cups can of course also used for more than one consumption, and then a similar decline is at stake with every next consumption before disposing.

3.4. Reusable cups not better or worse than disposable PS (Potting 2013)

The impact results for the reusable cup life cycles from the screening LCA have been compared with the average impact results for the disposable PS cup life cycle with incineration from the in-depth LCA (for which the number of hot beverage consumptions is kept at one time). Similarly as reusable cups, disposable cups can also be used for more consumptions before disposing them. A fair comparison therefore should be based on using reusable and disposable cups for the same number of consumptions. This number of consumptions can be any, as long as it is similar between reusable and disposable cups. This comparison put the number on one consumption, however, since Figure 1 expresses the impact result for the reusable cups as ratio with the impact results for one consumption. Based one consumption for both reusable and disposable cup, the impact results for the reusable cup life cycle with dishwashing are better in some and worse in other impact categories, whereas the impact results for the reusable cup life cycle with handwashing are worse in all impact categories than the impact results for the disposable PS cup life with incineration. As already mentioned in Section 3.3, however, the impact results for the reusable cup life cycle with handwashing are strongly influenced by the user-dependent amounts of hot water, soap and paper towels applied in the screening LCA (which represent reasonable worst case amounts).

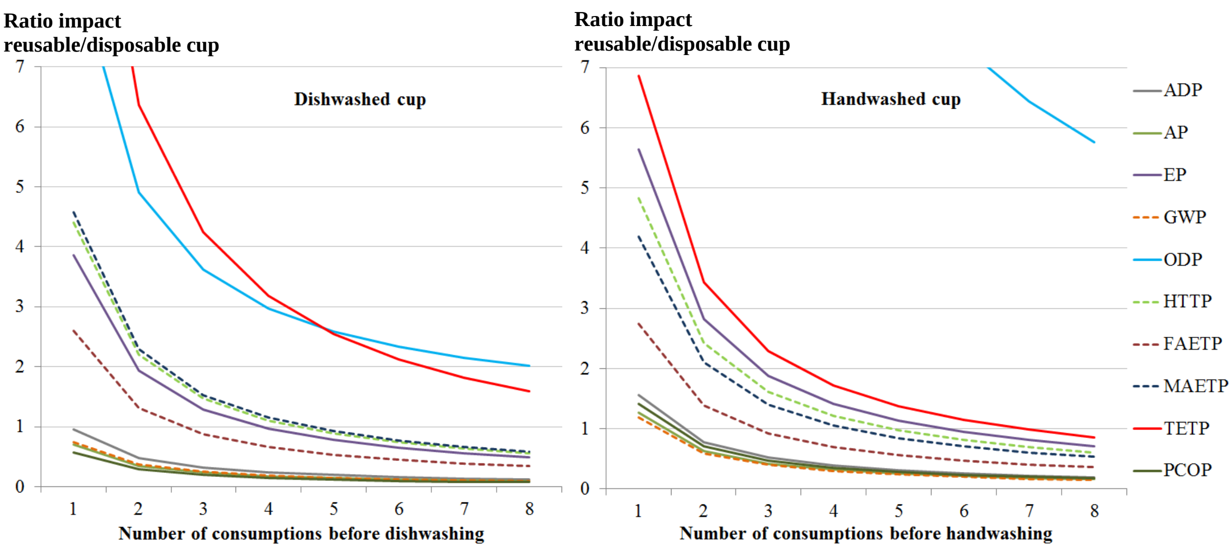

Figure 1. Impact results for the reusable cup life cycles, with dishwashing on the left and with handwashing on the right, expressed as ratio of the average impact results for the disposable PS cup life cycle with incineration as waste treatment (for which the number of hot beverage consumptions is kept one time)

3.5. Facility arrangements improving the environmental performance of all cups

While the overall comparison does not allow any preference for one of the three disposable cup materials, and neither for disposable versus reusable cups, Figure 1 does indicate for the reusable cups a considerable environmental gain from a second and possibly third hot beverage consumption with the reusable cups before washing it. This environmental gain obviously also exist for increasing the number of consumptions of the disposable cup before throwing it away. A second or third consumption is roughly the number of hot beverages that a consumer takes during one morning or one afternoon. Since pathogens probably not multiply so fast, and consumers usually do not share cups, there seems no real public health issue here. Facility arrangements can encourage a second or third serving with the same cup by financial incentives (e.g. paying for a new disposable cup), only putting on the dishwasher around noon and after working time, and/or consumer awareness activities. Consumer awareness activities should also point to the fact that more than two to three servings with the same cup hardly add environmental gain.

4. Conclusion

The overall results do not allow any preference for one of the three disposable cup materials (large and overlapping spread in impact results), and neither for disposable versus reusable cups (impact results for the latter too uncertain and too close to those for the disposable cups). All cups can be used more than once before getting rid of a disposable cup or washing a reusable cup. This gives a considerable environmental gain for the second and third hot beverage consumption with the reusable as well as disposable cups. Facility arrangements can encourage a second or third serving with the same cup by financial incentives (e.g. paying for a new disposable cup), only putting on the dishwasher around noon and after working time, and/or consumer awareness activities. Consumer awareness activities should also point to the fact that more than two to three servings with the same cup hardly add environmental gain.

It was not possible to indicate a preference for one of the three disposable cups, but comparison of waste treatment processes for each cup material gave some basis to express some preferences on the basis of average impact results. Composting is the least preferred waste treatment for both biocups. Anaerobic digestion performs better than incineration for the disposable PLA cup in most impact categories, though this trend does not apply for the biopaper cup. The average impact results suggest a slight preference of recycling over incineration for the PLA cup and biopaper cup, i.e. the impact of recycling is smaller than for incineration, but not for the PS cups which average impact results are better in five and worse in six impact categories for recycling as compared to incineration. The comparison of recycling and incineration, however, is biased by the relative large credits for avoided "dirty" Dutch electricity production. Against this background, there is a slight preference for recycling for all three disposable cup materials.

The in-depth LCA study comparing the disposable cups deliberately applied multiple inventory data sets for the processes contributing most to the impact results, as well as multiple crediting principles for recycling. This led to a large spread in impact results, though for energy related impact categories smaller than for the others. The large spread in impact results may be less easy to interpret, but they represent more robust results.

5. Acknowledgement

This paper has been made possible by funding of the Province of Gelderland in the Netherlands. Additional financial support has been provided through the VINNMER-programme from Vinnova - Swedish Governmental Agency for Innovation Systems. The comparison between disposable and reusable cups elaborated for the reusable cups from the BSc-thesis of Robert Hoeboer who was at that time a student at Wageningen University.

6. References

Anonymous (1995): Dixie Cup Company History Lafayette. College Libraries, Easton, Pennsylvania (United States of America). (http://academicmuseum.lafayette.edu/special/dixie/company.html; retrieved 16/4/2014)

Boustani A., Sahni S., Gutowski T., Graves S. (2010): Appliance Remanufacturing and Energy Savings. Sloan School of Management, Cambridge, Massachusetts (United States of America).

Bramberg G., Rasmanis V., Westerdahl M., Karlberg C. (2011): A comparative LCA of ceramic cups and disposal paper cups. KTH Royal Institute of Technology, Stockholm (Sweden).

Butijn C., Ploum L., Heuvelmans K., Potting J. (2014): Disposable cups, a small product with a big influence in the user's mind. Ready for submission.

CBS (2012): Renewable energy in the Netherlands 2010. Statistics Netherlands, The Hague/Heerlen (the Netherlands).

Davison, A. (1991): Health lessons. Book 1. American Book Company, New York, Cincinnati, Chicago (United States of America)

Dutch association of detergent manufacturers (2012): Detergent for hand-washing dishes. (http://www.isditproductveilig.nl/was_en_reinigingsmiddelen/pages/view.php?page_id=69; retrieved 15/6/2012)

European Commission (2012): Energy. Country factsheets. 2012.V.1.3.

Eclectsite (2013): (http://www.eclecticsite.be/calc/waterVerwarmen.htm; retrieved 28/5/2013)

Ecoinvent Centre (2010): Ecoinvent Data v. 2.2. Final Reports Ecoinvent. Dübendorf (Switzerland).

Eurostat (2012): Electricity production and supply statistics. (http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Electricity_production_and_supply_statistics; retrieved on 21/4/2014).

Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Dones R., Hellweg S., Hischier R., Humbert S., Margni M., Nemecek T., Spielmann M. (2003): Implementation of Life Cycle Impact Assessment Methods. Final Reports Ecoinvent 2000 No. 3: Dübendorf.

Guinée J.B., Gorrée M., Heijungs R., Huppes G., Kleijn R., Koning A.d., Oers L.v., Wegener Sleeswijk A., Suh S., Udo de Haes H.A., Bruijn H.d., Duin R.v., Huijbregts M.A.J. (2002): Handbook on Life Cycle Assessment. Operational Guide to the ISO Standards. Kluwer Academic Publishers, Dordrecht (the Netherlands).

Hoeboer R. (2012): How user behaviour can change the environmental impacts of an earthenware coffee mug. An LCA. Wageningen University, Wageningen (the Netherlands). Internal report, not published.

Jacobs (2006): Pulp and Paper Industry Energy Bandwidth Study. American Institute of Chemical Engineers, New York, USA(Greenville, South Carolina, USA) and Institute of Paper Science and Technology (at Georgia Institute of Technology Atlanta, Georgia, USA)

Jager L.C. (2008): Consumers appreciate biological degradable packaging (Consumenten waarderen biologisch afbreekbare verpakking). BioKnowledge News (BioKennis nieuws).

Kok, R., R.M.J. Benders, H.C. Moll (1996). EAP-analyses of the Dutch consumption spending in 1996. Addendem of the report Energy intensities of the Dutch consumption spending in 1996 (in Dutch). IVEM, University of Groningen, Groningen (the Netherlands)

Montreal Gazette (1908): Death in school drinking cups. Montreal Gazette, July 25, 1908.

NatureWorks LLC (2011): Sourcing Ingeo: Raw materials. (http://www.natureworksllc.com/The-Ingeo-Journey/Raw-Materials; retrieved on 13/2/2011)

Potting J. (2013): A biocup of coffee (biobakkie koffie) ? Wageningen University, Wageningen, the Netherlands.

Reading Eagle (1909): Dangers of water drinking in public places. Reading Eagle, June 12, 1909.

Reinink M., Oosterkamp I. and Savelkouls X. (1991): No future for disposables? Research into the use of disposable plastic cups and packaging materials at Wageningen University (Report nr. 55). Sociology of Consumers and Households, Wageningen University, Wageningen (the Netherlands).

Tork (2006): Tork Premium Hand Towel Interfold Soft. (http://www.tork.nl/product/100288; retrieved 15/6/2012)

Van der Harst E., Potting J., (2013): A critical comparison of ten disposable cup LCAs. Environ. Impact Assess. Rev. 43:86-96.

Van der Harst E., Potting J. (2014): Variation in LCA results for disposable polystyrene beverage cups due to multiple data sets and modelling choices. Environmental Modelling & Software 51:123-135

Van der Harst E., Potting J., Kroeze C. (2014): Multiple data sets and modelling choices in a comparative LCA of disposable beverage cups. Submitted to Science of the Total Environment.

Wikiversity (2014): Design for the Environment / Disposable Coffee Cups. (http://en.wikiversity.org/wiki/Design_for_the_Environment/Disposable_Coffee_Cups; retrieved 16/42014)

This paper is from:

Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector

LCA Food 2014

8-10 October 2014 - San Francisco

Rita Schenck and Douglas Huizenga, Editors
American Center for Life Cycle Assessment

The full proceedings document can be found here:
http://lcacenter.org/lcafood2014/proceedings/LCA_Food_2014_Proceedings.pdf

It should be cited as:

Schenck, R., Huizenga, D. (Eds.), 2014. Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), 8-10 October 2014, San Francisco, USA. ACLCA, Vashon, WA, USA.

Questions and comments can be addressed to: staff@lcacenter.org

ISBN: 978-0-9882145-7-6