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Single-use beverage cups and their alternatives

Recommendations from Life Cycle Assessments

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Executive Summary

Single-use beverage cups are amongst the top items found littered on beaches around the world. Typically made from polystyrene (PS) or polymer-lined paperboard, these disposable cups are widely used as a cheap and convenient way to consume takeaway drinks. But due in part to variable recycling habits and waste management practices globally, too many of the 500 billion single-use cups consumed each year end up discarded as litter.

As with all mismanaged plastic waste, **single-use beverage cups contribute significantly to marine pollution with impacts on marine biodiversity loss, as well as impacts on industries like tourism fishing and shipping.**

The use of disposable beverage cups **is set to rise exponentially in line with changing food trends that favour convenience,** especially in middle- to low-income countries. Urgent action is therefore needed – at policy, business and citizen level – to find sustainable alternatives for consuming beverages outside of the home. In recent years, a number of alternatives have been put forward, including reusable cups and improved management at end-of-life. However, these are not without challenges of their own.

This report summarises current knowledge about the environmental performance of single-use beverage cups and their alternatives in order to help guide policy actions to regulate their use. It is a meta-analysis of ten Life Cycle Assessment (LCA) studies that can be grouped in three distinct clusters: LCA studies comparing single-use beverage cups; LCA studies comparing single-use and reusable beverage cups – hot drinks; and LCA studies comparing single-use and reusable beverage cups – cold drinks. These studies and their key findings are summarised in the table at the end of the Executive Summary.

The analysis demonstrates, there are multiple variables that affect the environmental impacts of beverage cups across their value chain, whether single-use or reusable. Overall, **reusable cups emerge as the better alternative,** dependent on specific conditions; and in regions where renewable electricity makes up a high proportion of the grid mix, recycling rates are low, and consumers are aware and responsible with regards to washing practices and number of reuses, **reusable cups are the clear choice.**

Because of the degree of variability revealed in the studies, a key message of this meta-analysis is that **policy solutions** will need to be **context specific and locally relevant** and take into consideration the role of human behaviour. **There is no one-size-fits-all approach.** Instead, policy makers can draw on best practice and make sure that this is adapted in a way that will work for their own country and population.

Overall, **reusable cups emerge as the better alternative**. In regions where renewable electricity makes up a high proportion of the grid mix, recycling rates are low, and consumers are aware and responsible with regards to washing practices and number of reuses, **reusable cups are the clear choice.**

This meta-analysis suggests:

- Single-use cups have similar environmental impacts regardless of the material they are made of (whether bio-plastic, fossil-based plastic or paper). When choosing between single-use options, **the least environmentally problematic choice may be to use paper cups, especially if the currently low recycling rates can be turned around.**
- Hot drinks should be served in reusable cups (e.g., ceramic cups, glass cups, reusable plastic cups, and melamine and bamboo cups; depending on the design these cups can have silicon or cork bands; and silicone or rubber lids). These **reusable options are more environmentally sound than any other single-use alternative**, as long as washing of the reusable cups between uses is efficient. This means using an efficient, fully-loaded dishwasher or, if handwashed, using cold water. The case becomes even more compelling as older, inefficient dishwashers are replaced and there is increased penetration of renewables in the regional electricity grid mixes. Along with consumer behaviour in the use phase, the end-of-life technology used and the available recycling infrastructure are also important. So much so that **paper cups can become the better option in terms of climate impact than reusable cups if recycling of paper cups exceeds 80%, although this recycling rate is seldom achieved.**
- **For cold drinks, reusable cups are also a better option** (e.g., stainless steel, polycarbonate, etc.) and have lower environmental impacts compared to any other single-use alternative. This holds true for public events, especially smaller events which have a lower percentage of losses.
- For both hot and cold drinks most studies identify a breakeven point for reusable cups, which is the number of times a reusable cup needs to be used for the impact to be similar or better than a single-use cup. **In all cases, the number of reuses required to breakeven is well within the assumed life span of the reusable cups.**

CRITICAL PARAMETERS INFLUENCING THE ENVIRONMENTAL IMPACT OF BEVERAGE CUPS AND THEIR ALTERNATIVES

Based on the studies analysed, several parameters should be considered when conducting and interpreting LCAs of single-use beverage cups and their alternatives. Below is a non-exhaustive list of these.

- **Single- or multi-use:** Reusable cups have lower climate impact than single-use cups, regardless of material, although the number of reuses to breakeven with single-use cups in terms of climate impact varies with the material. The number of reuses ranged from 10 to 670, depending on the materials compared, end-of-life assumptions and especially washing assumptions. Reusable cups also have lower impacts across most of the other impact categories considered in the studies, although this varies even within the studies with different use and behaviour scenarios. Consumer behaviour is uncertain, and the number of reuses is an assumption in most studies.
- **Material used:** No material consistently performs the best or worst across the studies, although some trends are evident: paper cups are comparable to recycled plastic (rPET); paper and bio-plastic cups have lower impacts than polystyrene cups (PS and HI-PS); paper cups lined with plastic (PE) have lower impacts than paper lined with bio-plastic (PLA); and wax-lined paper cups have lower impacts than PE-lined paper cups. Manufacturing is the largest contributor to the life cycle environmental impacts of single-use cups. Using recycled materials to produce beverage cups reduces fossil fuel resource depletion and impact on climate change substantially.
- **End-of-life treatment:** After manufacturing, the management of single-use cups at end-of-life is an important contributor to life cycle impact. Neither recycling, composting, landfilling or incinerating consistently give the lowest life cycle impacts across the studies and across all environmental impact categories considered. Nonetheless, for all materials, recycling the cups at end-of-life is preferred to landfill. Furthermore, the higher the recycling rate, the lower the potential impact on climate change; especially pertinent to paperboard cups. This is due to differences in degradation rates assumed for the different materials across the studies, and also whether – and to what degree – recycling credits are applied.
- **The role of consumer behaviour:** While reusable cups offer a lower impact than single-use cups across most impact categories, this is contingent on the number of uses of the reusable cup. As a result, consumer behaviour plays a major role in determining the impact of a reusable cup, regardless of the material type. Furthermore, consumer behaviour in how cups are washed, for example, whether they are washed by hand or in a machine, and at what water temperature is an important determinant of the degree to which reusable cups are environmentally preferable to single-use cups. Washing reusable cups is the most significant contributor to the life cycle environmental impacts of reusable cups, followed by manufacturing. Most of the studies analysed determine a breakeven point ranging from 10 to 670 uses depending on the materials compared, end-of-life assumptions and washing assumptions.

Manufacturing is the **largest contributor to the life cycle environmental impacts of single-use cups.** Using recycled materials to produce beverage cups reduces fossil fuel resource depletion and impact on climate change substantially.

- **Choice of environmental impact indicators:** The purpose of an LCA is to assess all types of environmental impacts to better understand trade-offs and avoid burden shifting. There is a tendency to focus on climate impact due to its relevance and the fact that it is a priority for policy makers. In some cases, results for other impact categories are not presented, or given far less attention. Impact on water scarcity tends to be neglected (even omitted in many studies) despite water use being higher and potentially significant in some regional contexts in reusable cup systems. Most studies also assume all cups end up in formal waste management systems at end-of-life (rather than being littered or informally disposed). Potentially important aspects, such as litter impacts on biodiversity and ecosystems, and further disamenity impacts associated with the higher waste volumes of single-use cups are not well assessed by the LCA studies (if at all).
- **Geographical context:** The environmental impacts of beverage cups have been shown to be strongly influenced by technologies and energy sources for production and end-of-life management. These are parameters that are region- and country-specific. For example, in Europe, incineration is a commonly employed waste management option where the energy value of the waste is recovered. In other regions, incineration is an unacceptable waste management option with landfilling the most common alternative. In the developing country context, formal waste management may be lacking with many single-use items ending up as litter or in informal waste management systems. Similar geographical disparities can be observed in the availability of bio-based feedstocks, electricity grid mix, acceptability of reusable alternatives to consumers, available recycling infrastructure, and so forth. It is also vital to consider and geographically differentiate consumer behaviour. This includes consumer attitudes to alternatives (especially to reusable cups), washing practices and waste behaviours, such as likelihood of recycling and littering single-use cups.
- **Functional equivalence:** The cups compared in the studies were all fairly similar in terms of the size of cup and function, particularly for hot drinks. However, they were less consistent in terms of the other functions provided by a certain beverage cup, specifically lids to prevent spilling when transporting hot drinks or bands or sleeves to make the cup more handleable when hot. The functional equivalence of these "add-ons" were not often discussed but might be relevant to consumers particularly when considering a transition from a single-use to a reusable system. Lids and sleeves were also shown to potentially add a sizable increase to the environmental impacts.

RECOMMENDATIONS FOR POLICY MAKERS

This meta-analysis serves to highlight important aspects that policy makers should consider when evaluating environmental information (often in the form of LCA studies) on single-use beverage cups and their alternatives to inform policy development that is context specific and locally relevant. These contexts and the preferences for the different beverage cups under different scenarios are summarised in the matrix below.

Preferred type of beverage cups depending on waste management context and behavioural considerations

This matrix helps countries, regions and cities to identify the closest scenario and most appropriate options for their context.
The content of the matrix is simplified. Please refer to the full narrative of the meta-study for details.

Eco- or cost-conscious Consumer

Indifferent Consumer

Considerations of geographical and technological context

	EFFICIENT WASHING during use-phase (energy efficient dishwasher or hand wash in cold water)	CUPS REUSED many times	UNLIKELY TO LITTER / likely to recycle or compost	INEFFICIENT WASHING during use-phase (Hand wash in hot water)	INSUFFICIENT REUSE of cups (Little consumer awareness)	LIKELY TO LITTER / unlikely to recycle
NO FORMAL WASTE MANAGEMENT & POOR RECYCLING SUPPORT unsanitary landfill, open dumps, open burning, no policy support for recycling and/or composting	**Reusable** regardless of energy mix	**Reusable** Ceramic; glass; stainless steel; bamboo	**Reusable** Ceramic; glass; stainless steel; bamboo	**Reusable** in case of renewable energy mix **Single-use** in case of carbon intensive energy mix	**Single-use** Wax-, PE- or bioplastic-lined paper	**Reusable** Ceramic; glass; stainless steel; bamboo
FORMAL WASTE MANAGEMENT BUT POOR RECYCLING SUPPORT sanitary landfill, incineration with energy recovery, but no or low policy support for recycling and/or composting	**No clear preference** in case of carbon intensive energy mix **Reusable** in case of renewable energy mix	**Reusable** Ceramic; glass; stainless steel; bamboo; PP	**No clear preference** between reusable and single-use (EPS) If incineration with energy recovery and **importantly** if single-use are being collected and managed.	**Single-use** in case of carbon intensive energy mix **No clear preference** in case of renewable energy mix	**Single-use** EPS; wax-, PE- or bioplastic-lined paper	**Reusable** Ceramic; glass; stainless steel; bamboo
FORMAL WASTE MANAGEMENT & RECYCLING INFRASTRUCTURE sanitary landfill and/or incineration with energy recovery	**Single-use** in case of carbon Intensive energy mix **Reusable** in case of renewable energy mix	**Reusable** especially recyclable materials such as PP, glass, and stainless steel	**Single-use** PE- or bioplastic-lined paper; rPET **Reusable** especially recyclable materials such as PP, glass and stainless steel	**Single-use** regardless of energy mix	**Single-use** PE- or bioplastic-lined paper; rPET	**Reusable** PP; ceramic; glass; stainless steel; bamboo

Reusable cups preferred | Single-use cups preferred | No clear preference for reusable or single-use cups

Overall the meta-analysis recommends the following:

- **Policies must take a systems perspective** and consider the whole life cycle of the beverage cup/take-away drink system. In addition to the material of the cup, it is also important to consider a wider set of factors including energy sector developments, current and future waste management infrastructure, complementary and conflicting policies in place, implementation costs, consumer awareness, perceptions and behaviour change required (especially around reuse and responsible disposal of cups after use), and related implementation barriers. Many of these considerations are not only country specific, but also vary with time.
- **Policies must consider regional and country-specific differences** including any transportation, washing (and drying) technologies and practices as well as barriers to uptake. For example, reusable cups may be unpractical in situations where facilities for washing are absent, limited or inconvenient. Geographical differences are also evident in waste treatment processes. It is important that the end-of-life fate of material is correctly and appropriately modelled taking into account the geographic location and limitations of existing infrastructure and technologies (as well as the potential of future technologies). For example, although most bio-plastics are compostable under the correct conditions in industrial facilities, there are often limited or no facilities for the separate collection of materials and infrastructure for industrial composting, so most will be disposed of in landfill or end up as litter. Other factors that are influenced by geography include the availability of feedstocks for bio-plastics, the type of power generation technology, whether handwashing or machine washing is most prevalent and consumer perceptions with regard to reuse and recycling.
- **Policies should be based on studies that use the best available data and account for likely future developments in production processes and related systems.** Every effort should be made to critically evaluate the data used in the studies and source the most recent and representative data possible. Newer technologies may be at a disadvantage to other more established technologies due to their smaller scale. Where possible, likely improvements in terms of environmental performance should be included. Energy, transport and waste management systems as well as appliance efficiencies and recycling processes may change over time, influencing the relative environmental performance of different beverage cups.
- **Policies must take into account consumer behaviour and perceptions,** for example perceptions around hygiene and public health, which vary from country to country, will have a significant impact on the uptake of reusable cups. Heightened concerns around hygiene during the Covid-19 pandemic have hampered efforts to address single-use plastic products and stalled the uptake of reusable alternatives, with some countries even reversing or delaying single-use plastic product bans[1]. The characteristics of the consumer population will influence policy uptake in other ways too. For example, littering is common behaviour in certain countries and non-existent in others. Changing consumer behaviour in this regard is necessary to tackle plastic pollution. However, influencing consumer behaviour through policies – such as charging for single-use cups, incentivising mug-share schemes and product bans – is complex and care must be taken that devised policies have the desired effect and do not lead to unintended consequences themselves. Interventions that are accompanied by clear environmental messaging and social marketing campaigns can increase success.
- **Policies must recognise and manage trade-offs and the risks of burden-shifting between environmental impacts and should not focus solely on climate impact just because it is relevant, urgent and familiar.** Policy makers should also seek to be cognisant of environmental impacts not quantified in life cycle assessments, most notably marine litter, health and safety aspects, biodiversity and land use change impacts. Ideally, LCA results need to be considered together with other sources of relevant information on environmental aspects, particularly where gaps exist in LCA methodology.

1 *Although these fears have been countered by experts as without substance, see https://www.greenpeace.org/usa/wp-content/uploads/2020/06/Health-Expert-Statement_Final.pdf*

Table E1: Overview of studies included in the meta-analysis

The option with the lowest climate impact

Study	Functional unit	Material					Geographic scope	Main conclusions
		Single-use			Reusable			
		Bio-based plastic	Fossil-based plastic	Plastic	Plastic	Other		
LCA studies comparing single-use beverage cups								
A critical comparison of ten disposable cup LCAs *Van der Harst, E. and Potting, J. (2013)* This study is a meta-analysis that compares 10 LCA studies of single-use cups (for both hot and cold drinks) made from a variety of fossil fuel- (HI-PS, EPS, PP, PET and rPET) and bio-based plastics (PLA) as well as paperboard (PE, PLA and wax lined).	Number of cups or amount of cups needed to serve an amount of liquid	PLA	HI-PS; EPS; PP; PET & rPET	PE lining; PLA lining; wax lining			North America, Europe	The global warming potential (GWP) both within and across studies shows that for single-use cups no one material is consistently better or worse than other materials and the differences in GWP are due to a number of factors, including cup material, cup weight, production processes, waste process, allocation options and data used.
Multiple data sets and modelling choices in a comparative LCA of disposable beverage cups *Van der Harst, E., Potting, J. and Kroeze, C. (2014)* This study incorporates and translates the variability in inventory data into a spread in LCA results by applying multiple data sets. The range of applicable modelling choices are also applied (e.g., different waste management processes and allocation methods). Three types of single-use beverage cups were included in the analysis.	Provision of a disposable beverage cup fit for serving 180ml hot drinks by vending machines	PLA	PS	PLA lining			Global	

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Study	Functional unit	Material					Geographic scope	Main conclusions
		Single-use			Reusable			
		Bio-based plastic	Fossil-based plastic	Plastic	Plastic	Other		
LCA studies comparing single-use and reusable beverage cups – HOT drinks								
How small daily choices play a huge role in climate change: The disposable paper cup environmental bane *Foteinis, S. (2020)* This study compares the environmental footprint of single-use paperboard cups with reusable plastic cups. Two different end-of-life scenarios are assessed for the paper cup, namely landfilling and recycling.	One typical paper cup, intended for the consumption of one medium (hot) drink (340ml)			PE lining	PP cup with silicone band		Europe (UK)	Recycling single-use paperboard cups rather than sending them to landfill could reduce their climate impact by 36%. However, a far greater decrease in environmental impacts can be achieved by switching to a reusable plastic cup. The reusable cup option has the potential to reduce climate impact by 69% (assuming 500 uses and compared to a landfilled paper cup).
Taking a closer look at paper cups for coffee *VTT (2019)* *This study compares several single-use and reusable beverage cups and investigates the impact of recycled content, washing efficiency and different end-of-life scenarios.*	1,000 servings of coffee in sit-down or take-away context			PE lining; PLA lining with and without PS lid	PP cup with silicone band	Ceramic; Stainless Steel	Europe	This study demonstrates that paper cups can be a better option in terms of climate impact than reusable cups under certain situations. In particular, if recycling of paper cups exceeds 80% or if washing of reusable cups between uses is inefficient (e.g., if washed in an older or partially-loaded dishwasher)
Join the reusable revolution *CupClub (2018)* This study compares the quantitative environmental profile of CupClub – a returnable packaging service for drinks in the United Kingdom – to three single-use cups and a ceramic reusable cup.	One CupClub cup and lid delivered and collected from manufacture, used 132 times, backhauled, washed and dried 133 times and then recycled		EPS with PS lid	PE liner and PS lid; PLA liner and PLA lid	PP cup with LDPE lid	Ceramic	Europe	The PP plastic cup with lid (CupClub) has lower environmental impacts than both types of single-use paper cups across all environmental impact category indicators and has lower environmental impacts than the single-use polystyrene cups and ceramic cups in nine and 17 of the impact category indicators respectively.
Case Study: Ceramic cup vs. Paper cup *Martin, S., Bunsen, J. and Ciroth, A. (2018* This study compares the environmental impacts of a traditional reusable ceramic cup, with and without a lid, and a paper cup with a PE lining and PS lid, with various use scenarios.	750 x 300 ml of coffee served in cup – washed in dishwasher			PE lining and PS lid		Ceramic, with and without rubber lid – washed in dishwasher	Europe (Germany)	The study recommends that hot drinks should be served in reusable cups, but that the washing method (dishwasher or handwashing) and water temperature have a major effect on the overall environmental impacts of the reusable cup.
	750 x 300 ml of coffee served in cup – washed by hand			PE lining and PS lid		Ceramic, with rubber lid – washed by hand		

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Study	Functional unit	Material					Geographic scope	Main conclusions
		Single-use			Reusable			
		Bio-based plastic	Fossil-based plastic	Plastic	Plastic	Other		
Reusable coffee cups life cycle assessment and benchmark *Almeida, J., Pellec, M. L. and Bengtsson, J. (2018)* This study assesses the environmental impact of three KeepCups and three other single-use and reusable cups. It aims to understand the environmental hotspots along the KeepCups supply chain in three key markets: Europe, Australia/Asia and the US.	One year of coffee drinking			PE lining and PS lid; PLA lining and PLA lid	PP cup and lid, with and without silicone band	Melamine and bamboo cup with silicone lid and band; Glass cup with silicone or cork band and rubber lid	Australia, New Zealand, Australia, North America and Europe	The reusable cups (KeepCups, bamboo and PP) have lower GWP and energy use than single-use cups but higher water consumption as a result of washing. The GWP of the three KeepCups and the bamboo cup are relatively similar and are 88% lower than the paper cup with PLA lining.
Reusable vs. disposable cups revisited: guidance in life cycle comparisons addressing scenario, model, and parameter uncertainties for the US consumer *Woods, L. and Bakshi, B. R. (2014)* This study compares the impact of reusable cups and single-use cups in the United States, evaluating the influence of different dishwashing appliance models and subnational electricity grid mixes.	Impact per use		EPS			Ceramic	US	Reusable cups perform better in terms of their climate impact across most regions of the United States compared to single-use polystyrene cups. The case for reusable cups in the US will strengthen further as older inefficient dishwashers are replaced and there is increased penetration of natural gas and renewables in the regional electricity grid mixes.

Table E1: Overview of studies included in the meta-analysis

Study	Functional unit	Material					Geographic scope	Main conclusions
		Single-use			Reusable			
		Bio-based plastic	Fossil-based plastic	Plastic	Plastic	Other		
LCA studies comparing single-use and reusable beverage cups – COLD drinks								
Choice of materials for takeaway beverage cups towards a circular economy *Changwichan, K. and Gheewala, S. H. (2020)* This study compares three plastic single-use beverage cups with lids, both bio-based and fossil, with a reusable stainless steel beverage cup with a plastic lid.	Providing a 650ml container for one drink each workday (five days a week) for a year (52 weeks) or 260 drinks per year	PLA	PP PET			Stainless steel with plastic lid	Asia (Thailand)	Handwashed reusable stainless steel cups have lower environmental impacts compared to single-use PP, PET and PLA. Both handwashed and machine-washed stainless steel cups have lower potential contribution to climate change than the plastic alternatives. The inclusion of recycled materials decreases the impacts of all cup types, with the stainless steel cup showing the largest reductions. Recycling at end-of-life also significantly decreases the potential climate and human toxicity impact of the PP and PET cups.
Life cycle assessment and eco-efficiency analysis of drinking cups used at public events *Vercalsteren, A., Spirinckx, C. and Geerken, T. (2010)* The objective of this study is to gain insight into the environmental impacts and costs related to existing systems for serving drinks at public events in Belgium. The study uses LCA and an eco-efficiency analysis* to evaluate four alternative types of drinking cups used at small and large public events.	Serving 100 litres of beer or soft drinks at small-scale indoor event (2,000 - 5,000)	PLA	PP	PE coating	PC		Europe (Belgium)	The LCA does not clearly identify the best cup type for both types of events. However, in the eco-efficiency analysis the reusable PC cup performs best in terms of environmental impacts at small events, although the costs are higher than single-use cups.
	Serving 100 litres of beer or soft drinks at a large-scale outdoor event (›30,000 visitors)	PLA	PP	PE coating	PC			

* A single environmental score and economic (cost) score

Abbreviations

TERM	DEFINITION
EPS	Expanded polystyrene
FU	Functional Unit
GHG	Greenhouse gas
GWP	Global warming potential
HI-PS	High impact polystyrene
LCA	Life cycle assessment
PB	Paperboard
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene terephthalate
PLA	Polylactic acid
PP	Polypropylene
PS	Polystyrene
RFID	Radio frequency identification
rPET	Recycled PET
UNEP	United Nations Environment Programme
WTE	Waste To Energy (incineration)

01 Introduction

01 INTRODUCTION

1.1 BACKGROUND

Plastic products and packaging are pervasive in modern society, with an estimated nine billion tonnes of plastic produced to date, mostly from fossil fuels (Geyer, Jambeck and Law, 2017; UNEP, 2018). Most of the plastic is in the form of packaging or other single-use items and quickly ends up as waste. The scale of the problem is already immense, with plastic production continuing to increase. At the same time, plastic recycling rates remain very low with only 9% of all plastic ever produced recycled (Geyer, Jambeck and Law, 2017). As a result, plastic waste is steadily accumulating in landfills, and where solid waste management is inadequate, it ends up littering and polluting the natural environment, waterways and oceans. In poorer countries, abundant plastic waste is used as a fuel for cooking and heating. This releases toxic emissions, which negatively impact human health.

Plastic litter not only has impacts on marine, freshwater and terrestrial ecosystems, but also an economic impact, particularly on industries like tourism, fishing and shipping. And because most plastic does not biodegrade, but rather breaks down over time into smaller and smaller pieces eventually becoming microplastics, plastic particles have been found in almost every natural habitat on earth and in a wide range of organisms and animals. Plastic debris has even been found in the deep ocean, with microplastics ingested by deep sea amphipods in six of the deepest marine ecosystems on Earth (Jamieson et al., 2019).

Single-use beverage cups are one of the top ten items found littered on beaches around the world (Ocean Conservancy, 2011). Used for take-away drinks such as coffee, they are typically made from polystyrene (PS) or polymer-lined paperboard. Globally, over 500 billion disposable cups are consumed annually, of which between 250 and 300 billion are plastic-lined paper cups (Martin, Bunsen and Ciroth, 2018; Foteinis, 2020). Demand for single-use beverage cups is expected to grow exponentially in middle- and low-income countries where beverage cup consumption is currently relatively low (Foteinis, 2020). As recycling is costly and problematic and waste management is often inadequate, a significant proportion of these single-use cups may end up as litter. Various solutions to address the issues associated with single-use beverage cups have been put forward in recent years including reusable cups and improved management at end-of-life (composting and recycling systems). However, these alternatives have their own challenges, not least of which is changing entrenched consumer behaviour.

Resolution 9 of the Fourth United Nations Environment Assembly (UNEA4) in March 2019, on "Addressing single-use plastic products pollution" (UNEP/EA.4/R.9), "encourages member states to take actions, as appropriate, to promote the identification and development of environmentally-friendly alternatives to single-use plastic products,[2] taking into account the full life cycle implications of those alternatives" (UNEP, 2019). One of the actions under UNEP/EA.4/R.9 is to make available existing information on the full life cycle environmental impacts of single-use plastic products compared to their alternatives.

Guided by UNEA4 resolution 9, this study aims to provide insight into how LCAs can be used to make informed decisions on single-use plastic products and their alternatives. In particular, it addresses single-use plastic beverage cups and their alternatives. It is part of a series of reports covering other widespread single-use plastic products and their alternatives, including bags, bottles, take-away food packaging, tableware, nappies, feminine hygiene products and face masks (personal protective equipment).[3]

Single-use beverage cups are one of the **top ten items found littered on beaches around the world.** Globally, over 500 billion disposable cups are consumed annually, of which between **250 and 300 billion are plastic-lined paper cups.**

2 *Although these fears have been countered by experts as without substance, see https://www.greenpeace.org/usa/wp-content/uploads/2020/06/Health-Expert-Statement_Final.pdf*

3 *All of these reports are available from https://www.lifecycleinitiative.org/single-use-plastic-products-studies*

1.2 PURPOSE, SCOPE AND METHOD

This report provides insights on how Life Cycle Assessments (LCAs) can inform policy decisions on single-use plastic beverage cups and their alternatives. The report is based on the review and analysis (meta-analysis) of selected existing LCA studies that compare single-use beverage cups and their alternatives. The different solutions for providing customers with a means to consume beverages outside of the home considered in this report thus follow those that have been covered in the LCA literature. Beverage cups for containing both hot and cold beverages are covered in the report, with the following single-use and reusable options considered:

- Bio-based plastic, single-use: biodegradable[4] thermoplastic made from renewable resources (PLA)
- Fossil-based plastic, single-use: polystyrene (HI-PS and EPS), virgin thermoplastics (PP, PET) and recycled thermoplastic polymer (rPET)
- Paper, single-use: Paperboard lined with plastic, both conventional (PE) and bio-based (PLA), and wax-lined paperboard
- Plastic, reusable: virgin thermoplastics (PP and PC)
- Other, reusable: Ceramic, bamboo, glass and stainless steel

Searches were initially performed on Web of Science to identify relevant peer-reviewed studies published between 2000 and 2020. Further searches were performed using Google Scholar and Google to ensure the literature search was comprehensive and included both academic literature as well as company-sponsored LCA studies. With input from UNEP and the Technical Advisory Committee (TAC), the initial list of 27 identified studies was narrowed down using the following criteria:

- **Type of packaging studied:** Studies that focused on single-use and reusable beverage cups for both hot and cold beverages were included. This meta-analysis therefore did not include other types of take-away packaging, even if the packaging was similar to beverage cups (e.g., plastic-lined paper cups or tubs for yoghurt or ice cream). Beverage bottles and cans were also excluded. The studies were required to focus on the cups themselves and exclude any assessment of beverage contents.

4 *The bio-based plastic included in the options is PLA, which only biodegrades under industrial composting conditions (i.e. at high humidity and temperatures of around 60°C).*

- **Completeness of the study:** Full LCA studies were preferred over preliminary or screening LCA studies.
- **Transparency of the study:** It was important that as much detail as possible was included in the publication, particularly on methodological assumptions and sources of underlying data and selected impact assessment methods.
- **Geographic coverage:** Electricity grid mix, available waste management technologies and efficiencies, and local recycling rates differ significantly by geographic region. Thus, including studies from as many regions as possible was important for the meta-analysis. This report is intended to have global applicability, which provided further rationale for broad geographic coverage.
- **Publication date:** Technologies improve over time and so although the original screening considered publications from 2000 onwards, more recent studies were given preference in the final selection.
- **Language:** The meta-analysis only included studies published in English.
- **Peer-reviewed studies:** Preference was given to studies that have been through a peer-review to ensure a level of rigour and quality from expert reviewer input. Compliance with international standards was not used as a selection criterion as this is often not explicitly stated in publications. Furthermore, it is assumed that the peer review process would focus on compliance with relevant standards.

Ten studies fulfilled the criteria and were selected for the meta-analysis (Table E1). These studies can be clustered as follows:

- LCA studies comparing single-use beverage cups
- LCA studies comparing single-use and reusable beverage cups – hot drinks
- LCA studies comparing single-use and reusable beverage cups – cold drinks

In terms of geographic scope, an existing meta-study that compares the results of ten studies covering Europe and North America was included for the comparison of single-use beverage cups. The authors of this meta-study published a second study on single-use beverage cups, which used multiple data sets to account for geographic differences. For the hot drinks cluster, four European, one North American and one global study were reviewed. For cold drinks, one Asian and one European study were analysed.

1.3 LCA METHOD IN BRIEF

LCA is a well-established tool for assessing the potential environmental impacts associated with a product or service, providing a structured framework within which to model its consequences on the natural environment and society. All stages of a product's life cycle are considered, from mining, extraction or growing of raw materials, to its manufacturing, distribution and use, right up to the final disposal of its components. LCAs have a number of benefits including:

- Creating awareness that decisions are not isolated, but that they influence a larger system;
- Promoting decision-making for the longer-term, by considering all environmental issues and potential knock-on effects associated with a decision choice; and
- Improving entire systems, and not just single parts of systems, by avoiding decisions that fix one problem but cause another unexpected issue.

LCAs provide a robust framework for analysing environmental impacts along the entire product value chain and life cycle, considering different material types and subsequent stages such as use and end-of-life. This method allows the user to draw conclusions and make recommendations on the impact and significance of each life cycle stage of the product analysed and makes possible comparisons with different products or systems. International standards on LCAs (ISO 14040 and ISO 14044) divide LCAs into four main stages:

- **Goal and scope definition:** Objective (goal) and the methodological approach (scope).
- **Inventory analysis:** All raw materials and emissions (inputs and outputs) are considered for each of the unit processes that make up the life cycle of the product. Inputs include the use of natural resources, such as land and water, as well as manufactured materials such as fuels and chemicals. Outputs are released to air, water and land, as well as all products and by-products. Taken together these unit processes make up the life cycle system to be analysed, as defined by the product system boundary. The Life Cycle Inventory (LCI) is a comprehensive list of resources and emissions (inputs and outputs).

- **Impact assessment:** Assesses the life cycle inventory by connecting resources and emissions to their corresponding impacts on the environment and human health. In this way, the inputs and outputs are summed up into common areas of environmental concern, for example, impacts on human health, impacts on ecosystems etc. This can be done at varying degrees of complexity, and a number of different Life Cycle Impact Assessment (LCIA) methods have been developed to quantify the potential environmental impacts of a product system.
- **Interpretation:** Findings are evaluated in relation to the defined goal and scope in order to reach conclusions and make recommendations.

It is important to note that although the LCA method is standardised, there is still room for a range of methodological choices that impact the results. Additionally, LCAs predict potential environmental impacts or damages, as the necessarily global nature of the predictive LCIA models means they do not take the specific receiving environment into account. Life cycle inventory data (the basis for impact assessment) span multiple geographical locations across countries and continents in today's global supply chains, thus LCIA's predictive models are not like environmental impact assessment (EIA) models that accurately characterise the actual risks associated with emissions at a particular location. Indeed, the value of an LCA study lies not so much with the final numbers, but rather with the exploration and consequent understanding of the system it assesses. Especially valuable is an LCA's ability to highlight hotspots along the value chain (i.e., show the areas of highest potential impact), and also to highlight trade-offs between different sustainability impacts. It is seldom that one system or decision option performs better than another in all aspects of environmental impact. Understanding these trade-offs is a prerequisite towards improving the sustainability of product systems.

02 Meta-analysis of the LCA studies

This chapter presents the **main findings and results of the analysed LCA studies.** For each study a short description is provided together with a summary of the results and main conclusions. This is followed by a tabular summary of the study, which presents details on the products studied and highlights key assumptions.

Results are summarised using colour coding to depict the relative performance of products across the impact indicators considered in the study.

The colour coding is shown in the Figure below. Note that the colour coding only denotes relative and not absolute impacts and the reader is referred to the original reference to appreciate the range and scale of the impacts calculated by the studies. All LCA studies have an inherent degree of uncertainty and variability in their results. In order not to over emphasise findings, where the difference in impact category scores between two options is less than 10%, they are ranked equally in the tables. For example, if the 2nd lowest option has an impact score less than 10% higher than the lowest option, both options are ranked "green" in the tables.

Figure 1. Color-coding for the impact indicators.

Lowest relative impact

In-between (neither highest nor lowest)

Highest relative impact

2.1 LCA STUDIES COMPARING SINGLE-USE BEVERAGE CUPS

2.1.1 Existing meta-study of single-use beverage cups made from HI-PS, EPS, PP, PET and rPET, PLA and paperboard lined with PE, PLA and wax: Van der Harst and Potting, 2013

This study is a meta-analysis that compares ten LCA studies of single-use cups (both hot and cold) made from a variety of fossil fuel-based plastics (HI-PS, EPS, PP, PET), recycled plastic (rPET) and bio-based plastic (PLA), as well as paperboard (PE, PLA and wax lined) (Van der Harst and Potting, 2013). The meta-analysis focused on only one impact category indicator, global warming potential (GWP), as this was the only common impact category indicator across all the studies. The studies considered are listed in Table 1 together with the type of single-use beverage cups covered.

The studies analysed considered a number of waste treatment options for the cups including landfilling, incineration with energy recovery, use as a fuel substitute, recycling, composting, and a combination of several waste options. Most studies applied energy credits for avoided production of conventional energy due to recovered energy during incineration.

TABLE 1: Studies and products included in the meta-study of Van der Harst and Potting (2013)

Study	Title	(HI)-PS	EPS	PP	PET & rPET	PLA	PB + PE lining	PB + PLA lining	PB + wax lining
(Franklin Associates, 2006)	Life cycle inventory of five products produced from polylactide (PLA) and fossil fuel-based resins.	x		x	x	x			
(Franklin Associates, 2009)	Life cycle inventory of 16-ounce disposable hot cups.		x		x		x		
(Franklin Associates, 2011)	Life cycle inventory of foam polystyrene, paper-based, and PLA foodservice products.		x			x	x	x	x
(Garrido and Alvarez del Castillo, 2007)Scope and Background. The objective of the study was to. determine the environmental effects of the reusable cup used during a major event (which took place in Barcelona, Universal Forum of Cultures, 2004	Environmental evaluation of single-use and reusable cups.			x					
(Hakkinen and Vares, 2010)	Environmental impacts of disposable cups with special focus on the effect of material choices and end-of-life.				x			x	
(PE Americas, 2009)	Comparative life cycle assessment of Ingeo biopolymer, PET and PP drinking cups.			x	x	x			
(Ligthart and Ansems, 2007)	Single-use cups or reusable (coffee) drinking systems: an environmental comparison.	x					x		
(Pladerer et al., 2008)	Comparative life cycle assessment of various cup systems for the selling of drinks at events.	x			x	x	x		
(Uihlein, Ehrenberger and Schebek, 2008)	Utilisation options of renewable resources: a life cycle assessment of selected products.	x				x			
(Vercalsteren et al., 2006)	Comparative LCA of 4 types of drinking cups at events.			x		x	x		

Summary of results and conclusions

In order to compare the results within and across each study, the GWP results were ordinally ranked from lowest to highest within each study. Secondly, to allow for a quantitative comparison between studies, the GWPs were adjusted to reflect a cup with a volume of 473 ml (16 oz).

- Based on the ranking of GWP only, no cup material ranked consistently better than the other cup materials across all studies. However, there were several common outcomes: the GWPs of paperboard cups were comparable to rPET cups, and lower than the GWPs of PS cups, while PLA cups have lower GWPs than HI-PS cups. Within the paperboard material group paperboard PLA-lined cups for hot beverages ranked higher in terms of their GWP than PE-lined ones, and paperboard PE-lined cups for cold beverages rank higher than wax-lined ones. There were also a number of contradictory results between rPET and EPS, PET and HI-PS, PLA and PET, PLA and PP, paperboard and EPS, paperboard and rPET and paperboard and PLA. The rankings within the fossil fuel-based plastic group were also inconsistent.
- The quantitative assessment similarly did not yield clear results regarding the preferred cup material in terms of its climate impact. A large variation in results is observed across the studies, especially within the paperboard group. In general, paperboard cups with incineration or a combination of landfill and incineration have lower GWPs, although where higher degradation rates are applied paperboard appears towards the middle or higher end of the range in GWPs. Across all cup materials, PET cups that are incinerated or landfilled have GWPs at the top end of the range, but if recycled or a combination of recycled and incinerated PET cups fall in the middle of the GWP range.

The differences in results within and across studies are attributed to differences in methodological choices, particularly allocation methods, and data sources. The factors contributing to differences in GWP highlighted by the meta-analysis include:

- The weight of the cup, with GWP increasing almost proportionally to the weight of the cup.
- Differences in the production of cup material and manufacturing of the cup.
- Differences in waste treatment processes. For fossil fuel-based plastics, incineration in comparison to landfilling can significantly increase GWP (by as much as 60% for PET cups). Landfilling fossil fuel-based plastics contributes less than 2% to GWP whereas incineration contributes between 30 and 40% to GWP. The contribution of recycling to GWP is not consistent between studies, but in general recycling can decrease GWP compared to landfilling.
- Bio-based plastics (PLA), like fossil fuel-based plastics, are considered inert during landfilling and thus contribute little to GWP. Contrary results were reported for composting PLA.
- For paperboard, incineration can decrease GWP in comparison to landfill, depending on the degradation rate assumed in the landfill.
- Differences in contribution to GWP from waste treatment processes is strongly affected by the degree of energy credits applied, recycling credits applied and degradation assumptions in landfilling and composting.
- The contribution of transport to GWP is small in most studies.

Table 2: Summary table: Van der Harst and Potting (2013)

		Products considered in studies included in the meta-analysis							
		Beverage cup – hot and cold							
Study scope	**Material**	**HI-PS**	**EPS**	**PP**	**PET & rPET**	**PLA**	**PB with PE**	**PB with PLA**	**PB with wax**
	Functional unit	Either based on the number of included cups or on the amount of cups needed to serve an amount of liquid							
	Capacity [ml]	473							
	Number of uses	Varies according to study and FU							
	Weight per container [g]	Varies according to study							
	Geographic region	EU and US							
	Life cycle stages	Cradle-to-grave (material production, production, use and waste disposal)							
	End-of-life assumptions L = landfill; I = incineration; FS = fuel substitute; R = recycling; C = composting	Varies with study and scenario (see below)							
Indicator – Global warming potential **Ranking as in Van der Harst and Potting (2013),** **1 = lowest GWP,** **4 = highest GWP**	(Franklin Associates, 2006)	3 (L/I)		1 (L/I)	4 (L/I)	2 (L/I)			
	(Franklin Associates, 2009)		1 (L/I)		1 (R); 2 (open-loop R)		1 (L/I)		
	(Franklin Associates, 2011) – max decomposition of PB – no decomposition of PB – max decomposition of PB – no decomposition of PB		 1 (L/I) 3 (L/I) 1 (L/I) 3 (L/I)			 1 (L/I) 4 (L/I)	 3 (L/I) 2 (L/I) 2 (L/I) 1 (L/I)	 2 (L/I) 1 (L/I)	 3 (L/I) 2 (L/I)
	(Hakkinen and Vares, 2010)				1 (L) 2 (I)			1 (L) 1 (I)	
	(PE Americas, 2009)			2 (L)	3 (L)	1 (L)			
	(Ligthart and Ansems, 2007)	2 (R)					1(I)		
	(Pladerer et al., 2008)	4 (I) 4 (I)			3 (I) 2 (I/R)	2 (I) 3 (C)	1 (I) 1 (I)		
	(Uihlein, Ehrenberger and Schebek, 2008)	2 (I)				1 (I)			
	(Vercalsteren et al., 2006) Small events Large events			 3 (I) 2 (I/FS)		 2 (I/C) 3 (I/C)	 1 (I) 1(I/FS)		
Method	EI99, IPCC, CML 2001 and Impact 2002+								
Other comments	The weight of the cups is an influential factor and the GWP outcomes within a study increased nearly proportional to the weight of the cup across cup systems. Other influencing factors on GWP include cup material, production of cup material, manufacturing of cup, waste treatment option, input data sources and allocation methods.								

2.1.2 Single-use PS, PLA and paperboard cups lined with PLA using multiple data sets: Van der Harst, Potting and Kroeze, 2014

The authors of the meta-analysis described in the previous section recognised the limitations of using single data sets and limited modelling choices in LCAs to draw conclusions that were more widely applicable to different types of single-use beverage cups. As described above, the variation in outcomes observed in the meta-analysis were due to a number of parameters, namely:

- Single-use beverage cup material and weight
- Production processes and technology maturity
- Sources of fuel and electricity (fossil or renewable)
- Waste management processes (e.g. landfilling, incineration, recycling, composting)
- Modelling assumptions and allocation approaches, particularly around credits for recycled material and/or energy substitution
- Representativity of data sets used.

This study incorporates and translates the variability in inventory data into a spread in LCA results by applying multiple data sets. In the same way, the range of applicable modelling choices are applied (e.g., different waste management processes and allocation methods). Three types of single-use beverage cups were included in the analysis:

- Single-use polystyrene (PS) cup
- Single-use bio-plastic (PLA) cup
- Single-use paper cup lined with bio-plastic (PLA)

Summary of results and conclusions

No one cup material has the lowest environmental impacts across all impact categories, neither is there a single best waste management option across all environmental impact categories. However, using multiple data sets, the study shows the following consistent results for the beverage cups under consideration:

- The most significant processes are production of the primary cup material, cup manufacturing and waste treatment.
- The differences observed due to the different data sets relate to the amount and type of energy used, whether energy is fossil fuel-based or renewable, the allocation approaches applied and the feedstocks for PLA (corn, tapioca, sugarcane or sugar beet).
- For the PLA cup, recycling results in lower impacts than anaerobic digestion and incineration.
- Recycling is slightly preferred over incineration for the PLA-lined paper cup.
- Composting is the least preferred option for PLA and PLA-lined paper cups as no credits are associated with this treatment option.

Table 3: Summary table: Van der Harst, Potting and Kroeze (2014)

		Products considered in study		
		PS cup	PLA cup	Biopaper
Study scope	Material	Polystyrene	PLA (produced from corn)	Paper cup with bio-plastic lining (PLA)
	Functional unit	Provision of a disposable beverage cup fit for serving 180ml hot drinks by vending machines		
	Capacity [ml]	180		
	Number of uses	1	1	1
	Weight per container [g]	4.2	4.2	5.6
	Geographic region	Netherlands		
	Life cycle stages	Cradle-to-grave (extraction of fossil fuels, production of materials and cup, transport, use and disposal)		
	End-of-life assumptions	Incineration, recycling	Incineration, recycling, composting, anaerobic digestion	Incineration, recycling, composting, anaerobic digestion
Indicators	Cumulative energy demand			
	Global warming potential			
	Abiotic depletion			
	Acidification			
	Eutrophication potential			
	Photochemical oxidation			
	Human toxicity			
	Fresh water aquatic Eco toxicity			
	Marine aquatic Eco toxicity			
	Terrestrial Eco toxicity			
	Ozone layer depletion			
Method	CML Baseline 2000			
Other comments	Multiple data sets and modelling choices illustrate the variability in LCA results. None of the cup materials can be considered best or worst and there is no preferred waste treatment option.			

Highest relative impact | In-between (neither highest nor lowest) | Lowest relative impact

2.2 LCA STUDIES COMPARING SINGLE-USE AND REUSABLE BEVERAGE CUPS – HOT DRINKS

2.2.1 Single-use PE-lined paper cups and reusable PP cups: Foteinis, 2020

This study evaluates and compares the environmental footprint of single-use paperboard cups with a reusable plastic (PP) cup. Two different end-of-life scenarios are assessed for the paper cup, namely landfilling and recycling. The following three scenarios were modelled:

- Single-use paper cup with plastic (PE) lining, landfilled
- Single-use paper cup with plastic (PE) lining, recycled
- Plastic (PP) cup with silicone band, dishwashing and handwashing

Summary of results and conclusions

Recycling paper cups rather than sending them to landfill significantly reduces their environmental impacts. However, by far greater decreases in environmental impacts can be achieved by switching to a reusable plastic cup.

- When comparing the environmental impacts of the two paper cup scenarios, the environmental footprint[5] of paper cups that are recycled is 40% lower than that of landfilled paper cups, owing to avoided carbon emissions. Paper cups that are recycled don't degrade in the landfill and therefore the release of carbon dioxide and methane are avoided. In addition, recycling avoids emissions from the production of virgin paper and plastic.
- For both scenarios, secondary packaging and transportation contributed very little to the overall environmental impact, with the manufacturing stage accounting for the majority of impact. For landfilled paper cups, the manufacturing stage accounts for 63% of emissions, with disposal (landfilling) accounting for the remaining 37%. The most significant impact category for single-use paper cups is potential damage to ecosystems, due to the large quantities of cellulose fibres required for their manufacture.
- Switching to a reusable plastic cup achieves a greater reduction in environmental impacts than a change in waste management. The emissions from the reusable cup, including washing after use, are 69% lower than for the landfilled paper cup, of which 9.5% is attributed to the manufacturing stage and 90.5% to the washing stage. The washing stage accounts for such a large portion of emissions largely due to the energy required to heat water for washing, coupled with a long lifespan (500 uses). The impact category most affected by the reusable cup is human health. This is linked to the electricity generation required for the dishwasher, heating water and to wastewater treatment.
- Extensive introduction of reusable cups in the UK would result in a 76% and 60% reduction in environmental footprint compared to the landfilling and recycling scenarios for paper cups respectively. These substantial decreases in environmental footprint assume the reusable plastic cups are used 500 times, although they only have to be used 21 times to breakeven with the paper cup if the paper cup is landfilled after use, and 41 times if the paper cup is recycled after use.

Recycling paper cups rather than sending them to landfill significantly **reduces** their **environmental impacts.** However, **switching to a reusable plastic cup** achieves a **greater** reduction in **environmental impacts** than a change in waste management.

5 *Environmental footprint according to aggregated ReCiPe endpoint damage categories, hierarchist (H) perspective.*

Table 4: Summary table: Foteinis (2020)

		Products considered in study		
		Paper cup		Plastic cup
Study scope	**Material**	**Paper cup, lined with PE**		**PP cup with a silicone band**
	Functional unit	One typical paper cup, intended for the consumption of one medium (hot) drink (340ml)		
	Capacity [ml]	340		340
	Number of uses	1		500
	Weight per container [g]	12		49*
	Geographic region	UK		
	Life cycle stages	Inputs/outputs of cup manufacturing, transportation, use and disposal. For paper and plastic recycling includes avoided emissions from virgin paper and plastic manufacturing.		
	End-of-life assumptions	Landfill	Recycling	Dishwashing (46%) and handwashing (54%)
Indicators	GWP			
	Environmental footprint			
	Human health			
	Ecosystems			
	Resources			
Method	IPCC 2013 and ReCiPe endpoint method			
Other comments	Large scale paper cup recycling schemes could reduce the environmental footprint of disposable paper cups by up to 40% compared to landfilling in the UK (assuming a 100% recycling rate). This author notes the lack of suitable models and impact assessment methods to account for the impact of microplastics on aquatic ecosystems and human health.			

Highest relative impact **In-between (neither highest nor lowest)** **Lowest relative impact**

* Data on the reusable cup taken from Almeida et al. (2018)

2.2.2 Single-use paper cups (PE- and PLA-lined) and reusable PP, stainless steel and ceramic cups in sit-down and take-away contexts: VTT, 2019

This LCA study was jointly commissioned by Huhtamaki and Stora Enso. The full LCA study is confidential as it contains company data on paper cup production. The review included here is therefore based on the publicly available executive summary. The study compares the following single-use and reusable beverage cups:

- Paper cup with fossil-based plastic (PE) coating
- Paper cup with plant-based plastic (PE) coating
- Paper cup with bio-plastic (PLA) coating
- Reusable ceramic cup used in a sit-down café
- Reusable plastic cup used for take-away
- Reusable stainless steel cup used for take-away

The functional unit of the study was 1,000 beverages in two contexts: a sit-down café context, which compares the paper cups to ceramic cups, and a take-away context, where paper cups with polystyrene lids are compared to reusable plastic and stainless steel cups. The study investigates the impact of recycled content, washing efficiency and different end-of-life scenarios.

Summary of results and conclusions

This study demonstrates that paper cups can be a better option in terms of climate impact than reusable cups under certain situations. Recycling paper cups decreases their potential impact on climate change – although this is also dependent on how the cup is manufactured. Ensuring reusable cups are efficiently washed and selecting light-weight designs reduces their impact.

For the café context it was found that ceramic cups would need to be used 350 times in order to breakeven with paper cups in terms of climate impact. The main contributor to the impact on climate change of the ceramic cups is dish-washing (90% of total impact). If the washing of ceramic cups is inefficient or if more than 80% of the paper cups are recycled after use, then the paper cups perform better from a climate perspective (the ceramic cup never reaches a breakeven point).

The take-away results show that the breakeven point for reusable plastic cups is approximately 20 uses. If the paper cups are recycled the breakeven point increases to 32 uses. Stainless steel cups need to be reused a minimum of 130 times to have a climate impact that is equivalent to a paper cup with PS lid. The PS lid is the main contributor to the single-use paper cup impact, due to the manufacturing stage and the fact that PS is not recycled. The authors note that a fibre lid would reduce the impact of paper cups in this context substantially.

In terms of the different types of paper cups considered in the study, the plant-based PE lined paper cup had the lowest GWP of approximately 10 gCO_2-eq per cup. The lower GWP is due to the technology used in this cup's production increasing its recyclability, with the fibres able to be recycled up to seven times, which if accounted for, reduces the carbon footprint of the cup by 64%.

Ensuring reusable cups are **efficiently washed** and selecting **light-weight designs** reduces their environmental impacts. If the washing of ceramic cups is inefficient or if **more than 80% of the paper cups are recycled** after use, then the **paper cups perform better** from a climate perspective.

Table 5: Summary table: VTT (2019)

		Products considered in study					
		Paper cups			Plastic	Stainless steel	Ceramic
Study scope	Material	Paper cup, fossil-based PE lining (with and without PS lid)	Paper cup, plant-based PE lining (with and without PS lid)	Paper cup, PLA lining (with and without PS lid)	Reusable plastic cup with lid	Stainless steel cup with plastic lid	Ceramic cup
	Functional unit	1,000 uses in a café setting (paper cups without lids vs ceramic cup) and take-away setting (paper cups with PS lids vs. reusable plastic and stainless steel cups)					
	Capacity [ml]	Not available					
	Number of uses	1	1	1	1,000	1,000	1,000
	Weight per container [g]	Not available					
	Geographic region	Europe					
	Life cycle stages	Cradle to grave (raw materials, manufacturing, use, transport, end-of-life disposal and recycling)					
	End-of-life assumptions	European averages: 30% to landfilling, 34% to incineration and 36% to recycling					Landfilling and incineration
Indicators	GWP - used in café				-	-	
	GWP – take-away						-
Method	Product Environment Footprint (PEF) category rules for intermediate paper products. Only Climate Change results provided in the publicly-available Executive Summary. Cut-off allocation was applied, but to evaluate the impact of recycling the circular footprint formula was used.						
Other comments	Although not shown in the executive summary, the study concludes that compostable cups perform well when composted in the appropriate facilities.						

Highest relative impact In-between (neither highest nor lowest) Lowest relative impact

2.2.3 Single-use paper cups (PE- and PLA-lined), single-use EPS cups and reusable PP and ceramic cups: CupClub, 2018

This study compares the environmental profile of CupClub – a returnable packaging service for drinks in the United Kingdom – to three single-use cups and one alternative reusable cup. CupClub cups are made from plastic (PP) with a plastic (LDPE) lid. CupClub utilises automatic sorting technology (Radio frequency identification or RFID), which provides traceability across the entire supply chain. The study analyses a number of scenarios:

- **Reusable plastic CupClub cup,** including backhauling, washing and drying, and waste management (90% recycled; 5% landfilled; 5% incinerated).
- **Single-use paper cup[6] with plastic (PE) lining, plastic (PS) lid and cardboard sleeve.** End-of-life disposal: 1% recycled; 49.5% incinerated; 49.5% landfilled.
- **Single-use paper cup with bio-plastic (PLA) lining and cardboard sleeve.** End-of-life disposal: 1% recycled; 49.5% incinerated; 49.5% landfilled.
- **Single-use paper cup with bio-plastic (PLA) lining and cardboard sleeve.** End-of-life disposal: 1% industrial composting; 49.5% incinerated; 49.5% landfilled.
- **Single-use polystyrene (EPS) cup with plastic (PS) lid.** End-of-life disposal: 50% landfill and 50% incinerated.
- **Ceramic cup.** End-of-life disposal: 100% landfill.

The functional unit is taken as the predicted duty cycle of a CupClub cup, i.e., 132 uses.

Summary of results and conclusions

CupClub has lower environmental impacts than both types of single-use paper cups across all environmental impact category indicators and has lower environmental impacts than the single-use polystyrene cups and ceramic cups in nine and 17 of the impact category indicators respectively.

- The GWP of paper cups with PE lining is 90.5% to 101.7% higher than the CupClub cup. Paper cups with PLA lining and polystyrene cups also have higher climate impacts than the CupClub cup, with GWPs that are 87% and 34.6% higher than that of the CupClub cup respectively.
- For the CupClub cup, electricity (used to wash and dry cups and lids) accounts for at least 80% of the impacts across all impact categories, except water consumption.
- The bio-plastic lined paper cup has the highest water consumption, the highest land-use demand, as well as the highest human non-carcinogenic toxicity potential (from plant material production, fuel use and the use of fertilisers and pesticides in plant production).
- No differences are discernible between the 1% recycled and 1% composted scenarios for the PLA-lined paper cup (the percentage varied is too low to register a difference).
- For both paper cups, the higher the recycling rate, the lower the carbon footprint. This trend is also observed with the composting rate for paper cups with PLA lining.
- The breakeven point for the CupClub cup and lid to have a lower climate impact than the single-use paper cups with 1% recycling is 72 uses and for single-use polystyrene cups it is 100 uses. The recycling rate of both paper cups would have to increase to over 80% to equal the GWP of the CupClub cup and lid (assuming 132 uses of the CupClub cup).
- The GWPs of the ceramic cup and CupClub cup are relatively similar. For a ceramic cup used 800 times there is less than 1 gCO2eq difference between the two (to breakeven the ceramic cup has to be used 2,000 times)
- Three sensitivity analyses were performed: producing the cup and lid in China, reducing energy to wash and clean the lid, and increasing the distance to the CupClub washing facility. The first sensitivity analysis had a negligible effect on the life cycle environmental impacts since washing the cup and lids accounts for over 88% of the impacts, whereas shipping the product from China accounts for just 0.4%. Similarly, increasing the distance travelled to collect and return the CupClub by 10 times results in an increase of less than 0.5% for all indicators, with the exception of terrestrial ecotoxicity, which increased by 187% due to the increase in diesel use.

Table 6: Summary table: CupClub (2018)

		Products considered in study				
		CupClub	**PE-lined paper cup**	**PLA-lined paper cup**	**Polystyrene cup**	**Ceramic cup**
Study scope	**Material**	**PP cup with a low-density PE lid. Includes RFID tag**	**Bleached board paper with PE liner and PS lid**	**PLA-lined with a PLA lid, cardboard sleeve**	**EPS cup with PS lid**	**Ceramic**
	Functional unit	One CupClub cup and lid delivered and collected from the manufacturer, used 132 times, backhauled, washed and dried 133 times and then recycled.				
	Capacity [ml]	355				
	Number of uses	132	1 (132 cups used)	1 (132 cups used)	1 (132 cups used)	132
	Weight per container [g]	Cup: 49.3, lid: 22.03 and RFID: 0.1	Cup: 11.2, corrugated outer: 3.7 and PS lid: 3.2. PE liner: 1	Cup: 10.6, PLA lid: 3.6, PLA liner: 1. Corrugated outer: 3.7	Cup: 3.2 and lid: 3.2	442.7
	Geographic region	Europe				
	Life cycle stages	Cradle to grave (manufacturing, distribution, washing and drying, end-of-life disposal and recycling)				
	End-of-life assumptions	Recycling (90%), landfill (5%) and incineration (5%)	Landfill (49.5%), incineration (49.5%), recycling (1%)	Landfill (49.5%), incineration (49.5%), recycling or composting (1%)	Landfill (50%) and incineration (50%)	Landfill (100%)
Indicators	Global warming potential					
	Stratospheric ozone depletion					
	Ionising radiation					
	Ozone formation, human health					
	Fine particulate matter formation					
	Ozone formation, terrestrial ecosystems					
	Terrestrial acidification					
	Freshwater eutrophication					
	Marine eutrophication					
	Terrestrial ecotoxicity					
	Freshwater ecotoxicity					
	Marine ecotoxicity					
	Human carcinogenic toxicity					
	Human non-carcinogenic toxicity					
	Land use					
	Mineral resource scarcity					
	Fossil resource scarcity					
	Water consumption					
Method	ReCiPe midpoint method					
Other comments	Potential manufacturing in China did not affect the results significantly. Increasing the energy efficiency of washing had a proportional decrease in the impacts of the CupClub cup. Increasing the backhauling distance did not have an appreciable effect on the results for the CupClub.					

Highest relative impact **In-between (neither highest nor lowest)** **Lowest relative impact**

2.2.4 Single-use plastic-lined paper cup and reusable ceramic mugs: Martin, Bunsen and Ciroth, 2018

This study compares the environmental impacts of a traditional reusable ceramic cup, with and without a lid, and a paper cup with a plastic (PE) lining and plastic (PS) lid. The study evaluates various use scenarios:

- Reusable ceramic cup with and without lid, handwashing
- Reusable ceramic cup with and without lid, dishwashing
- Single-use paper cup with plastic (PE) lining and plastic (PS) lid, incineration

Summary of results and conclusions

The study concludes that hot drinks should be served in reusable cups, but that the washing method (dishwasher or handwashing) as well as water temperature have a major effect on the overall environmental impacts of the reusable cup.

- The ceramic cup (both with and without a lid) washed using a dishwasher has the lowest environmental impacts. A ceramic cup with a lid, washed by hand, has the highest environmental impacts. For most of the environmental impact categories the paper cup falls between the two extremes of the ceramic cup, other than for land use and freshwater ecotoxicity, where it has the highest impacts, and freshwater eutrophication, where it has the lowest impact.
- For the ceramic cup, the use phase (washing) has the highest contribution in 13 of the 15 impact categories, with electricity used for heating the water used in washing the cups contributing between 19 and 99% of the impact category results. Given the significant contribution of electricity for water heating on the overall impact of ceramics cups, alternative scenarios were tested using cold water and reducing the frequency of washing. A ceramic cup with no lid handwashed in cold water is the scenario with the lowest results in 13 of 15 environmental impact categories. If the frequency of the washing is reduced to washing after the third use, the impact is greatly reduced and the paper cup becomes the worst alternative.
- For the paper cup, the production phase has the greatest contribution to all impact categories, except freshwater ecotoxicity and non-carcinogenic effects, where waste management is the largest contributor to impacts.
- For both reusable and single-use cups, where they are produced and the associated transport requirements have no significant effect on the life cycle environmental impacts.
- The breakeven point for a ceramic cup washed in a dishwasher to equal the climate impact of a paper cup is 11 uses for a cup without a lid and 13 uses for a cup with a lid. A ceramic cup without a lid and washed in a dishwasher needs to be used 140 times for it to have lower results than the paper cup in all but one environmental impact category (freshwater eutrophication, for which the paper cup has the lowest impact).
- The handwashed ceramic cup, which has a greater contribution to climate change from washing, requires 89 uses to breakeven in terms of climate impact. Adding the lid (which also requires washing) pushes the breakeven point to beyond the chosen functional unit for the study (at 750 uses).

Hot drinks should be served in reusable cups, noting that the **washing method** (dishwasher or handwashing) as well as **water temperature** have a **major effect on the overall environmental impacts** of the reusable cup.

Table 7: Summary table: Martin, Bunsen and Ciroth (2018)

		Products considered in study				
		Ceramic cup		**Ceramic cup with lid**		**Paper cup with lid**
Study scope	**Material**	**Ceramic**		**Ceramic and synthetic rubber**		**Paper cup with inner PE coating and a PS lid**
	Functional unit	750 x 300 ml of coffee served, i.e. 750 drinks.				
	Capacity [ml]	300				
	Number of uses	750, with 1% breakage in use, 1% breakage in handwashing and 0.1% breakage in dishwashing				1
	Weight per container [grams]	310 g		300 g cup, 35 g lid		8.3 g cup, 0.1 g inner coating and 0.93 g lid
	Geographic region	Berlin, Germany				
	Life cycle stages	Cradle-to-grave (production, use, end-of-life)				
	End-of-life assumptions	Landfill		Landfill (cup), incineration (lid)		Incineration
Indicators	Global warming potential	Handwash	Dishwash	Handwash	Dishwash	
	Freshwater and terrestrial acidification	Handwash	Dishwash	Handwash	Dishwash	
	Freshwater eco toxicity	Handwash	Dishwash	Handwash	Dishwash	
	Freshwater eutrophication	Handwash	Dishwash	Handwash	Dishwash	
	Ionising radiation	Handwash	Dishwash	Handwash	Dishwash	
	Marine eutrophication	Handwash	Dishwash	Handwash	Dishwash	
	Terrestrial eutrophication	Handwash	Dishwash	Handwash	Dishwash	
	Carcinogenic effects	Handwash	Dishwash	Handwash	Dishwash	
	Non-carcinogenic effects	Handwash	Dishwash	Handwash	Dishwash	
	Ozone layer depletion	Handwash	Dishwash	Handwash	Dishwash	
	Photochemical ozone creation	Handwash	Dishwash	Handwash	Dishwash	
	Respiratory effects, inorganics	Handwash	Dishwash	Handwash	Dishwash	
	Land use	Handwash	Dishwash	Handwash	Dishwash	
	Mineral, fossils and renewables	Handwash	Dishwash	Handwash	Dishwash	
Method	ILCD Midpoint method					
Other comments	The study only considers incineration of paper cups, making the results less applicable to regions with alternative waste management practices.					

Highest relative impact **In-between (neither highest nor lowest)** **Lowest relative impact**

2.2.5 Reusable plastic (PP) and glass KeepCups, reusable bamboo and plastic cups and single-use PE- and PLA-lined paper cups: Almeida, Pellec and Bengtsson, 2018

This study assesses the environmental impact of three KeepCups and other typical single-use and reusable cups. KeepCup is an internationally recognised manufacturer of reusable plastic and glass coffee cups. The study aims to understand the environmental hotspots along the KeepCups supply chain in three key markets: Europe, Australia/Asia and the US, and compares KeepCup's environmental performance against four competing single-use and reusable products. Three use intensities[7] are defined: light use (one coffee per day), medium use (two coffees per day) and heavy use (three coffees per day). The following products are assessed:

- "Original" plastic (PP) KeepCup with silicone band
- "Brew" glass KeepCup with silicone band
- "Cork" edition glass KeepCup with cork band
- Single-use plastic (PE) lined paper cup with plastic lid
- Single-use paper cup with bio-plastic (PLA) lining
- Reusable bamboo cup with plastic lid
- Reusable plastic (PP) cup with plastic lid

Summary of results and conclusions

- The reusable cups (KeepCups, bamboo and PP) have lower GWP and energy use than single-use cups but higher water consumption as a result of washing. The GWP of the three KeepCups and the bamboo cup are relatively similar and are 88% lower than the paper cup with PLA lining.

- When compared to the other reusable cups, the KeepCups have lower GWPs and energy use than the PP cup because of the shorter life span assumed for the PP cups (30 uses compared to four years for the KeepCups and bamboo cup).

- The "Brew" KeepCup made from glass has a GWP, energy use and water use more than 50% higher than the plastic "Original" KeepCup. The GWP and energy use of the silicone band is double that of the cork band. The Brew cork however requires lower water use due to the requirement to handwash the cork band rather than washing in a dishwasher.

- When evaluated as weighted midpoint indicators, GWP is the most significant contributor to the aggregated life cycle impacts of all the cups. Fossil fuel resource depletion is a significant contributor to the life cycle impacts of all the cups, but especially the plastic cups (Original KeepCup and the PP cup). Demand for agricultural land, ecotoxicity (freshwater and marine) and human toxicity are significant impact categories for the paperboard cups.

- The use stage is the main contributor to GWP, water use and energy use for all KeepCups, accounting for 91%, 99% and 88% respectively. Manufacturing and assembly are the second and third largest contributors respectively. The GWPs of KeepCups manufactured in the UK are 15 to 30% higher than those made in Australia. This is due to the use of solar electricity at the Melbourne manufacturing facility.

- The breakeven point for all KeepCups to have a lower climate impact than a paper cup with PE lining and a paper cup with PLA lining is 24 and 10 days at one coffee a day, respectively.

- The environmental impacts of KeepCups can be reduced further through the choice of materials, material and energy efficiency, increased use of recycled materials, increased use of renewable energy and shrinking the supply chain. Behavioural changes offer additional opportunities to lower their impact such as encouraging handwashing over dishwashing, promoting energy and water efficiency in washing and encouraging the purchase of water and energy efficient dishwashers. Consumers can also be encouraged to replace parts, which prevents the user from buying an entirely new cup in the event of damage or loss, thereby extending the lifespan of the cup.

7 *Assuming 250 working days in a year*

Table 8: Summary table: Almeida, Pellec and Bengtsson (2018)

		Products considered in study						
		Paper cup with plastic lid	**Compostable cup**	**Bamboo cup**	**PP cup with plastic lid**	**"Original" KeepCup**	**"Brew" glass KeepCup**	**"Cork" edition KeepCup**
Study scope	**Material**	**Paperboard with PE lining and PS lid**	**Paperboard with PLA lining and PLA lid**	**Melamine and bamboo, silicone lid and band**	**PP**	**PP with silicone band**	**Tempered glass with silicone band, synthetic rubber and PP lid and lid over-mould**	**Tempered glass with cork band, synthetic rubber and PP lid and lid over-mould**
	Functional unit	One year of coffee drinking						
	Capacity [ml]	340						
	Number of uses	1		Three use intensities: 250, 500 or 750 coffees per year				
	Number of cups in one year	250 / 500 / 750	250 / 500 / 750	0.25 (life span of four years)	8.33 / 16.7 / 25 (life span of 30 uses)	0.25 (life span of four years)	0.25 (life span of four years)	0.25 (life span of four years)
	Weight per container [kg]	Lid: 0.003, Cup: 0.009	Lid: 0.004, Cup: 0.013	Lid: 0.008, Cup: 0.099, Band: 0.018	Lid: 0.014, Cup: 0.042	Lid: 0.021, Plug: 0.006, Cup: 0.049, band: 0.014	Lid: 0.018, Lid over-mould: 0.009, Plug: 0.006, Cup: 0.220, Band: 0.014	Lid: 0.018, Lid over-mould: 0.009, Plug: 0.006, Cup: 0.220, Band: 0.014
	Geographic region	Australasia and Asia (Australia, New Zealand, Singapore and China), North America (Canada and USA) and Europe						
	Life cycle stages	Cradle-to-grave (raw materials, transport, manufacture, customer use and end-of-life disposal)						
	End-of-life assumptions	Australia: 37% PP and 10% paperboard (PE lining) recycled, all other materials 100% landfill Europe: 30% PP and 21% paperboard (PE lining) recycled, all other materials 23% WTE and 77% landfill North America: 9% PP and 10% paperboard (PE) lining recycled, all other materials 12% WTE and 88% landfill						
Indicators	Climate change							
	Water use							
	Energy use							
Method	ReCiPe method (Hierarchist) and Cumulative energy demand							
Other comments	Results presented as weighted midpoint impacts give the same trend between cups as the climate change indicator; No notable differences in the results were observed for the three different regions and the trends between cups were the same across the regions.							

Highest relative impact **In-between (neither highest nor lowest)** **Lowest relative impact**

2.2.6 Single-use and reusable cups: Woods and Bakshi, 2014

This study compares the impact of reusable cups and single-use cups in the United States, evaluating the influence of different dishwashing appliance models and sub-national electricity grid mixes. Although the study looked at polyethylene coated paper and polystyrene (EPS) as single-use options and ceramic, glass and varying plastic blends for reusable options, the article focuses on single-use polystyrene (EPS) cups and reusable ceramic cups. Ceramic cups represent a "worst case" amongst the reusable options as they tend to have higher impacts than the other reusable cups designed for a similar lifespan. Statistical methods are used to quantify parameter uncertainty.

Summary of results and conclusions

Where a statistical difference is observed between the reusable and single-use cups, the results favour reusable cups:

- Reusable ceramic cups perform better in terms of their potential impact on climate change across most regions of the United States, compared to single-use polystyrene cups.
- Assuming the oldest, least energy efficient dishwasher model is used (2004), reusable cups have a higher climate impact in only 32% of households in the US. If a newer dishwasher model is used (a minimally compliant 2013 model) reusable cups only have a higher climate impact in 16% of households. Thus, the preference for reusable cups in terms of climate impact is likely to get stronger as older, inefficient dishwashers are replaced.
- The case for reusable cups in the US, in terms of their impact on climate change, is also shown to get stronger with increasing penetration of natural gas and renewable electricity in the electricity grid mixes of the different regional utilities.
- The study shows that if consumers rinse reusable cups between uses, i.e., two uses per wash, the preference for reusable cups is strengthened further.
- For all other ReCiPe midpoint impact categories other than ozone depletion, reusable cups have equivalent or lower impacts than single-use cups.
- The single-use cup scenarios do not include film sleeves, lids, and printing and apply conservative shipping weights and distances. They thus reflect a "best-case" scenario for single-use cups.

Table 9: Summary table: Woods and Bakshi (2014)

		Products considered in study	
		EPS cup	**Ceramic**
Study scope	**Material**	**Expand polystyrene foam**	**Ceramic**
	Functional unit	Impact per use of cup, with one wash or disposal for each use	
	Capacity [ml]	473	
	Number of uses	1	500
	Weight per cup [g]	4.4 – 5.0	292 – 700
	Geographic region	US	
	Life cycle stages	Cradle-to-grave (material production, manufacturing, use, disposal)	
	End-of-life assumptions	Incineration (11.7%) and landfill (88.3%)	Landfill (100%)
Indicators	Climate change		Ranges from better or the same as single-use across all subregions when dishwasher 2013 (best available technology), to better or the same in 15 out of 26 subregions when 2004 dishwasher
	Particulate matter formation		Better or the same as single-use across all subregions for dishwashers 2007 to 2013; Better or the same in 25 out of 26 subregions when 2004 dishwasher
	Ozone depletion		
	Human toxicity		
	Photochemical oxidant formation		Better or the same as single use across all subregions for dishwashers 2007 to 2013; better or the same in 25 out of 26 subregions when 2004 dishwasher
	Ionising radiation		
	Terrestrial acidification		
	Freshwater eutrophication		
	Marine eutrophication		Ranges from better or the same as single use across all subregions for 2013 dishwashers, to better or the same in 23 out of 26 subregions when 2004 dishwasher
	Terrestrial ecotoxicity		Better in 8 out of 26 subregions when dishwasher 2013 Best available technology, else the same
	Freshwater ecotoxicity		Better in 2 to 8 out of 26 subregions across the dishwasher models, else the same
	Marine ecotoxicity		Better in 8 out of 26 subregions when dishwasher 2013 Best available technology, else the same
	Fossil fuel depletion		
Method	ReCiPe midpoint		
Other comments	Use scenarios cover five dishwashing appliance models from 2004 to 2013 and 26 electricity grid mixes from different regional utilities across the US.		

Highest relative impact **In-between (neither highest nor lowest)** **Lowest relative impact**

2.3 LCA STUDIES COMPARING SINGLE-USE AND REUSABLE BEVERAGE CUPS – COLD DRINKS

2.3.1 Single-use PLA, PP and PET cups and reusable stainless steel cup: Changwichan and Gheewala, 2020

This study compares three plastic single-use beverage cups and one reusable beverage cup. The study applies the ReCiPe LCIA method but presentation of the results focuses on global warming potential, fossil fuel depletion, human toxicity and terrestrial acidification as these four impact categories were found to be representative of the full set of ReCiPe impact categories. The study evaluates the following beverage cups:

- Single-use bio-based plastic cup plus lid (PLA derived from sugarcane)
- Single-use plastic (PP) cup plus lid
- Single-use plastic (PET) cup plus lid
- Reusable stainless steel cup plus plastic (ABS) lid

For the reusable stainless steel cup, both handwashing and washing in a dishwasher are considered. In addition, the study considered the impact of including recycled content in the manufacturing of the beverage cups. In terms of end-of-life scenarios, for the fossil-based plastic cups, both incineration and recycling are considered. For the bio-based plastic (PLA) cups, anaerobic digestion, composting and recycling are considered. The stainless steel cup is recycled at end-of-life. No recycling credits are applied to the cups (the cut-off approach is applied).

Summary of results and conclusions

Reusable stainless steel cups have lower GWP, fossil fuel depletion and terrestrial acidification impact than single-use PP, PET and PLA cups in both the handwashing and dishwashing scenarios. When recycled, the PP cup has a lower potential human toxicity impact than the machine-washed stainless steel cup.

- The reusable stainless steel cup (both handwashed and machine washed) has the lowest GWP and fossil fuel resource depletion, followed by the single-use bio-based plastic (PLA) cup and lastly the single-use fossil fuel-based plastic (PP and PET) cups. Stainless steel cups also have the lowest potential terrestrial acidification and human toxicity impacts when handwashed.
- When comparing the machine washing and handwashing scenarios for the stainless steel cup, washing in a dishwasher results in higher impacts, even though handwashing uses more water and detergent. This is because the electricity required to run the dishwasher is a significant contributor to the impacts, especially GWP.
- Comparing the single-use options, the PLA cup has the lowest GWP and fossil fuel resource depletion, followed by the PP cup and, lastly, the PET cup. When compared on potential human toxicity impact, the PP cup scores the lowest and the PET cup the highest.

Using **recycled materials** to produce beverage cups (for all materials) **substantially reduces the impacts of each cup,** with the stainless steel cup showing the largest reductions by a significant margin.

- Two waste disposal options were considered for PP and PET cups – incineration and recycling. Recycling has the potential to substantially decrease the GWP and potential human toxicity impact of both cups. If incinerated at end-of-life, the PP cup has a GWP comparable to a recycled PET cup (but a substantially lower GWP than the PET cup if recycled itself).

The production of raw materials is the highest contributor to environmental impacts in the fossil-based single-use cups and in the reusable cups when these are handwashed and used for a year.

- For the stainless steel cups the production stage is a significant contributor to GWP since the cups are assumed to be produced from virgin steel in the base scenario. The use of the stainless steel cup is the stage accounting for the highest share of GWP if the cups are washed in a dishwater, with the proportional importance of the use phase relative to material production stage increasing with the number of years for which the cup is used.
- For the fossil-based plastic cups (PP and PET), the main contributor to GWP is the resin production stage. The higher energy and material inputs of the PET resin production process relative to PP resin production, along with the slightly higher weight of the PET cup than the PP cup, accounts for its higher impacts than the PP cup.
- For the bio-based cups, the cup manufacturing stage is the highest contributor to GWP. This is because the PLA is derived from sugarcane and credits for carbon fixing during photosynthesis results in resin production having a relatively low GWP. The resin production stage does, however, contribute the most to fossil fuel depletion and terrestrial acidification in the PLA cups.

Using recycled materials to produce beverage cups (for all materials) substantially reduces the impact of each cup, with the stainless steel cup showing the largest reductions by a significant margin.

- Including 25% recycled resin to produce a PP cup reduces the GWP by 27% and fossil fuel resource depletion by 40%.
- For PET, including 25% recycled resin increases the GWP, but fossil fuel resource depletion is reduced by 22%.
- For PLA, a 25% recycled content reduces the GWP by 35%. However, it should be noted that although PLA recycling is technically feasible, it is not a widely established waste management route as it needs to be collected and recycled separately from fossil fuel-based plastics.
- Including 50% recycled steel in the reusable cup decreases the GWP by 94% and fossil fuel resource depletion by 97%.

The breakeven point for the environmental impacts of the stainless steel cup to be lower than all the single-use cups is 140 uses. After 20, 40 and 70 uses the GWP of the handwashed stainless steel cup is lower than the PET, PP and PLA cups respectively. If washed in a dishwasher, the stainless steel cup has to be used for slightly longer to breakeven with the single-use cups in terms of its GWP, requiring around 100 uses. The environmental impacts of the stainless steel cup are shown to decrease with the length of time for which they are used. Although the functional unit compares the cups on a single year of use, the stainless steel cups are expected to last well in excess of three years.

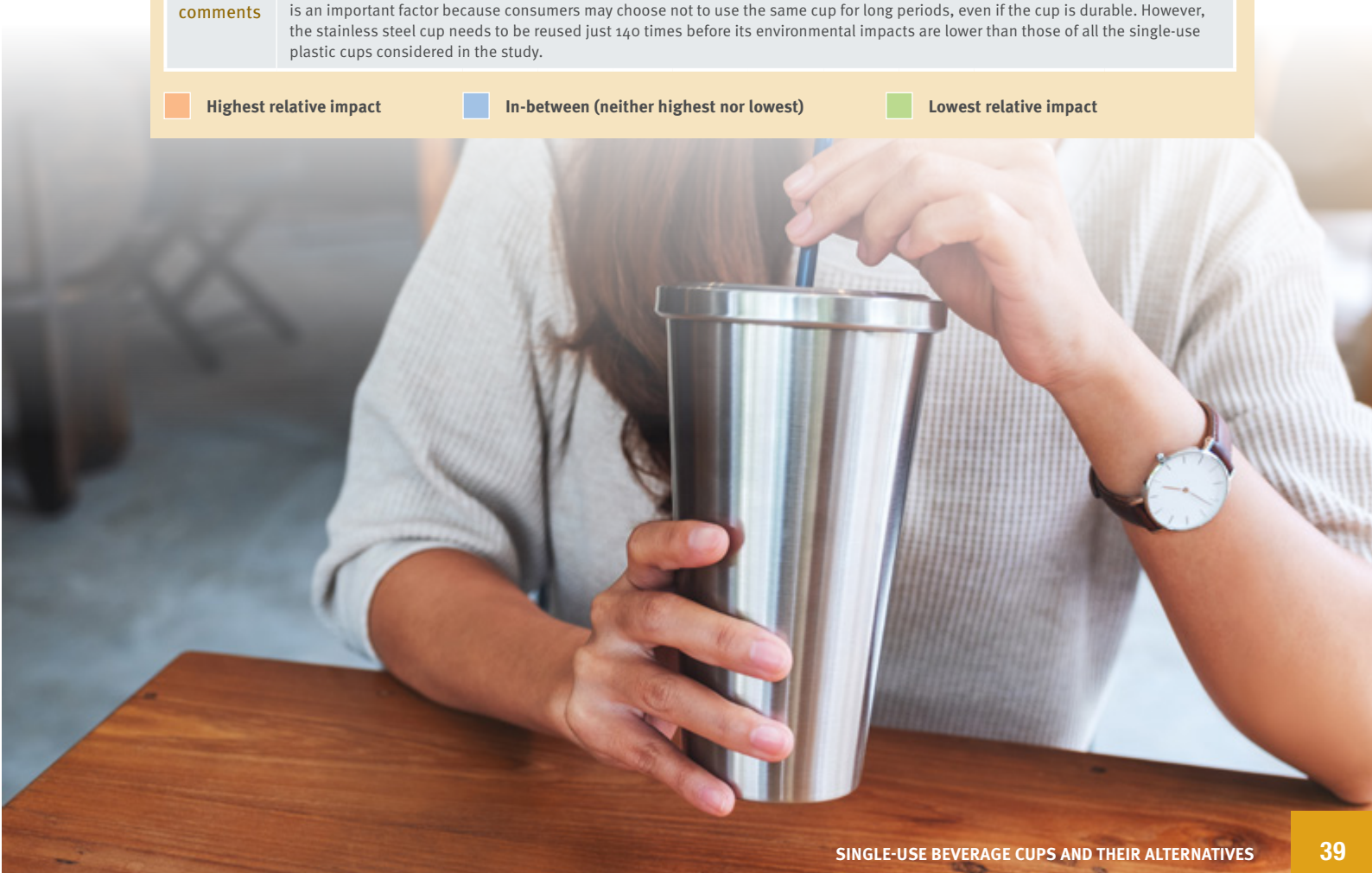
The authors of this study make the following observations regarding wider factors that will influence the preference for one cup system over another. These include:

- End-of-life needs to consider more than just the disposal phase. Waste segregation, collection, transport and pre-processing processes and infrastructure are important considerations. The propensity of consumers to separate waste types at source may also be an influencing factor.
- Although reusable cups are favoured in terms of their environmental impacts, particularly when used for long periods, consumer behaviour should be taken into account. Here, attractive, functional and durable product design can influence consumers to choose reusable cups.
- The role of coffee shops and other beverage sellers in promoting the use of reusable cups is important, for example by offering discounts to consumers bringing their own cups.
- While bio-based plastic cups show some environmental benefits relative to fossil-based plastic cups, they are currently more expensive and may need government support to stimulate their uptake.

Table 10: Summary table: Changwichan and Gheewala (2020)

		Products considered in study								
		PLA cup			PP cup		PET cup		Stainless steel cup	
Study scope	**Material**	**PLA from sugarcane**			**PP**		**PET**		**Stainless steel with ABS (acrylonitrile butadiene styrene) lid**	
	Functional unit	Providing a 650ml container for one drink each workday for a year (or 260 drinks per year)								
	Capacity [ml]	650								
	Number of uses	1			1		1		260 (to meet functional unit, cup life span exceeds this)	
	Weight per container [kg]	0.020 (5.2 per FU)			0.015 (3.9 per FU)		0.019 (4.94 per FU)		Stainless steel cup: 0.34kg, ABS lid: 0.05 (cup assumed to be used for one year, well within its expected life span)	
	Geographic region	Thailand								
	Life cycle stages	Cradle-to-grave (input materials, production, use, end-of-life)								
	End-of-life scenarios	Recycling (R), composting (C), and anaerobic digestion (AD)			Recycling (R), incineration (I)		Recycling (R), incineration (I)		Recycling	
Indicators	Global warming	AD	C	R	R	I	R	I	Handwashing	Dishwashing
	Fossil fuel depletion	AD	C	R	R	I	R	I	Handwashing	Dishwashing
	Terrestrial acidification	AD	C	R	R	I	R	I	Handwashing	Dishwashing
	Human toxicity	AD	C	R	R	I	R	I	Handwashing	Dishwashing
Method	ReCiPe life cycle impact assessment method, with the Hierarchist perspective									
Other comments	Increasing the use of recycled materials by 25% reduces the environmental impacts in the range of 35 to 56%. Consumer behaviour is an important factor because consumers may choose not to use the same cup for long periods, even if the cup is durable. However, the stainless steel cup needs to be reused just 140 times before its environmental impacts are lower than those of all the single-use plastic cups considered in the study.									

Highest relative impact **In-between (neither highest nor lowest)** **Lowest relative impact**



2.3.2 Single-use PP, PLA and PE-lined paper cups and reusable PC cups: Vercalsteren, Spirinckx and Geerken, 2010

In this study an LCA and eco-efficiency analysis[8] were performed for four alternative types of drinking cups used at small and large public events to gain insight into the environmental impacts and costs related to existing systems in Belgium. The following cups were evaluated:

- Reusable polycarbonate (PC) cup, incinerated at end-of-life
- Single-use PP cup, half incinerated and half co-combusted in a cement kiln after use
- Single-use cardboard cup lined with PE, half incinerated and half co-combusted in a cement kiln after use
- Single-use PLA cup, half incinerated and half composted after use

A functional unit of 100 litres of beer served at the event in 330 ml cups (250 ml drinking volume) required 400 single-use cups. Using data representative of events in Belgium, the reusable PC cup was assumed to be used 2.5 times per event, with the number of events it is used at (called the trip rate) assumed to be 45 for the small-scale events and 20 for the large-scale events.

Summary of results and conclusions

For both types of events there is no single cup type that consistently performs the worst or best across all environmental impact categories, however the following factors are observed:

- Between small and large events, the environmental impact of the reusable PC cup increases substantially at large-scale events. This is a result of a higher loss rate at large-scale events (12.5% of cups need to be replaced vs. 5.5% at small-scale events) together with the effects of machine cleaning rather than manual cleaning. Manual cleaning uses less water, requires no additional transport and no electricity consumption. For the single-use cups the differences between small and large events are negligible.
- For the reusable PC cup, at small events, the largest contributor to environmental impact is the production of the cup and the transport of the cups between the distributor and the event. At large outdoor events, the machine cleaning of the cup as well as the production of the cup are major contributors to the environmental impacts. For single-use cups, the production of the cup is the most significant contributor to the total environmental impact, for both large and small events.
- Sensitivity analyses were performed to investigate the influence of the number of events the cup is used at (trip rate), the amount of water and soap used for cleaning, machine cleaning of cups after small scale events rather than manual cleaning, and different end-of-life scenarios. Trip rate is the most significant factor affecting the environmental impacts of reusable PC cups at both large and small events. For the single-use plastic (PP) and paper cups, a higher percentage of cups co-combusted in cement kiln lowers the environmental impacts. The study also analysed a "next generation" scenario for PLA cups, which showed PLA cups to have potential for significantly lower environmental impacts in the future (with a decrease in impact categories of between 10% and 60%, largely attributed to a 15% decrease in the weight of the cups).
- In terms of life cycle costs, the single-use PP cup and the reusable PC cup have the lowest and highest cost indicators respectively, at both small and large events.
- The results of the eco-efficiency analysis – with its subjective weighting choices and inherent limitations – found that at small-scale events the reusable PC cup is the preferred option by a significant margin, whilst the single-use cups all score comparably at small-scale events. However, the reusable PC cup has the poorest score when used at large-scale events. All the cups (both single-use and reusable) were shown to have relatively similar eco-efficiency scores at large-scale events, with none shown to be significantly preferred (with the possible exception of the next generation PLA cup).

8 *A single environmental score and economic (cost) score.*

Table 11: Summary table: Vercalsteren, A., Spirinckx, C. and Geerken, T (2010)

		Products considered in study							
		PC cup		PP cup		Cardboard cup		PLA cup	
Study scope	Material	Polycarbonate		Polypropylene		Cardboard coated with PE		PLA	
	Functional unit	The recipients needed to serve 100l of beer or soft drink at a small-scale indoor (S) or a large-scale outdoor (L) event							
	Capacity [ml]	250		250		250		250	
	Number of uses	Small-scale: 112.5 (2.5 x 45) ; large-scale: 50 (2.5 x 20)		1		1		1	
	Geographic region	Flanders, Belgium							
	Life cycle stages	Cradle-to-grave (production, use and processing of waste)							
	End-of-life assumptions	Incineration (100%)		Landfill (50%) and co-combustion in cement kiln (50%)		Landfill (50%) and co-combustion in cement kiln (50%)		Incineration (50%) and composting (50%)	
Indicators	Carcinogenic	S	L	S	L	S	L	S	L
	Respiratory organics	S	L	S	L	S	L	S	L
	Respiratory inorganics	S	L	S	L	S	L	S	L
	Climate change	S	L	S	L	S	L	S	L
	Ozone layer	S	L	S	L	S	L	S	L
	Ecotoxicity	S	L	S	L	S	L	S	L
	Acidification/ eutrophication	S	L	S	L	S	L	S	L
	Extraction of minerals	S	L	S	L	S	L	S	L
	Extraction of fossil fuels	S	L	S	L	S	L	S	L
Method	Eco-indicator 99 methodology								
Other comments	Sensitivity analyses were performed to assess the impact on the trip rate, the amount of water and soap used in cleaning the cups, and the cleaning of cups by machine instead of by hand. It was confirmed that the trip rate was a sensitive factor. A sensitivity analysis on end-of-life scenario did not change the overall conclusion of the comparison. A sensitivity analysis using a more recent data set for PLA and assumed future improvements (including a 15% reduction in the weight of the cup) showed PLA has potential to become the lowest impact option in the future, especially for large-scale events, if future improvements are realised.								

S = small indoor event; L = large outdoor event

Highest relative impact **In-between (neither highest nor lowest)** **Lowest relative impact**

03 Discussion and conclusions

03 DISCUSSION AND CONCLUSIONS

The conclusions of this meta-analysis are provided in three sections. The first section provides a synthesis of the findings in terms of the environmental impacts of single-use beverage cups and their alternatives. The second section provides a list of aspects which should be considered when undertaking and interpreting LCAs. The final section provides specific guidance for policy makers when using LCAs to develop policy that addresses the environmental concerns associated with single-use beverage cups.

3.1 ENVIRONMENTAL IMPACTS OF SINGLE-USE PLASTIC BEVERAGE CUPS AND THEIR ALTERNATIVES

3.1.1 Comparison of different single-use beverage cups

Based on the meta-analysis of single-use beverage cups, **no material consistently performs the best or worst across the studies.** A 2013 review study (van der Harst and Potting, 2013) found some common trends: paper cups are comparable to recycled plastic (rPET); paper cups have lower impacts than polystyrene cups (PS and HI-PS); paper cups lined with conventional plastic (PE) have lower impacts than paper cups lined with bio-plastic (PLA); and wax-lined paper cups have lower impacts than plastic-lined paper cups. However, more recent studies have not confirmed these trends, with polystyrene cups shown to have lower impacts than paper cups when there is little or no recycling of paper cups.

Bio-plastic cups and lining paper cups with bio-plastic rather than fossil-based plastic are not necessarily better options (Vercalsteren, Spirinckx and Geerken, 2010. CupClub, 2018; Changwichan and Gheewala, 2020) Paper cups lined with the bio-plastic PLA are consistently shown to have higher impacts than paper cups lined with polyethylene (both fossil and bio-based). However, it is worth noting that PLA is to some degree still an emerging technology, with different feedstocks and scales of production leading to less certain life cycle inventory data sets on the material. LCI data sets on paper and plastic are comparatively more representative, leading to higher certainty in the life cycle impacts of the paper and conventional plastic cups.

It is important to note that age of data is important for all materials; the latest data set for solid bleached board included in the ecoinvent database has a climate impact half that of the previous data set.[9] Many of the older studies, including those in the meta-analysis, applied the older (now outdated) ecoinvent data set in their study.

Largest contributors to environmental impacts

For all types of single-use beverage cups the largest contributor to the environmental impacts is the production of raw materials. Using recycled materials to produce beverage cups reduces fossil fuel resource depletion and climate impact substantially.

The end-of-life scenario has a substantial influence on the environmental impacts of single-use beverage cups. In general, **the higher the recycling rate the lower the climate impact.** This is especially notable for paper cups, where the assumed recycling rate is an important determinant of their relative preference (potentially becoming the best option at high recycling rates, although these are seldom observed in practice). After recycling, for lined paper cups, incineration is favoured over landfilling. For fossil fuel-based cups, recycling is the best end-of-life option from a climate perspective followed by landfill and lastly incineration. Studies observed contradictory results with regards to composting PLA. Nonetheless, there are discrepancies in the waste treatment results, which are influenced by allocation choices and the degree of credits applied (incineration and composting), and degradation assumptions (landfilling and composting). The influence of particular data sets on results should be noted. In particular, the degradation rate assumed for materials disposed to landfill is influential in the overall climate impact of paper and bio-plastic cups, with higher degradation rates leading to high methane emissions associated with paper cups disposed to landfill in some data sets.

Transport has a minor or negligible influence on the life cycle environmental impacts.

9 *Personal communication (2020) Marjukka Kujanpaa, Manager Sustainability LCA, Stora Enso.*

Table 12: Breakeven points for reusable cups in terms of climate impact

Study	Reusable cup type	Breakeven point	Number of reuses considered
Fonteinis (2020)	PP cup with silicone band	41 – PE lined paper cup with recycling 21 – PE lined paper cup with landfilling	500
VTT (2019)	Ceramic cup	350 –PE-lined paper cup Never – PE-lined paper cup (80% recycled) Never – Plant-based PE lined paper cup (80% recycled)	1,000
	Plastic cup	20 –PE-lined paper cup with PS-lid 32 – PE-lined paper cup (80% recycled) with PS lid 36 – Plant-based PE lined paper cup (80% recycled) with PS lid	1,000
	Stainless steel cup	130 – PE lined paper cup with PS lid	1,000
CupClub (2018)	CupClub (PP with PE lid)	72 – PE and PLA lined paper cup, with PS/PLA lid and corrugated sleeve with 1% recycling 78 – PLA lined paper cup with PLA lid and corrugated sleeve with 1% composting 100 – EPS cup with PS lid 132 – PE and PLA lined paper cup, with PS/PLA lid and corrugated sleeve with 80% recycling 94– PLA lined paper cup, PLA lid and corrugated sleeve with 80% composting	132 (actual number of reuses)
	Ceramic cup	90 – 97 - PE and PLA lined paper cup, with lid and sleeve, with 1% recycling/composting 122 – EPS cup with PS lid	132 (to be comparable to the CupClub)
Martin, Bunsen and Ciroth (2018)	Ceramic mug	11 – PE lined paper cups with 100% incineration and dishwashing of ceramic cups 89 – PE lined paper cups with 100% incineration and handwashing of ceramic cups	750 with a "breakage factor"
Almeida, Pellec and Bengtsson (2018)	KeepCups (PP or glass)	24 – PE lined paper cup with PS lid 10 – PLA lined paper cup with PLA lid	One year's worth of uses at 1,2 or 3 uses per day (although manufacturers estimate cups to last 4 years)
Woods and Bakshi (2014)	Ceramic cup	60 – 670 - PS cup	500
Changwichan and Gheewala (2020)	Stainless steel	20 – PET cup (handwashing SS cup) 30 – PP cup (handwashing SS cup) 70 – PLA cup (handwashing SS cup) 25 – PET cup (dishwashing SS cup) 42 – PP cup (dishwashing SS cup) 115 – PLA cup (dishwashing SS cup)	260 (one-year's worth of uses, although cup is anticipated to last at least 3 years)

3.2 IMPORTANT ASPECTS OF LCAs OF SINGLE-USE BEVERAGE CUPS AND THEIR ALTERNATIVES

Based on the studies reviewed in the meta-analysis, the following aspects should be considered when undertaking and interpreting LCAs of single-use beverage cups and their alternatives:

Geographical context: The environmental impact of beverage cups has been shown to be strongly influenced by technologies and energy sources for production and end-of-life treatment. These are parameters that are region- and country-specific. For example, in Europe, incineration is a commonly employed waste management option where the energy value of the waste is recovered. In other regions, incineration is an unacceptable waste management option with landfilling the most common alternative. In the developing country context, formal waste management may be lacking with many single-use items ending up as litter or in informal waste management systems. In addition to the different waste management options, the various materials are recycled at different levels across the world. The study by Almeida, Pellec and Bengtsson (2018) is one of the few studies that compared results across regions, taking into account average percentages of waste diverted to each treatment option. Here, for Europe, 21% of PE-lined paper beverage cups were assumed to be recycled, with only 10% of the same material recycled in Australia and the US. Other European studies have different recycling rates for paper beverage cups. For example, Foteinis (2020) suggests that in the UK only one in 400 paper beverage cups is recycled (0.25%). Interestingly, no studies considered litter as the fate of beverage cups with all studies limited to formal waste management.

Similar geographical disparities can be observed in the availability of bio-based feedstocks, electricity grid mix, acceptability of reusable alternatives to consumers, available recycling infrastructure, and so forth. All these parameters influence the environmental impact of the studied system, some significantly. Studies should be clear on the impact of these parameters on their conclusions, with deviations explored through appropriate sensitivity analyses that consider the most influential processes.

Functional equivalence: The cups compared in the studies were all fairly similar in terms of the size of cup and function, particularly for hot drinks. However, they were less consistent in terms of the other functions provided by a certain beverage cup, specifically lids to prevent spilling when transporting hot drinks or bands or sleeves to make the cup more handleable when hot. Those studies that did consider lids found they added a very substantial portion of the impacts of the beverage cup system; in VTT (2019) the impacts of the polystyrene lid are greater than the impacts of the paper cup. The functional equivalence of these "add-ons" were not often discussed, but might be relevant to consumers particularly when considering a transition from a single-use to a reusable system.

Reuse: When modelling reusable beverage cups, the assumptions regarding reuse should be examined carefully given the impact on overall results. This includes the number of reuse cycles and the washing behaviour. In particular, handwashing and dishwashing results varied with no clear preference between the two. The studies by Changwichan and Gheewala (2020) and Almeida, Pelle and Bengtsson (2018) show a clear preference for handwashing over dishwashing, whereas the results of Martin, Bunsen and Ciroth (2018) show dishwashing having a better environmental performance over handwashing. Here, the energy efficiency of the appliance, loading, water use, water temperature, and the source of electricity are all influential in the impacts of reusable cups, as shown by Woods and Bakshi (2014). The impacts associated with washing can be reduced if the cups are washed in cold water, rinsed between uses and washed less frequently (Almeida, Pellec and Bengtsson, 2018).

Consumer behaviour: While reusable cups often offer a lower impact than single-use cups, this is contingent on the number of uses of the reusable cup. As a result, consumer behaviour plays a major role in determining the impact of a reusable cup, regardless of the material type (Vercalsteren, Spirinckx and Geerken, 2010; Woods and Bakshi, 2014; Changwichan and Gheewala, 2020; Foteinis, 2020). This applies both to cups that are owned by the consumer and those that form part of a deposit or return scheme (CupClub, 2018). Losses may be greater for non-consumer-owned reusable cups due to the additional steps in returning them to service as well as quality control requirements.

Most of the studies analysed determine a breakeven point ranging from 10 to 140 uses depending on the materials compared, end-of-life assumptions and washing assumptions. Although not considered in any of the studies, if a single-use cup is used for a second time, the environmental impacts are halved and the breakeven points doubled.

Choice of environmental impact indicators: The purpose of an LCA is to assess all types of environmental impacts to better understand trade-offs and avoid burden shifting.

There is a tendency noted in the studies in this report (and also by policy makers) to focus on climate impact due to its relevance and priority to policy makers. In some cases, results for other impact categories are not presented, or given far less attention. This is evidenced by the existing meta-analysis of Van der Harst and Potting (2013) where the only consistently reported indicator was global warming potential.

Life cycle practitioners have a responsibility to ensure that their results are properly communicated and interpreted.

The limitation of LCAs in terms of the environmental impact indicators included: Concern over marine plastics is high and a number of studies have highlighted both the very large volumes of plastics entering the oceans annually and the potential long-term impact of this pollution.

Single-use cups are often contaminated with organic material which **reduces their likelihood of being recycled.** This aspect makes **bio-plastic lined paper cups** a potentially promising option, as they could be **composted along with the food waste.**

Currently, LCAs do not quantify the impact of macro- and microplastic pollution on aquatic ecosystems. Including the impact of litter (both plastic and other materials) on biodiversity, human health and other relevant indicators will add an important dimension in the comparison of single-use plastic and plastic-lined beverage cups and their alternatives, which is currently lacking in comparisons focussing primarily on climate and water. Of the studies reviewed, only Foteinis (2020) recognised this limitation. All studies assumed 100% of cups end up in formal waste management systems at end-of-life, which does not reflect the reality of single-use products so often ending up as litter. Micro-plastics can also be found in detergents and so are also relevant to the use phase of reusable cup systems. Encouragingly, projects are under way to develop characterisation factors, models and methods to account for the impact of plastic pollution in the marine environment.

These include the MariLCA project, which aims to integrate potential environmental impacts of marine litter into LCAs (MariLCA, 2020) and the Plastic Leak Project (PLP) that aims to develop a methodology to quantify plastic leakage along value chains (Quantis, 2020). In the interim, the issue of litter and plastic in the environment should be recognised in LCA studies comparing single-use products and their alternatives, but may have to be raised qualitatively or explored with other complementary studies until these impacts are integrated into LCIA methods.

Modelling choices: LCA studies should be clear on the impact of modelling choices and adhere to best practice in terms of methodological approaches. As noted by Van der Harst and Potting (2013), there are differences as regards whether or not cut-off rules are applied, in allocation choices, how credits are applied for recovered energy or recovered materials as well as the treatment of biogenic carbon dioxide. These types of modelling choices should be clearly articulated in LCA studies and the implications of these choices on outcomes properly understood.

The treatment of recycling: In many of the studies analysed, recycling in comparison to incineration and landfilling is the best end-of-life option (Van der Harst and Potting, 2013; CupClub, 2018; Changwichan and Gheewala, 2020; Foteinis, 2020). However, in reality, recycling rates are low and some materials present additional challenges. For example, paper cups with PE lining are recyclable, however, in many countries paper cups are not widely recycled (Foteinis, 2020). Single-use beverage cups and lids are also commonly made from polystyrene (Hi-PS and EPS, used for hot beverages). Although technically possible to recycle, both forms of polystyrene have low recycling rates and few countries include polystyrene as part of the recycling stream. Polystyrene is bulky with a low density, which has repercussions for collection and transport costs (Ellen Macarthur Foundation, 2016). In addition, recycled polystyrene (as with most recycled materials) has a lower

The **use of disposable beverage cups** is set to **rise exponentially in line with changing food trends** that favour convenience, especially in middle- to low-income countries. **Urgent action is therefore needed** – at policy, business and citizen level – to find sustainable alternatives for consuming beverages outside of the home.

quality than virgin polystyrene. This "downcycling" is an important aspect to consider when allocating credits for recycling. Single-use cups are often contaminated with organic material (mainly food) which reduces their recyclability. This aspect makes the bio-plastic lined paper cups a potentially promising option, as they could be composted along with the food waste. However, the lack of industrial composting facilities and infrastructure for separating out compostable waste from general and recyclable waste in most countries, means this is currently only a niche possibility.

The use of bio-based plastics: There are a number of considerations that relate to bio-based plastics for single-use beverage cups. PLA is the most widespread bio-plastic, the only bio-plastic analysed in the meta-analysis, and is currently commercially produced. PLA is typically made from renewable feedstocks such as food crops (e.g., corn, sugarcane and sugar beet) but also agricultural waste and fossil fuels. Production of bio-based plastics is a less mature technology than fossil fuel-based plastics production. The implications of this are that process-specific data is often lacking, which increases uncertainty. Furthermore, PLA production has the potential to improve and become more efficient over time, which will decrease uncertainty in the results and possibly improve environmental performance.

The modelling of the degradation of beverage cups in landfills or open dumps: There is high uncertainty regarding these model parameters (Franklin Associates, 2011), leading to high variability in climate impact, particularly for the paper cups. The geographic context is also important here, both in terms of climate (which affects degradability) and also in terms of whether landfills are managed and fitted with efficient methane capture systems.

3.3 IMPORTANT ASPECTS IN POLICY MAKING

This meta-analysis is not intended to provide definitive environmental guidance on the "best" beverage cup choice and in so doing promote policies that prohibit or limit the use of other alternatives. Rather, this report serves to highlight important aspects that policy makers should consider when evaluating environmental information (often in the form of LCA studies) to inform policy development that is context specific and locally relevant.

The first notable aspect, and one that is highlighted throughout the application of the LCAs, is that **policies should take a systems perspective.** LCA studies employ a systems perspective in that they consider the life cycle of a product from resource extraction to production through to use and end-of-life. It is also important to recognise that the "beverage cup system" sits within a wider social, economic and environmental system. There are thus additional factors that need to be considered in order to develop appropriate policy related to single-use beverage cups. These include available and future technologies, energy sector developments, current and future waste management infrastructure, complementary and conflicting policies in place, implementation costs, consumer awareness, perceptions and behaviour change required, and related implementation barriers. Many of these considerations are not only country specific, but also vary with time.

Additionally, **policies must consider regional and country-specific differences.** Many of the aspects that impact environmental performance are geographically dependent, such as the availability of feedstocks for bio-based options, power generation technologies, consumer behaviour with regard to reuse and recycling, and transportation, washing (and drying) technologies and practices. For example, reusable cups require rinsing and cleaning, which makes them unpractical in situations where facilities for washing are absent, limited or inconvenient (Van der Harst and Potting, 2013; Changwichan and Gheewala, 2020).

Available waste management systems and end-of-life practices are also influenced by geography. The end-of-life treatment of single-use and reusable beverage cups is a significant determinant of its overall environmental impact. Therefore, it is important that the end-of-life fate of material is correctly and appropriately modelled taking into account the geographic location and limitations of existing infrastructure and technologies (as well as the potential of future technologies). For example, although paper cups and plastic cups are technically recyclable, recycling rates are very low in most countries, so most are incinerated, disposed of in landfill or end up as litter. Most bio-plastics are compostable under the correct conditions in industrial facilities, although there are limited or no facilities for the separate collection of these materials and for composting them. Hence, they end up in the general waste stream or as litter. PLA – the bio-plastic considered in the studies for beverage cups – is not suitable for home composting. In addition, bio-plastics and conventional plastics are indistinguishable (most notably to PET, which currently has a relatively high recycling rate in many countries), which raises concerns regarding contamination of the recycling stream. Near-infrared technology (NIR) can be employed to separate out the recycling stream, however, this technology is costly.

The **"beverage cup system"** sits within a **wider social, economic and environmental system.** There are thus factors related to available and future technologies, energy sector developments, waste management infrastructure, policies, consumer behaviour and costs that need to be considered in order to develop appropriate policy related to single-use beverage cups. **These factors will vary by country and region.**

Policies should be based on studies that use the best available data and account for likely future developments in production processes and related systems. Life cycle inventory data is often taken from widely available databases. With ongoing improvements in energy efficiency even in established processes, data contained in these databases may be out of date, which then impacts the results. Every effort should be made to critically evaluate the data used in the studies and source the most recent and representative data possible. Newer technologies may also be at a disadvantage to other more established technologies. Where possible, likely improvements in terms of environmental performance should be included. This extends to production and recycling technologies for bio-based plastics, for example. Current LCA results may also change if future developments in energy, transport and waste management systems are incorporated. Similarly, power generation systems, transportation, appliance efficiencies and recycling processes may change over time, influencing the relative environmental performance of different beverage cups.

Policies must take into account consumer behaviour and perceptions, as well as barriers to uptake. Single-use cups offer convenience at a low cost to consumers, and part of their popularity is driven by a need for improved public health practices (Woods and Bakshi, 2014; Foteinis, 2020). Perceptions around hygiene and public health, which vary from country to country, will have a significant impact on the uptake of reusable cups. Heightened concerns around hygiene during the Covid-19 pandemic have hampered efforts to address single-use plastic products and stalled the uptake of reusable alternatives, with some countries even reversing or delaying single-use plastic product bans. In policy development, consumer perceptions need to be balanced by expert recommendations.[10]

In the same way that policies need to take into account country or region-specific characteristics, they also need to take into account the characteristics of the consumer population that will be impacted by the policy. For example, littering is common behaviour in certain countries and non-existent in others. Changing consumer behaviour in this regard is necessary to tackle plastic pollution. However, influencing consumer behaviour through policy is complex and care must be taken that devised policies have the desired effect and do not lead to unintended consequences themselves. In terms of financial interventions, charges (at an appropriate level) are seen to be more effective than discounts on beverages purchased in a reusable cup. Charges for single use beverage cups have led to an increased uptake in reusable alternatives, particularly if combined with other supporting mechanisms (Poortinga, Nash and Hoeijmakers, 2019).

Although charges are likely to be effective in influencing behaviour with regards to single use beverage cups, it is noted that they may not be as effective as plastic bag charges as it requires more forward planning on the part of the consumer, which is not always congruous with the on-the-go nature of beverage purchases. In terms of other interventions, mug-share schemes, bans and initiatives to increase recycling rates of single-use beverage cups may also be effective and part of a portfolio approach to their management (Poortinga, Nash and Hoeijmakers, 2019). Clear environmental messaging and social marketing campaigns are other influencing factors (Poortinga and Whitaker, 2018). Another factor impacting success in changing consumer behaviour is location, with closed locations such as workplaces and campuses showing a greater uptake of reusable alternatives than other locations.

Policies must recognise and manage trade-offs and risks of burden-shifting between environmental impacts. There is a tendency in LCA studies and by policy makers to focus on single issues, most notably climate change due to its relevance, priority and familiarity. Care must be taken to recognise and manage the trade-offs between other quantified and unquantified environmental impacts, most notably marine litter, as well as those less well characterised in LCA studies, such as biodiversity and land use change impacts. With regards to unquantified environmental impacts, the issue of macro- and microplastic pollution is critical to include in the context of single-use plastic products (including bio-plastics) and their alternatives.

Related to the above, policies must be based on several sources of information for environmental impact. LCA results need to be considered together with other sources of relevant information on environmental aspects, particularly where gaps exist in LCA methodology. Notable in the context of beverage cups are health and safety aspects.

10 *See Health Expert Statement Addressing Safety of Reusables andCOVID-19, available at: https://www.greenpeace.org/usa/wp-content/uploads/2020/06/Health-Expert-Statement_Final.pdf*

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