UNIVERSITY OF CAPE TOWN

Department of Chemical Engineering

Environmental and Process Systems Engineering

Inclusion of Leakage into Life Cycle Management of Products Involving Plastic as a Material Choice

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Doctor of Philosophy

Abstract

The accumulation of plastic waste in the natural environment has been a major environmental concern for many decades. However, the environmental impacts associated with leakage are not taken into consideration under current life-cycle based approaches, despite packaging being a major application area of life cycle assessment. Furthermore, there is limited quantitative information on the leakage propensities and rates of different products. This presents a critical limitation during the life cycle management (LCM) of products destined for regions where they are likely to be dumped or littered.

This thesis investigates the feasibility and influence of using product specific leakage rates as a proxy indicator for potential marine environmental impacts, to inform the life cycle management of products in which plastic is a material choice. In particular, it explores whether a realistic understanding of leakage rates, differentiated by major use, may facilitate the development of effective interventions to mitigate the growing problem of marine plastic pollution. This entails the quantification of leakage rates for selected plastic items identified as highly prone to leakage based on a series of beach surveys. The potential influence of providing such specific knowledge is investigated via the exploration of current LCM practices for plastic products employed by key value-chain actors in the plastics industry. In addition, the life cycle management of three key items identified as problematic (straws, cotton bud sticks and beverage bottle lids) is explored via a case study approach.

Beach accumulation surveys are often used to estimate plastic flows into the marine environment. Thus, two series of beach surveys were conducted across five beaches with varying catchment area characteristics in Cape Town, over two periods in 2017 and 2018 – 2019 respectively. Daily accumulation rates varied across all sites ranging from 38 – 2962 items.day^{-1}.100m^{-1} during the first sampling period and 305 – 2082 items.day^{-1}.100m^{-1} during the second. Plastic was the major contributor accounting for 85.6 – 98.9% of all items by count. Despite the variations in litter accumulation rates and composition, there was significant commonality in the items which were identified as major contributors. The top 12 most prevalent and abundant identifiable plastic items accounted for 43 – 66% during the first sampling period, and 41 – 73% during the second. Ten of these items were prevalent during both periods, eight of which were associated with food consumed on-the-go, including beverage bottle lids, polystyrene food containers, single sweet wrappers, snack packets and straws. This indicates that the high litterability of these items was consistent across catchment areas and sampling periods. Furthermore, when ratioed to waste generation, items found to be major contributors were found to have significantly higher leakage rates in comparison to less prevalent items.

The increasing concern surrounding plastic pollution has pressured value-chain actors to review their approaches to the life cycle management of plastic products. This has led to the development of strategies focussed on plastic packaging which were not commonplace across all companies. However, these strategies are not necessarily aimed at mitigating plastic pollution but are more broadly concerned with sustainable product design, emphasising design for recycling and supporting recycling activities at end-of-life as part of their extended producer responsibility. Thus, the extent to which these strategies address plastic pollution is limited. Furthermore, value-chain actors reported varied approaches to product prioritisation for intervention which are often not grounded in empirical evidence but instead based on anecdotes and limited logic. This may be attributed to a lack of reliable product-specific information surrounding plastic pollution. Such approaches have the potential to prioritise products

which are not major contributors to marine pollution in lieu of those that are. Interventions targeted towards products that were identified as prone to leakage, including straws and cotton bud sticks, were catalysed by consumer pressure and societal expectations at large.

Ultimately, this thesis demonstrates the need for product-specific knowledge on leakage to facilitate responsible and effective life cycle management of products involving plastic as a material choice. Furthermore, it has demonstrated the feasibility of providing such information through the use of leakage rates. Leakage rates have the potential to play an important role in product life cycle management, allowing for the identification of products which are highly prone to leakage into the environment. Thus, their integration into LCM practice has the potential to facilitate the development of targeted strategies to address plastic pollution.

Statement of Originality

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List of Acronyms

DEA	Department of Environmental Affairs, South Africa
EPR	Extended Producer Responsibility
EU	European Union
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
HDPE	High Density Polyethylene
IWMP	Industry Waste Management Plan
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCIA	Life Cycle Impact Assessment
LCM	Life Cycle Management
LDPE	Low Density Polyethylene
LLDPE	Linear Low-Density Polyethylene
MSW	Municipal Solid Waste
PE	Polyethylene
PET	Polyethylene Terephthalate
PETCO	PET Recycling Company
PLA	Polylactide (Polylactic Acid)
PMMI	Association for Packaging and Processing Technologies
POLYCO	Polyolefin Responsibility Organisation NPC
POP	Persistent Organic Pollutants
PP	Polypropylene
PRO	Producer Responsibility Organisation
SA	South Africa
SLCA	Social Life Cycle Assessment
SWM	Solid Waste Management
UNEP	United Nations Environment Programme

US	United States
WWTP	Wastewater Treatment Plant

Chapter 1 Introduction

The waste associated with packaging has been a major environmental concern for many decades, particularly due to the non-biodegradable nature of some materials employed, primarily plastic (Rundh, 2005; Rokka & Uusitalo, 2008; Williams, Wikström & Löfgren, 2008; Venter et al., 2011). In addition, the "throw-away" culture associated with plastic materials related to food and beverage products has resulted in many developing countries, often lacking adequate solid waste management (SWM) policies and infrastructure, being faced with an increasing litter problem (Barnes et al., 2009; European Commission, 2011; UNEP, 2018a). As such, plastic waste is commonly investigated from the perspectives of behaviour and/or waste management infrastructure or practices. Whilst the important of these factors is acknowledged the role of product design is gaining in importance. In 2017, the World Economic Forum & Ellen MacArthur Foundation suggested that "fundamental redesign and innovation" of packaging identified as unlikely to be recovered is necessary to reduce plastic leakage into natural systems. This opening chapter explores and defines the problem and presents the objectives of the thesis.

1.1 The Problem of Plastic Waste

Plastic packaging has been identified as prone to leakage into the natural environment due to its size, high dispersion rate and low residual value (Barnes et al., 2009; Ellen MacArthur Foundation, 2016). There are a variety of sources of leakage including direct dumping and littering, as well as wind or water-borne transport from open dumps and landfills (Barnes et al., 2009). As such, it is a major contributor to litter streams, with one highly visible claim being that an estimated 32% of globally produced plastic packaging is leaked into the environment annually (World Economic Forum, Ellen MacArthur Foundation & McKinsey & Company, 2016). This leakage rate, i.e. the fraction of generated waste that is leaked into the natural environment, was based on a study conducted by Jambeck et al. (2015) which estimated global flows of plastic from land into the oceans (critiqued in section 2.1.1). It is projected that there will be a significant increase in plastic use in developing and emerging economies which may lack adequate solid waste management infrastructure to deal with the increase in plastic waste (European Commission, 2011; Ocean Conservancy & McKinsey Center for Business and Environment, 2015; UNEP, 2018a). It has been claimed that compared to other regions sub-Saharan Africa has the highest plastic fraction in the waste stream (13%) but with some of the lowest solid waste collection efficiencies ranging from 18–55% (Hoornweg & Bhada-Tata, 2012). Furthermore, according to Jambeck et al. (2015), of the top 20 countries which contributed to plastic marine debris in 2010, 12 were low and lower middle-income countries. The consequential increased accumulation of plastics in the environment is of concern due to the direct threat they pose to wildlife, humans and ecosystems (elaborated further in section 2.2). Incidents of entanglement and ingestion by wildlife have been well documented in both marine and terrestrial environments (Allsopp et al., 2006; Barnes et al., 2009; Gall & Thompson, 2015). In addition, the toxicity associated with chemical additives in plastic polymers is also a major area of concern, however exposure mechanisms to organisms are poorly understood (Barnes et al., 2009; Andrady, 2011; Hermabessiere et al., 2017).

In terms of knowledge as to how large the plastic waste problem is and the extent of plastic accumulation in the natural environment (discussed further in section 2.1.2), numerous studies have been conducted monitoring abundance and composition of debris in the marine environment (Derraik, 2002; Allsopp et al., 2006; Ryan et al., 2009; Eriksen et al., 2014; Galgani, Hanke & Maes, 2015;

Lebreton et al., 2018). Previous studies have found that 40-80% of macro- (> 20 mm in diameter) marine debris is plastic, most of which is associated with food and beverage products including bottles, lids/caps, bags, drinking straws and polystyrene fragments (Barnes et al., 2009; Andrady, 2011; Ryan, 2014b; Galgani, Hanke & Maes, 2015). In 2012, the same items were found to be major contributors to plastic debris in Table Bay, South Africa during a study conducted by Lamprecht (2013). A South African beach survey conducted in 2015 yielded similar results with plastic packaging, including candy and chip wrappers, and other single use applications accounting for 84.1% of the total items collected (Plastics|SA, 2015). Discarded and/or lost fishing gear (e.g. nets and lines) is also a significant contributor to marine pollution with an estimated 0.6 million tonnes lost to the environment in 2015 (UNEP, 2018b). The increasing concern surrounding plastic marine pollution has seen more concerted efforts to quantify plastic flows to the marine environment (discussed further in section 2.1) (Jambeck et al., 2015; UNEP, 2018b; Ryberg et al., 2019). However, there is limited research into product-specific leakage rates with quantification studies rarely categorising beyond material types and/or sector.

In comparison to the marine environment, relatively fewer studies have been conducted on plastic accumulation on land. The majority of African studies explore litter prevalence qualitatively with more emphasis placed on the accumulation of plastic bags (Adane & Muleta, 2011; Mangizvo, 2012; Wachira, Wairire & Mwangi, 2014). In South Africa, studies have been conducted into litter accumulation in urban stormwater drainage systems, which offer a conduit for transport of debris from terrestrial to marine environments (Armitage et al., 1998; Arnold & Ryan, 1999; Marais & Armitage, 2003). Plastic was consistently found to be a major contributor to litter loads, however the loads were rarely characterised further into form or function. UNEP (2014) suggests that the measurement and understanding of plastic use and disposal is essential in identifying ”context specific measures to maximise the benefits of plastics whilst decreasing negative consequences”.

1.2 End-of-Life Management in Life Cycle Assessment

A life-cycle based approach is often employed when assessing the environmental impacts associated with packaging. Thus packaging design has been a major focus area of life cycle assessment (LCA) application, with one of the first comprehensive LCA studies commissioned by the Coca-Cola Company in 1969 on its beverage packaging options (Sonneveld, 2000). LCA is now commonly used as a decision support tool in packaging design and is an integral aspect of product life cycle management (LCM) in the food and beverage industry (UNEP/SETAC Life Cycle Initiative, 2013; Schenker, Espinoza-Orias & Popovic, 2014). It is noteworthy that when plastic packaging options are compared to paper and cardboard packaging options, the former generally are reported to perform better (James & Grant, 2005; Sevitz, Brent & Fourie, 2012; Kimmel et al., 2014).

Current LCA approaches only take into consideration formal disposal methods for product end-of-life, namely landfilling, recycling, incineration, and composting (Curran, 2012). This approach is adequate in countries with effective waste management policies and infrastructure. However, as shown in section 1.1, not all waste is diverted to formal disposal methods particularly in developing countries. The lack of guidelines on the consideration of improper waste disposal in LCA methodology is of particular concern in the packaging industry which is recognised as a major contributor to pollution (Williams, Wikström & Löfgren, 2008). Furthermore, current methodologies are unable to address broader environmental issues posed by some packaging materials, particularly the threat posed by plastic litter in the environment (Woods et al., 2016). This critical limitation is becoming more apparent with the new global agenda on plastic marine pollution and is becoming a priority area in LCM as evidenced by the Medellin Declaration on Marine Litter in Life Cycle Assessment and Management (Sonnemann & Valdivia, 2017).

1.3 Problem Statement

Plastic packaging has been identified as a major contributor to litter streams, particularly in developing countries which are commonly characterised by low municipal solid waste collection rates and/or poor solid waste management practices. However, there is limited available quantitative data on the rate of plastic leakage into the natural environment, particularly in African countries. Furthermore, the environmental impacts associated with leakage are not taken into consideration under current life-cycle based approaches, despite packaging being a major application area of LCA. This presents a critical limitation during the life cycle management of products destined for regions where they are likely to be dumped or littered. It is of interest to determine whether a realistic understanding of leakage rates, differentiated by major use, could possibly help industries to strongly reduce the problem of accumulation of plastics in the environment without foregoing the quantifiable environmental advantages of plastic as a material choice in the bulk of its applications.

1.4 Thesis Objectives

This PhD thesis aims to make a knowledge contribution to the increasingly recognised problem of plastic accumulation in the global environment. It recognises that the plastic accumulation problem is multi-faceted and that many initiatives have already been started to address it. In particular, it recognises that leakage is commonly approached from the perspective of littering behaviour and/or waste management infrastructure and practices and agrees improvements in these domains are essential. However, this thesis aims to contribute within the domain of product environmental life cycle management with a focus on the potential mitigation of the impacts associated with leakage through product design interventions. Specifically, it investigates the feasibility and potential influence of using product specific leakage rates as a proxy indicator for potential marine environmental impacts to inform the life cycle management of products in which plastic is a material choice. This entails the quantification of leakage rates for selected plastic items widely reported as being highly prone to leakage into the marine environment, based on a series of beach surveys, and demonstrating that vastly different leakage propensities exist for products with differing characteristics. The potential influence of providing such specific knowledge on plastic leakage is investigated via the exploration of current approaches to the life cycle management of plastic products. This includes the development of three product specific case studies, for items identified as prone to leakage, whereby their LCM is investigated, and the sustainability performance of different interventions evaluated. The case studies serve to provide practical demonstrations of how the increasing concern surrounding plastic pollution has influenced value-chain actor practices.

1.5 Thesis Scope

This thesis investigates the feasibility of integrating leakage into product life cycle management within the South African context. Thus, product LCM is investigated within the geographical scope of South Africa, including the development of the case studies.

The quantification of plastic flows is performed for the City of Cape Town, South Africa. Thus, product specific leakage rates are developed for Cape Town. Furthermore, the quantification is focused on the leakage of macroplastic (>20mm in diameter) into the marine environment from land. However, it does not investigate specific pathways into the marine environment.

1.6 Thesis Structure

The structure of this thesis is presented schematically in Figure 1-1. It begins with the background and motivation of the study and its aims as presented in the introduction (Chapter 1). This is followed by the literature review which analyses current knowledge, further contextualising the research (Chapter 2). This includes an analysis of quantifications of plastic waste flows with an emphasis on plastic flows into the natural environment, as well as environmental considerations during packaging design. The research approach and methods are presented in Chapter 3, including the research questions which guided the research.

The research findings are presented and discussed in Chapters 4 – 8. More specifically, Chapter 4 is focussed on the quantification of plastic flows into the marine environment from Cape Town, culminating in the development of leakage rates for plastic items that have been reported as highly prone to leakage. Whilst, Chapters 5 – 8 investigate approaches to plastic product LCM in South Africa, including the exploration of the potential influence of leakage rates as developed in Chapter 4, with the results of the three LCM case studies presented in Chapters 5 – 7 respectively. Chapter 8 provides an integrative discussion, exploring approaches to plastic product LCM in South Africa more broadly, drawing in part on the results of the LCM case studies.

The results presented in Chapters 4 – 8 are consolidated in Chapter 9, which provides concluding remarks based on the research findings in relation to the objectives outlined in the introduction.

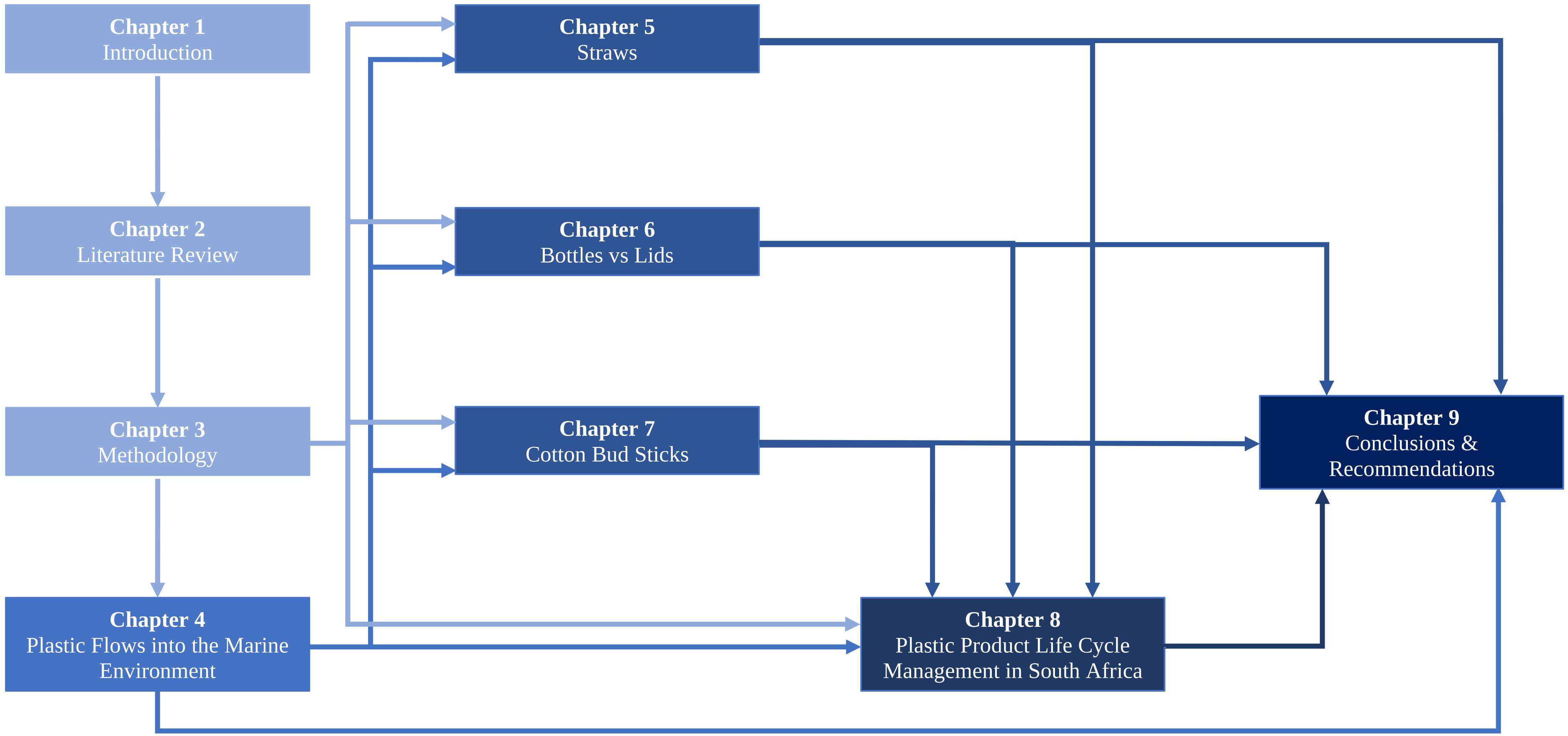

Figure 1-1: Thesis structure

Chapter 2 Literature Review

The aim of this literature review is to provide an analysis of previous studies on the fate of plastic waste, with a focus on improper disposal, and its consideration in the product design process. The review begins with an analysis of previous studies into plastic waste flows, emphasising the lack of quantitative studies on improper disposal despite plastic being considered as particularly prone to leakage, and highlighting the limitations and uncertainty associated with current estimates. The review then goes on to discuss the environmental impacts associated with improper waste disposal. This is followed by an overview of the status quo regarding environmental considerations during packaging design and the influence of plastic pollution on product design. The literature review concludes with an overview of life cycle management, including key drivers for its implementation and tools and techniques employed. This section aims to further contextualise the theory underpinning the research objective.

2.1 Plastic Flows at End-of-Life

The fate of plastic waste at the end-of-life is often dependent on a number of factors including solid waste management infrastructure and practices, as well as the presence of recycling industries in that region. More specifically, it is dependent on the availability and effectiveness of adequate solid waste management infrastructure and practices. Similar to MSW collection efficiency, waste disposal methods can also be related to income level. More than 50% of waste in high-income countries is diverted from landfills and is instead recycled, composted or incinerated (Hoornweg & Bhada-Tata, 2012). Most low-income countries have lower collection efficiencies, and dispose of their collected waste in uncontrolled open dumps and/or landfills which lack appropriate infrastructure including access control, protective layers and leachate and gas treatment (Coffey & Coad, 2010; Khatib, 2010; Guerrero, Maas & Hogland, 2013; UNEP, 2018a). Furthermore, landfills in developing countries are often poorly managed, and may be described as controlled dumps. In many African countries, uncollected household waste is disposed of in a variety of methods, including backyard and communal dumps, open burning and burying (Hoornweg & Bhada-Tata, 2012; UNEP, 2018a). Littering prevalence is dependent on a number of factors related to the socio-economic profile of the area, including income level, population density, development type and the level of personal environmental concern (Arnold & Ryan, 1999; Marais & Armitage, 2003; Santos et al., 2005; Garg & Mashilwane, 2015).

An estimate of global packaging waste flows in 2013 (shown in Figure 2-1) found that 68% of plastic waste was properly managed and formally directed to landfilling, incineration or recycling (World Economic Forum, Ellen MacArthur Foundation & McKinsey & Company, 2016). This estimate was based on work conducted by Jambeck et al. (2015) (discussed further in section 2.1.1) whereby their results were used as a basis for estimating a global plastic waste leakage rate of 32%. Of the formally disposed waste, 58.8% was landfilled. Despite the emphasis placed on recyclability during packaging design (discussed in section 2.3) only 14.1% of generated plastic packaging waste was recycled in 2013. In 2013, approximately 48% of all plastic packaging waste recycled globally, was recycled in the European Union (EU) while the United States (US) accounted for 17% (World Economic Forum, Ellen MacArthur Foundation & McKinsey & Company, 2016). This can be attributed to the increasing emphasis on recycling in these regions (section 2.3) coupled with effective solid waste management practices which facilitate material recovery and recycling. A similar situation was observed for disposal via incineration and/or energy recovery whereby 51% occurred in the EU and 20% in the US (World Economic Forum, Ellen MacArthur Foundation & McKinsey & Company, 2016).

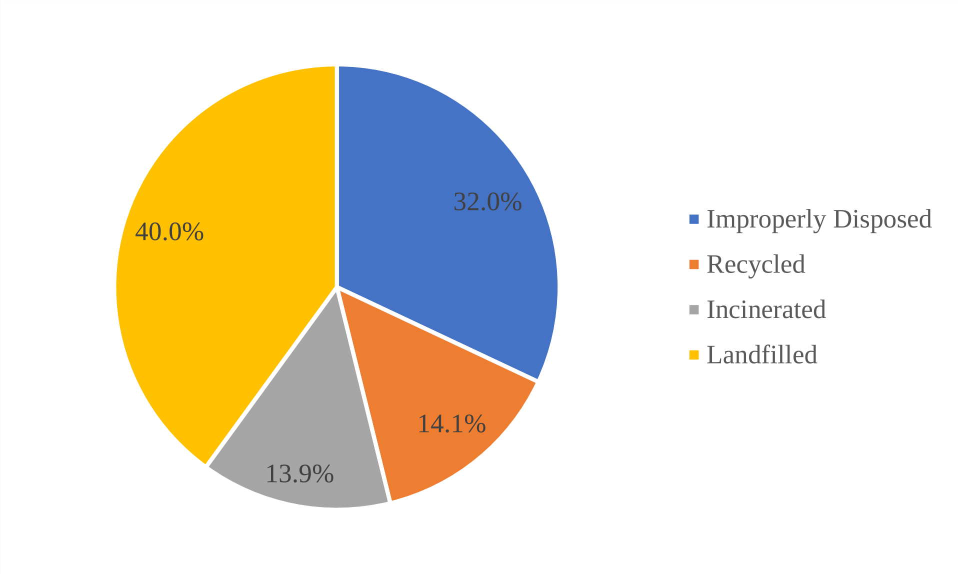

Figure 2-1: Estimation of global plastic packaging waste flows in 2013 (World Economic Forum, Ellen MacArthur Foundation & McKinsey & Company, 2016)

2.1.1 Quantification of improperly disposed plastic waste

Studies regarding quantification of flows of plastic waste typically only consider flows to formal disposal treatments namely landfilling, recycling and incineration (e.g. Sandgren, 1996, Mutha, Patel & Premnath, 2006, Kuczenski & Geyer, 2010 and GreenCape, 2016). A mass balance approach is usually taken whereby the amount of plastic being produced and consequentially disposed of is assumed to be equal, and the waste treated formally. This is particularly problematic in countries with high incidences of improper disposal whereby the results reflect all plastic waste as being properly disposed. Furthermore, these studies commonly focus on the quantification of waste when it reaches the various disposal treatments and do not take into consideration the complexities that exist within the waste value chain (see Coetzee, von Blottnitz & Hamann, 2014). The application of such an oversimplified approach is potentially problematic in developing countries where the informal waste sector plays a key role in waste diversion.

Growing concern surrounding the issue of plastic pollution has seen more estimates of improperly disposed plastic waste. These are often based on reported municipal collection rates and not supported by physical data collection (see Kellen, 2014; Jambeck et al., 2015; UNEP, 2018b). In 2015, Jambeck et al. estimated global flows of plastic waste from land into the ocean based on available data for population size, waste generation and municipal solid waste collection rates. In their estimations, the authors assumed that 15 – 40% of mismanaged waste would potentially flow into the ocean. Mismanaged waste included waste that was either littered or inadequately disposed, wherein the latter referred to waste disposed in dumps and uncontrolled landfills (Jambeck et al., 2015). Although the authors acknowledge some key sources of uncertainty including data quality, the exclusion of the role of the informal waste sector and the impact of the global trade of waste on plastic flows, the impacts of these could greatly influence the results particularly for developing countries. An effort to estimate plastic flows into the ocean by UNEP (2018b) followed a similar approach to Jambeck et al. (2015), however they assumed that 10% of mismanaged waste would potentially flow into the ocean. In both studies there was no scientific basis for the assumed fraction, increasing the uncertainty associated with the respective estimates. Ryberg et al. (2019), also followed a similar approach to Jambeck et al. (2015) to estimate the amount of mismanaged waste entering the natural environment using a lower fraction of 10%, as they considered the original fraction to be an overestimate of the likelihood of waste escaping dumps and uncontrolled landfills. However, they acknowledge that there is a lot of uncertainty associated with the estimate due to a lack of reliable data (Ryberg et al., 2019).

The aforementioned definition of mismanaged waste, put forward by Jambeck et al. (2015), has the potential to distort the rate of plastic leakage in developing countries which rely on dumps and uncontrolled landfills as their primary disposal methods. This may lead to a highly inflated figure for mismanaged waste particularly in sub-Saharan Africa where 44% of collected waste is disposed of in dumps and 50% in landfills, most of which are characterised as uncontrolled (Hoornweg & Bhada-Tata, 2012).

The exclusion of the informal sector, which often plays a vital role in developing countries (UNEP, 2018a), potentially excludes a significant flow of waste material. The utilisation of municipal collection rates as a proxy for properly managed waste does not provide an accurate estimate of waste flows, particularly in countries with a large informal sector. For example, at least 68% of all recycled plastic in South Africa is estimated to be recovered by the informal sector (GreenCape, 2015), though due to the nature of recycling, this volume is ultimately captured in formal industry recycling data.

Although studies have been conducted into alternative waste disposal practices such as burning and burying (Boadi & Kuitunen, 2005; Babayemi & Dauda, 2009), these are commonly not considered during plastic material flow analyses. Studies into improper disposal often do not differentiate between types of improper disposal. Instead, more emphasis is placed on plastic leakage and accumulation in the natural environment and alternative disposal methods such as burning or burying are not considered. Estimates of the proportion of waste burned have been made, and are based on household interviews (Boadi & Kuitunen, 2005; Babayemi & Dauda, 2009). Studies have found varying proportions of waste burned in different African cities, including 5% in Ethiopia (Tadesse, Ruijs & Hagos, 2008), 14.3% in Ghana (Boadi & Kuitunen, 2005) and 54.2% in Nigeria (Babayemi & Dauda, 2009).Numerous studies have been conducted into the prevalence of plastic waste in the natural environment (discussed in section 2.1.2). In particular, an increasing focus on plastic marine pollution in recent years has resulted in more concerted efforts to quantify the amount of plastic currently in the marine environment (Eriksen et al., 2014; van Sebille et al., 2015) as well as plastic flows into the oceans (Jambeck et al., 2015). However, there has been limited research into the quantification of leakage rates, which represent the proportion of waste that is leaked into the natural environment (as defined in section 1.1).

2.1.2 Plastic accumulation in the natural environment

There are many sources of plastic accumulation in the environment including direct dumping and littering, as well as wind or water-borne transport from open dumps and landfills (Barnes et al., 2009). The increased amounts of plastic waste in the marine environment are a global concern. Over the past decades numerous studies have been conducted on plastic in the marine environment, including studies monitoring abundance and composition (Derraik, 2002; Allsopp et al., 2006; Ryan et al., 2009; Eriksen et al., 2014; Galgani, Hanke & Maes, 2015; Lebreton et al., 2018). Estimates of plastic accumulation in the marine environment vary widely due to a lack of empirical data coupled with a lack of understanding of the sources, transportation mechanisms to and within the ocean as well as residence times within the different ocean compartments (surface, water columns, floor and shoreline) and degradation mechanisms (Eriksen et al., 2014; van Sebille et al., 2015; Koelmans et al., 2017; UNEP, 2018c). Standing stocks of plastic accumulated in the sea are commonly estimated using models that take into consideration empirical observational data. A study by Eriksen et al. (2014), estimated a minimum of 268 940 tons of plastic particles afloat in the ocean, of which macroplastics accounted for 75.4%, mesoplastics 11.4% and microplastics 13.2% . In 2015, van Sebille et al., (2015) estimated 93 000 – 236 000 tonnes of microplastics afloat in the ocean. When it comes to estimating plastic flows into the ocean, Jambeck et al. (2015) estimated 4.8 – 12.7 million tonnes entered the oceans from coastal areas in the year 2010. Whilst Ryberg et al. (2019) estimated 9.2 million tonnes of plastic entered the natural environment in 2015 from losses across the value chain, of which 0.8 million tonnes was attributed to littering and 5.1 million tonnes were lost at end-of-life. Furthermore, they estimated that 6.2 million tonnes of the losses were in the form of macroplastics whilst the remainder was microplastics (Ryberg et al., 2019).

Previous studies have found that 40-80% of macro- (> 20 mm in diameter) marine debris is plastic, most of which is associated with food and beverage products including bottles, lids/caps, bags, drinking straws and polystyrene fragments (Barnes et al., 2009; Andrady, 2011; Ryan, 2014b; Galgani, Hanke & Maes, 2015). Discarded and/or lost fishing gear is also a significant contributor to marine debris, including lines, nets and cages (Barnes et al., 2009; Li, Tse & Fok, 2016; Lebreton et al., 2018; UNEP, 2018b). An investigation into the size and composition of the Great Pacific Garbage Patch estimated that fishing nets accounted for 46 % of the mass (Lebreton et al., 2018). Furthermore, a study by UNEP (2018b) estimated that 0.6 million tonnes of fishing gear was lost to the environment in 2015. The extent to which these products contribute to plastic flows into the ocean is highly region dependent and can be influenced by a variety of factors including consumption rates, user behaviour and SWM infrastructure and practices (UNEP, 2018c). Whilst these products have been identified as major contributors to global marine pollution from a composition perspective, there have been limited studies into the quantification of product flows to the marine environment (as discussed in section 1.1).

Beach surveys of litter (discussed further in section 2.1.3) are often used to inform the abundance, characteristics and origin of plastic debris into the marine environment; these commonly target macro-debris due to the difficulty associated with sampling smaller sizes (Ryan et al., 2009). Beaches provide the most accessible area for studying marine debris, thus numerous beach surveys have been conducted globally for decades (Derraik, 2002; Barnes et al., 2009; Ryan et al., 2009; Galgani, Hanke & Maes, 2015). Accumulation rates resulting from beach surveys may be used as proxy indicators for litter flows into the ocean (Cheshire et al., 2009; Ryan et al., 2009). However, studies have shown that litter loads and compositions are influenced by different factors, including proximity to metropolitan areas and access to the public (Madzena & Lasiak, 1997; Lamprecht, 2013; Willis et al., 2017) as well as beach characteristics and water movements (Critchell & Lambrechts, 2016; Ryan et al., 2018).

There has been increasing research into the generation and accumulation of microplastics in the marine environment. Although there is some dispute on the size fraction, they are generally categorized as particles smaller than 5 mm in diameter (GESAMP, 2015). Microplastics are introduced into the environment either via the weathering of larger particles in the environment, or through runoff of manufactured microparticles such as those present in cosmetic products. Unlike larger plastics, microplastics are often not visible to the naked eye therefore specialised equipment is often used for collection and characterisation.

There are relatively fewer studies into plastic waste accumulation on land and in freshwater as well as pathways through the natural environment (Barnes et al., 2009; European Commission, 2011). A previous study in the United States quantified the total amount of litter in the country; however, as the characterisation method was item counts it gave no indication of the mass proportion of different items (Mid-Atlantic Solid Waste Consultants, 2009). Although accumulation of plastic waste is a major concern in African countries, studies into litter prevalence in urban areas are commonly conducted only qualitatively, focussing on disposal practices and littering behaviour amongst residents (Adane & Muleta, 2011; Mangizvo, 2012; Wachira, Wairire & Mwangi, 2014; Garg & Mashilwane, 2015; Tanyanyiwa, 2015). Furthermore, the majority of studies are focused on plastic bags (Adane & Muleta, 2011; Mangizvo, 2012; Wachira, Wairire & Mwangi, 2014). The emphasis of these studies contrasts with the majority of studies conducted in the marine environment which are concerned with plastic waste in general as demonstrated in the previous discussions.

Rivers provide a transportation route for land-based litter sources to enter the ocean. Lebreton et al. (2017) modelled global flows of plastic flows from rivers into the ocean based on a similar approach as that used by Jambeck et al. (2015) to estimate mismanaged waste coupled with hydrological information for the relevant regions. The study estimated that 1.15 – 2.41 million tonnes of plastic waste is transported annually by rivers into the ocean with 16 rivers in Asia accounting for 67% of inputs (Lebreton et al., 2017). In comparison, Schmidt, Krauth & Wagner (2017) estimated annual flows of 0.41 – 4 million tonnes with 10 rivers accounting for 88 – 95% of litter loads. Both studies acknowledged the uncertainty associated with their models due to the availability and quality of empirical data as well as the complexity associated with the dynamics of plastic transportation in riverine systems.

Urban drainage systems can also be considered a significant conduit for litter transfer from terrestrial to marine environments. In South Africa, a number of studies have been conducted into the quantification and characterisation of litter loads in urban catchment areas (Armitage et al., 1998; Arnold & Ryan, 1999). Plastic was consistently found to be the primary form of litter in all the areas observed (Armitage et al., 1998; Arnold & Ryan, 1999; Marais & Armitage, 2003). In these cases, the plastic was rarely characterised further as the primary aim of the studies was to investigate litter loads entering storm water drainage systems.

2.1.3 Beach survey litter sampling methods and classification

There are two general beach litter assessment methods that are used; standing stock surveys or accumulation rate surveys (Cheshire et al., 2009; Ryan et al., 2009). Standing stock surveys report the amount of litter at a particular moment in time. Due to the fact that litter loads are impacted by a number of factors including weather conditions and changes in human activities, standing stock surveys do not provide an indication of changes in litter abundance (Ryan et al., 2009; GESAMP, 2019). However, they can be used to monitor changes in litter composition. Assessments of accumulation rates report the rate of litter accumulation in the sample area and may be used as a proxy for litter flows into the ocean (Cheshire et al., 2009; Ryan et al., 2009; GESAMP, 2019). This requires an initial clean up to remove all litter followed by regular surveys whereby all accumulated litter is removed and recorded. As such they require more effort and resources to conduct. Like standing stock surveys, accumulation rates can be influenced by a number of factors potentially leading to variability in accumulation rates according to the length of sampling intervals (Ryan et al., 2009). For example, the movement of debris according to weather conditions is likely to result in short-term variability of litter loads from day to day which would influence results from daily sampling. There are variations in litter sampling intervals whereby some studies collect samples weekly for a fixed period of time (Armitage et al., 1998; Ryan et al., 2009), whereas others only sample annually (Cheshire et al., 2009). However, the impacts of sampling intervals on accumulation variability is yet to be determined concretely; Ryan et al. (2009) suggest that weekly intervals provide a "buffer" to short-term changes in weather conditions. Accumulation assessments can be used to investigate the impact of different factors on litter loads.

Litter loads are commonly reported in relation to a sample unit which represents the length or area of where the sample was taken. Ryan et al. (2009) suggest that ideal sample lengths be at least 50 m for standing stocks and 500 m for accumulation surveys, whereas Cheshire et al. (2009) recommend a general length of 100 m. It is recommended that both item count and weight are recorded during the analysis of litter loads (Cheshire et al., 2009; Ryan et al., 2009). Counts provide a relatively accessible quantitative indicator of items whereby mass is particularly useful in cases where items are of differing sizes or fragmented into smaller pieces.

Although there are inconsistencies in sampling methods, plastic litter is commonly characterised according to size, function or material type (Ryan et al., 2009). UNEP/IOC guidelines on marine litter surveys recommends the use of a litter classification system which first identifies items by general material type (e.g. plastic, glass, metal, etc.) followed by function (e.g. bottle, straws, etc.) (Cheshire et al., 2009). Ryan et al. (2009) recommend the classification of litter by composition and function. Furthermore, they recommend the size fraction of interest be explicitly stated.

2.2 Environmental Impacts of Improper Plastic Disposal

Improper plastic waste disposal poses a direct threat to the environment through the pollution of natural resources and ecology. However, the severity of the associated impacts is dependent on a number of factors including size, chemical composition and degradability. Leachate from decomposing waste that has been dumped or buried can percolate through the soil contaminating groundwater sources with serious environmental and social consequences. Improperly disposed waste can also be a potential breeding ground for vermin and scavenging animals, increasing the incidence of air- and water-borne diseases (Coffey & Coad, 2010; Hoornweg & Bhada-Tata, 2012). Open burning of waste contributes to atmospheric pollution potentially leading to an increase in the incidences of respiratory ailments in surrounding areas (Boadi & Kuitunen, 2005). This is of particular concern for plastics which contain toxic chemicals such as dioxins and furans (Coffey & Coad, 2010).

In the marine environment, the types of impacts of plastic on marine life, namely entanglement, smothering and ingestion, have been well documented (Derraik, 2002; Gall & Thompson, 2015; Kühn, Bravo Rebolledo & van Franeker, 2015; Rochman et al., 2016; Worm et al., 2017). Entanglement hinders an organism's ability to move, breathe and feed. In some cases, marine life may mistake plastic items for food leading to accumulation of ingested plastic in their stomachs affecting their overall health and at times directly causing their death. On the seabed, plastic may suffocate organisms or inhibit their ability to perform essential functions due to a reduction in light levels. A review conducted by Rochman et al. (2016) found that of the documented deaths associated with plastic debris, 63% were due to ingestion, 29% to entanglement and 8% to smothering. However, they noted that many of the demonstrated impacts were on an organism level and more research was needed to determine the impacts on a population level (Rochman et al., 2016). Plastics also have the potential to transport and distribute alien species which could be potentially harmful to different ecosystems (Allsopp et al., 2006; Galgani, Hanke & Maes, 2015).

The toxicity of associated chemicals added to plastics are also a major area of concern (Rochman, 2015; Hermabessiere et al., 2017; Worm et al., 2017). This is due to the potential for leaching of hazardous additives from the plastic material making them bioavailable for marine life. In addition, plastics have the potential to attract hydrophobic contaminants, such as persistent organic pollutants (POP) and metals, transferring them to an organism's system upon ingestion (Barnes et al., 2009; European Commission, 2011; Worm et al., 2017). Of particular concern is the potential for bioaccumulation of chemicals within the food chain resulting in each tier being exposed to greater concentrations, as bio-accumulating substances move up the food chain (Barnes et al., 2009; Andrady, 2011; Galgani, Hanke & Maes, 2015; Rochman, 2015). Conversely, the absorption of contaminants may decrease their potential for exposure to organisms in cases where the plastics are buried in the sea bed (European Commission, 2011). However, the transfer process and fate of chemical contaminants both absorbed onto and leached from plastic is complex and dependent on a variety of factors including the characteristics of the plastic as well as the organism (Rochman, 2015; Hermabessiere et al., 2017; Worm et al., 2017). Thus, there is a need for further research to provide a greater understanding of the toxicity associated with plastic debris in the marine environment.

The fragmentation of plastics into smaller fractions (i.e. microplastics) makes them more difficult to remove from the environment whilst increasing the potential for ingestion by a wider range of organisms (Barnes et al., 2009; Andrady, 2011). Exposure to microplastics can adversely affect an organism's feeding and fertility (Worm et al., 2017), but documented impacts are rarely lethal (Galloway, Cole & Lewis, 2017). In addition, microscopic plastics have the potential to be absorbed into body tissues due to their small size whilst nano-sized plastics can transfer across cell walls (Lusher, 2015; Worm et al., 2017). The increased likelihood for ingestion increases the bio-availability of chemical pollutants to marine species and consequently the likelihood of accumulation in the food web (Andrady, 2011; Rochman, 2015). Furthermore, the greater surface-to-volume ratio may increase the potential toxicity associated with these particles (Galloway, Cole & Lewis, 2017; Worm et al., 2017). However, the impacts of microplastics on food webs and populations are not well understood (Lusher, 2015; Galloway, Cole & Lewis, 2017).

There have been relatively fewer studies into the impacts of plastic pollution in terrestrial environments (Barnes et al., 2009; Malizia & Monmany-Garzia, 2019). Areas of concern include the impacts on wildlife as well as on plant species and on livestock, particularly in agricultural areas. Cases of entanglement and ingestion of plastic by wildlife have been documented to a lesser extent than those in the marine environment (Barnes et al., 2009; Thompson et al., 2009).

2.3 Environmental Considerations in Packaging Design

Globally, the packaging industry is viewed as a major source of litter and pollution, with increasing pressure on this industry to improve their environmental performance. This has been compounded by growing consumer awareness on environmental issues, with the end-consumer preferring what they perceive as more environmentally friendly alternatives (Rundh, 2005; Rokka & Uusitalo, 2008; Williams, Wikström & Löfgren, 2008; Venter et al., 2011). Therefore, many companies are integrating environmental performance into their business strategies. In order to obtain a science-based evidence base, numerous LCAs have been conducted on packaging, particularly in the food and beverage industry (UNEP/SETAC Life Cycle Initiative, 2013).

There has been increasing emphasis placed on packaging designs that aim to mitigate the potential environmental impacts associated with packaging waste. This has led to the development of packaging legislation in many countries including the European Union. As far back as 1994, the European Commission developed a directive promoting reuse, recycling and incineration for energy recovery with the aim of reducing environmental impacts (European Union, 1994). The importance of increased recycled content, reusability and recovery for energy or recycling, is also emphasised in a number of packaging sustainability frameworks (Huang & Ma, 2004; Sustainable Packaging Coalition, 2009; The Consumer Goods Forum, 2011; Galotto & Ulloa, 2013). These approaches seek to increase the proportion of packaging material being recovered and consequentially lead to a decrease in the flow of material to landfill and/or the natural environment via improper disposal. This is in line with the waste hierarchy whereby the most favoured options are commonly associated with significant reductions in environmental impacts, although the hierarchy may not always lead to an overall reduction in environmental impacts (UNEP/SETAC Life Cycle Initiative, 2013). From a consumer perspective, recyclability and recycled content has been found to increase packaging attractiveness as it is commonly perceived as an environmental protective measure (Williams, Wikström & Löfgren, 2008; Venter et al., 2011). The Association for Packaging and Processing Technologies (PMMI) (2015) identified the increasing influence of recycling and environmental issues as one of the top three trends forecast to impact the packaging industry. In particular, the recyclability and reusability of PET and glass bottles respectively, was expected to make them a more attractive choice for consumers, driving growth in those industries (PMMI, 2015). However, the consequential environmental impacts of this increase in growth will be highly dependent on the fate of the packaging at the end-of-life.

Traditionally, the majority of methodologies and frameworks for packaging design do not explicitly consider the improper disposal of waste and associated consequences (Huang & Ma, 2004; Sustainable Packaging Coalition, 2009; The Consumer Goods Forum, 2011). Although Galotto & Ulloa (2013) name litter (improperly disposed packaging waste) as one of the environmental challenges of packaging, their proposed sustainability framework does not allow for its consideration. Litter is also mentioned by the UNEP/SETAC Life Cycle Initiative (2013) as a consumer concern, however no guidance is provided as to how it may be integrated into LCAs for food and beverage packaging.

Increasing focus on transitioning towards a circular economy has resulted in more explicit consideration of the fate of a product during the design process. The reduction of plastic leakage is viewed as integral to the transition towards a circular economy in the plastics industry through the reduction of negative externalities associated with systemic leakage (World Economic Forum & Ellen MacArthur Foundation, 2017). Subsequently in 2018, the Ellen MacArthur Foundation in partnership with UNEP proposed the New Plastics Economy Global Commitment in which one of the key visions is that "all plastic packaging is 100% reusable, recyclable, or compostable" (Ellen MacArthur Foundation, 2018).

2.3.1 Influence of plastic pollution on product design

Although plastic leakage is commonly investigated within the scope of solid waste management and consumer behaviour, its potential role in product design is gaining in importance. In 2017, the World Economic Forum & Ellen MacArthur Foundation put forward a number of key strategic areas for the plastics industry, including recommending the replacement of polystyrene packaging materials due to their propensity for leakage alongside low recycling potential due to low economies of scale. In addition, they recommend the redesign of small plastic packaging, including sweet wrappers and lids, due to their high propensity for leakage (World Economic Forum & Ellen MacArthur Foundation, 2017).

Increasing accumulation of plastic waste in the natural environment coupled with public concern has resulted in more pressure being placed on relevant industries to move away from materials prone to leakage. Most notably, the shift away from polystyrene fast food packaging in favour of biodegradable paper based alternatives, which began in the early 1990s (Holusha, 1990). Previous LCAs have shown the comparison between paper and polystyrene to be a complex issue, with neither being conclusively more environmentally benign (Franklin Associates, 1990, 2006; Hocking, 1991; van der Harst & Potting, 2013). However, a key factor in the decreasing popularity of polystyrene is its propensity for leakage and accumulation in the environment. This has resulted in many multinational fast food companies phasing out the use of polystyrene foam food packaging and cups (Caliendo, 2013), as well as the banning of polystyrene in some jurisdictions (K. Ryan, 2014). Beyond the food industry, in 2017, Johnsons & Johnsons UK switched from plastic cotton bud sticks to biodegradable paper alternatives (Johnson, 2017). In addition, two of the largest UK supermarket chains, Tesco and Sainsbury's, pledged to make the transition by the end of 2017 (Carrington, 2016). This shift is credited to the increased pressure placed on firms by environmental groups citing the increasing accumulation of plastic cotton buds in the marine environment (Allen, 2017).

2.3.2 Policy responses to plastic pollution

The growing concern surrounding the impact of plastic pollution has also led to a myriad of policies being developed across city, national and regional levels in an effort to mitigate the problem (see UNEP, 2018a). More specifically, there has been an increasing number of policies developed which aim to address problematic products that have been identified as major contributors to marine litter. A notable example is the widespread response to the threat posed by plastic bag pollution which began in the early 1990s and has seen many countries implementing interventions varying in range and scope (Xanthos & Walker, 2017). Policy interventions range from taxes/levies on the sale of plastic bags, bans on thin and lightweight bags, and in some cases complete bans on the production, import, sale and use of plastic bags (see UNEP, 2018d; Xanthos & Walker, 2017). Recent years have also seen a spotlight being placed on single-use food related plastic products including utensils and polystyrene containers. In 2018, Jamaica and Dominica announced bans on food related plastic items, effective from January 2019 (Government of the Commonwealth of Dominica, 2018; JIS, 2018). More broadly, in the same year, the European Union approved a ban on single-use plastics which had been identified as major contributors to marine pollution by 2021 including straws, cutlery, plates, polystyrene cups and cotton bud sticks (European Parliament, 2018), with India making a similar pledge to ban single-use plastics by 2022 (Withnall, 2018).

2.3.3 Life cycle impact assessment categories of relevance

As mentioned in section 1.2, current LCA approaches do not provide any guidelines for the integration of improper disposal. Based on the environmental impacts outlined in section 2.2, it is clear that one major and tangible concern surrounding plastic pollution is its toxicity to humans, wildlife and ecosystems. These impacts may be considered under the LCA impact categories human toxicity and ecotoxicity. However, there are currently no toxicity assessment models for the impacts of plastic waste. More research is required to not only understand the impacts of plastic on the marine ecosystem, but the behaviour of plastic within the marine environment including residence times in the different compartments and fragmentation rates so as to enable the development of robust effect models (Rochman, 2015; Woods et al., 2016). Isolated studies have considered their integration into LCA methodology via the use of rudimentary indicators, but there are currently no guidelines. This serves as a major constraint when LCAs are conducted on plastic materials destined for regions where improper disposal is prevalent as the results will not provide a realistic representation of the potential environmental impacts. However, in recent years, this shortcoming of LCA has been an increasing area of focus within the research community (Woods et al., 2016; Sonnemann & Valdivia, 2017). James & Grant (2005), integrated improper disposal into an LCA study of carrier bags from two perspectives; an aesthetic perspective based on the degradation rate, as well as risk to marine biodiversity based on how long the bag would float or sink as an indication of its potential for ingestion or entanglement. In 2019, Civancik-Uslu et al. proposed a “littering potential” indicator which took into consideration the probability of leakage based on cost, weight as an indicator of dispersion potential as well as biodegradability.

A more in-depth review of relevant impact categories is available in Appendix A.

2.4 Life Cycle Management

Life cycle management is a concept centred on the incorporation of sustainable development principles into modern business practice (Sonnemann et al., 2015). It can be considered a business management approach that aims to minimize the environmental and socio-economic burdens associated with an organization’s products or services from a life cycle perspective (Hunkeler et al., 2004; UNEP/SETAC, 2007; Sonnemann et al., 2015; Bey, 2018; Nilsson-Lindén, Rosén & Baumann, 2019). More practically, it provides a toolkit for business sustainability, built on the tenets of life cycle thinking. LCM employs a number of tools and techniques including: life cycle assessment, life cycle costing, social life cycle assessment, material flow analysis and hotspot analysis. It also includes conventional business tools such as stakeholder analysis and SWOT (strength, weaknesses, opportunities and threats) analysis (Bey, 2018). LCM employs a number of design concepts such as eco-design, sustainable product design, design for recycling and design for circularity (Sonnemann et al., 2015; Bey, 2018). In addition, it encompasses several policies and strategies including sustainable production and consumption, circular economy, industrial ecology and extended producer responsibility (EPR) (UNEP/SETAC, 2007; Sonnemann et al., 2015). LCM allows for the systematic integration of product sustainability across departments in an organisation as can be seen in Figure 2-2, with different potential outcomes.

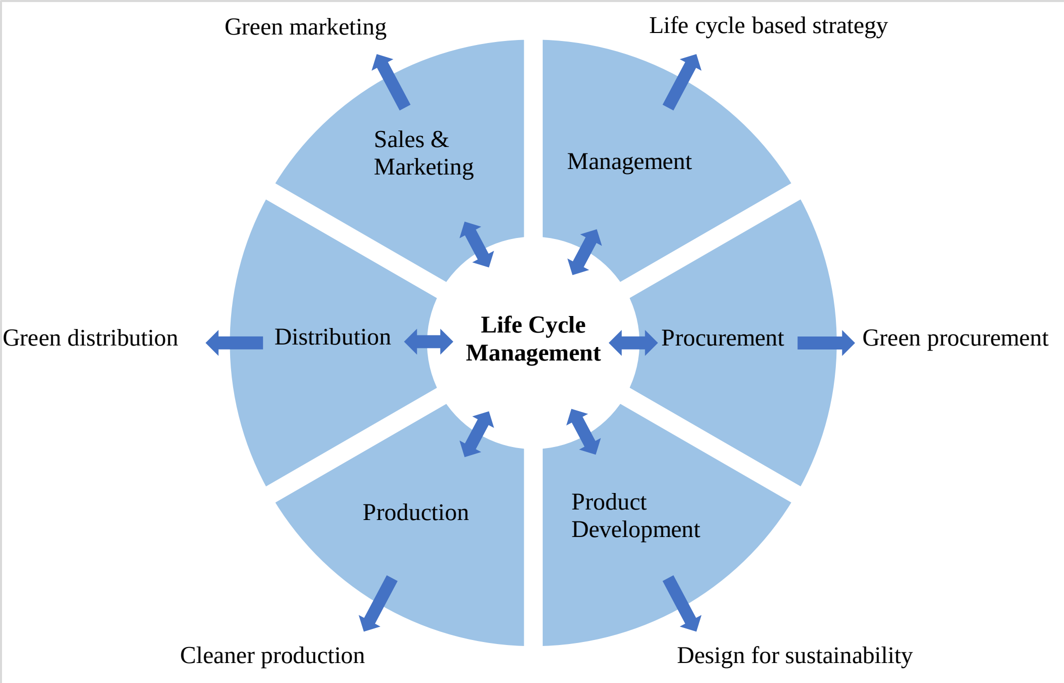

Figure 2-2: Life Cycle Management as the central influencer of different departments and the potential outcomes (Bey, 2018)

There are a number of key drivers for an organization to implement a life cycle approach including business strategy, market requirements, regulations and legislations as well as international agreements (Hunkeler et al., 2004; UNEP/SETAC, 2007; Sonnemann et al., 2015). Mapping value chains and developing criteria for product enhancement and value creation may enable organisations to gain a competitive advantage (UNEP/SETAC, 2007; Sonnemann et al., 2015). In addition, the implementation of LCM may contribute to an improved public perception. Government regulations and legislation surrounding environmental impacts may force organisations to employ a life-cycle based approach to ensure compliance.

Multinational fast-moving consumer goods companies are increasingly employing LCM tools and concepts in their business operations to varying extents (discussed further in section 8.1) (UNEP/SETAC, 2009; Adams, Schenker & Loerincik, 2015; Stewart et al., 2018). A notable example is, Nestlé which engaged in the development of a life-cycle based eco-design tool – EcodEX. This tool provides a simplified approach for incorporating LCA into the development of food and beverage products (Schenker, Espinoza-Orias & Popovic, 2014). The tool takes a life-cycle perspective, evaluating all impacts across the product life-cycle including consumer behaviour. The tool reportedly enabled the widespread integration of life cycle assessment across different departments without the need for specific LCA expertise, facilitating the integration of environmental criteria into decision-making during product design (Adams, Schenker & Loerincik, 2015).

2.5 Summary

This chapter has aimed to review the current state of knowledge on the quantification of plastic waste flows with a focus on leakage, and the inclusion of leakage in product life cycle management. Although material flow analyses of plastics have been conducted, waste flows were commonly only considered for formal treatment, namely landfilling, recycling and incineration. In cases where improper disposal was considered, this was commonly based on municipal waste collection rates, with a recent study estimating 32% of global plastic waste being leaked into the environment. However, assumptions used in the analyses and associated estimates of quantities of improperly disposed waste need to be treated with caution. Furthermore, there is limited knowledge on the fraction of plastic waste which enters the marine environment, particularly on a product level basis.

Environmental considerations during packaging design emphasise recyclability and reusability as measures of environmental friendliness at end-of-life. However, improper disposal and the associated impacts are generally not considered in current design frameworks. The physical impacts of plastic on marine life have been well documented, but there is a limited understanding of the broader impacts associated with improper disposal particularly exposure mechanisms and its toxicity to humans, wildlife and ecosystems. The complexity of impact causation thus presents a critical limitation to the integration of improper disposal into environmental assessment and management methodologies, including life cycle management approaches.

Chapter 3 Research Methodology

The literature review presented in Chapter 2 identified some key gaps in literature pertaining to the fate of plastic materials at the end of life, particularly the lack of product-specific quantitative data on the rate of plastic leakage into the environment. In addition, current product design approaches do not take into consideration the likelihood of product leakage at the end of its life.

The limited understanding of the diverse impacts associated with plastic accumulation in the environment presents a critical limitation to the quantification of these impacts and the subsequent development of a robust impact assessment methodology. Thus, this research does not pursue the development of a Life Cycle Impact Assessment (LCIA) method.

As stated in Chapter 1, this research aims to investigate the feasibility and influence of providing specific knowledge on leakage rates, as a proxy indicator for potential marine environmental impacts, to inform the life cycle management of products including plastic as a material choice. This includes the quantification of leakage rates for products identified as prone to accumulation in the marine environment and contrasting them with leakage rates for less prevalent items. The potential influence of providing such specific knowledge on plastic leakage is explored within the context of life cycle management of products that have been identified as particularly prone to leakage.

This chapter begins with an overview of the research questions followed by the research approach and the methods employed.

3.1 Research Questions

To achieve the objectives of this research, two main research questions pertaining to the determination of leakage rates and the potential influence of this knowledge in product life cycle management, respectively, were developed. The first main question investigated is as follows:

1. What are the leakage rates of plastic items which have been identified as prone to accumulation in the marine environment?

This question is informed by the finding of the literature review that product-specific leakage rates have not been studied, nor have methods for doing so. As stated in section 1.1, leakage rate represents the fraction of waste that is leaked into the natural environment. Therefore, it is necessary to determine the amount of waste generated as well as the amount flowing into the marine environment on a product specific basis. Thus, the following questions are investigated:

a. *What are the accumulation rates of plastic items in the marine environment?*
b. *How do these accumulation rates relate to quantities sold?*

As discussed in section 2.3, environmental issues are gaining in importance during packaging design, with the increase of more environmentally conscious consumers. Although plastic leakage is acknowledged as a major problem its impacts are not commonly considered in packaging design frameworks (discussed in section 2.3). Instead, there is increasing emphasis on the recycled content and recyclability of packaging at its end-of-life, as well as its potential for reuse. Thus, it is of interest to investigate the potential influence of providing specific knowledge on plastic leakage (as generated in question 1) on the life cycle management of products as follows:

2. What is the feasibility and influence of providing specific knowledge on plastic leakage on the life cycle management of products in which plastic is a material choice?

In order to investigate the above question, it is important to develop an understanding of product LCM in South Africa. This includes the extent to which a life cycle perspective is employed, and any tools and/or techniques utilized. As this thesis is focused on taking a design approach to plastic pollution, the key metrics that influence packaging design are of interest. It is also necessary to explore the influence of plastic pollution on value-chain actor approaches to plastic product LCM including any challenges, barriers or drivers for the development of interventions and/or strategies to mitigate plastic pollution. Ultimately, this enables the exploration of the potential influence which providing specific knowledge on plastic leakage may have on current approaches to life cycle management. Thus, the following set of questions are investigated:

a. *How is plastic product environmental management, and specifically LCM approached in South Africa?*
b. *What are the key criteria informing packaging design and what is their relative influence?*
c. *What is the influence of plastic pollution on plastic product LCM?*
d. *What are the key barriers, challenges and drivers for the development of strategies to mitigate plastic pollution?*

3.2 Research Design

To effectively address the research questions posed and achieve the objectives of the thesis, the study is structured into two main steps corresponding to the main research questions (Figure 3-1);

i) Firstly, the quantification of plastic flows into the marine environment so as to develop specific knowledge on leakage rates for different items (section 3.3).
ii) Then, the investigation of the feasibility and potential influence of integrating leakage into life cycle management via the exploration of approaches to plastic product LCM in South Africa and the influence of plastic leakage on current practices (section 3.4). This includes the development of LCM cases for specific products that have been identified as prone to leakage. The case studies provide a practical basis for exploring value-chain actor approaches to the life cycle management of plastic products that are highly prone to leakage.

A mixed methods research approach was employed. More specifically, quantitative methods were used for the quantification of product-specific leakage rates. The second step was primarily grounded in qualitative methods via engagement with relevant plastic value-chain actors in the form of interviews. Interviews were employed as they enable the in-depth exploration of value-chain actor perspectives and how they were formed (Kvale, 1996; King, 2004). This was integral to the investigation of the potential integration of leakage rates into product life cycle management. Quantitative methods were employed in the case studies to evaluate the sustainability impacts associated with the different focus items (discussed further in 3.4.2).

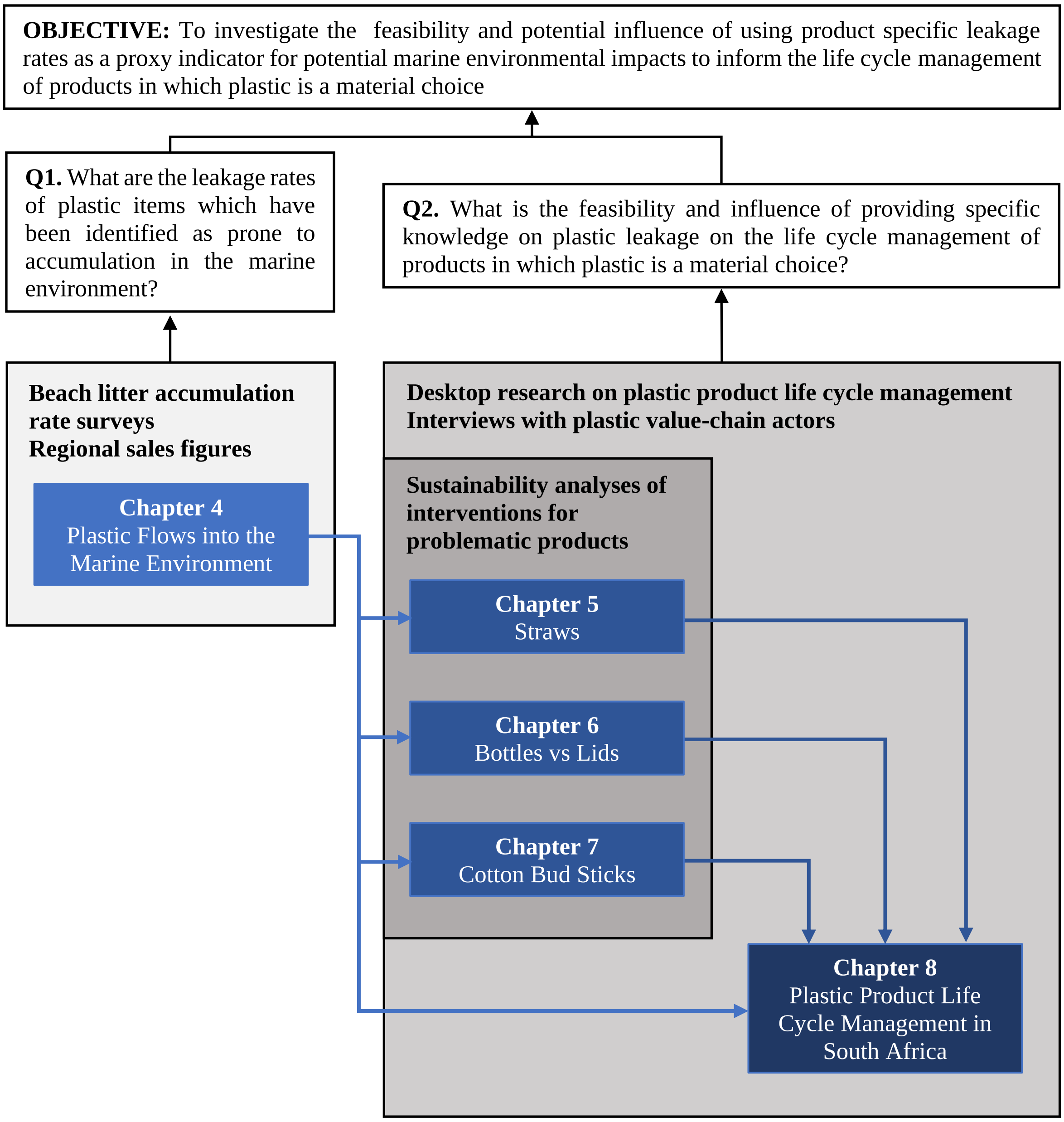

Figure 3-1: Research design schematic showing relationships between the key questions, methods and results chapters

3.2.1 Quantification of product-specific leakage rates

The quantification of leakage rates of plastic items which have been identified as prone to leakage into the marine environment was informed by sub-questions 1a – b.

The accumulation rates of plastic items in the marine environment were quantified utilising beach accumulation rate surveys which are often used as a proxy for waste flows to the marine environment, as discussed in section 2.1.3. Thus, the quantification of plastic flows into the marine environment was based on a series of beach surveys (section 3.3.1).

How the observed accumulation rates related to quantities sold were demonstrated by ratioing the results of the beach surveys to sales figures. It is acknowledged that beach accumulation rates are influenced by a range of factors (as discussed in sections 2.1.2 and 2.1.3). Furthermore, the selection of sample areas (shown in Figure 3-2), all in close proximity to water inputs from land into the ocean , may introduce bias though the nature of that bias is not fully understood (discussed in section 4.4.1). Consequentially, any extrapolation of the daily accumulation rates, including scaling by coast length and by time, is subject to these factors and as such cannot be considered definitive nor exact. Thus, leakage ratios (section 3.3.2) were developed based on the daily accumulation rates determined from the beach surveys, so as to demonstrate that vastly different leakage propensities can be observed for items based on their characteristics, including consumptions patterns. This is done by calculating ratios of the daily accumulation rates to daily sales figures which were used as a proxy for waste generation (section 3.3.2). As the thesis also aims to explore the feasibility of developing and integrating leakage rates into LCM practise, the development of such knowledge is also demonstrated (section 3.3.4). This was based on the extrapolation of the average daily accumulation rates to obtain annual estimates, which were then related to annual sales figures in order to determine the fraction of generated waste that potentially enters the marine environment, i.e. leakage rate.

3.2.2 Investigating the feasibility and potential influence of integrating leakage rates into LCM

The feasibility and influence of providing specific knowledge on plastic leakage on the life cycle management of products in which plastic is a material choice was informed by the exploration of the sub-questions 2a – d.

Approaches to plastic product environmental management and specifically LCM in South Africa were explored via engagement with relevant actors across the plastics value chain, with a focus on the fast-moving consumer goods sector, in the form of semi-structured interviews (section 3.4.1). Interviewees selected were limited to value-chain actors who are directly involved in plastic value chain activities (discussed further in section 3.4). The interviews investigated the application of LCM concepts in South Africa, including the extent to which a life cycle perspective is employed, the utilisation of any tools and techniques as well as any systems and procedures in place.

The key criteria informing packaging design and their relative influence were also explored as part of the interview process. Product design approaches were explored through the identification of key metrics informing packaging design including the extent to which plastic pollution is taken into consideration, and determining their relative influence using preference elicitation (discussed further in section 3.4.1). Preference elicitation was only conducted with interviewees directly involved in the packaging design process within their respective firms.

The influence of plastic pollution on plastic product LCM was investigated through examining value-chain actor responses to plastic pollution. This was done via a combination of desktop research on corporate responses as well as through the interview process (discussed in section 3.4). The potential influence of product-specific leakage rates was also explored including their potential adoption by value-chain actors. This was achieved by presenting interviewees with the concept of leakage rates, their development and how they can provide information on relative leakage propensities (which was demonstrated via the leakage rates calculated as part of the study).

The key challenges, barriers and drivers for the development of strategies to mitigate plastic pollution in the South African context, were explored directly with value-chain actors during the interview process.

Three product case studies were developed (section 3.4.2), which included a combination of recyclable and non-recyclable items. The focus products were selected based on their propensity for leakage based on the calculated leakage rates. The three case studies were focused on straws, cotton bud sticks and beverage bottles and lids. The LCM cases were developed in partnership with relevant value-chain actors to ensure they were representative of the South African context. The case studies investigated their approaches to the LCM of items that have been identified as problematic, and the sustainability implications of specific strategies and interventions to mitigate their accumulation in the marine environment. Furthermore, the case studies served as practical demonstrations to directly inform the research question including how the pollution associated with the identified items had influenced value-chain actor practices as well as exploring key challenges, barriers and drivers for the development of any interventions.

3.3 Quantification of Plastic Flows to the Marine Environment

3.3.1 Litter accumulation rates

The accumulation rate of a type of non-biodegradable item, or group of items, in a specific environmental compartment, is defined as the amount that collects per unit area over a specified period. A series of beach accumulation rate surveys were conducted to determine plastic litter accumulation rates along five beaches in Cape Town (shown in Figure 3-2), namely Hout Bay, Milnerton, Muizenberg, Paarden Eiland and Wolfgat.

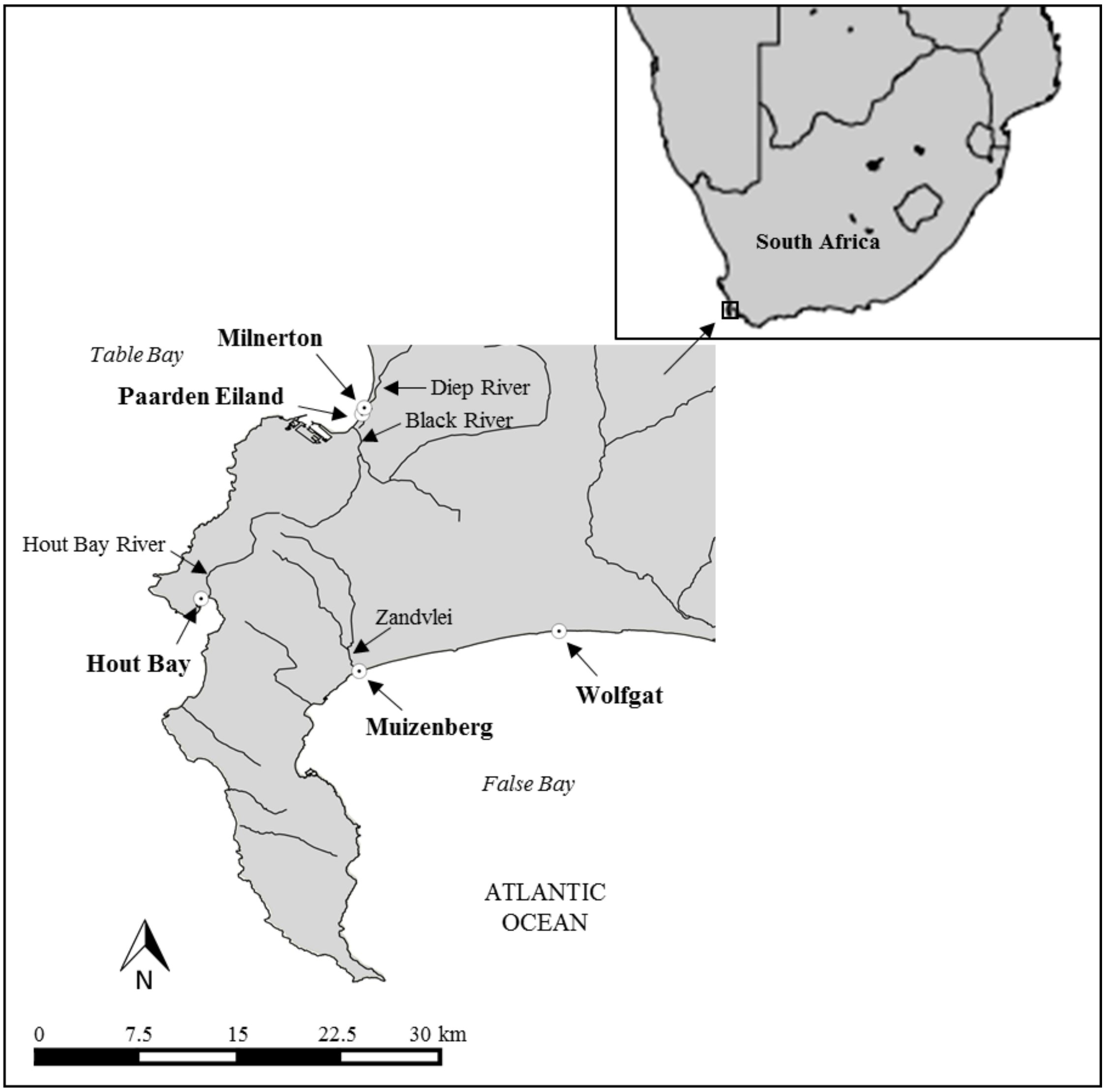

Figure 3-2: Map showing sample areas

The beach accumulation rate survey methodology, outlined in section 2.1.3, was followed. It commenced with an initial clean-up of the sample area whereby all litter was removed and disposed. This was followed by daily collection of all litter on the identified length of beach, between the sea and the highest strandline. The collected litter was transported to a University of Cape Town (UCT) laboratory where all items were cleaned, counted and weighed. The litter was quantified by mass which is particularly useful in cases where items are of differing sizes or fragmented into smaller pieces, and in terms of counts, which provide a relatively accessible quantitative indicator of items. Similarly to previous surveys, the litter was then categorised into distinguishable item types identified across material types and functional type categories (Cheshire et al., 2009; Ryan et al., 2009). Due to the lightweight nature of plastic and its easy dispersion, daily sampling was chosen to establish the amount of plastic actively deposited in a sample area. The sampling was conducted for five to ten days per site for a beach length of 100m, as recommended by Cheshire et al. (2009). Variability in sampling duration was due to significant safety issues at some of the sample areas that limited accessibility. Due to the variable nature of beach surveys two series of beach surveys were conducted during the transition from winter to spring season from August – October 2017 and during the summer season from December

2018 – January 2019 respectively, as shown in Table 3-1. The repetition of the beach surveys aimed to provide further insights into the influence of different factors such as seasonality and beach usage.

Table 3-1: Sample area survey periods

Location	Survey Period	
	Winter/Spring	Summer
Hout Bay	26 August – 30 August 2017	4 December – 10 December 2018
Milnerton	15 September – 22 September 2017	4 January – 11 January 2019
Muizenberg	26 September – 5 October 2017	13 January – 20 January 2019
Paarden Eiland	15 September – 22 September 2017	4 January – 11 January 2019
Wolfgat[1]	8 August – 18 August 2017	20 November – 30 November 2018

Five sample areas were taken into consideration, with varying catchment area characteristics including proximity to metropolitan areas and usage rates (Table 3-2). Furthermore, each of the sites were in close proximity to a water flow into the ocean in the form of an estuary or stormwater drain outlet which provided transportation for debris from land-based sources to the marine environment. Beach cleaning activities, commonly conducted by the respective municipalities, varied at the sample sites with different levels of frequency observed during the surveys. In cases where cleaning activities occurred, arrangements were made with municipal staff to ensure the sample area was not cleaned during the sampling period. Daily weekday cleaning was observed in Hout Bay, whereas less frequent cleaning was observed in Milnerton and Muizenberg. Despite its proximity to the Milnerton site, there were no cleaning activities taking place in Paarden Eiland. Although Wolfgat Nature Reserve is a protected area, the site was rarely cleaned due to limited financial resources and human capacity as well as safety concerns (Wolfgat Nature Reserve Office, personal communication, 2017).

Table 3-2: Beach survey sample area characteristics

Location	Site Details	Catchment Area Description			
		Land Use	Income Level	Population Density (capita/km^2)	Water outlet
Hout Bay	Harbour and popular recreational beach	Mixed commercial and residential area	Segregated low and high income	630	Hout Bay river estuary
Milnerton	Popular recreational beach	Residential area	Middle income	2200	Diep river estuary
Muizenberg	Popular recreational beach	Mixed commercial and residential area	Middle income	2400	Zandvlei estuary
Paarden Eiland	Poorly accessible beach close to the commercial harbour	Light industrial zone, but with rivers flowing through residential areas incl. high, medium and low income	n/a	n/a	Black river estuary
Wolfgat	Coastal nature reserve	Residential area	Low income	7100	Stormwater drain

[1] Due to safety concerns it was only possible to sample during the week at Wolfgat resulting in 5 sample collection days

Average daily beach accumulation rates for each site were calculated based on the results of the daily sampling. Average item unit weights were calculated for the defined item categories. As accumulation rates can be influenced by a number of factors, statistical analyses were conducted to determine the variance amongst daily rates. More specifically, the standard error (s.e.) and coefficient of variation (CV) were calculated per site. Further statistical analyses were conducted using non-parametric tests as they were deemed more appropriate due to the relatively small beach survey sample sizes. More specifically, correlations were analysed using Spearman's Rank (r_s), whilst the results of the two sampling periods were compared using the Mann-Whitney-U test. In addition, the influence of weather conditions such as rain and wind were taken into consideration when analysing variations in daily accumulation rates. The results of the respective sets of beach surveys were compared and analysed for any variations.

Total accumulation rates for Cape Town were based on extrapolation of the data generated from the different sample areas, according to the following equation:

$$\begin{aligned} total\ accumulation\ rate\ \left(\frac{items}{yr}\right) \\ &= average\ daily\ accumulation\ rate\ \left(\frac{items}{100m.day}\right) \times \frac{1000m}{km} \\ &\times coast\ length\ (km) \times \frac{365days}{year} \end{aligned}$$

Total accumulation rates were calculated based on the results of each individual beach so as the show the spread in variation. In addition, the average total accumulation rate was calculated as well as the associated standard error and coefficient of variation.

Total accumulation rates were reported according to counts as sales are often reported on a unit basis.

3.3.2 Waste generation rates

The waste generation rate was based on the quantities sold, which provided an indication of consumption rates and thus waste generation as all of the items under consideration are short-lived.

$$waste\ generated = sales$$

The quantities sold were determined using direct sales data, industry data or market research dependent on availability. Sales data for Cape Town was calculated based on National figures. More specifically, per capita consumption for Cape Town was calculated based on the difference between food, beverage, tobacco household expenditures for South Africa vs Cape Town as follows:

$$\frac{sales\ (Cape\ Town)}{capita} = \frac{sales\ (South\ Africa)}{capita} \times \frac{consumption\ expenditure\ (Cape\ Town)}{consumption\ expenditure\ (South\ Africa)}$$

As consumption expenditure was only available on a provincial and national scale, the expenditure for Western Cape Province was assumed to be representative of that for Cape Town.

Total sales for Cape Town were then calculated using the Cape Town population for 2017:

$$total\ sales\ (Cape\ Town) = \frac{sales\ (Cape\ Town)}{capita} \times population\ (Cape\ Town)$$

3.3.3 Leakage ratios

Daily leakage ratios were calculated by ratioing the average observed accumulation rates with daily sales figures as follows:

$$leakage\ ratio(100m^{-1}) = \frac{average\ daily\ accumulation\ rate\ \left(\frac{items}{day.100m}\right)}{waste\ generated\left(\frac{items}{day}\right)}$$

Leakage ratios were calculated for key items that were identified as prone to leakage as demonstrated by their accumulation rates coupled with their prevalence across the five beaches. Leakage ratios were also calculated for items that were not prevalent and had relatively low accumulation rates so as to demonstrate the relative differences in leakage rates for products with different characteristics.

Leakage ratios were calculated for 2017, as sales data was only available for this year.

3.3.4 Leakage rates

To determine leakage rates, it was necessary to determine the waste generation rate of the items of interest.

The leakage rate was then calculated as follows:

$$leakage\ rate\ (\%) = \frac{total\ accumulation\ rate\ \left(\frac{items}{yr}\right)}{waste\ generated\ \left(\frac{items}{yr}\right)} \times 100\%$$

Leakage rates were calculated for the same products for which leakage ratios were calculated (section 3.3.3).

3.4 Influence of Leakage on Plastic Product Life Cycle Management in South Africa

The influence of plastic leakage on product environmental and life cycle management was explored using a combination of primary and secondary data sourcing. More specifically, the application of any LCM tools, design concepts and strategies (shown in Table 3-3) employed by FMCG companies operating in South Africa were explored using secondary data sources, including annual reports, websites and media releases.

Table 3-3: Life cycle management tools, design concepts and strategies

Tools	Design Concepts	Strategies
Life Cycle Assessment	Sustainable Product Design	Sustainable Procurement
Life Cycle Costing	Design for Recycling	Cleaner Production
Social Life Cycle Assessment		Green Marketing
Materiality Assessment		Extended Producer Responsibility

Furthermore, companies which operated in multiple countries were characterised according to their business strategies (described in Table 3-4) as well as whether they were listed on any stock exchanges.

Table 3-4: Company business strategies (Bartlett & Ghoshal, 1998; Hill, 2013)

International	• Product research and development (R&D), marketing and strategy centralized in home country • Limited customization of products to local markets
Global	• R&D, manufacturing and marketing concentrated in a few locations but strong headquarters in one country • Homogenized product offering to maximise on economies of scale
Multinational	• Manufacturing and marketing in different markets • Product offering customized to local markets
Transnational	• R&D, marketing and decision-making powers distributed amongst different markets • Products differentiated according to local markets

Primary data was sourced via semi-structured interviews with key value-chain actors (discussed further in section 3.4.1). This included industry associations who can speak with authority regarding relevant industry perceptions and product designers who would have intimate knowledge on the design decision-making process. Brand owners and retailers (who all had in-house brands) were also engaged as they play a pivotal role in bringing products to market. A total of 15 value-chain actors were interviewed as shown in Table 3-5. All value-chain actors were directly involved in value-chains for items that were identified as major contributors to marine pollution. Furthermore, their market share was also taken into consideration. Accessibility to value-chain actors was a limitation as not all identified actors were willing to participate in the research.

Table 3-5: List of participating value-chain actors including their contributions to the case studies

	Case Study		
	Straws	**Beverage bottles vs lids**	**Cotton bud sticks**
Retailer A	✓	✓	✓
Retailer B	✓		✓
Retailer C	✓		✓
Retailer D	✓	✓	✓
Brand Owner A			
Brand Owner B			
Brand Owner C	✓	✓	
Recycler A		✓	
Recycler B		✓	
Recycler C		✓	
Industry Association A			
Industry Association B		✓	
Restauranteur A	✓		
Restauranteur B	✓		
Engineer A			✓

The interviews explored the depth of knowledge regarding the extent of the plastic pollution problem and how the increasing concern surrounding plastic pollution has influenced their practices. An initial set of interviews were conducted in March 2017. This was followed by more extensive interviews which were conducted from November 2018 – March 2019. The two sets of interviews enabled a comparison of value-chain actor perspectives as the rhetoric surrounding plastic pollution evolved. Thus, the results of the interviews were integrated during the analysis enabling the identification of any differences or similarities. The interviews were also used to inform the case studies, with a specific focus on value-chain actor responses to the focus on the product in question as a major contributor to marine pollution.

3.4.1 Interview procedure and analysis

Semi-structured interviews were conducted to explore the extent to which LCM principles (discussed in section 2.4) were employed in South Africa for plastic products. Semi-structured interviews allow for the exploration of concepts and relationships that are relatively well understood, through the use of open-ended questions based on the aims of the research (Given, 2008). They are characterised by questions with no fixed responses which allow for the interviewer to ask probing questions to elicit further information and explore different avenues which arise. Furthermore, the interview protocol also allows for the interviewer to move back and forth between questions based on the participant's responses. Interview questions were developed based on the themes discussed in section 3.2. The questionnaires were tailored according to individual participant roles to ensure the questions were relevant. In addition, case study specific questionnaires were developed. The semi-structured interview questionnaires are available in Appendix D.

The relative influence of the identified metrics was investigated through the completion of a preference elicitation exercise which was conducted during the interview. The exercise required interviewees to rate and assign relative weights to the metrics using the "Max100" method, explored by Bottomley & Doyle (2001), whereby the most important metric is assigned 100 points and the rest assigned points relative to it. This method was found to be relatively less cognitively demanding than other methods, as well as having a high reproducibility of 91% (Bottomley & Doyle, 2001). The preference elicitation exercise also served to explore the extent to which the challenges associated with plastic alternatives influence packaging design.

Interviews were conducted face-to-face or via electronic communication, including online platforms, e-mail and telephonically, depending on the preference of the participant. Audio recordings of the interviews were made and later transcribed. The interviews were on average one-hour long.

A hybrid thematic approach was taken for interview analysis whereby a combination of a priori and grounded theory approaches were employed. A priori analysis is a deductive approach whereby themes are identified during the interview structuring phase based on the aims of the research (Miles, Huberman & Saldaña, 2014). In this case, specific themes were identified based on the research questions. Grounded theory is an inductive approach to interview analysis, focussed on the exploration of new theory or phenomena that arises from data (Corbin & Strauss, 2012). The use of a hybrid approach allowed for a more in-depth analysis of the key themes based on the research questions (a priori) through the identification of additional themes that emerged from the interviews. The interview analysis was conducting using NVivo 12 qualitative data analysis software.

3.4.2 Development of life cycle management cases

Interviews were conducted to investigate value-chain actor approaches to the LCM of the focus item, including the development of any interventions. Only value-chain actors with direct relevance to the focus item were interviewed to provide input to the case study as shown in Table 3-5. Sustainability performance evaluations were conducted for identified product interventions, which took into consideration environmental, technical and socio-economic factors. Life cycle assessments were conducted to assess the environmental performance and were modelled using SimaPro LCA Software. The life-cycle models were based on desktop research including available industry data, as well as data sourced from relevant value-chain actors including manufacturers and distributors.

3.4.2.1 Straws

Material substitution was found to be a popular intervention in the case of straws. Thus, a comparative LCA was conducted on different straw materials available on the South African market, which included a combination of disposable and reusable straws. Value-chain actor motivations for their choice of intervention with regards to straw substitution were explored via interviews.

3.4.2.2 Beverage bottles vs lids

This case study was focused on the disparity that exists between the leakage of bottles vs lids, whereby the latter is commonly found to be highly prone to leakage. Thus, the case study explored the potential implications of tethered lids as an intervention to reduce the leakage of lids into the environment. As bottles are widely recycled in South Africa, this intervention was explored from a recycling perspective with regards to the technical and economic impacts. It was also explored from a product design perspective.

3.4.2.3 Cotton bud sticks

Unlike other items which are directly littered into the natural environment, wastewater treatment plants have been identified as a pathway for cotton bud sticks into the environment. Thus, the flow of cotton bud sticks through key Cape Town wastewater treatment plants was investigated, providing an understanding of the removal of cotton bud sticks through the process. The plants differed in capacity and wastewater sources (domestic vs industrial) but had the same treatment processes (Table 3-6). The raw data for this study was based on work conducted by Matthews & Jamieson (2018), whereby they investigated flows of cotton bud sticks through the inlet works and in the final effluent. Sampling was conducted for two days per plant, in the morning and the afternoon. Based on this raw data, the concentration of cotton bud sticks in the plant influent and effluent was calculated as well as the removal efficiency of preliminary treatment which serves to remove inorganic debris including plastic items. Differences between concentrations during the different sampling period were analysed using the Mann-Whitney-U test, whilst Spearman's Rank was used to investigate any correlations between preliminary treatment removal efficiency and influent flowrate. Although influent and effluent flows were collected during each sampling period, it was not possible to calculate overall plant removal efficiency due to a lack of data on plant hydraulic retention times in the various unit operations.

Table 3-6: Wastewater treatment plants

Wastewater treatment plant	Capacity	Industrial contribution
Athlone	105	<15%
Cape Flats	200	<5%
Mitchells Plain	45	0%

Similar to straws, material substitution was also found to be a popular intervention for cotton bud sticks. Thus, a comparative LCA was conducted on different cotton bud stick materials available in South Africa.

Interviews were used to explore plastic pollution in the context of wastewater treatment, including the challenges associated with the removal of plastic debris, as well as value-chain actor motivations for material substitution.

3.5 Research Ethics

To ensure that the research complied with ethical practices, the research was reviewed by the UCT Engineering and Built Environment Ethics in Research Committee (EiRC) prior to data collection. Prior to the commencement of any interviews, the objectives of the research were explained to the participants as well as the protocol regarding confidentiality and anonymity. In addition, all participants were required to complete an informed consent form. To maintain anonymity no direct reference to the participants is made and instead identities are presented in an anonymised form. Whilst the interviews were transcribed, the transcriptions are not included in this thesis due to the presence of identifying information. Instead, interview summaries are available in Appendix E. Participants were afforded the opportunity to review their interview summaries as well as findings based on the interviews, for approval prior to publication.

Relevant documentation for the ethics approval is available in Appendix C.

Chapter 4 Plastic Flows into the Marine Environment

This chapter aims to meet the thesis objective to generate product-specific knowledge on plastic leakage and demonstrate that vastly different leakage propensities exist for products with different characteristics. As such, it is focused on the quantification of plastic flows into the marine environment from the City of Cape Town. It begins with the results of two series of beach accumulation rate surveys conducted in 2017 and 2018-2019, referred to as sampling periods “1” and “2” respectively. This includes the analysis and comparison of litter accumulation rates and compositions as well as the identification of items which are highly prevalent. This is followed by the development of product leakage rates for key items identified as prone to leakage into the marine environment, based on the accumulation rates resultant from the beach surveys coupled with waste generation rate estimates.

4.1 Plastic Flows from Cape Town into the Marine Environment

Using the methods and sampling programme described in section 3.3, a total of 65 455 items (103 kg) were collected with 540 distinguishable item types identified across 10 material types and 19 functional type categories. The vast majority of items showed signs of weathering and transport via water (example shown in Figure 4-1A), which was to be expected due to the proximity of water flows from land to the ocean as shown in Figure 3-2. This implied that they were unlikely to have originated from direct littering by beach goers. However, during the second sampling period, there was evidence of direct litter by beach goers at the Milnerton and Muizenberg sites as some items did not show noticeable signs of weathering (example shown in Figure 4-1B).

A B

Figure 4-1: Litter sample images depicting (A) weathered and (B) not weathered items

4.1.1 Mass distribution

Of the total number of items collected, 96% had an average unit mass less than 5 g. The average unit mass of the identified items ranged from 0.01 – 626 g. Items weighing 0.1 – 1.0 g were the largest contributors across all site during both sampling periods, ranging from 59 – 85% during the first and 48 – 82% during the second (Figure 4-2).

Overall, the appearance of heavier items was sporadic with items weighing more than 100 g contributing from 0.02% (Wolfgat 1) to 1.09% (Hout Bay 2) of the total collected mass.

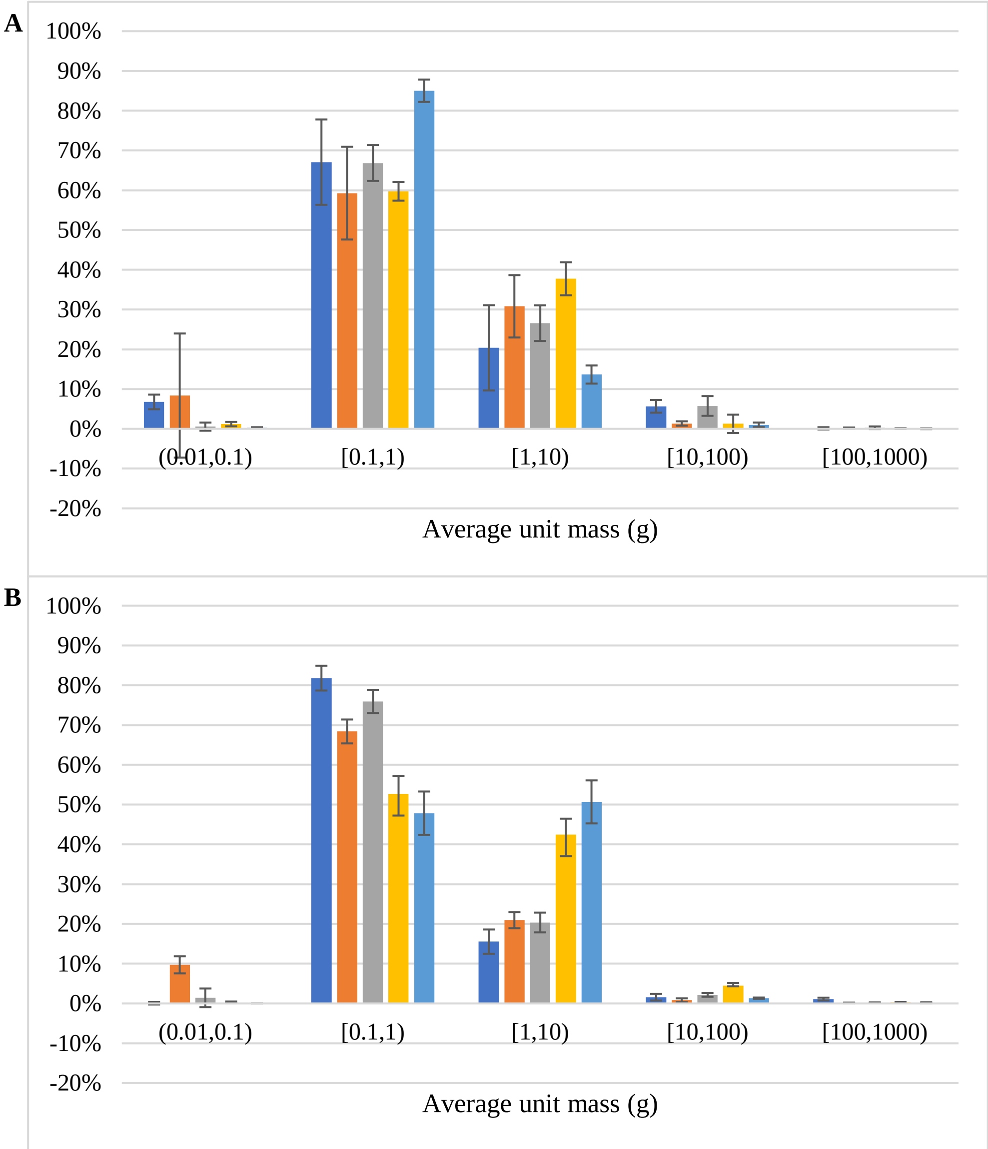

Figure 4-2: Fractional total mass distribution across the sample sites for (A) sampling period 1 and (B) sampling period 2. Error bars indicate standard error.

4.1.2 Litter accumulation rates

Varying accumulation rates were observed across the beaches during both sampling periods (Table 4-1). During period 1, the highest average accumulation rates were observed at Paarden Eiland (2962 items.day^{-1}.100m^{-1}) and Wolfgat (2202 items.day^{-1}.100m^{-1}). These beaches were also observed to have the highest accumulation rates during the 2nd sampling period, however there was a noticeable decrease at Paarden Eiland which had a rate of 853 items.day^{-1}.100m^{-1}, whereas a similar rate was maintained at Wolfgat with a rate of 2082 items.day^{-1}.100m^{-1}. A decrease in accumulation rates was also observed at Hout Bay which decreased from 594 to 305 items.day^{-1}.100m^{-1}. Increases were observed at Milnerton and Muizenberg respectively. In particular, a statistically significant difference was observed at Muizenberg ($p<0.005$), whereby accumulation rates increased from 38 to 158 items.day^{-1}.100m^{-1}. At both beaches, increased usage rates were observed during the 2nd sampling period which took place during the tourist season. In addition, there was evidence of direct littering as some of the collected litter showed no signs of transport or weathering (Figure 4-1B).

Overall, a strong positive correlation was found between the items count and the number of identifiable item types ($r_s = 0.93$, $p < 0.0001$). A similar relationship was also observed between counts and weights overall ($r_s = 0.84$, $p < 0.0001$), however a stronger relationship was observed during the first sampling period ($r_s = 0.91$, $p < 0.0001$) in comparison with the second ($r_s = 0.63$, $p < 0.0001$).

Daily variations were observed in litter loads across the beaches with coefficients of variation ranging from 28 – 87% by count and 30 – 107% by weight. Lower coefficients of variation for item counts were observed for sampling period 2 except for the case of Wolfgat. However, in terms of weight, lower coefficients of variation were only observed for Milnerton, Muizenberg and Paarden Eiland. This can be attributed to differences in the composition of the litter loads (discussed in section 4.1.3) and consequentially mass distribution (section 4.1.1).

Variations may be linked to weather patterns and water movements to varying extents. Rainfall may lead to an increase in observed litter loads as it increases the flow of water and subsequently litter in transportation pathways, including rivers and stormwater drains. During the first sampling period, three rainfall events were witnessed at both Muizenberg and Wolfgat respectively. At Muizenberg (Figure 4-3A), there was no clear linkage between rainfall and accumulation rate. Whereas, at Wolfgat (Figure 4-3B), higher accumulation rates were observed with rainfall events suggesting an increase in litter flows through the stormwater drainage system. During the second sampling period, rainfall events were witnessed at each of the sample sites. One rainfall event was witnessed at Milnerton, Paarden Eiland and Wolfgat respectively, however there was no clear linkage observed between rainfall and accumulation rates. At Hout Bay, which experienced rainfall on four days (Figure 4-3C), litter loads seemed to increase with some of the rainfall events. At Muizenberg (Figure 4-3E), this relationship was more pronounced whereby litter accumulation rates seemed to follow a similar pattern to rainfall events. Despite the suggestion of a relationship between rainfall and accumulation rates at some sites, overall there was no statistically significant correlation ($p>0.05$) at any of the sites during both sampling periods.

Tides have the potential to influence litter accumulation rates due to changes in the beach area available for sampling as well as litter deposition through wave action. Negative correlations were found between tide height and litter accumulation rates at Hout Bay 1 ($r_s = -0.90$, $p < 0.05$) and Paarden Eiland 2 ($r_s = -0.76$, $p < 0.05$). However, these relationships were not observed at the same sites during the alternate sampling periods. No other relationships were observed between tide heights and accumulation rates at the other sites during both sampling periods.

Table 4-1: Average daily litter accumulation rates by count and weight

	Hout Bay		Milnerton		Muizenberg		Paarden Eiland		Wolfgat	
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
Total identified item types										
	162	110	114	215	79	158	249	246	218	183
Counts (items.day^{-1}.100m^{-1})										
Daily accumulation rate	594.0	304.6	523.0	776.0	37.8	403.1	2961.9	852.8	2201.6	2082.0
Standard error	230.0	54.4	209.6	91.9	9.1	61.1	902.4	85.4	370.0	702.4
Coefficient of variation (%)	86.6	47.2	69.4	33.6	76.1	42.9	80.6	28.3	37.6	75.4
Weights (g.day^{-1}.100m^{-1})										
Daily accumulation rate	1316.9	647.6	866.1	845.9	189.4	557.0	4429.7	1750.1	2351.7	3799.0
Standard error	317.4	178.4	481.4	181.6	64.0	122.8	1263.0	184.6	530.4	1103.6
Coefficient of variation (%)	53.9	72.9	96.3	60.7	106.8	62.3	75.4	29.8	50.4	65.0

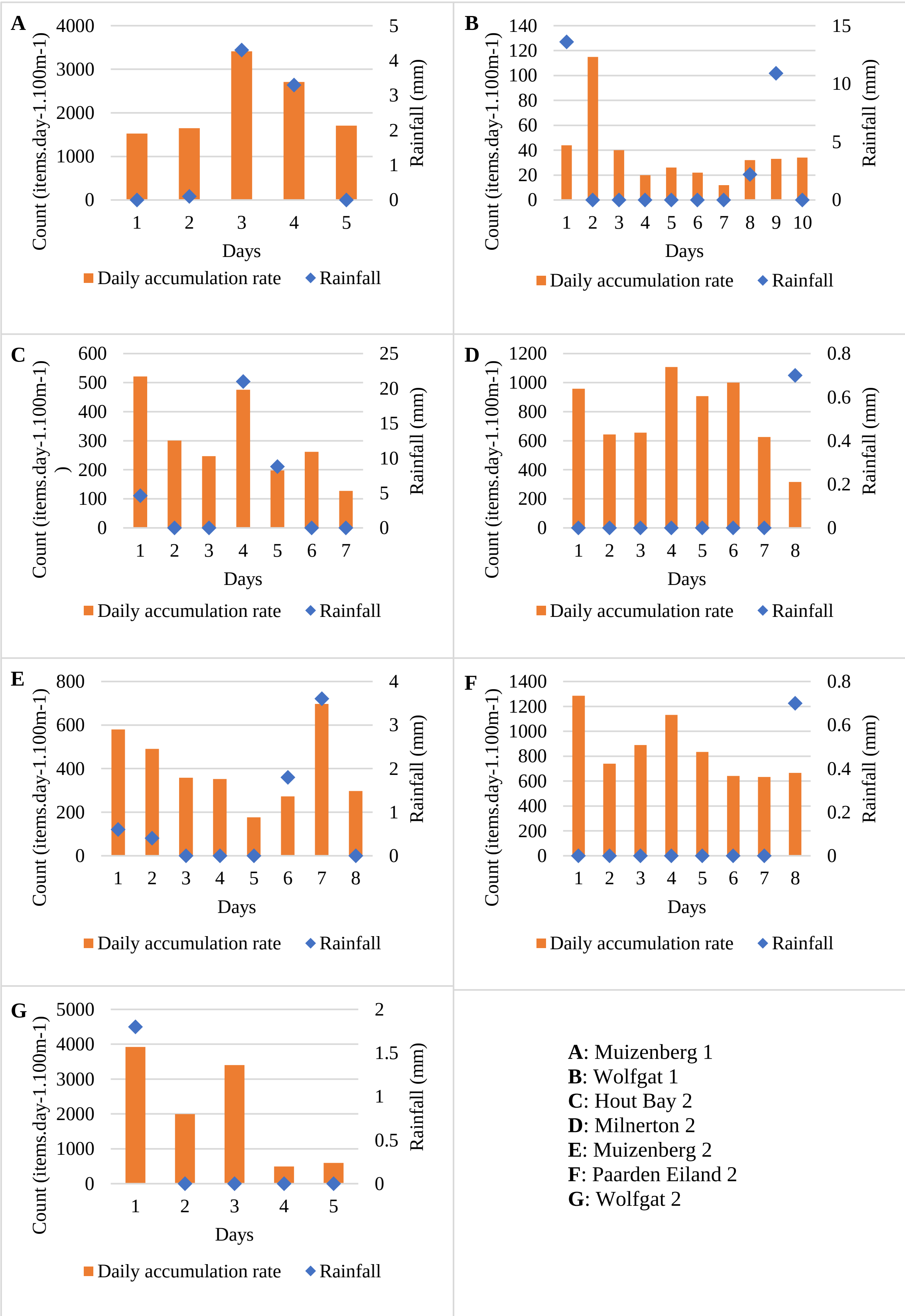

Figure 4-3: Changes in daily accumulation rates in relation to rainfall events

Although all sites were located near to a water flow from land into the ocean, this flow was not constant at all of the sites. In particular, the estuaries at Milnerton and Muizenberg are both classified by the South African Environmental and Observation Network as "temporarily open/closed". Thus, the observed litter accumulation rates were potentially influenced by whether the estuary was open or closed. For example, during the first sampling period, the Muizenberg estuary was closed on the first day of sampling (Figure 4-4A). On the second day, the barrier was removed opening the estuary (Figure 4-4B) and a sharp increase in accumulation was observed (Figure 4-3A). This may be attributed to an increased load due to the flow of litter which had accumulated upstream.

A

B

Figure 4-4: Photos of the Muizenberg estuary (A) closed and (B) open

4.1.3 Material type composition

Plastic was consistently the most dominant material type by both counts and weights. By count, it contributed 93 – 99% during the first sampling period, and 86 – 96% during the second (Table 4-2). The highest plastic proportion was observed at Paarden Eiland (99%) during the first sampling period and at Wolfgat (96%) during the second. During both periods, Muizenberg had the lowest plastic proportions. Overall, higher plastic proportions were observed during the first sampling period for each of the respective beaches. Significant differences ($p<0.05$) were noted for Milnerton and Paarden Eiland, whereby plastic proportions decreased by 9.5% and 7.7% respectively. Decreases in plastic proportions at Milnerton and Muizenberg were coupled with notable increases in paper items including toilet paper and receipts.

Whilst high site variability was observed for the daily accumulation rate, the opposite was observed for the proportion of plastic items per site by count. In particular, very low coefficients of variation were observed for sites with higher plastic proportions, i.e. Milnerton 1 (CV = 0.5%) and Paarden Eiland 1 (CV = 0.3%). The highest CV was observed at Muizenberg 2 (7.5%) which also had the lowest observed plastic proportion.

Similar to counts, plastic was the highest contributor by weight. However, more variation was observed across sites with plastic contributions ranging from 39 – 83% during the first sampling period and 38 – 84% during the second. Decreases in plastic weight from the first sampling period were observed for Hout Bay, Milnerton and Paarden Eiland, whereas slight increases were noted for Muizenberg and Wolfgat. This can be attributed to variations in the types of items collected and the mass distribution (Figure 4-2).

The proportional contribution of non-plastic items varied both within sites and across sites. Some of the non-plastic items would not be traditionally considered as common contributors to litter streams or household waste in general (e.g. clothing and furniture). Thus, their presence in litter streams would vary.

Table 4-2: Litter material type composition by count and weight (%)

	Hout Bay		Milnerton		Muizenberg		Paarden Eiland		Wolfgat	
	1	2	1	2	1	2	1	2	1	2
	Counts									
Plastic	96.0	92.1	97.1	87.7	93.4	85.6	98.9	91.2	96.9	95.7
Ceramic	0.0	0.1	0.1	0.0	0.3	0.2	0.0	0.1	0.0	0.0
Cloth	0.5	0.2	0.2	0.4	0.3	0.9	0.0	0.5	0.0	0.0
Glass	0.2	1.0	0.0	0.4	1.3	1.0	0.0	1.9	0.0	0.0
Metal	0.3	0.4	0.4	1.7	1.3	1.3	0.1	0.6	0.4	0.2
Other	0.6	0.4	0.3	1.1	0.3	0.8	0.4	0.6	0.4	0.4
Paper	1.5	2.7	0.8	5.8	1.9	7.6	0.0	1.9	0.1	0.2
Rubber	0.6	0.5	1.0	0.4	1.1	0.9	0.4	1.0	0.9	0.5
Wax	0.0	0.0	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Wood	0.2	2.6	0.0	2.5	0.0	1.6	0.1	2.2	1.2	2.9
	Weights									
Plastic	74.6	37.9	64.5	38.0	39.1	42.6	82.8	56.2	83.0	83.9
Ceramic	0.0	1.4	3.1	0.0	27.5	0.5	0.9	0.4	0.0	0.0
Cloth	8.3	0.1	1.1	1.7	1.7	0.6	0.1	1.4	0.0	0.1
Glass	1.7	2.7	0.0	26.9	5.1	3.8	1.9	8.0	2.3	0.1
Metal	2.0	0.8	2.5	8.9	4.4	2.9	0.3	1.0	2.7	2.9
Other	7.4	0.2	21.4	6.2	0.6	12.9	11.0	3.1	2.3	2.1
Paper	3.4	1.4	0.3	8.6	1.8	6.8	0.0	2.4	0.5	1.3
Rubber	1.3	1.9	6.9	0.9	19.8	0.4	2.8	3.4	4.2	2.2
Wax	0.0	0.0	0.2	0.0	0.1	0.0	0.0	0.0	0.2	0.0
Wood	1.2	53.6	0.0	8.8	0.0	29.6	0.2	24.0	4.7	7.4

4.1.4 Plastic functional types

The plastic items identified across the five beaches were classified according to their functional type as shown in Figure 4-5. Food and beverage related items, including bottles, lids, food packaging, lollipop sticks, polystyrene and utensils, were the most prevalent type of plastic litter across all beaches ranging from 40% - 61% of all plastic litter during the first sampling period and 24 – 59% during the second. In both cases, the highest proportion of food related litter was observed at Wolfgat. The relatively lower proportions observed at Hout Bay and Milnerton during the second period may be attributed to the sharp increase in cigarette butts. The majority of food packaging was associated with items commonly consumed on-the-go, including snack packets and single sweet wrappers. In addition, the bulk of polystyrene can be attributed to the food industry with a much smaller fraction associated with household packaging. Utensils mostly comprised of straws. “Unidentifiable” items included plastic fragments which were consistently large contributors to plastic litter at Paarden Eiland.

Certain functional types were observed to be more prevalent at specific sites, as they were related to activities that took place in the catchment area. For example, items associated with fishing activities were observed in Hout Bay due to the proximity of the harbour suggesting some of the litter may have originated from marine based sources. In addition, there was a higher prevalence of rubbish liners observed in Hout Bay suggesting higher incidences of dumping in the area. In Paarden Eiland, a relatively higher proportion of cotton bud sticks was observed which may be attributed to the presence of a wastewater treatment works upstream of the Black River estuary.

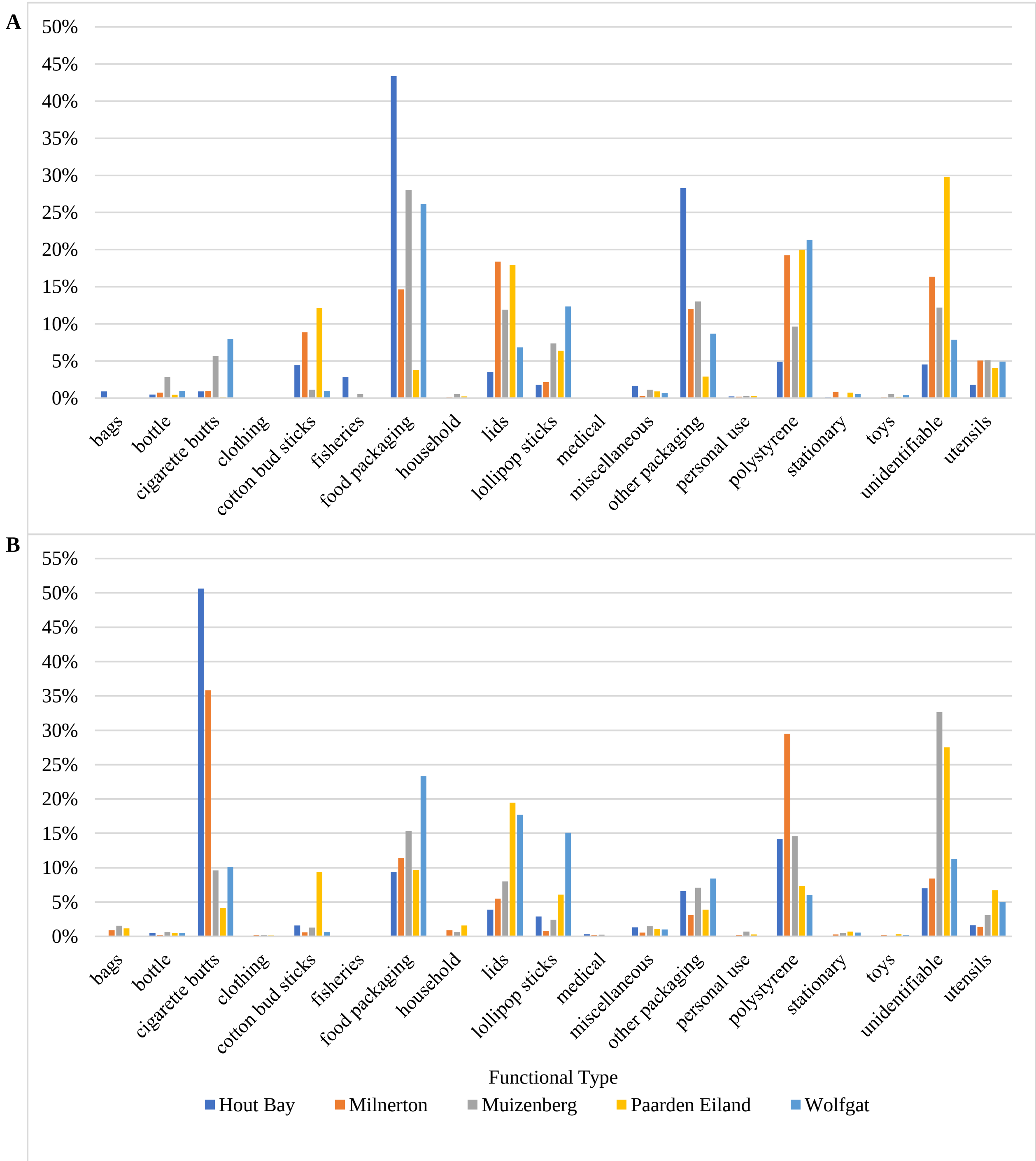

Figure 4-5: Plastic functional type distribution by count for (A) sampling period 1 and (B) sampling period 2

4.1.5 The "dirty dozen" - top 12 identifiable plastic items

The top 12 most prevalent and abundant identifiable plastic items accounted for 43 – 66% during the first sampling period, and 41 – 73% during the second (Table 4-3). Ten of these items were prevalent during both periods. The items not in common were still amongst the top contributors overall across sites. The majority of items were associated with food commonly consumed on-the-go and not necessarily in the household. However, during the second period polystyrene trays were identified as a top contributor despite the fact that they are commonly associated with foods packaged for at-home consumption e.g. meat and fruit. 28mm beverage bottle lids (widely used for water or carbonated beverage bottles) were found to be highly prevalent in comparison to other lid types (e.g. push pull lids commonly used for sports drink bottles).

The majority of top contributors had a density lighter than seawater (1.02 – 1.03g/cm^3), with the only exception being cigarette butts which are primarily made of cellulose acetate with a density of 1.22 – 1.34 g/cm^3. In addition, most of the items had an average unit mass <1g. Variations in the unit mass distributions between sampling periods is indicative of changes in the sizes of the items collected. This is particularly evident in the case of polystyrene whereby much larger pieces were found during the second sampling period.

Differences were observed in the proportional contributions of each of the products between the sampling periods, however there was no consistency in terms of whether increases or decreases were observed within the sites for each of the products. More specifically, some products at a site were observed to increase whereas others decreased. Furthermore, there was no consistency in the changes in contribution across the sites, e.g. the proportional contribution of a product neither increased nor decreased across all sites and instead varied. Cigarette butts were the only exception whereby an increase was observed across all sites.

In the case of food wrappers, it was possible to identify the brands associated with the products. Although items were not quantified according to brand, through a visual inspection of the samples it was possible to identify the predominant brand contributors as shown in Figure 4-6. The brand contributions observed were not necessarily representative of market share. For example, TAXI biscuits (owned by Unibisco Biscuits SA) accounted for the majority of biscuit wrappers on all beaches, which was not representative of the diverse options available on the market. The South African biscuit market is dominated by AVI brands with a market share of 47% in 2016, whilst in-house retailer brands had a combined share of 13% (Das Nair, Nkhonjera & Ziba, 2017). However, in the case of lollipops, Yogueta and Pin Pops (owned by Comestibles Aldor) which are market leaders with a combined 90% of the sales volumes (Das Nair, Nkhonjera & Ziba, 2017), were highly prevalent.

Table 4-3: Top 12 prevalent identifiable plastic items by count

Sampling Period 1

	Average Unit Mass (g)	Hout Bay 1	Milnerton 1	Muizenberg 1	Paarden Eiland 1	Wolfgat 1
Beverage bottle lids (28 mm)	2.27±0.02	1.3%	5.4%	1.1%	4.1%	1.8%
Biscuit wrappers	0.47±0.04	4.1%	1.0%	2.3%	0.3%	0.9%
Chocolate wrappers	0.34±0.03	1.9%	1.2%	2.5%	0.2%	0.8%
Cigarette butts	0.28±0.02	0.9%	1.0%	5.7%	0.1%	8.0%
Cotton bud sticks	0.15±0.003	4.3%	8.9%	1.1%	12.1%	1.0%
Lollipop sticks	0.53±0.01	1.8%	2.2%	7.4%	6.4%	12.3%
Lollipop wrappers	0.56±0.03	2.2%	2.9%	3.1%	0.9%	4.5%
Polystyrene clamshells	0.25±0.03	3.0%	13.2%	4.0%	11.9%	9.3%
Polystyrene cups	0.26±0.03	1.0%	2.6%	5.4%	1.9%	4.2%
Straws	0.50±0.02	1.2%	4.9%	5.1%	3.8%	4.7%
Snack packets	0.79±0.06	13.6%	2.0%	6.2%	0.5%	7.2%
Single sweet wrappers	0.21±0.01	7.2%	1.9%	7.4%	0.5%	9.6%
Total		42.5%	47.2%	51.3%	42.7%	64.2%

Sampling Period 2

	Average Unit Mass (g)	Hout Bay 2	Milnerton 2	Muizenberg 2	Paarden Eiland 2	Wolfgat 2
Beverage bottle lids (28 mm)	2.06±0.03	1.4%	1.6%	1.5%	3.0%	10.0%
Polystyrene trays	0.34±0.05	0.6%	4.7%	2.7%	1.2%	0.1%
Cigarette butts	0.21±0.003	50.6%	35.8%	9.6%	4.2%	10.1%
Cotton bud sticks	0.18±0.004	1.6%	0.6%	1.3%	9.4%	0.6%
Ice cream wrappers	2.31±1.60	0.4%	0.9%	0.3%	0.8%	1.0%
Lollipop sticks	0.78±0.15	2.9%	0.8%	2.4%	6.1%	15.1%
Lollipop wrappers	0.92±0.37	0.5%	1.0%	1.2%	1.6%	7.0%
Polystyrene clamshells	5.35±1.61	7.4%	1.9%	0.8%	0.7%	2.9%
Polystyrene cups	0.39±0.06	2.2%	3.7%	6.8%	0.8%	1.4%
Straws	0.81±0.29	1.1%	1.1%	2.9%	6.4%	4.5%
Snack packets	1.10±0.11	0.8%	1.0%	5.5%	1.9%	4.1%
Single sweet wrappers	0.17±0.01	3.4%	4.6%	4.7%	3.1%	6.2%
Total		72.9%	57.8%	39.8%	39.1%	63.0%

				Major Contributors (Brand Owners)
A				• Unibisco Biscuits SA (Taxi)
B				• Comestibles Aldor (Pin Pop & Yogueta) • Richester Foods (Chocolate Éclair Pop)
C				• PepsiCo (Nik Naks) • Truda Foods (Stylos, Snak Naks, Bigga Naks) • IQ Foods (Crack-A-Snack) • Frimax

Figure 4-6: Sample images showing brand contributor distributions for (A) biscuits, (B) lollipops and (C) snack packets

4.2 Leakage Ratios

As stated in the methodology (section 3.3.3), leakage ratios were developed to demonstrate the differences in leakage propensities for items with differing characteristics. Thus, leakage ratios were developed for key items that were identified as prone to leakage based on the results of the beach surveys as well as for items that had a relatively low prevalence. Leakage ratios were not calculated for all the top 12 identified items due to data constraints surrounding consumption of these products (discussed further in section 4.4.3).

Leakage ratios were calculated for the year 2017 and as such accumulation rates were based on the first series of beach surveys conducted during that year.

4.2.1 Daily product accumulation rates

Average daily observed accumulation rates were calculated based on the results of the first series of beach surveys. As to be expected, higher item accumulation rates were associated with beaches that had higher total litter accumulation rates. As mentioned in section 4.1.5, items associated with food consumed on-the-go were found to be highly prevalent, whereas items associated with food traditionally consumed within the household were associated with lower prevalence and significantly lower accumulation rates as demonstrated for the cases of margarine and single serving instant noodle packets in Table 4-4.

Table 4-4: Daily product accumulation rates for highly prevalent and uncommon items per sample site in 2017 (items.day^{-1}.100m^{-1})

	Hout Bay	Milnerton	Muizenberg	Paarden Eiland	Wolfgat	Average	Standard Error	Coefficient of Variation
High prevalence								
Beverage bottle lids (28 mm)	7.20	27.67	0.40	119.57	38.40	38.65	21.36	123.6
Biscuit wrappers	23.60	5.00	0.80	7.43	37.60	14.89	6.87	103.2
Chocolate wrappers	11.00	6.00	0.90	6.29	17.00	8.24	2.71	73.6
Cigarette butts	5.20	5.00	2.00	3.86	169.80	37.17	33.16	199.5
Cotton bud sticks	25.20	45.00	0.40	355.00	20.60	89.24	66.82	167.4
Lollipop sticks	10.20	11.00	2.60	186.71	263.20	94.74	54.54	128.7
Lollipop wrappers	12.40	14.67	1.10	27.71	95.20	30.22	16.79	124.2
Polystyrene clamshells	17.20	67.00	1.40	347.43	199.00	126.41	65.27	115.5
Polystyrene cups	5.80	13.33	1.90	55.57	89.80	33.28	17.07	114.7
Straws	6.80	25.00	1.80	111.14	101.00	49.15	23.61	107.4
Snack packets	77.40	10.33	2.20	15.57	152.80	51.66	28.59	123.8
Single sweet wrappers	41.00	9.67	2.60	14.71	204.80	54.56	38.12	156.2
Low Prevalence								
Beverage bottles (28 mm neck)	1.00	2.00	0.60	3.14	4.80	2.31	0.76	73.9
Nappies	0.00	0.33	0.00	1.14	0.40	0.38	0.21	124.5
Toothpaste tubes	0.00	0.67	0.00	0.57	0.00	0.25	0.15	137.6
Margarine tubs	0.00	0.00	0.00	0.86	0.20	0.21	0.17	175.6
Margarine tub lids	0.00	0.00	0.10	0.29	0.00	0.08	0.06	161.2
Noodle packets	0.80	0.00	0.00	0.14	0.60	0.31	0.17	119.5
Noodle flavour packets	0.20	0.33	0.00	0.14	0.10	0.16	0.06	79.2

4.2.2 Product waste generation

A combination of sales, industry and literature data was used to inform product consumption and consequentially waste generation based on availability (shown in Table 4-5). As all the items under consideration are short-lived, it was assumed that annual consumption was equal to waste generation. In general, the high prevalence items were associated with higher consumption rates. This can be related to the single-use nature of the items, as is also observed in the case of nappies which also had a relatively high waste generation rate. Items associated with multiple uses (i.e. toothpaste and margarine) had relatively lower waste generation rates due to the decreased frequency of replenishment.

Table 4-5: Product waste generation rates in Cape Town in 2017 (millions of items)

	Waste generation (millions)		Data Source
	Daily	**Yearly**	
High prevalence			
Beverage bottle lids (28 mm)	0.14	52.16	local sales
Biscuit wrappers	data unavailable		
Chocolate wrappers	data unavailable		
Cigarette butts	11.89	4339.02	national surveys
Cotton bud sticks	data unavailable		
Lollipop sticks	0.34	125.89	market research
Lollipop wrappers	0.34	125.89	market research
Polystyrene clamshells	data unavailable		
Polystyrene cups	data unavailable		
Straws	0.40	144.98	international consumption
Snack packets	0.18	66.32	local sales
Single sweet wrappers	data unavailable		
Low prevalence			
Beverage bottles (28 mm neck)	0.14	52.16	local sales
Nappies	0.38	139.69	local sales
Toothpaste tubes	0.03	9.62	local sales
Margarine tubs	0.02	5.48	local sales
Margarine tub lids	0.02	5.48	local sales
Noodle packets	0.04	12.85	local sales
Noodle flavour packets	0.04	12.85	local sales

4.2.3 Product leakage ratios

In general, items with a high littering prevalence were found to have higher leakage ratios than those that were less prevalent (Table 4-6). Overall, highly prevalent items had leakage ratios one to two orders of magnitude larger than those of less prevalent items. However, this was not the case for cigarette butts which were associated with a relatively high average accumulation rate, but this was offset by the significantly higher waste generation rate due to the higher consumption of cigarettes.

Table 4-6: Daily product leakage ratios in Cape Town in 2017 (100 m^{-1})

	Leakage Ratio (100 m^{-1})	Standard Error
High prevalence		
Beverage bottle lids (28 mm)	2.70E-04	1.49E-04
Biscuit wrappers	data unavailable	
Chocolate wrappers	data unavailable	
Cigarette butts	3.13E-06	2.79E-06
Cotton bud sticks	data unavailable	
Lollipop sticks	2.75E-04	1.58E-04
Lollipop wrappers	8.76E-05	4.87E-05
Polystyrene clamshells	data unavailable	
Polystyrene cups	data unavailable	
Straws	1.24E-04	5.94E-05
Snack packets	2.84E-04	1.57E-04
Single sweet wrappers	data unavailable	
Low prevalence		
Beverage bottles (28 mm neck)	1.62E-05	5.34E-06
Nappies	9.80E-07	5.46E-07
Toothpaste tubes	9.40E-06	5.78E-06
Margarine tubs	1.41E-05	1.11E-05
Margarine tub lids	5.14E-06	3.70E-06
Noodle packets	8.79E-06	4.70E-06
Noodle flavour packets	4.42E-06	1.57E-06

Of note is the difference in leakage ratios between beverage bottles and the associated lids, which are sold as one complete unit, whereby the leakage ratio for the latter was ~17 times larger (Table 4-7). Such a large disparity was not observed with other associated products such as, margarine tubs and lids and noodle packets and the associated flavour packets. In these cases, both sets of products were observed to have a low prevalence during the beach surveys and consequentially had low leakage rates. Furthermore, a large disparity was not observed between lollipop sticks and wrappers, which both had high leakage rates.

Table 4-7: Comparison of leakage ratios for associated products

Items	Ratios
Beverage bottle lids (28 mm) : Beverage bottles (28 mm neck)	17 : 1
Lollipop sticks : Lollipop wrappers	3 : 1
Margarine tubs : Margarine tub lids	11 : 4
Noddle packets : Noodle flavour packets	2 : 1

4.3 Leakage Rates

Leakage rates were developed in order to investigate the feasibility of integrating leakage rates as a proxy for the impacts associated with leakage, during product LCM. As mentioned in section 3.2, it is acknowledged that the developed leakage rates are subject to many influencing factors associated with the determination of accumulation rates (discussed further in section 4.4.1). Thus, this section serves to demonstrate how such an indicator may be developed for use by LCM practitioners.

Leakage rates were calculated for the same products for which leakage ratios were developed (section 4.2).

4.3.1 Total product accumulation rates from Cape Town

Potential total accumulation rates were calculated for based on the results of each of the five beach surveys, as well as the average across the sites (Table 4-8). Similar to the variation of proportional contributions of top items across the five beaches (Table 4-3), variations were observed in the litter accumulation rates with the majority of coefficients of variation exceeding 100%.

Table 4-8: Product accumulation rates for highly prevalent and uncommon items in Cape Town in 2017 (millions of items)

	Hout Bay	Milnerton	Muizenberg	Paarden Eiland	Wolfgat	Average	Standard Error	Coefficient of Variation
High prevalence								
Beverage bottle lids (28 mm)	8.07	31.00	0.45	133.99	43.03	43.31	23.93	123.6
Biscuit wrappers	26.44	5.60	0.90	8.32	42.13	16.68	7.70	103.2
Chocolate wrappers	12.33	6.72	1.01	7.04	19.05	9.23	3.04	73.6
Cigarette butts	5.83	5.60	2.24	4.32	190.27	41.65	37.16	199.5
Cotton bud sticks	28.24	50.42	0.45	397.80	23.08	100.00	74.87	167.4
Lollipop sticks	11.43	12.33	2.91	209.22	294.93	106.16	61.11	128.7
Lollipop wrappers	13.89	16.43	1.23	31.06	106.68	33.86	18.81	124.2
Polystyrene clamshells	19.27	75.08	1.57	389.31	222.99	141.64	73.14	115.5
Polystyrene cups	6.50	14.94	2.13	62.27	100.63	37.29	19.13	114.7
Straws	7.62	28.01	2.02	124.54	113.18	55.07	26.46	107.4
Snack packets	86.73	11.58	2.47	17.45	171.22	57.89	32.04	123.8
Single sweet wrappers	45.94	10.83	2.91	16.49	229.49	61.13	42.71	156.2
Low Prevalence								
Beverage bottles (28 mm neck)	1.12	2.24	0.67	3.52	5.38	2.59	0.85	73.9
Nappies	0.00	0.37	0.00	1.28	0.45	0.42	0.23	124.5
Toothpaste tubes	0.00	0.75	0.00	0.64	0.00	0.28	0.17	137.6
Margarine tubs	0.00	0.00	0.00	0.96	0.22	0.24	0.19	175.6
Margarine tub lids	0.00	0.00	0.11	0.32	0.00	0.09	0.06	161.2
Noodle packets	0.90	0.00	0.00	0.16	0.68	0.35	0.19	119.5
Noodle flavour packets	0.22	0.37	0.00	0.16	0.11	0.17	0.06	79.2

4.3.2 Product leakage rates

The development of leakage rates was based on the marine accumulation rates (section 4.3.1) ratioed to the waste generated (section 4.2.2) as shown in the following equation:

$$leakage\ rate\ \% = \frac{total\ accumulation\ rate\ \left(\frac{items}{yr}\right)}{waste\ generated\ \left(\frac{items}{yr}\right)} \times 100\%$$

Similarly to leakage ratios (section 4.2.3), items with a high littering prevalence were found to have higher leakage rates than those that were less prevalent (Table 4-9).

Table 4-9: Product leakage rates in Cape Town in 2017 (%)

	Leakage Rate	Standard Error
High prevalence		
Beverage bottle lids (28 mm)	83.0	45.9
Biscuit wrappers	data unavailable	
Chocolate wrappers	data unavailable	
Cigarette butts	1.0	0.9
Cotton bud sticks	data unavailable	
Lollipop sticks	84.3	48.5
Lollipop wrappers	26.9	14.9
Polystyrene clamshells	data unavailable	
Polystyrene cups	data unavailable	
Straws	38.0	18.2
Snack packets	87.3	48.3
Single sweet wrappers	data unavailable	
Low prevalence		
Beverage bottles (28 mm neck)	5.0	1.6
Nappies	0.3	0.2
Toothpaste tubes	2.9	1.8
Margarine tubs	4.3	3.4
Margarine tub lids	1.6	1.1
Noodle packets	2.7	1.4
Noodle flavour packets	1.4	0.5

4.4 Discussion

4.4.1 Estimating plastic flows into the marine environment

Of the 65 455 items collected, 97% were found to weigh less than 5 g, the vast majority of which were plastic. This is to be expected due to the lightweight and easily dispersible nature of plastic items which are commonly cited as contributors to their propensity for being littered (Barnes et al., 2009; Ellen

MacArthur Foundation, 2016). Although lightweight items were found to be more prevalent, their relative abundance across the beaches ranged. More specifically, the proportional contribution by count of items weighing less than 1 g ranged from 48 – 85% over both sampling periods. There was no relationship observed between mass distribution and litter loads across the beaches. For example, the lowest proportion of 48% corresponded to a littering rate of 2082 items.day^{-1}.100m^{-1}, whilst the highest (85%) was associated with a rate of 2202 day^{-1}.100m^{-1}. In addition, both ranges were observed at Wolfgat with the lower proportion observed during the second sampling period.

Overall, a positive correlation was found between mass and count across the beaches ($r_s = 0.84$, $p < 0.0001$). This is similar to the strong correlation found by Ryan et al. (2018) between mass and count of mesodebris across 82 South African beaches ($r_s = 0.922$, $p < 0.001$). A strong correlation was also found between count and number of item types ($r_s = 0.93$, $p < 0.0001$), implying a wider range of items may be found with increasing litter loads.

Daily accumulation rates varied across all sites ranging from 38 – 2962 items.day^{-1}.100m^{-1} during the first sampling period and 305 – 2082 items.day^{-1}.100m^{-1} during the second. In addition, whilst some beaches experienced a decrease in litter loads during the second sampling period (Hout Bay, Paarden Eiland and Wolfgat), increases were observed at Milnerton and Muizenberg. This can be attributed to a variety of factors including beach usage, catchment area characteristics, weather patterns and ocean tides and currents. Increased beach usage was observed during the second sampling period at Milnerton and Muizenberg beaches, which are both popular tourist destinations. There was evidence of direct littering as some of the litter collected did not show signs of weathering. For example, there was an increase in the proportion of paper products found in the form of paper towels, toilet paper and serviettes which would not commonly maintain their integrity when transported via waterways.

During a study on litter loads in stormwater run-off in three different land-use areas, Arnold & Ryan (1999) found significantly higher litter loads at the industrial area (Paarden Eiland – 731.3 items.ha^{-1}.day^{-1}) in comparison to a mixed commercial/residential area (Sea Point – 29.4 items.ha^{-1}.day^{-1}) and a middle-income residential area (Milnerton – 9.6 items.ha^{-1}.day^{-1}). A similar relationship was found during the beach surveys in which Paarden Eiland was associated with the highest litter accumulation rate during the first sampling period (2961 items.day^{-1}.100m^{-1}) and the second highest during the second (853 items.day^{-1}.100m^{-1}). However, this relationship did not hold true in the case of Wolfgat which may be attributed to the fact that it is a low-income area, whereas the study by Arnold & Ryan (1999) only considered a middle income residential area. In particular, a study on litter loading in stormwater drains in South Africa found an inverse relation between income level and litter loads, whereby low income areas were associated with higher loads (Marais & Armitage, 2003). They attributed this to the greater availability of waste removal services in high income areas. During both sampling periods, Wolfgat (low-income) had significantly higher litter accumulation rates than Milnerton and Muizenberg which are both middle-income areas. In the case of Hout Bay, it is characterised by segregated low- and high-income areas which presents an additional layer of complexity. As such it ranged from having a higher accumulation rate than Milnerton and Muizenberg during the first period, to having a lower rate during the second.

Previous studies have explored the influence of wind, waves and tides on the spatial distribution of plastic debris (Browne, Galloway & Thompson, 2010; Lee et al., 2013). Inverse relationships between tide height and litter loads was observed at Hout Bay ($r_s = -0.90$, $p < 0.05$) during the first sampling period and Paarden Eiland during the second ($r_s = -0.76$, $p < 0.05$), whereby lower litter accumulation rates were observed with increasing tide height. However, this relationship was not observed at the same site during the alternate sampling periods, neither were they observed at any of the other sites.

Further influences of water movement are evidenced by the results of the Milnerton and Paarden Eiland sites which were located approximately 450 m away from each other. During the first sampling period, an average accumulation rate of 521 items.day^{-1}.100m^{-1} was observed at Milnerton, whilst Paarden Eiland had an average rate of 2961 items.day^{-1}.100m^{-1}. Furthermore, a previous survey conducted 1350 m north-east of the Milnerton site in 2012 observed an average accumulation rate of 1350 items.day^{-1}.100m^{-1} (Lamprecht, 2013). This suggests a lower rate of deposition at the Milnerton site in comparison to other beach lengths along the same coastline. Although an increase in litter loads was observed at Milnerton during the second sampling period, overall it maintained a lower accumulation rate than Paarden Eiland. As previously mentioned, the increase in the 2nd period is likely to be attributed to direct littering by beach goers as evidenced by increased beach usage coupled with an increase in items showing decreased signs of weathering.

The transportation of litter via wind or water, and consequentially observed litter loads, may be influenced by weather patterns (Ryan et al., 2009; Li, Tse & Fok, 2016). Numerous studies have found a positive correlation between rainfall and litter loads (Arnold & Ryan, 1999; Lee et al., 2013; Rech et al., 2014). However, Lamprecht (2013) did not observe any correlations between rainfall or wind data and daily litter loads. In this study, notable increases in daily litter accumulation rates were observed during rainfall events at Wolfgat during the first sampling period and Muizenberg during the second. However, no clear relationships were observed during rainfall events experienced at other sites. Ultimately, no statistically significant correlations were observed between rainfall and daily litter accumulation rates.

Historical studies on litter accumulation on South African coasts found plastic proportions ranging from 81.7% - 88% (Ryan & Moloney, 1990; Swanepoel, 1995; Madzena & Lasiak, 1997). The plastic proportions observed in the beach surveys (85.6% - 98.9%) were similar to recent surveys conducted in South Africa. A national survey conducted in 2015 observed an average plastic fraction of 93.8% across 82 beaches in South Africa (Plastics|SA, 2015). In addition, a survey of two Cape Town beaches by Lamprecht (2013) found fractions ranging from 93% - 98%.

Whilst there are commonly variations in litter compositions, there is an element of global uniformity in the major contributors to marine litter (Gregory & Andrady, 2003). This is often observed in the "dirty dozen" lists that are often resultant of marine litter studies. Items associated with food and beverages consumed on-the-go are common offenders on these lists (Barnes et al., 2009; Andrady, 2011; Galgani, Hanke & Maes, 2015; Hanke, 2016). Similarly to previous beach surveys conducted in South Africa (Lamprecht, 2013; Plastics|SA, 2015) and globally (Hanke, 2016; Walker et al., 2016), such items were found to be prevalent across all beaches, but with strongly differing abundance. Specifically, the top dozen items included snack packets, single sweet wrappers, polystyrene fragments, lids and straws, which were prevalent across all sites during both sampling periods. This indicates the high litterability of these items regardless of catchment area characteristics and sampling period. Of note was the relatively low proportions of plastic bags and bottles which are often cited as a major contributors to litter streams (Barnes et al., 2009). Furthermore, there was a stark contrast between the accumulation rates of plastic bottles in comparison to lids, despite the fact that they are sold to consumers as one product. This trend was also observed in work conducted by Ryan et al. (2009), where 50 South African beaches were sampled periodically from 1984 – 2005. This may be linked with the higher value of the former due to its widespread recycling, increasing the likelihood of them remaining in the value chain on the one hand, and with the density of PET bottles (1.30 – 1.40 g/cm^3) being higher than that of sea water whereas lids would float in water.

4.4.2 Estimating product leakage rates

In general, products with higher accumulation rates were associated with higher leakage rates. However, this was not the case for cigarette butts whereby the accumulation rate was offset by a significantly higher waste generation rate, resulting in a lower observed leakage rate (0.2%). This suggests that whilst cigarette butts were abundant, they were unlikely to enter the environment. However, similarly to the case of PET bottles, the relatively high density of cigarette butts may reduce their visibility in the marine environment resulting in lower observed accumulation rates.

Similar to the results of the beach surveys, items associated with food consumed on-the-go were associated with higher leakage rates in comparison with those designed for consumption in the home. Multi-use food products i.e. margarine tubs and lids had comparable leakage rates to single-use products consumed in the home, i.e. noodle packets and the associated flavour packets (4.3% and 1.6% vs 2.7% and 1.4% respectively).

As discussed in section 4.4.1, a noticeable disparity was observed between the prevalence of beverage bottles and the associated lids during the beach surveys. More specifically, lids were associated with a higher leakage rate (83.0%) in comparison to the bottles (5.0%). Such a disparity was not observed between other associated products including lollipop sticks and wrappers, and margarine tubs and lids. This supports the notion that the disparity is linked to the difference in characteristics between the bottle and lid, as previously discussed.

4.4.3 Data limitations

The robustness of leakage rates is influenced by the uncertainty associated with the product accumulation rates and waste generation rates. As discussed in section 4.4.1, marine litter accumulation rates are influenced by a wide range of factors which is evidenced by the range of rates observed at the different sample sites during the respective sampling periods. This should be taken into consideration when extrapolating the results of the survey accumulation rates as this introduces uncertainty with regards to the extent to which each of the survey results can be considered representative of the coastline of interest. Despite these variations, on a product level there is an element of consistency with regards to item prevalence and relative abundance across the sites.

It is also important to take into consideration the consumption data quality. In this case, a variety of sources were used including national surveys, market research, international consumption data and direct sales data. The direct sales data was based on barcode scanning information from major retailers and wholesalers. However, it is important to note that not all products are sold via the formal market, with one claim that in South Africa the informal food sector accounts for 40% of the market (Bhana, 2018). In addition, brand owners utilise different market distribution channels based on their target markets. For example, snack product brand owners Truda Foods and Frimax Foods are only sold via wholesalers for purchase and distribution by small independent grocers, spaza shops and street vendors (Libstar, 2018). When it comes to hard candies, small to medium-sized producers typically follow the aforementioned distribution channels, whilst larger producers access the market via formal retailers (Das Nair, Nkhonjera & Ziba, 2017).

4.5 Conclusions

Beach survey litter accumulation rates are influenced by a variety of factors including catchment area characteristics, weather patterns and ocean currents and tides. Although different litter accumulation rates were observed from the first to the second series of beach surveys, there was significant commonality in the items which were identified as major contributors. More specifically, the two series shared 10 out of 12 major contributors, of which 8 of these were associated with foods commonly consumed on-the-go. This indicated the high litterability of these items irrespective of catchment area characteristics and sampling periods. Thus, litter accumulation rates can provide valuable information regarding the prevalence of different items in the environment.

Whilst accumulation rates provide an indication of the abundance of a product in the marine environment, this is not necessarily related to the likelihood of it entering the marine environment. This was exemplified by the case of cigarette butts which had a high litter accumulation rate but a low leakage rate. Despite the uncertainty associated with calculating product leakage rates the estimates provide valuable insights into the leakage propensity of different products and enable the identification of products that are highly prone to leakage.

Chapter 5 Straws

Plastic straws have been identified as a major contributor to plastic marine pollution based on the results of the beach surveys presented in Chapter 4. This chapter explores the potential environmental impacts associated with popular straw material alternatives available on the South African market, via a comparative life cycle assessment. In addition, value-chain actor responses to the negative rhetoric surrounding plastic straws are explored, including the underlying motivations and any challenges faced. This is done via interviews with value-chain actors who supply straws, including retailers, brand owners and restauranteurs.

5.1 Introduction

The rising public concern surrounding plastic pollution has resulted in a spotlight being placed on specific items, considered to be high offenders. Straws are one of the items which have received a public outcry globally, with many consumer led campaigns calling for alternatives (i.e. material substitution) or the outright banning of plastic straws (Gibbens, 2019). This has led to a multitude of responses both from companies and governments, in an effort to reduce the consumption and subsequent waste generation of plastic straws. Consequentially, there has been increasing popularity of alternative straw materials, both disposable and reusable, which are often touted as more "environmentally friendly".

Given all the above, this case study aims to shed light on the environmental impacts of popular plastic straw alternatives available on the South African market (section 5.2). Specifically, it compares five material options for straws that are currently available on the South African market, including both reusable and single-use options. Furthermore, it investigates local responses to the plastic straw issue, and the motivation of value-chain actors when selecting an intervention including any challenges they faced (section 5.3).

5.2 Comparative Straw Life Cycle Assessment

A comparative LCA was conducted on five material options for straws available on the South African market: polypropylene (PP), paper and polylactide (PLA) which are single-use, as well as stainless steel and glass which are reusable. Due to the conflicting results surrounding the degradation rate of PLA in landfills, two scenarios were modelled; a "low" degradation rate and a "high" degradation rate (further details available in Appendix B).

As LCA currently does not have any guidelines for the consideration of marine pollution impacts, the potential impacts are explored as a function of the leakage rate (calculated in section 4.3.2), which represents the leakage propensity of an item and the degradation rate of the material, which provides an indication of the timeframe in which it represents a physical threat (i.e. the potential for ingestion and/or entanglement as discussed in section 2.2).

Details of the modelling approach, including cut-off criteria and allocation, as well as the data sources are available in Appendix B.

5.2.1 Functional unit and reference flows

The straws under consideration had equivalent functionality. More specifically, the straws had similar dimensions in terms of length and diameter and would be equally suited in the consumption of cold beverages. Previous studies which investigated the environmental impacts of reusable vs disposable food containers have used the functional lifespan of the reusable item as the functional unit (Harnoto, 2013; Potting & van der Harst, 2015). However, in this study, there were multiple reusable items with varying lifespans under consideration. In studies comparing single-use disposable food containers there have been various functional units employed. When comparing a range of single-use cups, plates and clamshells, Franklin Associates (2011) compared products on a one-to-one basis. A similar approach was taken by van der Harst, Potting & Kroeze (2014) in a comparative LCA of disposable cups. A one-to-one comparison was possible as the products under consideration could fulfil the same function with regards to capacity for food or beverages. In other studies, a seemingly arbitrary number of uses is selected as a functional basis. For example, Madival et al. (2009) and Suwanmanee et al. (2013) selected a functional unit of 10 000 uses whilst Häkkinen & Vares (2010) employed 100 000 uses. Plastic flows to the ocean are commonly reported in terms of annual flowrates into the marine environment. Thus, the functional unit for this study was the amount of straws consumed in a year by one person, i.e. straws.capita^{-1}.annum^{-1} (shown in Table 5-1).

Table 5-1: Straw LCA functional unit and reference flows

Material	Functional unit (straws.capita^{-1}.annum^{-1})	Individual straw weight (g)	Reference flow (g)
Polypropylene	36	0.52	18.78
Polylactide	36	0.81	29.25
Paper	36	1.15	41.53
Glass	1	24.25	24.25
Stainless steel	1	19.14	19.14

The calculation of reference flows was based on an estimate of annual per capita PP plastic straw consumption (Table 4-5). As alternative straw materials are being marketed as a replacement for PP straws, reference flows for glass, stainless steel, paper and PLA were based on the equivalent amount of straws required should each of the respective materials substitute PP straws. The number of alternative straws required, and subsequent reference flows are shown in Table 5-1.

5.2.2 System boundaries

Cradle-to-grave life cycle assessments were conducted for each of the straw types. This included raw material extraction and subsequent disposal. The life cycle assessments took both formal and informal disposal as options at end-of-life including leakage into the natural environment. In South Africa, formally managed domestic waste is either recycled or landfilled (DEA, 2018). Waste that is not collected (i.e. informally managed) may be disposed in personal or communal dumps or burned. Waste that is not properly managed also has the potential to enter the marine environment.

The life cycle stages associated with each straw are depicted in Figure 5-1.

5.2.2.1 Polypropylene life cycle stages

Locally, PP straws are manufactured nationwide from both imported and locally produced resin. This study modelled the straws manufactured from locally manufactured polypropylene due to insufficient information regarding the amount of imported resin and the associated production processes. In South Africa, propylene is produced using coal as a feedstock via the coal-to-liquids process (i.e. Fischer-

Tropsch synthesis) in Mpumalanga province (SASOL, n.d.). The propylene is then polymerised into polypropylene resin which is sold locally and exported. The major plastic straw manufacturers are located in Gauteng, KwaZulu-Natal and Western Cape Provinces. The straw manufacturing process commences with plastic compounding, wherein the resin is mixed with additives, melted and extruded into pellets. These pellets are then extruded into hollow tubes with the required thickness and diameter, which are subsequently cooled and cut to size forming straws. The end-of-life options for plastic straws include landfill, dumps, burning and the marine environment.

5.2.2.2 Paper life cycle stages

At the time of the study, there was no local production of paper straws. Based on information from major local distributors it was determined that locally available straws are principally manufactured in and imported from China. Straws are largely manufactured from food grade kraft paper. The paper is fed into a straw making machine with adhesive which produces tubes with the desired dimensions. Often, a hydrophobic wax coating is added to the straws which increases their durability when immersed in liquids. It was assumed that paper straws would have the same fate at end-of-life as polypropylene as they are both single-use disposable items. The major paper straw distributors are based in Gauteng and Western Cape provinces.

5.2.2.3 Polylactide life cycle stages

Polylactide is a starch-based polymer made from maize. PLA straws are manufactured by the extrusion of PLA granulate into hollow tubes with the required thickness and diameter, which are then cooled and cut to size. There are currently no local manufacturers of PLA, thus the majority of straws are imported from China. The PLA is manufactured according to the NatureWorks™ production process (Vink & Davies, 2015). There is one major PLA straw distributor, based in the Western Cape. Although PLA is compostable, it was assumed that it will not be composted due to the limited availability of industrial composting facilities which accept PLA in South Africa. Thus, PLA straws were assumed to have the same fate at end-of-life as polypropylene as they are both single-use disposable items.

5.2.2.4 Glass life cycle stages

In South Africa, reusable glass straws are made from imported borosilicate glass tubes. To fabricate straws, the glass tubes are cut to the desired straw length and polished. The reuse model assumed the straws would be handwashed, as the straws are often sold with brushes explicitly designed for this purpose. Based on the results of the beach surveys whereby no reusable utensils were found, it was assumed the glass was unlikely to enter the marine environment. In addition, glass straws are currently not recycled locally.

5.2.2.5 Stainless steel life cycle stages

Stainless steel straws are commonly manufactured from stainless steel grades 304 (i.e. stainless steel 18/8) or grade 316 to a lesser extent. In South Africa, a combination of imported and locally fabricated straws are available. Imported straws are predominantly sourced from China. In the case of locally fabricated straws, stainless steel tubes with the required thickness and inner diameters are imported from China. These tubes are then cut to the desired straw length and polished. This study modelled locally fabricated straws manufactured from stainless steel 18/8 based on a survey of steel straws currently available on the South African market. The majority of the burdens associated with steel straws are associated with the fabrication of the steel tubes thus it was assumed that steel straws manufactured in China and imported to South Africa would have similar burdens as those fabricated locally from tubes imported from China. The major steel straw manufacturers are based in Gauteng and Western Cape provinces. Similar to glass, it was assumed that the straw would be handwashed between uses. In addition, it was also assumed steel straws would be unlikely to enter the marine environment. Unlike the other materials, steel is highly recycled locally thus it was assumed the steel straws would also be recycled to a degree.

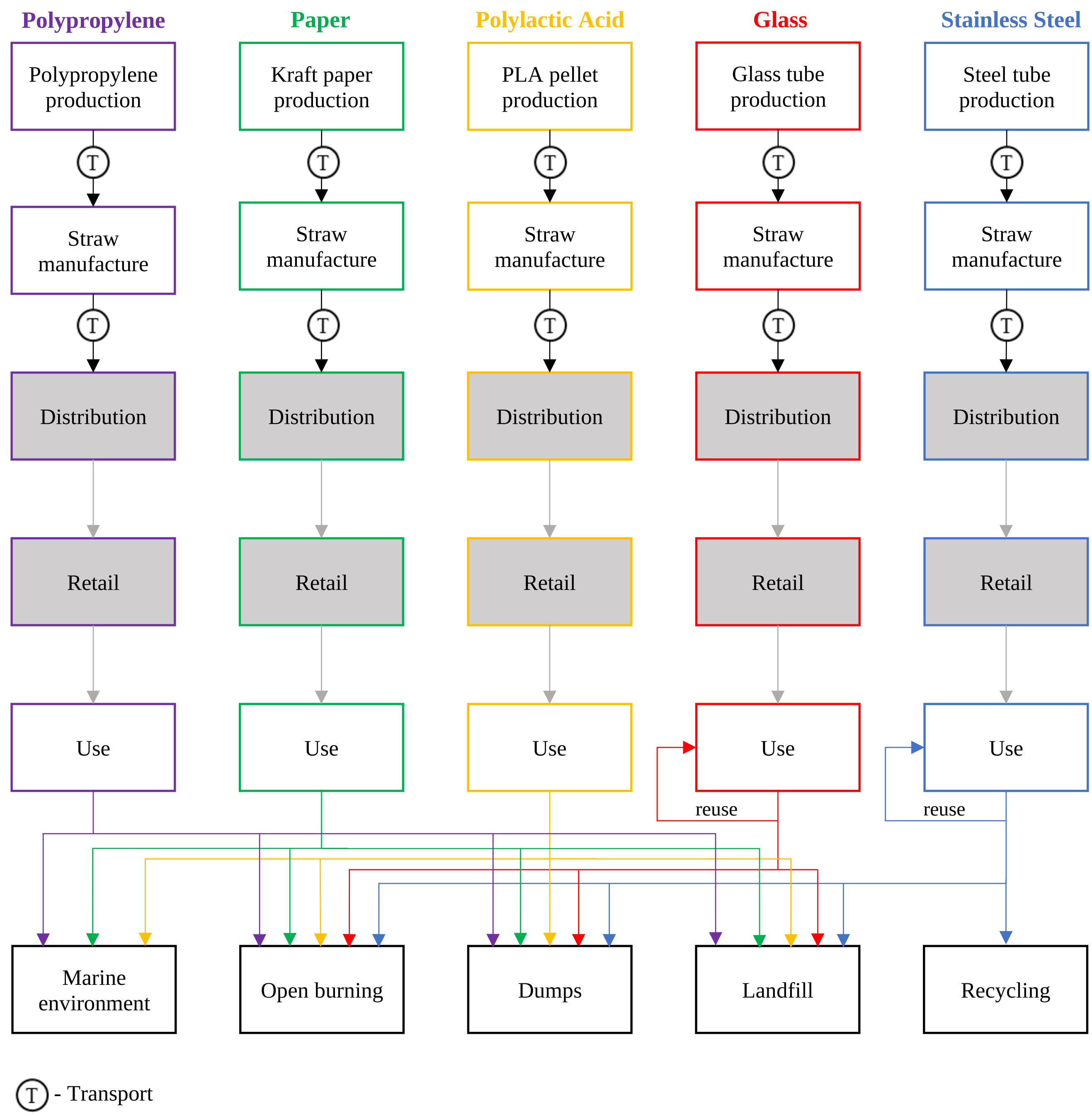

Figure 5-1: Straw life cycle stages

5.2.3 Life cycle impact assessment

The impact assessment was conducted using the ReCiPe Midpoint (H) method, which uses global models to evaluate environmental burdens in 18 impact categories. Due to the diversity of the materials under consideration it was necessary to use a comprehensive set of impact categories to ensure material specific impacts were not inadvertently overlooked. The results of the LCIA are presented in Figure 5-2 – Figure 5-4. Dominance analyses were conducted for each material in each of the impact categories.

The LCIA results were normalised according to World ReCiPe H values, to enable comparison of the relative significance of the different impacts.

5.2.3.1 Climate change

The climate change impacts for each material option and the respective life cycle stage contributions are shown in Figure 5-2. The highest contribution to climate change was observed for plastic straws with 0.205 kg $CO_{2\ eq}$, whereby resin production contributed 91%. This is due the use of coal as a feedstock for polypropylene production, as well as the primary energy source through the life cycle. Paper had the lowest with 0.119 $CO_{2\ eq}$, whereby paper production contributed 41%. The steel straw manufacturing process had the highest climate change emissions in comparison to the other materials and contributed the most to the straw life cycle accounting for 39% of emissions.

Paper had the highest contribution from the waste scenario due to its relatively higher degradability, accounting for 35% of emissions. The degradation rate of PLA has the potential to significantly impact climate change due to the variation in methane generation. A 23-fold increase in climate change was observed between the low and high degradation waste scenarios, from 2.04×10^{-3} kg $CO_{2\ eq}$ to 4.81×10^{-2} kg $CO_{2\ eq}$. This suggests that the waste management practices applied to PLA could greatly influence the potential climate change impacts associated with PLA products. A climate change break-even analysis was also conducted for reusable vs disposable straws. Table 5-2 shows the number of uses for which the reusable straw options will have lower climate change impacts than the disposable options. As expected, steel required more reuses before the environmental benefits were realised.

Table 5-2: Climate change break even matrix per number of uses

	Disposable			
Reusable	**Polypropylene**	**Paper**	**PLA (low)**	**PLA (high)**
Glass	23	39	37	27
Steel	37	63	59	44

5.2.3.2 Ozone depletion

The major contributor to ozone depletion for all materials was the use of petroleum and gas products, the production processes for which emit ozone depleting substances. The highest ozone depletion impact was observed for the glass straw (1.68×10^{-8} kg CFC-11_{eq}) due to relatively higher amounts of petroleum and gas products used as energy sources and fuel for transport. Glass production contributed 39% to emissions, transport 44% and straw manufacture 15%. Transport was also a major contributor to paper, accounting for 66%. PLA production was the major contributor in both PLA scenarios with 82%, whilst transport contributed 15%. For steel, pipe production contributed 70%, transport 14%, straw manufacture 10% and washing 8%.

The lowest was observed for plastic ($1.48x10^{-9}$ kg CFC-11_{eq}), as the process does not rely as heavily on natural gas and petroleum. Instead, the process for propylene production utilises coal as a primary feedstock unlike other propylene production processes which utilise natural gas (Franklin Associates, 2011b). In addition, the energy sources are also largely coal based.

5.2.3.3 Terrestrial acidification

The production of steel pipes (48%) and straw manufacturing (46%) were the major contributors to terrestrial acidification for steel ($1.60x10^{-3}$ kg $SO_{2\ eq}$) which had the highest emissions. Plastic had a comparable impact to steel ($1.19x10^{-3}$ kg $SO_{2\ eq}$) due to the use of coal as a feedstock for propylene production, which contributes 89%, as well as a primary energy source across the life cycle stages. For glass, transport had a relatively higher contribution of 34%, whilst tube production and straw manufacturing contributed 45% and 18% respectively. In the case of paper, paper production, transport and straw manufacturing contributed 52%, 24% and 23% respectively. A similar contribution by straw manufacturing was observed for PLA, accounting for approximately 23% in both scenarios, whilst PLA production contributed 65%.

5.2.3.4 Freshwater eutrophication

The major contributors to freshwater eutrophication for all materials was due to the treatment of mining waste via landfilling. Plastic had the highest emissions with propylene production contributing 95% and straw manufacturing 5%. This was due to the landfilling of spoil from coal mining (0.883 kg) which contributed 99%. In comparison, glass had significantly lower quantities of mining waste e.g. 0.0547 kg coal spoil and 0.108 kg lignite spoil which in total contributed 90% of emissions. Thus, it had the lowest emission with tube production contributing 72% and straw manufacturing 19%. There was no notable difference between the two PLA scenarios. In both cases PLA production contributed 89% and straw manufacturing 8%. For paper, paper production contributed 86% and straw manufacture 7%. For steel, pipe production contributed 32% and straw manufacture 64%.

5.2.3.5 Marine eutrophication

Unlike freshwater, plastic had the lowest marine eutrophication emissions with polypropylene production contributing 78% whilst the end-of-life contributed 15%. The paper end-of-life contributed significantly higher than the other materials, accounting for 29%. Glass had the highest emissions, with glass tube production contributing 89% and straw washing 4%. Unlike glass, straw washing had a relatively higher contribution to steel emissions accounting for 25%.PLA production contributed 96% of emissions in both scenarios, of which maize grain accounted 56%.

5.2.3.6 Human toxicity

Plastic had significantly higher human toxicity emissions than the other materials of $1.96x10^{-1}$ kg 1,4-DB_{eq}, with polypropylene production contributing 96%. Glass had the lowest emissions of $3.17x10^{-2}$ kg 1,4-DB_{eq} of which glass tube production contributed 72% and straw manufacture 17%. The production of steel pipes and straw manufacture contributed 57% and 31% respectively to steel emissions, whilst landfilling and dumping contributed a combined 9%. A notable contribution was also observed for the paper end-of-life which contributed 11%. PLA production contributed 85% and straw making 10% in both PLA scenarios.

5.2.3.7 Photochemical oxidant formation

Steel had the highest photochemical oxidation formation emissions, with pipe production contributing 48%, straw manufacture 43% and transport 8%. The lowest emissions in this category were observed for paper and PLA. Paper production contributed 51%, straw manufacture 14% and transport 28%. Degradability had a noticeable impact on PLA emissions with end-of-life contributions of 4.17×10^{-6} kg NMVOC (1%) and 2.52×10^{-5} kg NMVOC (5%) for the low and high scenarios respectively. For the low scenario, PLA production contributed 64%, straw manufacture 18% and transport 17%. In the high degradation scenario this corresponded to contributions of 61%, 17% and 16% respectively. Transport was a significant contributor in the case of glass, accounting for 41% of emissions. For plastic, polypropylene production was the major contributor accounting for 89%.

5.2.3.8 Particulate matter formation

Steel had the highest particulate matter emissions, which were more than double that of the other materials, with pipe production contributing 70% and straw manufacture 26%. Paper and glass had the lowest emissions. In the case of paper, paper production contributed 57%, transport 22% and straw manufacture 19%. For glass, tube production contributed 49%, transport 32% and straw manufacture 16%. Polypropylene was the major contributor to plastic emissions accounting for 88% whilst straw manufacture contributed 10%. Degradability did not have a notable effect on particular matter emissions for PLA straws. PLA production contributed 64%, straw making 23% and transport 12% in both scenarios.

5.2.3.9 Terrestrial ecotoxicity

PLA had significantly higher terrestrial ecotoxicity emissions (2.36×10^{-4} kg 1,4-DB_{eq}) which is resultant from the cultivation of maize which contributes 97%. The lowest emissions were associated with plastic (5.55×10^{-6} kg 1,4-DB_{eq}), whereby polypropylene production contributed 53%, transport 19% and dumping at end-of-life 21%. Glass had marginally higher emissions than plastic with tube production contributing 62%, transport 23% and straw making 12%. For steel, the production of pipes contributed 50% whilst the burning of straws (0.5% of waste flows) contributed 42%. The majority of contributions to paper were from the paper production process which accounted for 88%, whilst transport contributed 8%.

5.2.3.10 Freshwater ecotoxicity

Steel had the highest freshwater ecotoxicity emissions, with pipe production contributing 77% and straw manufacture 20%. Polypropylene production was a major contributor to plastic emissions, accounting for 96%. There was no notable difference between the two PLA scenarios, in which PLA production contributed 91% and straw manufacture 6%. Glass and paper had the lowest emissions. Glass tube production contributed 69%, straw manufacture 18% and washing 5%. For paper, paper production contributed 61%, straw manufacture 27% and landfilling 6%.

5.2.3.11 Marine ecotoxicity

Similar results to freshwater ecotoxicity were obtained for marine ecotoxicity. Steel had the highest emissions in this category, with pipe production contributing 79% and straw manufacture 18%. Polypropylene production was a major contributor to plastic emissions, accounting for 96%. For both PLA scenarios, PLA production contributed 89% and straw manufacture 7%. For glass, tube production contributed 68%, straw manufacture 17% and washing 6%. In the case of paper, paper production contributed 61%, straw manufacture 25% and landfilling 6%.

5.2.3.12 Ionising radiation

Glass had the highest ionising radiation impacts with tube production contributed 59%, transport 23% and straw manufacture 17%. Steel and PLA had comparable emissions to glass. Steel pipe production contributed 62% to steel emissions, with straw manufacture contributing 31%. There was no notable difference between the two PLA scenarios, whereby PLA production contributed 90%. Plastic had the lowest emissions with polypropylene production contributing 69% and straw manufacture 25%. For paper, paper production contributed 86% and transport 9%.

5.2.3.13 Agricultural land occupation

Paper had the highest agricultural land occupation which can be attributed to the cultivation of wood for paper production which contributed 99%. Cultivation was also a major contributor in the case of PLA, with maize cultivation contributing 92%. Plastic had the lowest occupation with polypropylene production contributing 92% and straw manufacture 6%. For glass, tube production contributed 86%, straw manufacture 8% and transport 5%. For steel, pipe production contributed 75% and straw manufacture 13%.

5.2.3.14 Urban land occupation

Glass had the highest urban land occupation, with glass production accounting for 88% and transport 6%. Plastic had the lowest occupation with polypropylene production contributing 85% and transport 9%. For paper, paper production contributed 74%, transport 15% and straw manufacture 6%. PLA production contributed 82% to land occupation in both scenarios with straw manufacture contributing 8% and transport 7%. Pipe production contributed 74% to steel land occupation, whilst straw manufacture contributed 13% and transport 10%.

5.2.3.15 Natural land transformation

Glass had the highest land transformation area with tube production contributing 57%, straw manufacture 11% and transport 33%. Plastic had the lowest area with polypropylene production contributing 90% and transport 9%. For paper, paper production contributed 78% and transport 21%. For steel, pipe production contributed 73%, straw manufacture 14% and transport 13%. In both PLA scenarios, PLA production contributed 79%, transport 15% and straw manufacture 9%.

5.2.3.16 Water Depletion

PLA straws exhibited the highest water depletion due to the irrigation of maize during its production which contributed 92%. Plastic had the lowest water depletion, with polypropylene production contributing 57% and straw manufacture 40%. Paper production was the major contributor to paper emissions, contributing 95%. For glass, straw manufacture contributed 83%, tube production 11% and washing 3%. For steel, straw manufacture contributed 15%, pipe production 74% and washing 10%. Steel washing had a higher contribution than glass due to a higher volume of water being used per wash than for glass (45 ml vs 25 ml).

5.2.3.17 Metal depletion

As expected, the highest metal depletion was for steel with pipe production contributing 99%. Plastic had the lowest metal depletion with propylene production contributing 85% and straw manufacture 7%.

In both PLA scenarios, PLA production contributed 90% and transport 7%. For paper, paper production contributed 73%, transport 16% and straw manufacture 11%. For glass, tube production contributed 73%, transport 14% and straw manufacture 7%.

5.2.3.18 Fossil depletion

Plastic had the highest fossil depletion with polypropylene production contributing 94% and straw manufacture 5%. Paper had the lowest fossil depletion with paper production contributing 66%, transport 17% and straw manufacture 15%. PLA production contributed 77% to emissions in both scenarios, with straw manufacture contributing 15%. For glass, tube production contributed 45%, transport 36% and straw manufacture. For steel, pipe production contributed 55% and straw manufacture 39%.

5.2.3.19 Potential marine pollution impacts

As mentioned in section 5.2.2, it was assumed that paper and PLA would have the same leakage propensity as plastic straws due to the similar design characteristics. In addition, reusable straws were considered unlikely to enter into the marine environment. Thus, only the disposable options are associated with potential impacts in the marine environment with a leakage rate of 38%, as estimated in section 4.2.3. Of the three materials, only paper is biodegradable in the marine environment (Greene, 2018). Although PLA is certified as compostable, a study conducted by Greene (2018) found that PLA is not degradable in the marine environment.

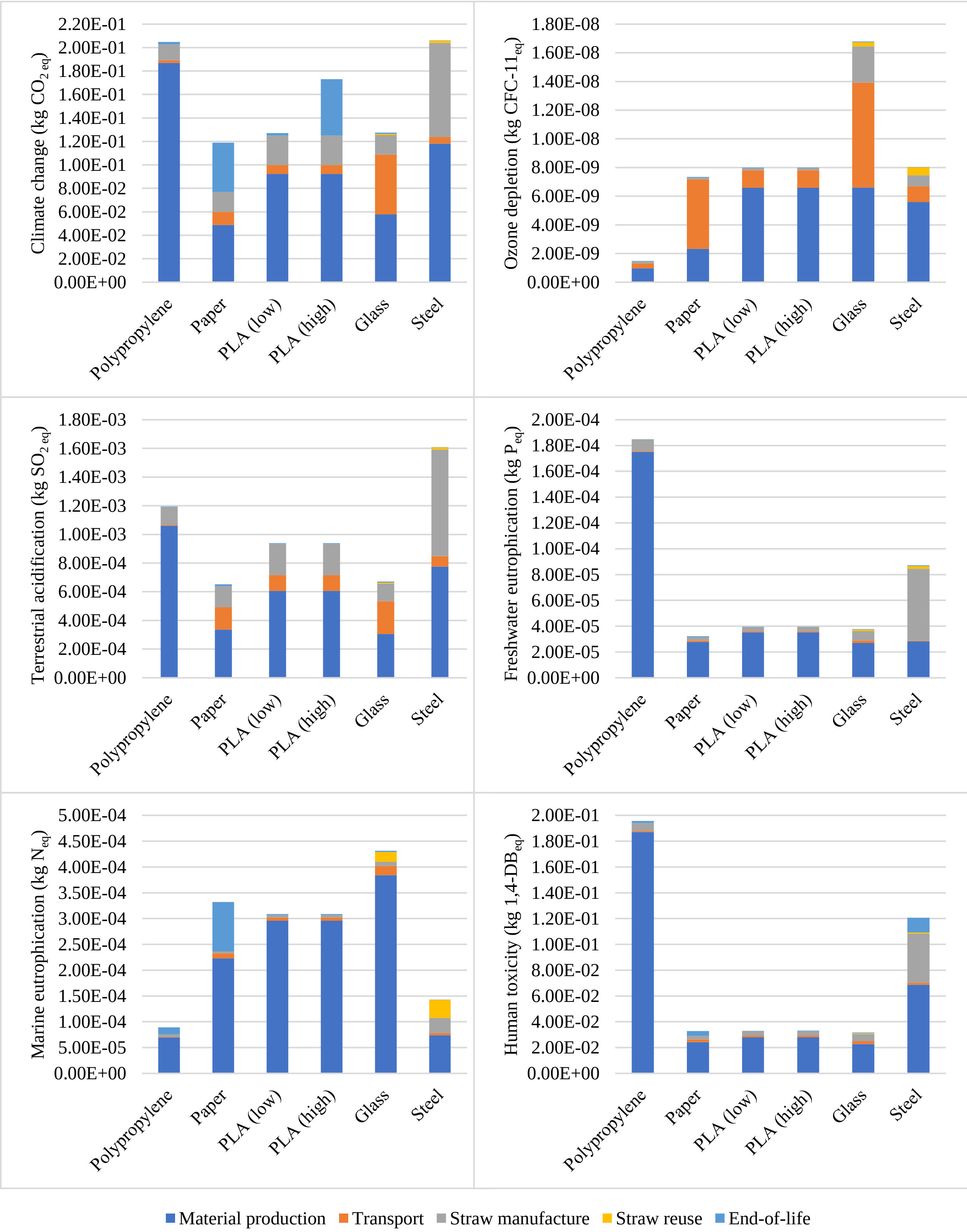

Figure 5-2: Straw LCIA results for climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication and human toxicity categories

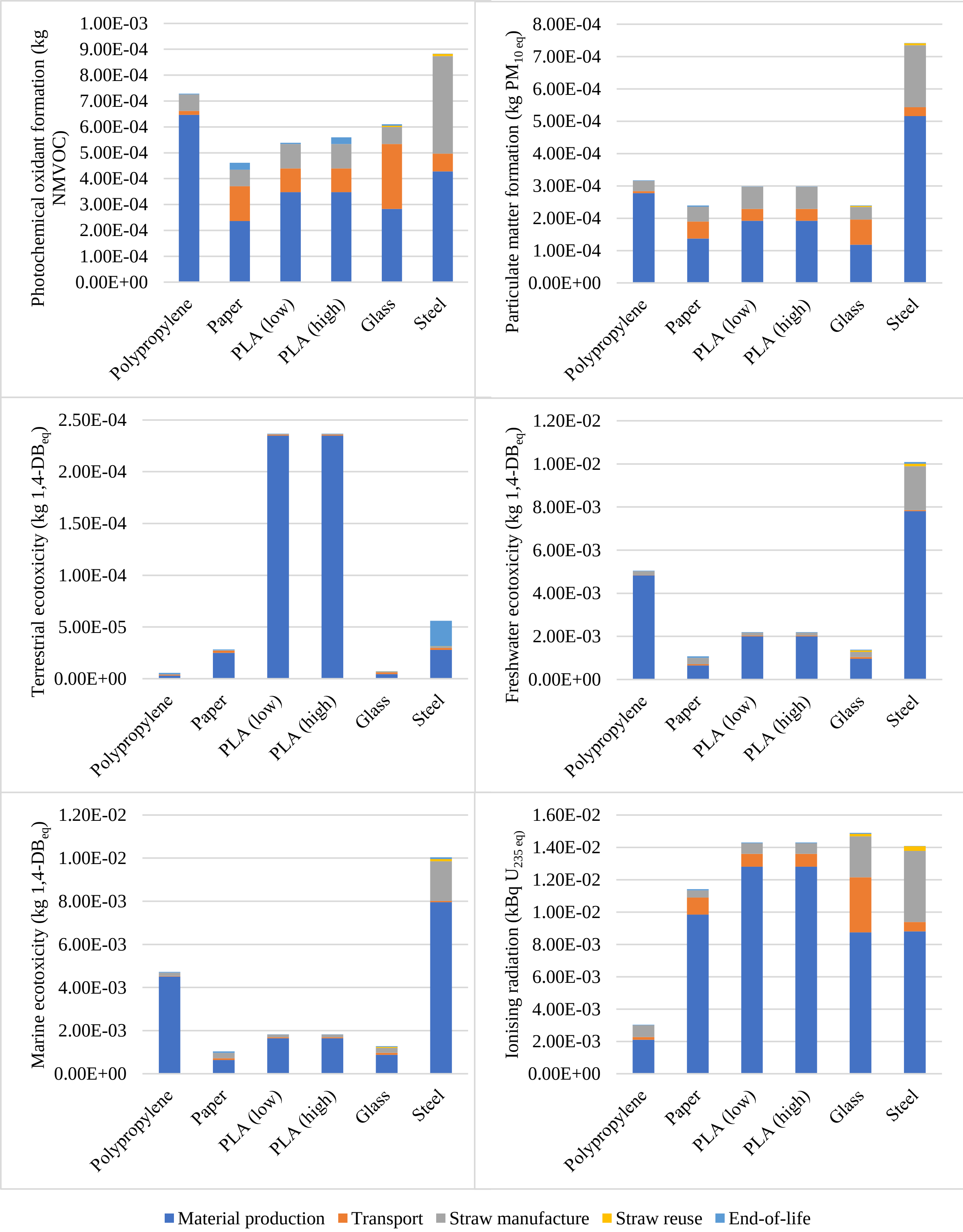

Figure 5-3: Straw LCIA results for photochemical oxidant formation, particulate matter formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity and ionising radiation categories

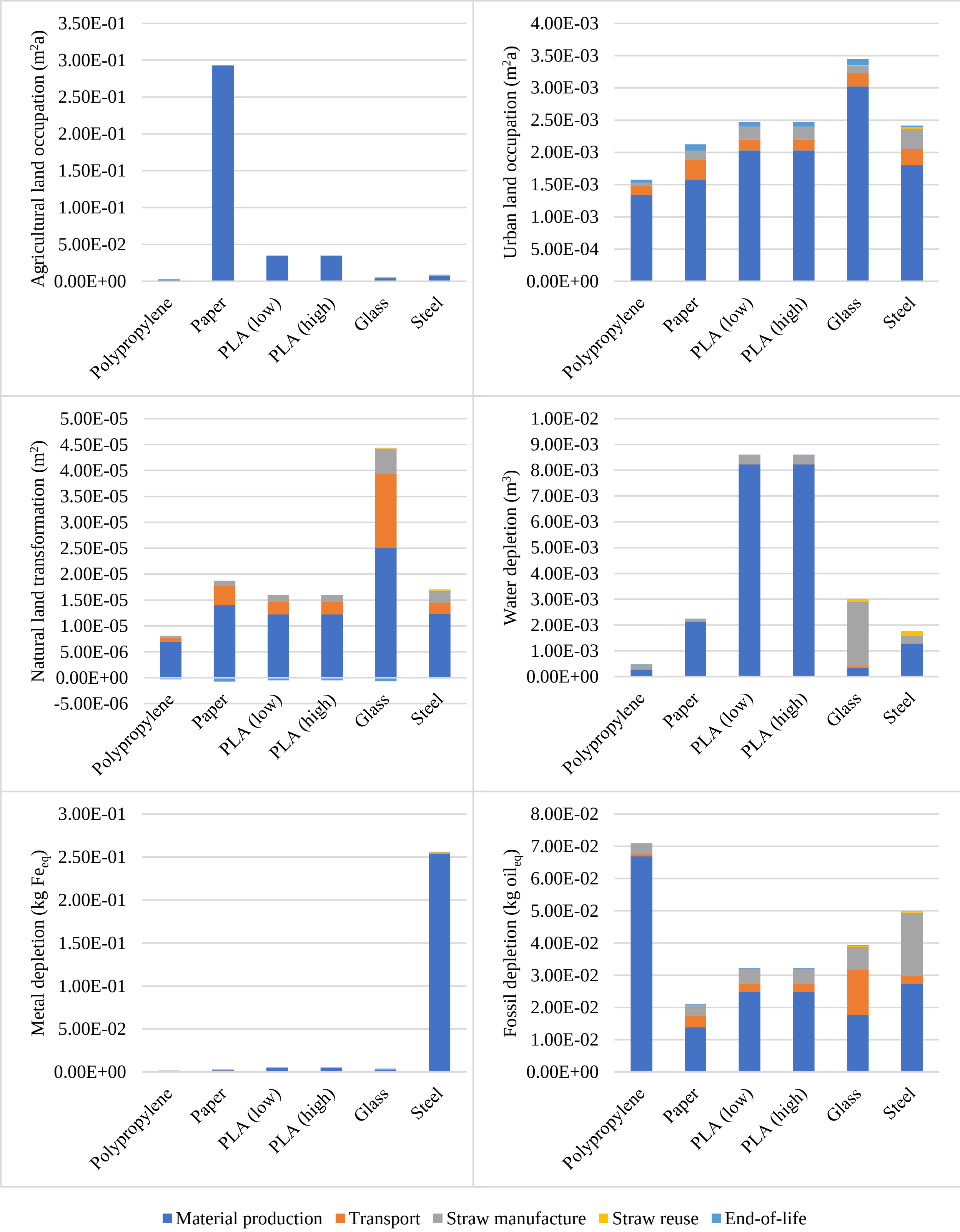

Figure 5-4: Straw LCIA results for agricultural land occupation, urban land occupation, natural land transformation, water depletion, metal depletion and fossil depletion categories

5.2.3.20 Normalisation

Upon normalisation (shown in Figure 5-5), freshwater and marine ecotoxicity were found to have a relatively higher significance than other impacts. In both cases, steel had the highest impacts followed by polypropylene. To a lesser extent, freshwater eutrophication and human toxicity were also found to be significant, but in these cases, polypropylene had the highest impacts followed by steel. Steel was also found to have relatively significant metal depletion impacts.

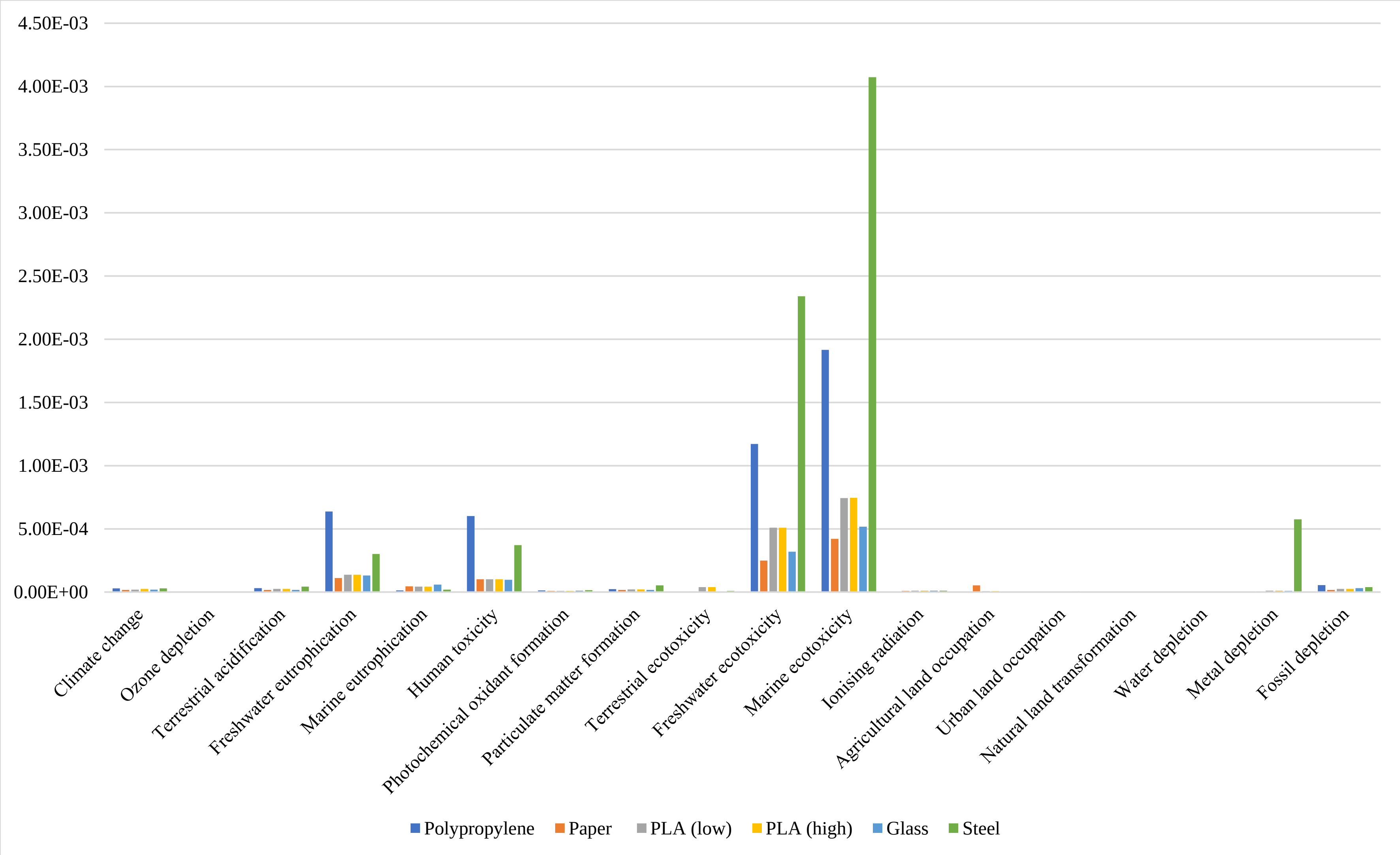

Figure 5-5: Straw LCIA normalised results

5.2.4 Variation analyses

Variation analyses were conducted on the volume of water used and the water temperature to account for different consumer practices (section 5.2.4.1). Variation analyses were also conducted on the market share of the paper, plastic and steel straw manufacturers, which would directly affect the distances from material producers to straw manufacturers (section 5.2.4.2).

5.2.4.1 Effect of washing water volume and temperature

In terms of washing water temperature, it was assumed that cold water was used (approximately 20 - 25°C). The effect of increasing this temperature was investigated based on a geyser temperature range of 50 – 60°C. More specifically, the maximum amount of energy required for a scenario where hot water was used to wash the straws was modelled to provide an indication of the maximum increase in impacts as shown in Table 5-3. For glass, the highest potential increases were observed for terrestrial acidification, freshwater eutrophication, human toxicity, freshwater ecotoxicity and marine ecotoxicity which had increases ranging from 65 – 86%. For steel, the highest potential increases were observed for climate change, terrestrial acidification, freshwater eutrophication, photochemical oxidant formation and fossil depletion which had increases ranging from 42 – 68%. Potential maximum increases for climate change of 38% and 42% were observed for glass and steel respectively.

Table 5-3: Effect of increasing washing water temperature on impact category emissions

	% Increase	
Impact category	**Glass**	**Steel**
Climate change	36.7	41.6
Ozone depletion	2.7	10.4
Terrestrial acidification	64.7	49.4
Freshwater eutrophication	86.3	68.3
Marine eutrophication	3.9	21.6
Human toxicity	69.8	33.6
Photochemical oxidant formation	36.1	45.6
Particulate matter formation	46.8	27.7
Terrestrial ecotoxicity	11.0	2.6
Freshwater ecotoxicity	86.4	21.6
Marine ecotoxicity	84.5	19.7
Ionising radiation	17.2	33.4
Agricultural land occupation	10.3	10.7
Urban land occupation	5.3	13.9
Natural land transformation	3.1	14.6
Water depletion	5.1	16.1
Metal depletion	19.2	0.5
Fossil depletion	29.2	42.2

The effect of increasing washing water was explored through a doubling of the volume modelled during the base case scenario. For glass, washing water had a relatively higher contribution to the life cycle impacts in 6 impact categories: freshwater and marine eutrophication, freshwater and marine ecotoxicity, water depletion and metal depletion. Thus, a doubling in the washing water volume resulted in the highest increases in these categories, ranging from 3 – 5%. In the case of steel, washing water had a relatively higher contribution in 3 categories: ozone depletion, marine eutrophication and water depletion. Thus the greatest increases were observed in these categories of 7%, 24% and 10% respectively, whilst increases of less than 2.5% were observed in the other categories.

Table 5-4: Influence of doubling washing water volume on impact category emissions

	% Increase	
Impact category	**Glass**	**Steel**
Climate change	0.9	1.0
Ozone depletion	1.8	6.7
Terrestrial acidification	1.2	0.9
Freshwater eutrophication	3.3	2.5
Marine eutrophication	4.6	24.4
Human toxicity	1.8	0.9
Photochemical oxidant formation	0.8	1.0
Particulate matter formation	1.3	0.8
Terrestrial ecotoxicity	2.9	0.6
Freshwater ecotoxicity	4.7	1.1
Marine ecotoxicity	4.5	1.0
Ionising radiation	1.1	2.0
Agricultural land occupation	0.8	0.8
Urban land occupation	0.5	1.2
Natural land transformation	0.3	1.3
Water depletion	3.2	9.8
Metal depletion	5.0	0.1
Fossil depletion	0.7	1.0

5.2.4.2 Effect of straw manufacturer market share

In cases where there were multiple straw manufacturers and distributors, the market split was not available thus the average distance was considered. The effect of this assumption was explored via the variation of transport distances between material producers and straw manufacturers.

In the case of steel, there were only two manufacturers of steel straws in South Africa (based in Gauteng and Western Cape provinces), wherein both manufacturers sourced their steel tubes from Gauteng. Hence identical changes in emissions were observed between the maximum (100% Cape Town market share) and minimum (100% Gauteng market share) distances in comparison to the base case, which considered an equal market share split (Figure 5-6). An increase in the market share for Western Cape manufacturers resulted in increased emissions due to the additional burden associated with transporting the tubes for approximately 1 400 km. Transport was a major contributor to ozone depletion, photochemical oxidant formation, agricultural and urban land occupation and natural land transformaiton. Thus relatively higher changes were observed in these categories, excluding agricultural land occupation, with the highest fluctuation range of ±5% observed for urban land occupation. The remaining categories were observed to fluctuate by under 1%.

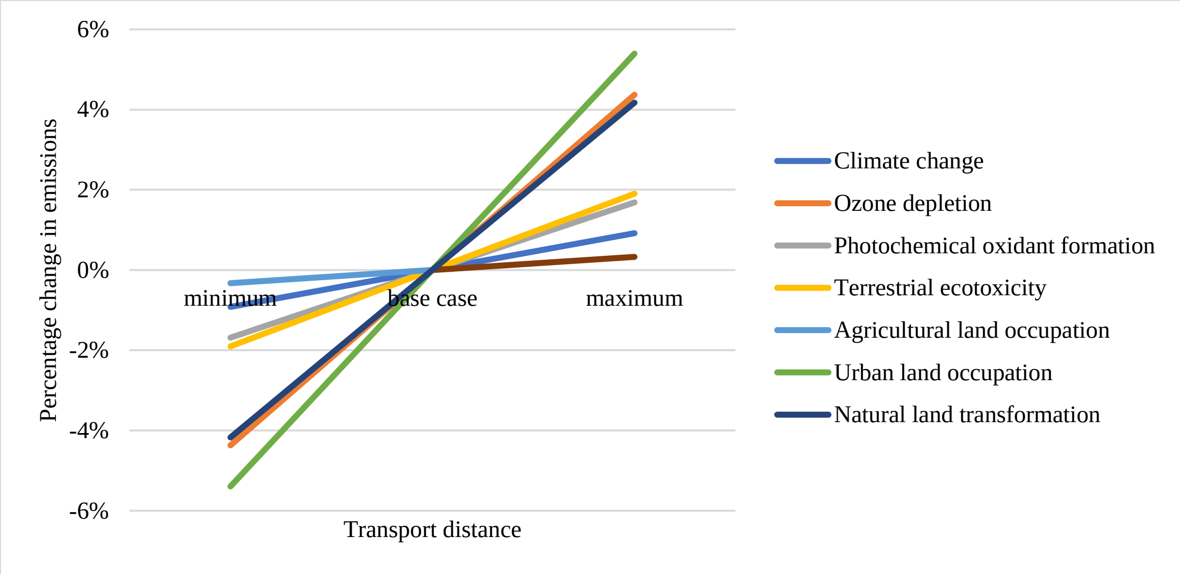

Figure 5-6: Effect of transport distance (i.e. market share) on steel straw emissions

Major plastic straw manufacturers are located in Gauteng, KwaZulu-Natal and Western Cape Provinces, whereby Gauteng was the closest to the polypropylene manufacturer and Western Cape the furthest. Transport had notable contributions to ozone depletion, terrestrial ecotoxicity, urban land occupation, natural land transformation and metal depletion hence the highest changes were observed in these categories. Higher rates of changes were observed for categories with higher transport contributions including ozone depletion which decreased by 20% at the minimum distance and 26% at the furthest and terrestrial ecotoxicity which fluctuated by -16% to +20% from the base case.

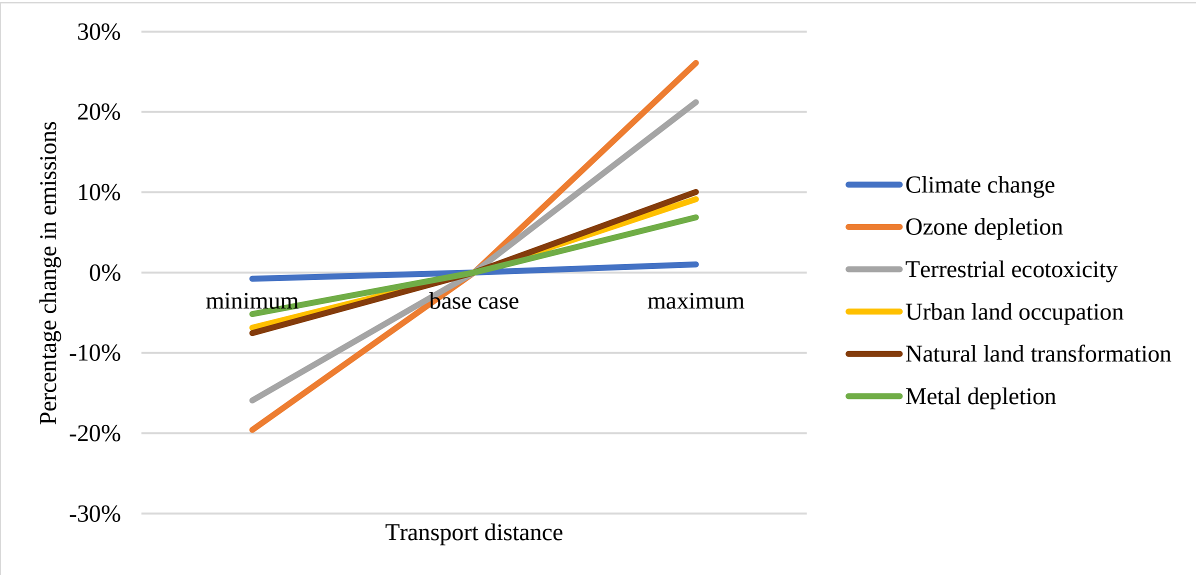

Figure 5-7: Effect of transport distance (i.e. market share) on plastic straw emissions

Paper straws are imported from China to distributors in Gauteng and Western Cape. For the Gauteng distributors it was assumed the straws were shipped to the Durban port and then transported to the distributor by road which was approximately 570 km. Whereas, in the Western Cape the straws were shipped to Cape Town port then were transported a considerably shorter distance by road to the distributors (~20km). Changes in market share would impact shipping distances as well as road transport to the distributor. More specifically, Gauteng was associated with a shorter shipping distance but a higher road transport distance, whilst the inverse was observed for Western Cape. The highest emissions were associated with a 100% Gauteng market share (maximum) whereby the lowest were associated with Western Cape (Figure 5-8). Similar to the case of steel, the highest fluctuation (±5%) was observed for urban land occupation.

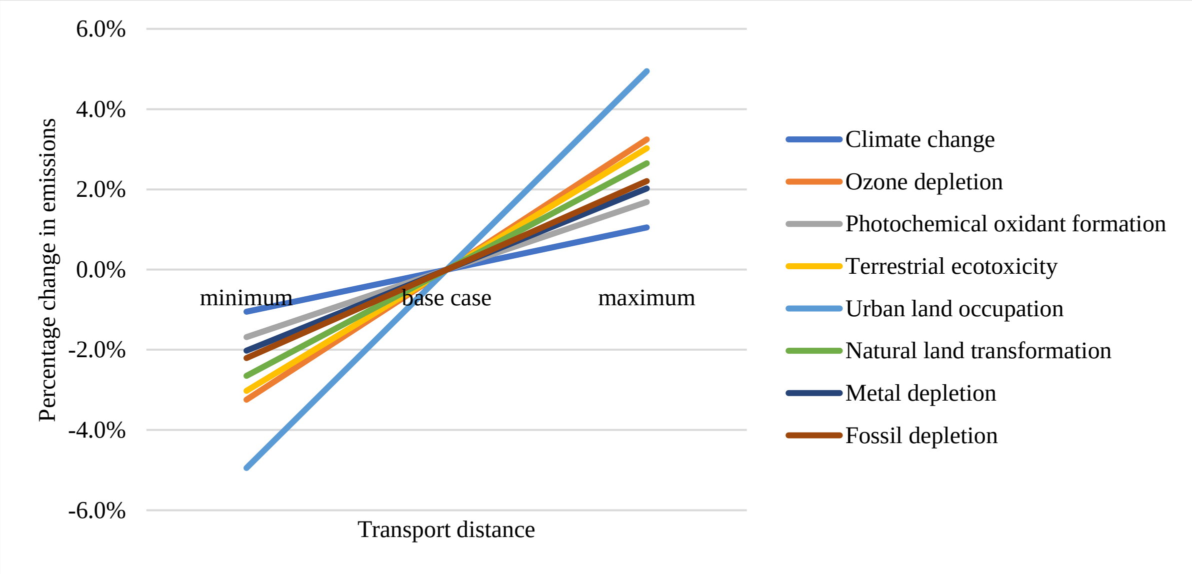

Figure 5-8: Effect of transport distance (i.e. market share) on paper straw emissions

5.2.4.3 Effect of transport mode on glass straw emissions

Overall, glass had the highest transport contributions across the impact categories. Glass is the only life cycle which includes air freight transportation. Should this air freight be replaced by road transport this would result in significant reductions in many impact categories including climate change and ozone depletion, as shown in Table 5-5. However, there would be a significant increase in terrestrial ecotoxicity as road transport is associated with higher emissions than air in that category.

Table 5-5: Influence of transportation mode on the glass life cycle

Impact category	Unit	base case	road substitution	percentage change
Climate change	**kg $CO_{2\ eq}$**	1.28E-01	9.72E-02	-23.8
Ozone depletion	**kg CFC-11_{eq}**	1.68E-08	1.13E-08	-33.0
Terrestrial acidification	**kg $SO_{2\ eq}$**	6.71E-04	5.64E-04	-16.0
Freshwater eutrophication	**kg P_{eq}**	3.77E-05	3.74E-05	-1.0
Marine eutrophication	**kg N_{eq}**	4.31E-04	4.25E-04	-1.5
Human toxicity	**kg 1,4-DB_{eq}**	3.17E-02	3.21E-02	1.3
Photochemical oxidant formation	**kg NMVOC**	6.10E-04	4.71E-04	-22.8
Particulate matter formation	**kg $PM_{10\ eq}$**	2.40E-04	2.07E-04	-13.8
Terrestrial ecotoxicity	**kg 1,4-DB_{eq}**	7.14E-06	8.56E-06	20.0
Freshwater ecotoxicity	**kg 1,4-DB_{eq}**	1.38E-03	1.38E-03	-0.1
Marine ecotoxicity	**kg 1,4-DB_{eq}**	1.28E-03	1.29E-03	1.0
Ionising radiation	**kBq $U_{235\ eq}$**	1.49E-02	1.28E-02	-14.2
Agricultural land occupation	**m^2a**	4.97E-03	4.94E-03	-0.5
Urban land occupation	**m^2a**	3.45E-03	3.68E-03	6.6
Natural land transformation	**m^2**	4.37E-05	3.29E-05	-24.7
Water depletion	**m^3**	3.00E-03	2.95E-03	-1.6
Metal depletion	**kg Fe_{eq}**	3.77E-03	3.77E-03	0.0
Fossil depletion	**kg oil_{eq}**	3.94E-02	2.90E-02	-26.3

5.3 Value-Chain Actor Responses

In South Africa, interventions for plastic straws started in 2017 (shown in Figure 5-9), which saw many individual restaurants removing plastic straws from their locations either replacing them with alternative materials or opting not to provide straws at all. In June 2018, major retailers Pick n Pay and Woolworths announced a set of initiatives to combat plastic pollution to coincide with World Oceans Day and World Environment Day respectively (Pick n Pay, 2018; Woolworths Holdings Limited, 2018). This included the phasing out of plastic straws from stores. Later that year, saw Famous Brands (parent company of a number of franchises including three of the top five fast food franchises in 2018) replacing plastic straws with paper straws in all of their franchises. In October, Coca-Cola, which provides straws to resellers, announced the same shift (Ramphele, 2018a). In 2019, the South African government announced a proposal to ban single-use plastic items including cotton bud sticks, straws, plastic cups and plates as well as polystyrene food packaging (SAnews, 2019).

Whilst ocean basket was the first major franchise to respond to the straw issue, they are a good example of the complexity associated with such a decision. Initially, they resolved to eliminate all straws from their restaurants in January 2018 (Pillay, 2018). However, as the year progressed the franchise had started offering paper straws and announced their intention to start providing straws made from compostable maize starch (Ramphele, 2018b).

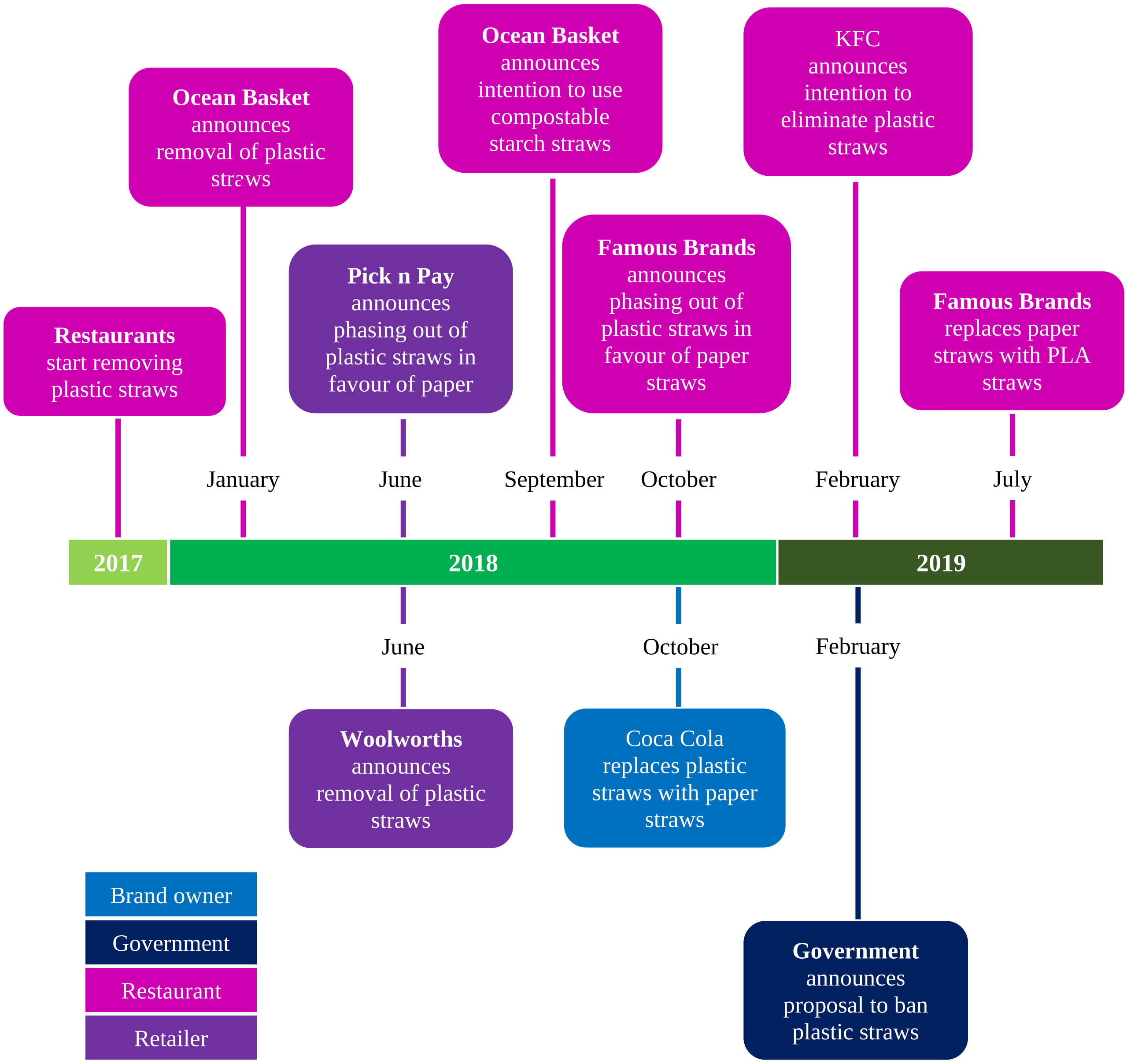

Figure 5-9: Timeline of straw responses in South Africa

The majority of value-chain actors consulted had shifted away from plastic straws to alternative materials as shown in Table 5-6. Paper was the most popular alternative amongst retailers, with Retailers A, B and D all replacing plastic with paper straws. In the case of Retailer B, they worked in partnership with their supplier, Brand Owner C, which had led to them deciding on paper straws. In addition, Brand Owner C was a supplier for Retailer D who had also reached out to the supplier to discuss a replacement. Unlike other retailers, Retailer C operates a decentralised model with different locations being operated by individual owners. Thus, there was no official stance on straws, with owners being given the freedom to offer any alternatives of their choosing if they so wished. Restauranteur A switched from plastic to PLA straws, whereas Restauranteur B used a combination of paper and glass straws for takeaway and sit-down beverages respectively.

Table 5-6: Consulted value-chain actor responses - straws

Participant	Response
Retailer A	Paper straws
Retailer B	Paper straws
Retailer C	No official response
Retailer D	Paper straws
Brand Owner C	Paper straws
Restauranteur A	PLA straws
Restauranteur B	Combination of paper and glass straws

5.3.1 Value-chain actor motivations

Consumer pressure was cited as a major contributing factor to the decision to transition away from plastic straws by the retailers. The international spotlight placed on straws as a major contributor to marine pollution made it a priority item to address for retailers. In the greater context of plastic pollution, straws were seen as a relatively easier item to address due to the ready availability of material alternatives. Furthermore, retailers were motivated by a desire to maintain their competitiveness amongst consumers.

"Everybody just saw it as a quick win!" – Retailer D

Unlike retailers, the restauranteurs cited that they were motivated by their own personal convictions and a desire to reduce their contribution to plastic pollution.

Brand Owner C cited the role they play as a supplier as a motivating factor stating:

"We romanticized the straw and that is why we need to now take responsibility of shifting the consumers' choices away from plastic straws."

Thus, they viewed their decision to switch to paper straws as a way of providing a product that would be less detrimental to the marine environment with current consumer practices (i.e. littering).

5.3.2 Considerations and challenges

When selecting an alternative, a number of factors were taken into consideration. Cost was cited as a major factor by all interviewees. In the case of retailers, they had the advantage of economies of scale due to the large quantities they require, which reduced the unit price. In addition, due to the size of their organisations they were more financially capable of absorbing the extra cost. Restauranteur A cited cost as a major inhibitor to the adoption of reusable straws due to the likelihood of theft by patrons. This was also cited as an issue by Restauranteur B, in addition to breakage of glass straws necessitating replacement. However, they were able to overcome this by partnering with a local glass straw manufacturer to supply their straws.

The functionality of the straw was a concern to participants, particularly in the case of paper straws. More specifically, the structural integrity of paper straws when immersed in beverages for an extended period of time was of concern, with Retailer A citing that they had received consumer complaints in this regard necessitating an internal review of locally available paper straws. Restauranteur A also cited this aspect as a consideration in their decision against adopting paper straws as they were perceived as likely to "disintegrate" in frozen beverages which are popular in their establishment. However, Retailer B acknowledged that it was a trade-off between straw quality and cost.

Hygiene was cited as a concern by Retailer A, when considering reusable straws. The retailer viewed reusable straws as taking food safety out of their hands whilst still leaving them vulnerable to liability. They used the example of a consumer improperly cleaning a straw bought from the retailer, getting sick from the poor hygiene and blaming the retailer. Restauranteur B also cited hygiene as a concern, whereby glass was seen as more favourable than steel as it was possible to visually inspect the interior for cleanliness.

When it came to the broader environmental impacts associated with straw alternatives, participants did not express any consideration of any impacts beyond the potential marine pollution impact. Thus, biodegradability was a major factor for participants. In this regard, retailers expressed concern surrounding the rising popularity of bio-based plastics and the amount of potential misinformation surrounding them. In particular, the marketing of compostable plastics as biodegradable which gave the impression that they were biodegradable in all environments. This was evidenced in the case of Restauranteur A who cited their perceived biodegradability of PLA in all environments due to how they had been marketed towards them, as a major motivating factor in their decision. Furthermore, whilst Restauranteur B expressed a desire to reduce their contribution to waste, their reasoning was based on anecdotes and not grounded in sound evidence.

5.4 Discussion

5.4.1 Environmental impacts of straw alternatives

Although plastic alternatives are generally reported to perform better than paper on a life cycle basis, this was not the case in this study. This was particularly evident in the case of climate change emissions whereby plastic emissions were 1.7 times higher than those of paper. Unlike Europe and the United States, where propylene is produced from crude oil and/or natural gas feedstocks, South Africa relies on coal as a primary feedstock (SASOL, n.d.). In addition, coal is the primary energy source for electricity generation in South Africa (Stats SA, 2018a). As a result, the production of polypropylene is significantly more carbon intensive South African with climate change emissions of 9.67 kg $CO_{2\ eq}$ per kg PP (Russo & von Blottnitz, 2018), in comparison to 1.97 kg $CO_{2\ eq}$ in Europe (Hischier, 2007) and 1,82 – 1.84 kg $CO_{2\ eq}$ in the United States (Franklin Associates, 2011b).

When it came to disposable options, paper seemed most favourable on average across the impact categories, including those found to be most significant upon normalisation (i.e. freshwater and marine ecotoxicity, human toxicity and freshwater eutrophication). However, relatively high emissions were observed for marine eutrophication, agricultural land occupation and natural land transformation which can be attributed to paper production including wood cultivation. Paper straw manufacture was significant contributor (>20%) to terrestrial acidification, freshwater and marine ecotoxicity, and to a lesser extent climate change (14%). Whilst shipping of paper straws was a significant contributor to ozone depletion, terrestrial acidification, photochemical oxidant formation and particulate matter formation. Polypropylene production was the major contributor to plastic straw emissions accounting for more than 75% of emissions in all categories except for ozone depletion and terrestrial ecotoxicity (where transport was a notable contributor), as well as ionising radiation and water depletion where straw manufacture contributed notably. In both scenarios, PLA production was the major contributor to straw impacts. The degradability of PLA had a notable impact on climate change and to a lesser extent photochemical oxidant formation. This can be attributed to the increase in methane emissions during the degradation process in landfills and open dumps.

In comparison to steel, glass had lower emissions across the majority of impact categories. However, it had significantly higher emissions for ozone depletion, marine eutrophication, ionising radiation, urban land occupation and natural land transformation. Straw washing during reuse was not a major contributor to impacts accounting for less than 5% of impacts in the majority of categories. However, this was found to vary with washing water volume and temperature whereby the latter had notable impacts on climate change, terrestrial acidification and freshwater eutrophication. Glass transport was found to be a significant contributor (>30%) in a number of categories accounting for 40% of climate change emissions. However, transport mode was shown to have significant impacts on a number of categories. Overall this did not impact the rankings when compared to other materials, except for the case of ionising radiation where glass emissions would now be lower than steel.

As shown by the results of the beach surveys (Chapter 4), reusable utensils are unlikely to enter the marine environment. Thus, steel and glass straws were considered to have no potential marine pollution impacts. In comparison, the disposable options were associated with a leakage rate of 38%, posing a threat to marine life. As mentioned in section 2.2, plastic poses a physical threat to marine life via entanglement and ingestion. Thus, the longer a product persists in the ocean, the greater a threat it poses in this regard. Although PLA was found to experience some degradation in the marine environment (see Greene 2012), the time it will take to completely degrade is unknown. Thus, PLA may be considered to pose a similar physical threat to plastic straws. In addition, the persistence of PLA and plastic, increases their potential to increase the bioavailability of contaminants including persistent organic pollutants in the food web upon their ingestion (Barnes et al., 2009; Andrady, 2011). Paper poses a significantly lower threat as it does not persist in the marine environment.

5.4.2 Value-chain actor responses

In South Africa, the majority of major retailers and restaurant chains have responded to the public concern surrounding plastic straws by choosing to replace them with alternatives. In addition, the South African government announced a proposal to ban straws, citing the ready availability of alternative materials. This is similar to global responses which have seen many countries including Jamaica, India and the European Union announcing bans on single-use plastics including straws (discussed in section 2.3.1) (European Parliament, 2018; JIS, 2018; Withnall, 2018).

A major motivating factor was the rising unpopularity of straws amongst consumers, due to their contribution to marine pollution. As straws currently have readily available material alternatives, they presented a relatively easy opportunity for retailers to be viewed as environmentally responsible to their consumer base. This is in line with a suggestion by Stafford and Jones (2019) that the visibility associated with plastic pollution creates an opportunity for “environmental branding” of individuals and corporations through the publicising of interventions (i.e. product substitution) or clean-up activities. However, in the case of Retailer C, no official response was made due to the operational model of the retailer whereby owners operated independently of the Head Office. Unlike retailers, restauranteurs cited their own desire to reduce their contribution to plastic pollution as their motivation. However, they did not demonstrate a sound knowledge base, relying instead on anecdotes and marketing. Brand Owner C took an EPR approach whereby they viewed it as their responsibility to provide an alternative that posed less of a threat to marine pollution, when viewed in the context of current consumer behaviour.

Overall, none of the interviewees demonstrated any consideration of the broader environmental impacts associated with the different straw materials beyond contribution to marine pollution. Thus, they selected material alternatives which they perceived to have a low risk of marine pollution impacts. In this regard, paper was a popular alternative due to its biodegradability in different environments. However, this focus made value-chain actors vulnerable to misleading marketing as shown in the case of Restauranteur A who was under the impression that PLA was marine degradable. Furthermore, this single-mindedness has the potential to distract from other environmental issues and result in environmental trade-offs being made unknowingly. Stafford and Jones (2019) suggest that the concern surrounding ocean plastic is potentially distracting from more serious and urgent environmental threats. More specifically, the high visibility of plastic pollution provides a "branding incentive" for corporations in contrast to an issue such as climate change whereby changes are not as visible.

5.5 Conclusions

When it came to disposable options, paper was most favourable across the majority of impact categories, including those found to be most significant after normalisation. For durable options, glass was more favourable in comparison to steel, the latter of which was observed to have relatively high emissions in impact categories identified as most significant. Overall, material production was the major contributor to potential impacts, for all material options. The relative contribution of transportation, including import of materials and straws, was dependent on the form of transportation used whereby higher variations were observed for changes in road transportation distances. In the case of reusable straws, the volume of washing water during reuse did not have a major impact on emissions. However, an increase in water temperature was found to notably increase emissions. From a climate change perspective, glass and steel options would require 23 – 39 and 37 – 63 uses respectively to break even with disposable options. From a marine pollution perspective, reusable straws were deemed to have the least risk due to their unlikelihood to be littered. Whilst disposable options were viewed to have a similar leakage propensity to plastic, paper was viewed to have the least potential physical impacts on marine life due to its degradability.

Although plastic is commonly cited as more favourable than paper, the use of coal as a primary feedstock resulted in significantly higher potential impacts in comparison with polypropylene produced in other regions, for example, in the global warming potential. Thus, a comparison of imported plastic straws may result in different results in terms of straw favourability.

Whilst the majority of value-chain actors selected a material option that performed relatively well from a life cycle assessment perspective (i.e. paper and glass) this decision was not based on a consideration of the broader environmental impacts associated with the material. Instead their material choice was motivated by a desire to address the issue of plastic marine pollution as this was the driving force necessitating the review of plastic straws. In addition to potential marine pollution impacts, cost and functionality were the major considerations when selecting a plastic straw alternative. Thus, for larger organisations (i.e. retailers and brand owners) the choice of alternative materials was a business decision to find a cost-effective way to respond to consumers' concerns surrounding plastic marine pollution. Whilst smaller value-chain actors (i.e. restauranteurs) expressed a personal desire to reduce marine pollution, they were more vulnerable to false marketing regarding the environmental impacts associated with a product.

Chapter 6 Bottles vs Lids

Beverage bottle lids have been identified as major contributors to marine pollution, both highly prevalent in beach surveys, and shown (in Chapter 4) to have a high leakage propensity. However, the associated bottles have been observed to be less prevalent, having a much lower propensity to occur in beach litter. This chapter explores the implication of a proposed redesign to tether lids to beverage bottles. As beverage bottles are widely recycled in South Africa, this is explored from a recycling perspective including economic and technical considerations. This includes value-chain actor perspectives on the proposal.

6.1 Introduction

Beverage bottle lids have frequently been identified as major contributors to marine litter, commonly appearing on many "dirty dozen" lists (Barnes et al., 2009; Andrady, 2011; Ryan, 2014b; Galgani, Hanke & Maes, 2015). Despite being components of one product, a disparity has been observed between the prevalence of lids vs bottles in the natural environment with a much higher prevalence associated with the former. Beach surveys conducted as part of this thesis (presented in Chapter 4) found average lid to bottle ratios of 17:1 and 50:1 (for bottles with a 28 mm neck and corresponding lids) over the two sampling periods respectively. Tethering of lids to bottles (examples shown in Figure 6-1) has been suggested as a potential intervention to mitigate the leakage of lids into the environment.

Figure 6-1: Examples of tethered lid designs (Aptar, 2019)

This case study explores the potential implications of tethering lids to beverage bottles, with a focus on 28 mm neck bottles which are commonly used for water and soft drinks ranging from 275 – 2 000 ml. As PET bottles are widely recycled in South Africa (statistics shown in Figure 6-3), the implications of this redesign on end-of-life flows and treatment of bottles and lids is explored in the context of the recycling industry. More specifically, it explores value-chain actor perspectives on the cause of the disparity between lid vs bottle prevalence in the environment, as well as potential implication of such a design on value-chain actors including converters, consumers and recyclers.

6.2 Fate of Beverage Bottles and Lids

As mentioned in section 2.1, there are a number of possible fates at end-of-life for plastic materials including landfilling, recycling and accumulation in the natural environment due to dumping and littering Beverage bottles and lids are subject to a similar fate as depicted in Figure 6-2. In South Africa, source separation of household waste is not yet a widely prevalent practice (Godfrey & Oelofse, 2017). Plastic disposed of via source separated waste is transported to a material recovery facility for sorting, following which the different material types are transported to the respective recyclers. As discussed in section 2.1, the informal sector plays a vital role in waste diversion to recycling with one claim that 90 % of PET bottles are sourced via informal trade (GreenCape, 2015). A governmental study estimated 36 700 waste pickers operating on landfill sites, and 25 500 so-called “trolley pushers” who collect waste from public and household garbage bins (DEA, 2016). Waste collected by waste pickers and trolley pushers is sold onto small collectors who then sell to large collectors who supply plastic recyclers.

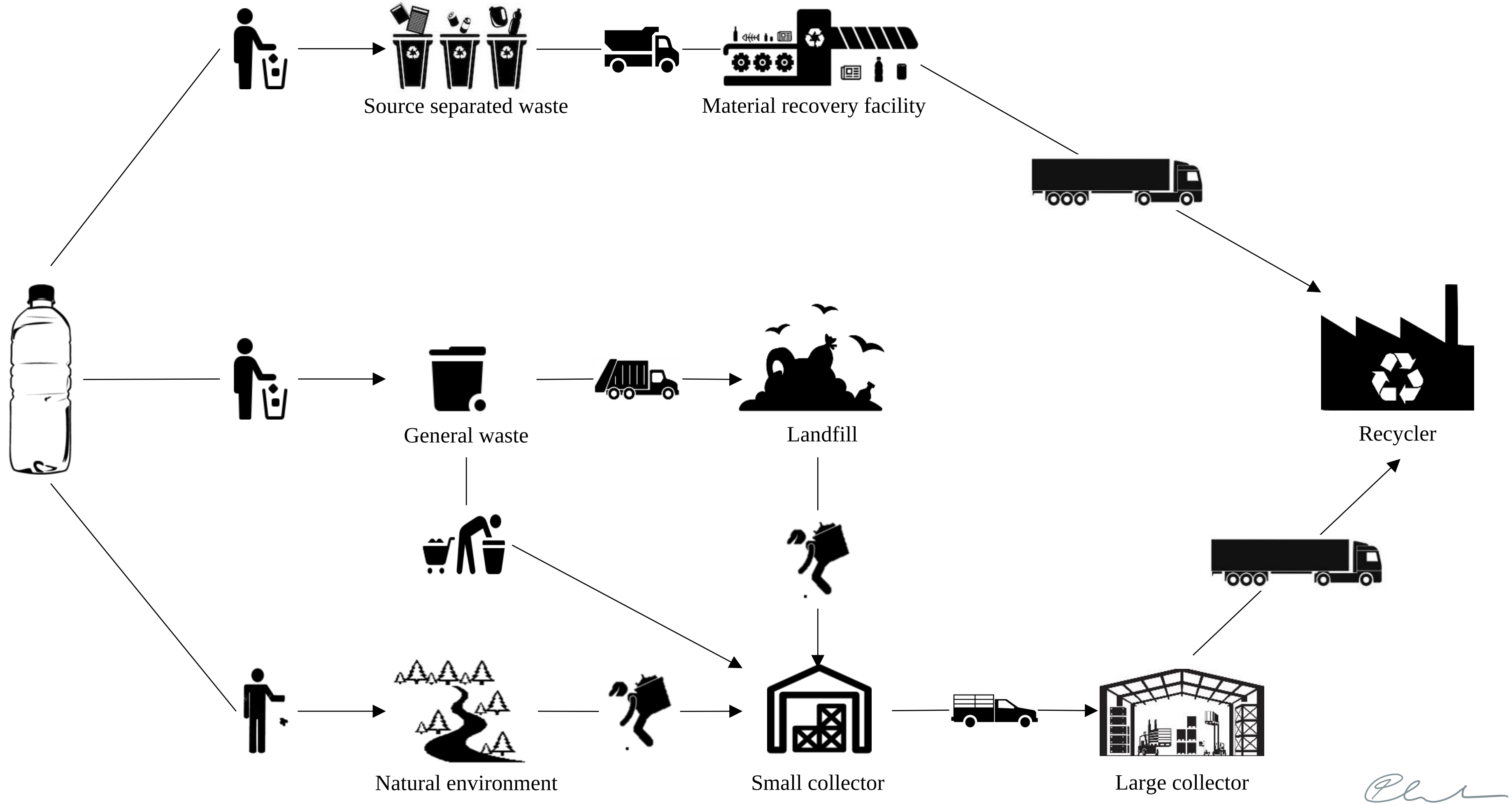

Figure 6-2: Flows of beverage bottle waste

6.2.1 Recycling

As mentioned in section 6.1, PET beverage bottles are widely recycled in South Africa. This may to an extent to attributed to the activities of PETCO, a voluntary Producer Responsibility Organisation (PRO) financed by industry as part of their EPR, which provides support to PET bottle recycling activities. Following its incorporation in 2004, there has been a marked increase in bottle recycling rates from 16 % in 2005 to 65 % in 2017 (Figure 6-3).

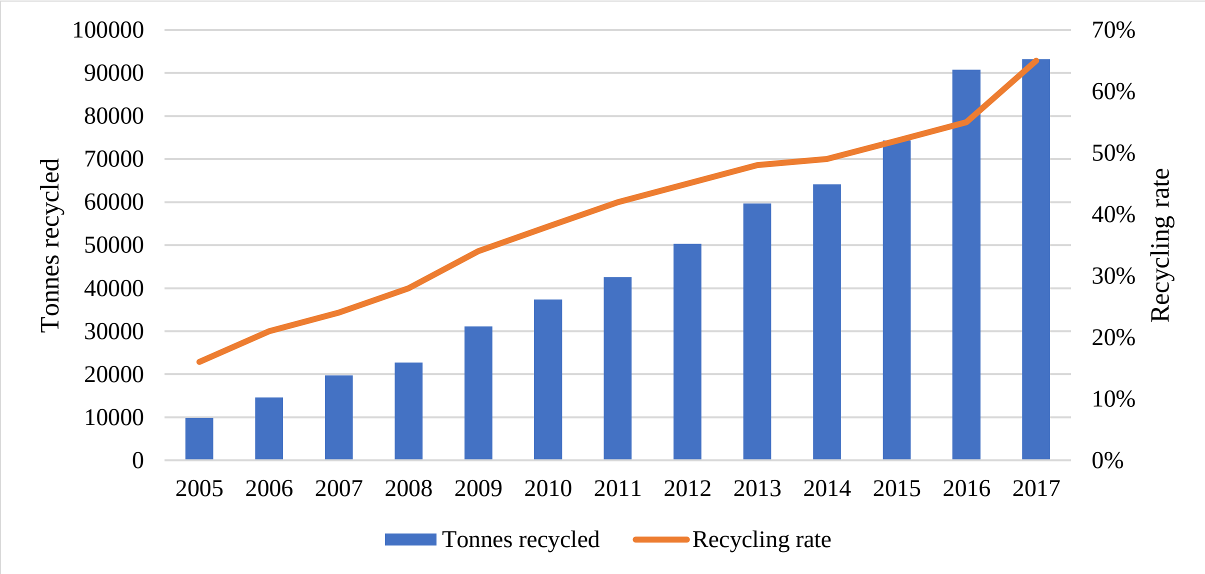

Figure 6-3: Recycling tonnages for PET bottles from 2005 to 2017 (PETCO, 2017a, 2018)

In 2017, beverage bottles which accounted for 68% of PET consumption in 2017, were reported to have a relatively high recycling rate of 65% during that same period (PETCO, 2018). The associated beverage bottle lids are primarily made from high density polyethylene (HDPE) and polypropylene (PP) but, may also be made from a combination of low- and high-density polyethylene in some cases. These materials are associated with relatively lower recycling rates than PET, with recycling rates of 28% and 15 % observed for HDPE and PP respectively (Figure 6-4). The low recycling rate for PP is attributed to the low demand due to limited uses for the post-consumer recyclate (Plastics|SA, 2018).

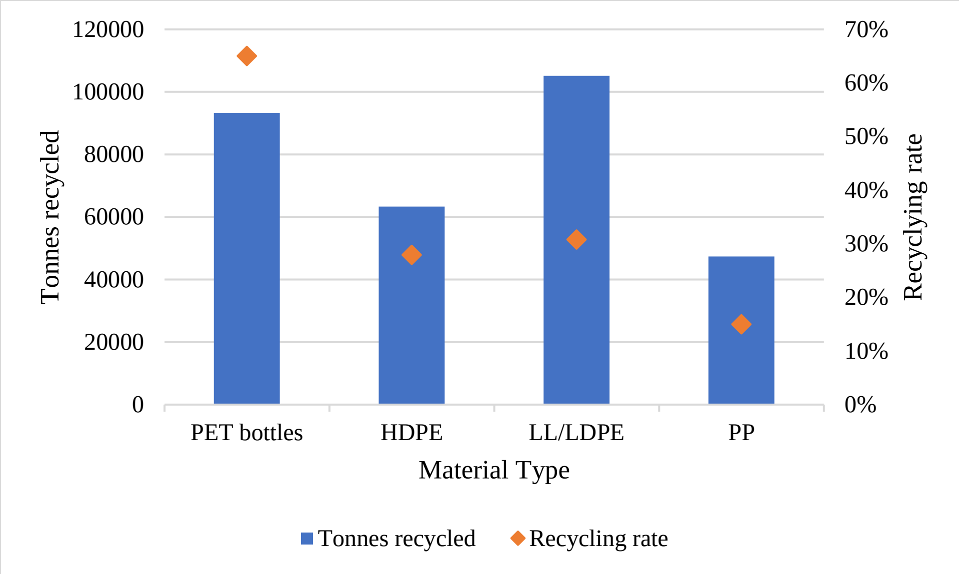

Figure 6-4: Recycling tonnages and rates of PET bottles (PETCO, 2018), HDPE, LDPE and PP (Plastics|SA, 2018) in 2017

According to Recycler B, there is a low demand for lids in the country due to the lack of standardisation for material types which resulted in limited end-uses for the recyclate. Packaging SA and PETCO (the PRO for PET recycling) both recommend the use of materials with a density less than 1 g/cm3 including PP, LDPE and HDPE for lids and closures to enable separation in the recycling process (discussed further in section 6.2.3) (Packaging SA, 2014; PETCO, 2017b). In addition, manufacturers are not required to include a resin code on the lid. Despite the stipulation by Packaging SA (2014) that HDPE closures should be 1mm shorter than PP closures, Plastics|SA (2018) highlight that the similarity between injection moulded HDPE and PP products make them difficult to differentiate visually during collection and sorting. This increases the risk of contamination of different material streams. In the absence of material properties, the lid recyclate was relegated to low-grade uses including outdoor furniture.

6.2.2 Accumulation in the natural environment

When it comes to leakage, lids have been observed in the natural environment more frequently than bottles. However, the reason for this disparity is unclear. As mentioned in section 4.3.1, this disparity may be due to the higher value of bottles making them more likely to be retained in the value chain for recycling, and/or the higher density associated with PET causing it to sink in water (both fresh and marine) reducing its visibility in the environment. In 2005, Ryan and Moloney (cited in Ryan et al. 2009) found 3 times as many lids than bottles per 100m across 14 beaches with no formal cleaning programmes (shown in Figure 6-5). This was an increase from a previous ratio of 1:1 observed in 1994. Incidentally, in 1998 the South African PET industry began providing guidance and financial support for post-consumer PET bottle recycling (PETCO, 2018). The ratio of 17:1 recorded in chapter 4 of this thesis may to some extent reflect the success of PETCO in recovering bottles.

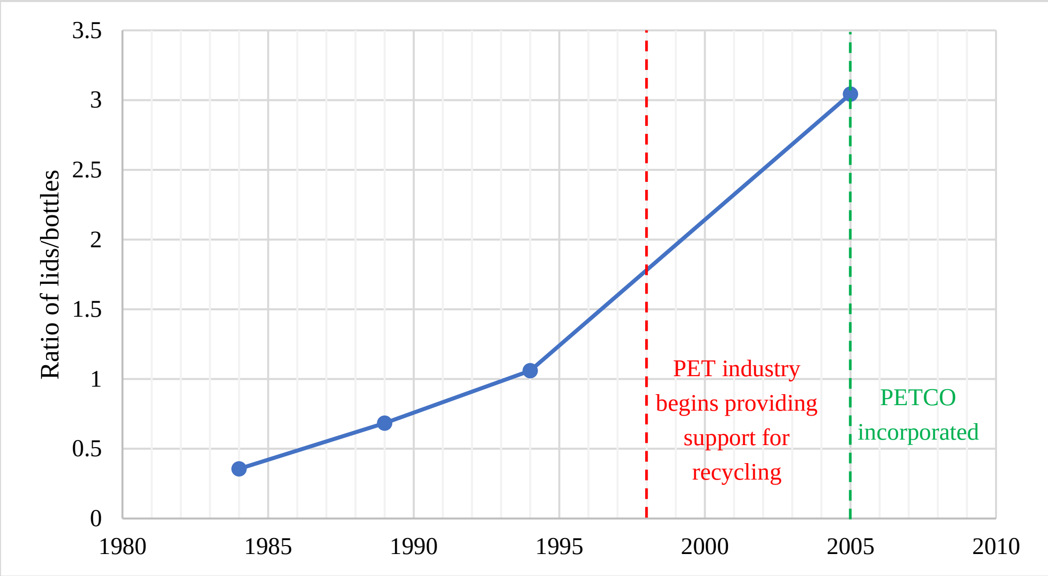

Figure 6-5: Ratios of lids/bottles across South African beaches from 1984 to 2005 (adapted from Ryan and Moloney cited in Ryan et al. 2009)

Recycler A and Recycler B believed that these disparity between the prevalence of bottles vs lids in the environment was due to the higher intrinsic value attached to bottles in comparison to lids. More specifically, lids were considerably lighter and associated with a lower value making them less desirable to collect. Recycler C believed it was a combination of factors; not only were lids unlikely to be collected due to their low value but were also more visible in the marine environment due to their low density. Industry Association B also viewed it as a combination of factors, including the behaviour of consumers when disposing their bottles (i.e. whether they close the lid or discard it separately), as well as the behaviour of collectors as to whether they remove attached lids during collection.

6.2.3 Separation of lids in PET bottle recycling

As mentioned in section 6.2.2, the fate of lids depends on consumer practices during disposal. According to interviewees, when recycling of PET bottles began people were advised to remove the lids. This was the ensure removal of the PVC liner that was previously used in the lids, as it would interfere with the recycling process through contamination of the PET. More specifically, due to the fact PVC has a higher density than water (shown in Table 6-1) it could not be removed by conventional methods which relied on water as the media for density-based separations. However, interviewees explained that the removal of lids was no longer a necessity as the PVC liners were phased out. Furthermore, design for recycling guidelines published by Packaging SA (2014) and PETCO (2017b) respectively, discourage the use of PET and PVC components in one product to avoid potential contamination. Lids were also removed to enable baling as the bottles were not easily compacted with the lids attached but the light-weighting of bottles has made them easier to compact irrespective of the presence of the lids. Though, lids are also potentially lost during the baling process if they are not tightly fastened.

Table 6-1: Plastic densities

	Density (g/cm^3)
HDPE	0.940 - 0.970
LDPE	0.917 - 0.940
PET	1.30 - 1.34
PP	0.900 - 0.910
PVC	1.30 - 1.70

In cases where the lids remain fastened to the bottle during the baling process, upon reaching the PET recycler they can be removed manually prior to recycling or as part of the recycling process. During PET recycling, PET is commonly separated from other plastic types (in the form of lids and labels) using a sink-float tank whereby plastics are separated via densities (shown in Table 6-1) using water as the flotation media (Dodbiba et al., 2002; Gent et al., 2009). More specifically, plastics with a density lower than that of water (e.g. PP, HDPE and LDPE) would float whilst plastics with a higher density (i.e. PET) would sink. This separation is often conducted after the bottles are shredded. The purity and recovery of the PET is dependent on a number of factors including the size of the tanks and shredded plastic flakes (Dodbiba et al., 2002). In addition, additives may be added to the flotation media to influence the hydrophilic properties of different plastic types (Dodbiba et al., 2002; Pongstabodee, Kunachitpimol & Damronglerd, 2008; Gent et al., 2009). Both PET recyclers, Recycler A and Recycler C, employ sink-float tanks in their recycling processes. In the case of Recycler C, the low-density fraction (including lids) is sent to disposal at landfills. In Recycler A's case, they viewed this as an opportunity to expand their business and started producing products from the recovered lids. However, the recycler admitted that the majority of the lids are sent to landfill for disposal. Furthermore, only lids entering the clean process whilst still attached to the bottle are recovered as the separation process only takes place after grinding.

6.3 Value-Chain Actor Responses to Tethering

Consulted value-chain actors are in favour of tethering as a solution to reduce the leakage of lids into the natural environment. Designers are reportedly actively exploring different options in this regard. In addition, interviewees anticipate the redesign to be a quick and smooth transition, viewing any challenges (discussed in sections 6.3.1 and 6.3.2) as easily surmountable. Similar to the case of straws (section 5.3.1), Brand Owner C views it as their extended producer responsibility to ensure collection of their materials after use. Recyclers view this an opportunity to retain more material in the value chain.

6.3.1 Bottle re-design considerations

Cost has been cited as a challenge, in relation to the capital costs for manufacturers. However, Retailer A highlighted that the advancements in technology in this regard may not necessitate new production lines to be installed and may just be a matter of retrofitting existing lines. Furthermore, Industry Association B highlighted that new machinery could be phased in when existing lines periodically came up for upgrading.

Consumer enjoyment was also a factor with concerns that the tethered cap may interfere with the drinking experience. However, Brand Owner C confidently stated that this was an issue that could easily be overcome; citing that the same issue was faced when the can tabs were tethered but now consumers had become accustomed to the new design. Retailer A cited their own personal experiences with tethered bottles admitting that they are “awkward” to drink out of, but they expressed confidence that newer designs would provide an improved experience.

6.3.2 End-of-life considerations

The tethering of lids has potential implications on recycling operations for both bottles and lids. More specifically, it can impact recycling operations both from a financial perspective as well as technically in terms of separation processes.

6.3.2.1 Recycling operations

Implications for PET recycling were highlighted as an immediate concern by Brand Owner C; particularly in the case of smaller recyclers who may not necessarily have the technology to separate lids within their processes. These recyclers currently rely on manually removing lids and labels before processing the PET bottle. However, this is not a concern for larger and more established recyclers, including Recycler A and Recycler C, which already have plastic separations processes (i.e. sink-float tanks) integrated into their process operations.

From the perspective of lid recyclers, lid tethering would result in a loss of this waste stream in its current form. Instead, the lids would now form part of a mixed plastic stream separated during the PET recycling process. In the scenario, where there is a continued lack of homogeneity in lid material types this will lead to a mixed plastic stream of variable compositions which would limit its applications. In 2017, an estimated 489.9 million 28 mm neck bottles and corresponding lids were produced (Table 6-2). This corresponds to 1089 – 1273 tonnes of lids, dependent on the lid design. Based on the reported bottle recycling rate in 2017 of 65% (PETCO, 2018), this would have potentially resulted in a mixed plastics stream of 707 – 828 tonnes. Furthermore, the majority of this would have been disposed of in landfills based on the current practices of major PET recyclers, Recycler A & B (discussed in section 6.2).

Table 6-2: National production volumes of 28 mm beverage bottle and lids

Total bottles (millions)	498.9
Individual bottle weights (g)	15.0 - 48.5
Total lids (millions)	498.9
Individual lid weights (g)	2.2 - 2.6
Total lid weights (tonnes)	1089.0 - 1273.1

6.3.2.2 Economic implications

Recyclers currently purchase PET in the form of bales. These bales contain compressed bottles in various states of completeness including the attachment of lids and/or labels. Recycler C highlighted that collectors were more inclined to keep the lids attached to increase the weight of the bales and consequentially gain more value when selling bottles to recyclers. Furthermore, the bales contain varying degrees of foreign contaminants including dirt dependent on the source of bottles. Thus, effectively the recyclers do not pay for pure PET in practice. Whilst the recyclers may negotiate based on the quality of the bales, this is subject to market demands. More specifically, recyclers have more room to negotiate in cases where there is a surplus of PET bottles on the market. Thus, PET recyclers did not view the attachment of lids as having significant financial implications. In particular, Recycler C cited the fact that lids did not make up a significant weight fraction of the complete bottle. In South Africa, 28 mm neck bottle weights range from 15 – 48.5g dependent on the volume of the bottle. Corresponding lids were found to range in weight from 2.2 – 2.6g (Table 6-2), with PP lid types found to be the heaviest on average. A wider range of weights was observed for PE lids (2.2. – 2.5 g), which may be attributed to differences in manufacturer aesthetic designs as they had equivalent functionality. Thus, on average lids can account for 4 – 15% of the total complete bottle weight.

"The reality in South Africa, it's more of a case of what you get is what you get" - *Recycler C*

The tethering of lids also potentially has implications from a PRO perspective. More specifically, due to their differing material types, bottles and lids are the responsibilities of different PROs: PETCO and POLYCO which are responsible for PET and polyolefins respectively. These PROs provide financial support to their respective recycling industries through the payment of levies by members, which include brand owners, converters and manufacturers. According to the IWMPs submitted for the packaging industries, each of these materials would be managed by their respective PROs including the payment of mandatory EPR fees which differ according to material type (Packaging SA, 2018). For example, the proposed EPR fee for PET in 2019 was R521 in comparison with R250 for rigid polyolefins, including lids (Packaging SA, 2018). The tethering of lids effectively results in their integration into the PET bottle waste stream. More specifically, they would be collected by PET bottle collectors and recovered during the PET recycling process. Thus, the costs associated with recovery of lids would effectively be borne by PET collectors and recyclers.

6.4 Discussion

Historical studies have shown an increase in the ratio of lids:bottles observed in the environment. This has coincided with an increase in the recycle rate of bottles. This may be viewed as evidence of the potential impacts of having a targeted and effective product EPR scheme (i.e. for bottles) which in this case is facilitated by a PRO.

All of the consulted value-chain actors were in favour of lid tethering and viewed it as an inevitability. The intervention would increase the collection rate of lids as they would remain attached to the widely recycled bottle. This would lead to an increase in lid flows into PET recycling operations, resulting in an increase in operational costs. In addition, there would potentially be an effective increase in PET cost as the fractional weight of lids is currently not taken into consideration during pricing, with the bale sold as pure PET. However, the PET recyclers were confident in their abilities to absorb this additional cost.

There is currently limited demand for lid recycling due to the lack of material standardisation coupled with poor grades. Tethering would result in a stream of mixed plastic of variable composition with limited application, potentially leading to an overall decrease in lid recycling. Whilst separation techniques exist for polyethylene from polypropylene, they are currently not employed in South Africa with recyclers relying on visual inspection. For example, Pongstabodee, Kunachitpimol & Damronglerd (2008) found that complete separation of PP and HDPE was possible via a three-stage float-sink process with an aqueous ethyl alcohol solution. Furthermore, in order to design an appropriate separation technique more knowledge is required on the material types and grades currently used.

6.5 Conclusions

Over the past decades there has been an increase in the ratio of lids-to-bottles observed across South African beaches. This has coincided with an increase in PET bottle recycling. This supports the notion suggested in Chapter 4 that the relatively low prevalence of bottles in the environment is due to their value for recycling increasing their likelihood for collection. It may also be viewed as evidence of the effectiveness of a targeted EPR scheme.

Whilst lid tethering would result in an overall increase in the collection of lids coupled with a decrease in leakage, this would not necessarily translate to an increase in recycling. Lack of standardisation when it comes to lid materials limits the potential applications of lid recyclate, which will be compounded by the inevitable mixing of crushed lid fragments during separation in the PET plastic recycling process.

Chapter 7 Cotton Bud Sticks

Cotton bud sticks have been identified as a significant contributor to marine plastic pollution. This chapter explores the flows of cotton bud sticks through wastewater treatment plants, which have been identified as a pathway for their release into the marine environment. It also investigates the potential environmental impacts associated with switching from plastic to paper cotton bud sticks, via a comparative life cycle assessment. This is followed by an exploration of value-chain actor responses to the increasing concern surrounding cotton bud stick leakage from retailer and wastewater treatment perspectives.

7.1 Introduction

Cotton bud sticks may be considered a priority item, as they are consistently found to be a major contributor to marine pollution. Wastewater treatment plants (WWTPs) have been identified as a major pathway for cotton bud sticks into the environment, which enter the wastewater system via flushing down toilets (Mourgkogiannis, Kalavrouziotis & Karapanagioti, 2018; Gatidou, Arvaniti & Stasinakis, 2019). Globally, interventions have ranged from bans on plastic cotton bud sticks in favour of paper or wood alternatives, as well as the exploration of technical interventions at WWTPs (ICF & Eunomia, 2018).

This case study explores the flows of cotton bud sticks through WWTPs in Cape Town, as a potential pathway to the marine environment (section 7.2). It also investigates the environmental impacts of substituting plastic cotton bud sticks with paper (section 7.3). Development of local strategies to mitigate cotton bud stick pollution is explored via engagement with relevant value-chain actors, including material substitution and intervention at WWTPs (section 7.4).

7.2 Cotton Bud Stick Flows Through Cape Town Wastewater Treatment Plants

The flow of cotton bud sticks though three Cape Town WWTPs was investigated based on raw data collected by Matthews and Jamieson (2018). This included exploring key removal processes for cotton bud sticks across the process.

7.2.1 Wastewater treatment process

The wastewater treatment process can be split into four generic stages (Figure 7-1): preliminary treatment, primary treatment, secondary treatment and tertiary treatment. Preliminary treatment aims to remove solid debris which may damage or disrupt wastewater treatment unit operations, including pipes and machinery, as well as to avoid visible waste in the discharged effluent (WEF & ASCE, 1998). The raw sewerage initially undergoes screening to remove large debris including plastic items. The removal efficiency is dependent on the size and type of the screens (WEF & ASCE, 1998; Qasim, 1999; Templeton & Butler, 2010). There are four types of screens: bar, drum, cutting and band. These screens differ in their construction and operation. Bar screens, which are commonly employed at medium to large plants, consist of inclined metal bars which trap debris that is too large to flow through the spacings (Qasim, 1999). Drum screens consist of a rotating hollow mesh drum through which water is fed and debris is trapped within the drum. Cutting screens involving the cutting of debris so it passes through the screens for removal further down the treatment process. Band screens consist of a perforated band mounted on a conveyer belt. Screen apertures range from >50mm for coarse screens, to fine screens of

3 – 15 mm (EPA, 1995). Municipal WWTPs commonly employ coarse screens followed by fine screens (EPA, 1995; WEF & ASCE, 1998). Following screening, heavy inorganic grit (such as sand and gravel) is separated out, commonly via settling in grit channels (Templeton & Butler, 2010).

Primary treatment is a physical process for the removal of organic, inorganic and suspended solids, commonly by sedimentation. In addition, floating materials, including oil, grease and plastics are often removed as scum which forms at the surface of tanks (WEF & ASCE, 1998). Secondary treatment involves biological treatment to enable the removal of dissolved organics through their conversion into suspended matter using cell biomass. Commonly employed processes include the activated sludge process, biological filters or rotating biological contactors (WRC, 2016). Sludge formed during primary and secondary treatment is treated to reduce odours, pathogens and its total volume prior to disposal. Anaerobic digestion is commonly used to treat the sludge, after which it is dewatered using a belt press or in drying beds (WRC, 2016). The final stage of wastewater treatment is tertiary treatment, which involves further removal of suspended solids or nutrients (e.g. nitrogen and phosphorous) and/or disinfection of the water. Disinfection is commonly achieved by chemical treatment using chlorine or ozone, or UV light (Templeton & Butler, 2010; WRC, 2016). Maturation ponds may also be employed to give a "final polish" to wastewater prior to discharge, by decreasing the bacterial quality (WRC, 2016). It also serves as a backup to the plant in the event of a breakdown upstream.

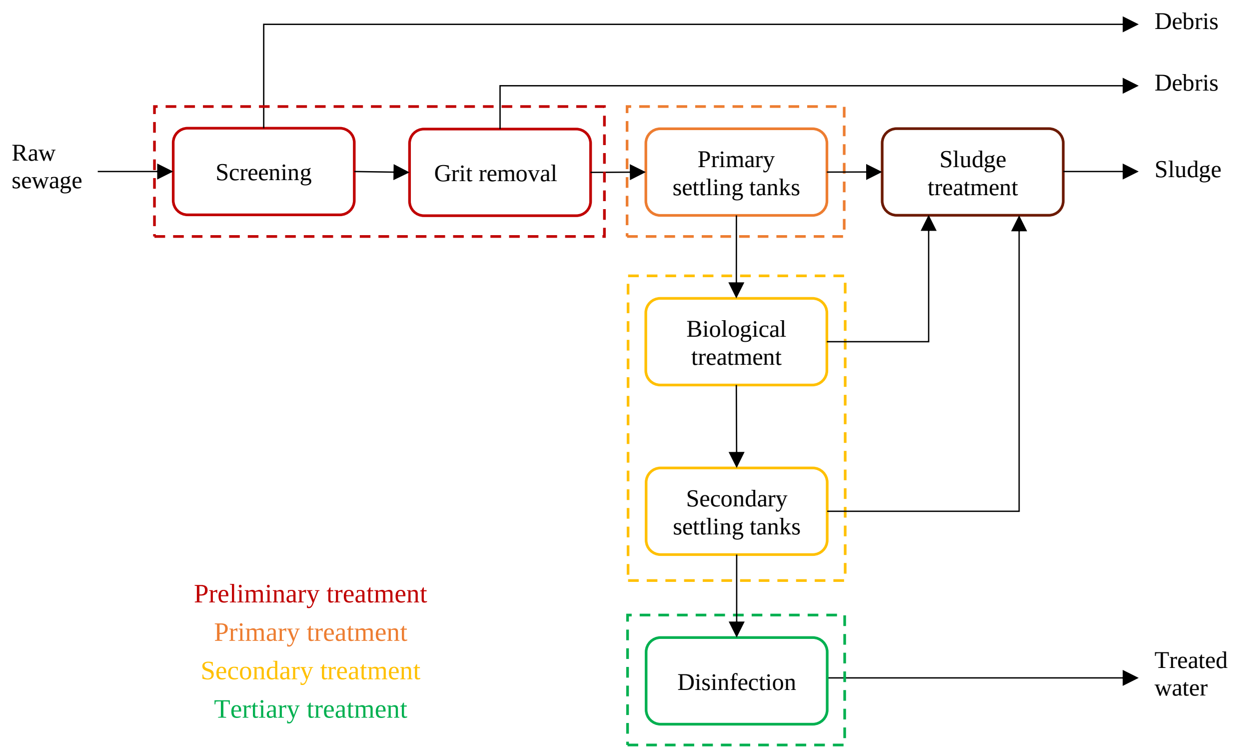

Figure 7-1: Wastewater treatment process diagram

Discharge of partially treated wastewater offshore via marine outfalls is commonly employed in coastal regions (Law & Tang, 2016). In South Africa, the wastewater undergoes screening prior to discharge, with no further processing (DWAF, 2004). In addition to 21 WWTPs, Cape Town has 3 marine outfalls.

7.2.2 Cotton bud stick flows entering and leaving wastewater treatment plants

The flow of cotton bud sticks was investigated for three wastewater treatment plants in Cape Town with different catchment area characteristics and capacities: Athlone, Cape Flats and Mitchells Plain. Cotton bud sticks were visible throughout the treatment process including secondary sedimentation, sludge treatment and the final effluent as shown in Figure 7-2.

A B

Figure 7-2: Evidence of plastic debris in the (A) dissolved air flotation tank and (B) effluent

A wide range of cotton bud stick concentrations in the influents and effluents were observed as shown in Table 7-1. A theoretical stick load is reported (based on the flowrate at the time of data collection), due to fluctuations in wastewater flowrates throughout the day. As mention in the methodology (section 3.4.2.3), it was not possible to calculate the overall plant efficiency due to the complexities associated with hydraulic retention times within the different plant operations. For example, primary sedimentation tanks may have retention times of 1 – 4 hours, whereas activated sludge treatment may have a time of up to 24 hours or more (WEF & ASCE, 1998). This is demonstrated by the case of Athlone, whereby the effluent concentration seemed to increase in the afternoons.

Overall, there was no relationship observed between influent flowrate and stick concentrations. Concentrations of cotton bud sticks entering the plants (influent), ranged from 4.4 – 97.2 sticks/ML. The largest variation in stick concentration was observed for Athlone which had both the highest and lowest concentrations. Higher concentrations were observed in the mornings for Athlone and Mitchells Plain, whereas the inverse was observed for Cape Flats which also had the lowest variation in concentrations. There was a significant difference observed for the concentrations of sticks over the two mornings at Athlone ($p<0.01$), whereby there was a sharp increase in stick concentration on the second day.

Concentrations of cotton bud sticks in the effluent ranged from 7.1 – 29.1 sticks/ML. The lowest effluent concentrations were observed for Mitchells Plain, which when coupled with the relatively low wastewater flowrate resulted in the lowest potential amount of cotton bud sticks flowing from the plant daily (72 – 144 sticks/day). The highest potential flowrates were observed for Athlone which had significantly higher wastewater flowrates, ranging from 1 600 – 6 300 sticks/day. Similar to the influent, a significant difference ($p<0.001$) was observed between the morning stick concentrations in the effluent at Athlone.

At Cape Flats and Mitchells Plain, the effluent is diverted to maturation ponds for disinfection prior to release into the waterways. Athlone also utilises maturation ponds, however a fraction of the effluent is immediately released to the waterways. Although ponds are often integrated into the wastewater treatment process, they also provide a habitat for local wildlife and birds and thus may be considered part of the natural environment in this context.

Table 7-1: Flowrates of cotton bud sticks entering and leaving wastewater treatment plants

	Influent								
	Athlone			Cape Flats			Mitchells Plain		
	Flowrate (ML/day)	Concentration (sticks/ML)	Theoretical stick load (sticks/day)	Flowrate (ML/day)	Concentration (sticks/ML)	Theoretical stick load (sticks/day)	Flowrate (ML/day)	Concentration (sticks/ML)	Theoretical stick load (sticks/day)
Morning 1	118.1	40.2±4.0	4752.0	86.0	27.6±4.1	2376.0	27.3	42.2±10.5	1152.0
Morning 2	129.6	97.2±8.5	12600.0	71.9	22.0±4.2	1584.0	22.3	74.3±11.8	1656.0
Afternoon 1	129.6	4.4±0.9	576.0	93.3	30.1±2.1	2808.0	18.2	23.7±6.5	432.0
Afternoon 2	125.3	4.6±1.4	576.0	92.5	35.0±7.0	3240.0	29.4	29.4±8.8	864.0
	Effluent								
	Athlone			**Cape Flats**			**Mitchells Plain**		
	Flowrate (ML/day)	**Concentration (sticks/ML)**	**Theoretical stick load (sticks/day)**	**Flowrate (ML/day)**	**Concentration (sticks/ML)**	**Theoretical stick load (sticks/day)**	**Flowrate (ML/day)**	**Concentration (sticks/ML)**	**Theoretical stick load (sticks/day)**
Morning 1	228.1	7.1±0.8	1620.0	74.2	7.8±3.2	576.0	26.3	5.5±3.7	144.0
Morning 2	217.7	29.1±4.1	6336.0	72.2	18.4±4.4	1331.7	19.7	7.3±4.9	144.0
Afternoon 1	222.0	10.7±2.0	2376.0	93.3	15.4±3.3	1440.0	21.8	6.6±4.4	144.0
Afternoon 2	226.4	10.8±3.6	2448.0	93.8	14.6±5.2	1368.0	20.2	3.6±3.6	72.0

7.2.3 Preliminary treatment removal efficiency

As mentioned in section 7.2.1, preliminary treatment serves to remove debris from wastewater. Each of the plants utilise 6mm screens during their preliminary treatment. Cape flats had the highest average removal efficiency with the lowest CV (Table 7-2). The lowest average removal was observed for Mitchells Plain which had the highest CV. There was no relationship observed between wastewater flowrate and removal efficiency.

Table 7-2: Cotton bud stick removal efficiency during preliminary treatment

	Athlone	**Cape Flats**	**Mitchells Plain**
Morning 1	45.5	60.6	56.3
Morning 2	58.9	59.1	26.1
Afternoon 1	56.3	38.5	-
Afternoon 2	25.0	48.9	33.3
Average	46.4	51.8	38.6
Standard deviation	15.4	10.3	15.7
Coefficient of variation	33.2	19.9	40.8

No removal efficiency is reported for the first afternoon at Mitchells Plain as the cotton bud sticks appeared to increase. This may be linked to limitations of the sampling methodology, specifically the short length of the sampling intervals[2].

7.3 Comparative Cotton Bud Stick Life Cycle Assessment

A comparative LCA was conducted on paper vs plastic cotton bud sticks. At the time of the study, locally produced paper cotton bud sticks were available in South Africa. Furthermore, many retailers had announced they would now be selling imported paper cotton buds (discussed further in section 7.4). Thus, two scenarios were modelled for locally produced and imported cotton bud sticks respectively. For plastic, locally produced cotton bud sticks were modelled.

The cotton bud sticks under consideration had equivalent functionality. They were both double tipped cotton buds with similar dimensions in terms of length and diameter. Thus, the functional unit for this study was one cotton bud stick and the reference flows corresponded to the weight of an individual stick (shown in Table 7-3).

Table 7-3: Cotton bud stick LCA functional unit and reference flows

Material	**Functional unit**	**Individual cotton bud stick weight (g)**	**Reference flow (g)**
Polypropylene	1	0.21	0.21
Paper	1	0.35	0.35

Details of the modelling approach, including cut-off criteria and allocation, as well as the data sources are available in Appendix B.

[2] Sampling periods were two-minutes long.

7.3.1 System boundaries

Cradle-to-grave life cycle assessments were conducted for each of the cotton bud stick types. This included raw material extraction and subsequent disposal. However, they did not take into consideration the application of cotton to the cotton bud stick as it was assumed this process would be the same regardless of stick material. The life cycle assessments took both formal and informal disposal as options at end-of-life including leakage into the natural environment. In South Africa, formally managed domestic waste is either recycled or landfilled (DEA, 2018). Waste that is not collected (i.e. informally managed) may be disposed in personal or communal dumps or burned. Waste that is not properly managed also has the potential to enter the marine environment.

The life cycle stages associated with each cotton bud stick are depicted in Figure 7-3.

7.3.1.1 Polypropylene life cycle stages

As mentioned in Chapter 5, in South Africa, polypropylene is manufactured via the polymerisation of propylene produced using coal as a feedstock (SASOL, n.d.). The cotton bud stick manufacturing process commences with plastic compounding, wherein the resin is mixed with additives, melted and extruded into pellets. These pellets are then extruded into hollow tubes with the required thickness and diameter, which are subsequently cooled and cut to size forming cotton bud sticks. The end-of-life options for cotton bud sticks included landfill, dumps, burning and the marine environment. The major cotton bud manufacturers are based on KwaZulu-Natal and Western Cape provinces.

7.3.1.2 Paper life cycle stages

To manufacture cotton bud sticks, paper is fed into a rolling machine with adhesive which produces cylindrical sticks with the desired dimensions. It was assumed that paper cotton bud sticks would have the same fate at end-of-life as polypropylene as they are both single-use disposable items.

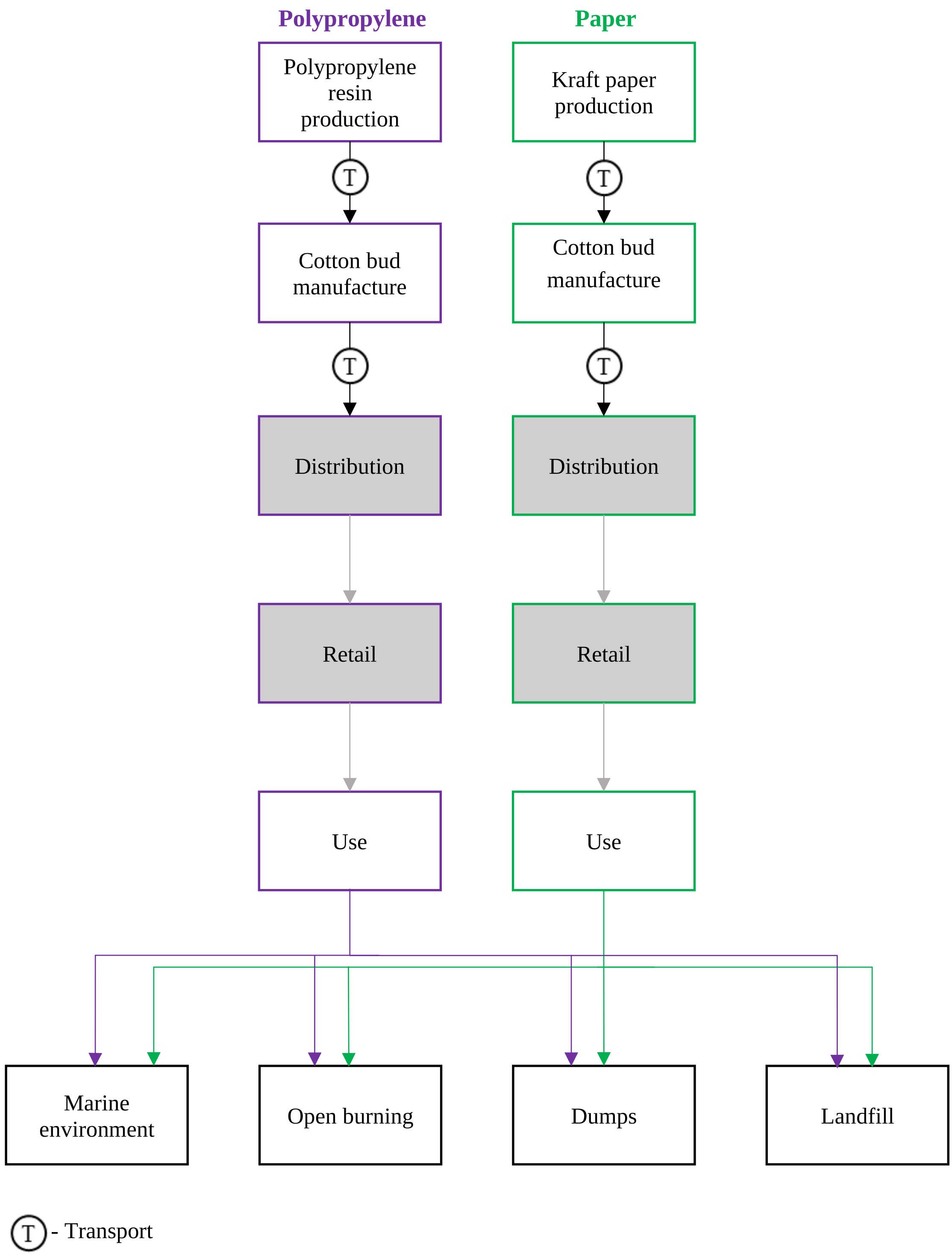

Figure 7-3: Cotton bud life cycle stages

7.3.2 Life cycle impact assessment

The impact assessment was conducted using the ReCiPe Midpoint (H) method, which uses global models to evaluate environmental burdens in 18 impact categories. The results of the LCIA are presented in Figure 7-4 – Figure 7-6. Dominance analyses were conducted for each material in each of the impact categories.

The LCIA results were normalised according to World ReCiPe H values, to enable comparison of the relative significance of the different impacts.

7.3.2.1 Climate change

Plastic was associated with significantly higher climate change emissions, totalling at least three times more than the paper options. This can be attributed to the use of coal as a feedstock in the production on polypropylene resin, which accounted for 96% of emissions. Material production was also a major contributor for both locally produced and imported paper cotton buds accounting for 75% and 66% of emissions respectively. Paper had the highest climate change emissions at end-of-life, accounting for 12 – 14% of emissions, due to its higher degradability in comparison to plastic.

7.3.2.2 Ozone Depletion

Material production was the major contributor to ozone depletion for all material options, accounting for 67% in the case of plastic and 75-77% for paper. Plastic had the lowest emissions ($1.07x10^{-11}$ kg CFC-11_{eq}), as it utilises relatively less petroleum and gas-based products as energy sources. The highest was observed for imported cotton buds ($4.48x10^{-11}$ kg CFC-11_{eq}) due to an increased use of petroleum-based products as energy sources, whereas in South Africa coal is often used as a primary source for energy generation. Transport was also a significant contributor to emissions, accounting for 28% for plastic, and 22% and 26% for imported and local cotton buds respectively.

7.3.2.3 Terrestrial acidification

Plastic had the highest terrestrial acidification emissions due to the use of coal as the primary feedstock polypropylene production, which contributed 94%, as well as the primary energy source. For local and imported paper cotton buds, paper production contributed 87% and 63% respectively. Imported sticks had a relatively higher transport contribution (27%), for the shipping of the cotton bud sticks to South Africa.

7.3.2.4 Freshwater eutrophication

Plastic had freshwater eutrophication impacts approximately 5 times has than the paper alternatives. This is due to the landfilling of coal mining spoils which contributed 99% to emissions. Similarly, local manufacture of cotton bud sticks had higher contributions ($3.15x10^{-8}$ kg P_{eq}) in comparison to manufacturing process in China ($6.43x10^{-9}$ kg P_{eq}), due to the use of coal-based energy.

7.3.2.5 Marine eutrophication

Unlike freshwater, plastic had the lowest marine eutrophication emissions with propylene production contributing 91%. Paper production had similar contributions in both local and import scenarios, accounting for 85% and 87% respectively. The landfilling and dumping of paper was also a notable contributor accounting for 13% and 9%, for locally produced and imported sticks respectively.

7.3.2.6 Human toxicity

Plastic had significantly higher human toxicity emissions which were at least 9 times higher than paper (2.11×10^{-3} kg 1,4-DB_{eq}), with polypropylene production contributing 98%. Paper production contributed 86% and 88%, in local and import scenarios respectively. Higher cotton bud stick manufacturing emissions were observed for locally produced sticks, in comparison to imported ones which can be attributed to the use of coal as a primary energy source.

7.3.2.7 Photochemical oxidant formation

The highest emissions were observed for plastic of which propylene production contributed 93%. For locally produced paper sticks, paper production contributed 82% whilst transport contributed 11%. In the case of imported sticks, material production contributed less with 62% whilst transport had a higher contribution of 31% associated with the shipping of the sticks.

7.3.2.8 Particulate matter formation

Plastic production had the highest particulate matter formation, which was associated with the use of coal as an energy source as well as the raw material in the production of polypropylene which contributed 93%. For locally produced paper sticks, similar contributions were observed as for photochemical oxidant formation whereby paper production contributed 86% and transport 8%. The same followed for imported sticks with paper production contributing 68% and transport 24%. Locally produced sticks had higher emissions than imported due to the use of coal as an energy source.

7.3.2.9 Terrestrial ecotoxicity

Plastic had the lowest terrestrial ecotoxicity emissions with propylene production contributing 63% and transport 26%. Both paper scenarios had comparable total emissions, however the contributions differed. For the import scenario, paper production contributed 93% and transport 5%, whereas for local sticks they contributed 86% and 13% respectively.

7.3.2.10 Freshwater ecotoxicity

Plastic had the highest emissions associated with the use of coal, with propylene production accounting for 98%. In addition to having comparable emissions (6.79×10^{-6} vs 8.87×10^{-6} kg 1,4-DB_{eq}), the two paper scenarios had similar life cycle stage contributions.

7.3.2.11 Marine ecotoxicity

Similar results to freshwater ecotoxicity were obtained for marine ecotoxicity. Polypropylene production was a major contributor to plastic emissions, accounting for 98%. Similar contributions were observed for both local and import paper scenarios, with paper production contributing 80% and 79% respectively and stick manufacture 12% and 10%.

7.3.2.12 Ionising radiation

Imported paper sticks had notably higher ionising radiation impacts with paper production contributing 90% and transport 9%. This is due to the relatively higher proportion of nuclear energy used. For the local scenario, paper production contributed 83%, transport 10% and stick manufacture 6%. Material production was also a major contributor to plastic stick production accounting for 80% of emissions, whilst transport and stick manufacture contributed 7% and 13% respectively.

7.3.2.13 Agricultural land occupation

Paper had significantly higher agricultural land occupation than plastic which can be attributed to the cultivation of wood for paper production which accounted for approximately 100%. For plastic, polypropylene production was the major contributor accounting for 96%

7.3.2.14 Urban land occupation

Unlike agricultural, urban land occupation was comparable for the three products. For plastic, polypropylene production contributed 88% and transport 10%. Similar contributions were observed for imported paper sticks with material production accounting for 86% and transport 11%. Higher transport contributions (20%) were observed for local paper sticks due to the transport distances between the paper and cotton bud stick manufacturers.

7.3.2.15 Natural land transformation

Imported paper had the highest land transformation area with paper production contributing 81% and transport 18%. In the local scenario, paper production contributed 84% and transport 16%. Plastic had the lowest transformation area, with polypropylene production contributing 88% and transport 10%.

7.3.2.16 Water depletion

Paper had the highest water depletion with comparable results for both scenarios, including contributions whereby paper production accounted for 98%. Cotton bud stick manufacture had a relatively higher contribution for plastic accounting for 37%, whilst polypropylene production accounted for 61%.

7.3.2.17 Metal depletion

Imported paper had the highest metal depletion with material production accounting for 81% and transport 14%. Similar contributions were observed for the local scenario whereby material production accounted for 84% and transport 11%. Polypropylene contributed 89% to plastic impacts, whilst transport contributed 8%.

7.3.2.18 Fossil depletion

As expected, plastic had the highest fossil depletion, due to the use of coal as a primary feedstock for polypropylene production which accounted for 97%. Higher transport contributions were observed for imported sticks due, associated with the shipping of the sticks to South Africa.

7.3.2.1 Potential marine pollution impacts

As mentioned in section 7.3.1, it was assumed that paper cotton bud sticks would have the same leakage propensity as plastic due to the similar design characteristics. Thus, both plastic and paper sticks are associated with potential impacts in the marine environment with a leakage rate of 85%, as estimated in section 4.2.3. Unlike plastic, paper is biodegradable in the marine environment (Greene, 2018).

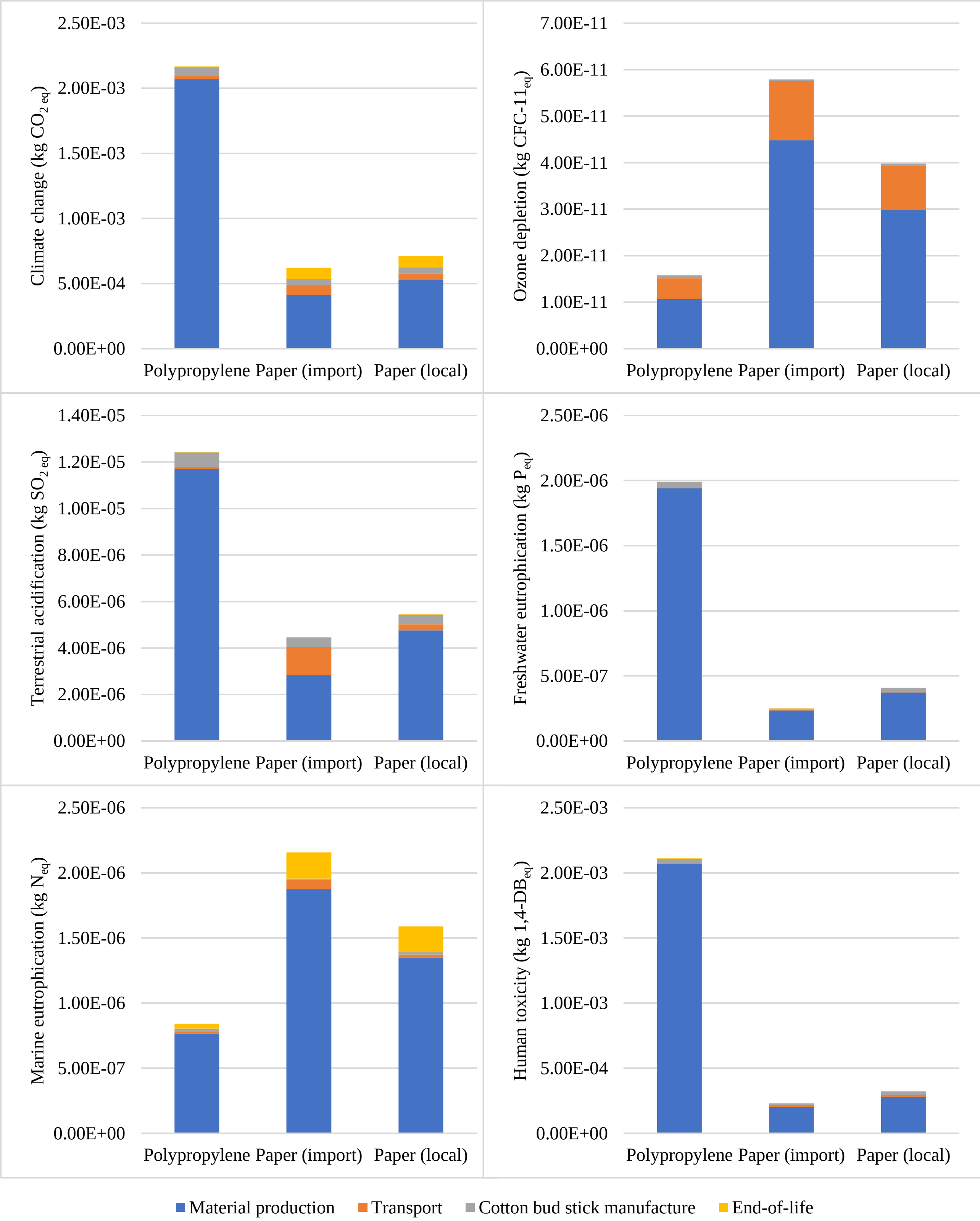

Figure 7-4: Cotton bud stick LCIA results for climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication and human toxicity categories

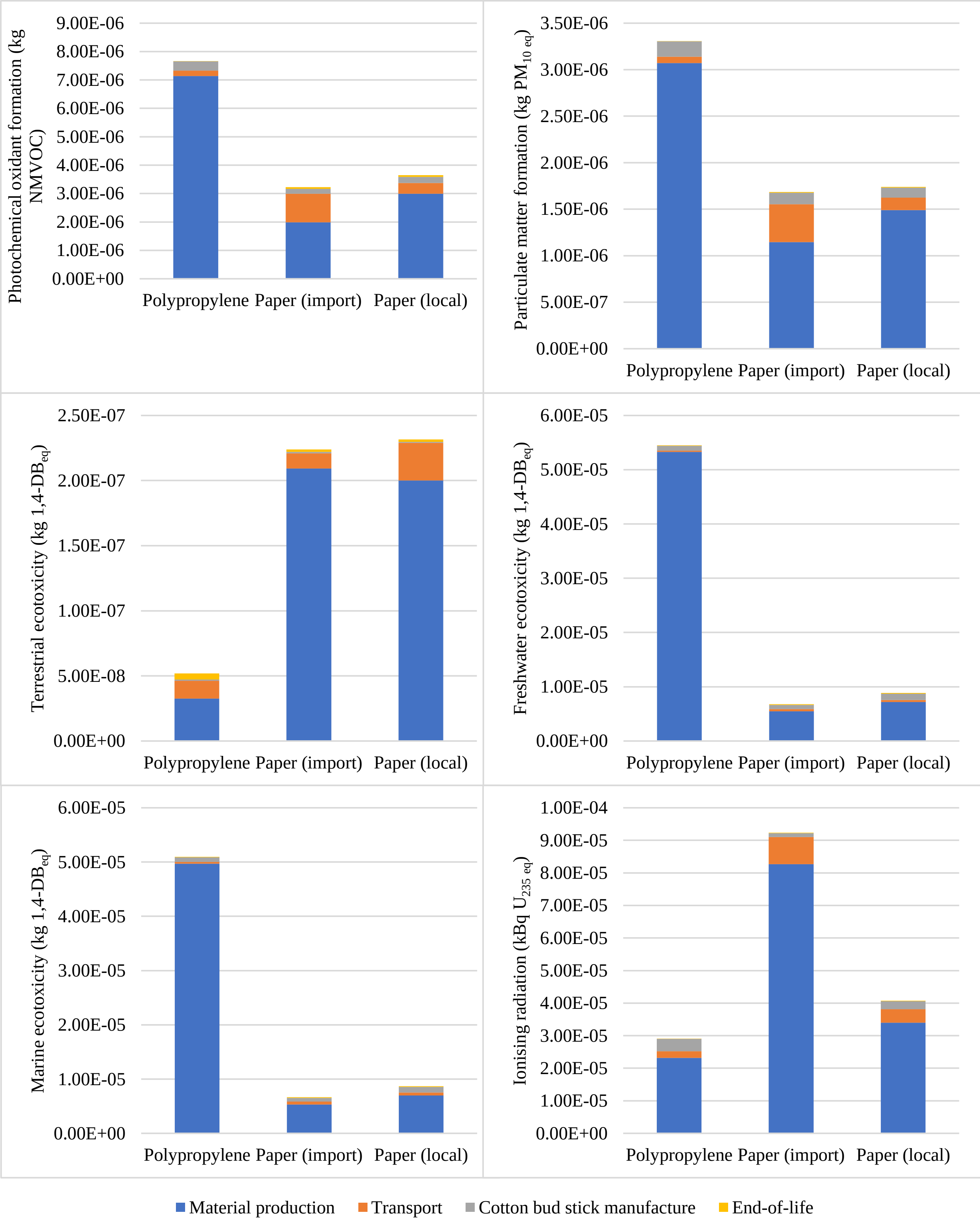

Figure 7-5: Cotton bud stick LCIA results for photochemical oxidant formation, particulate matter formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity and ionising radiation categories

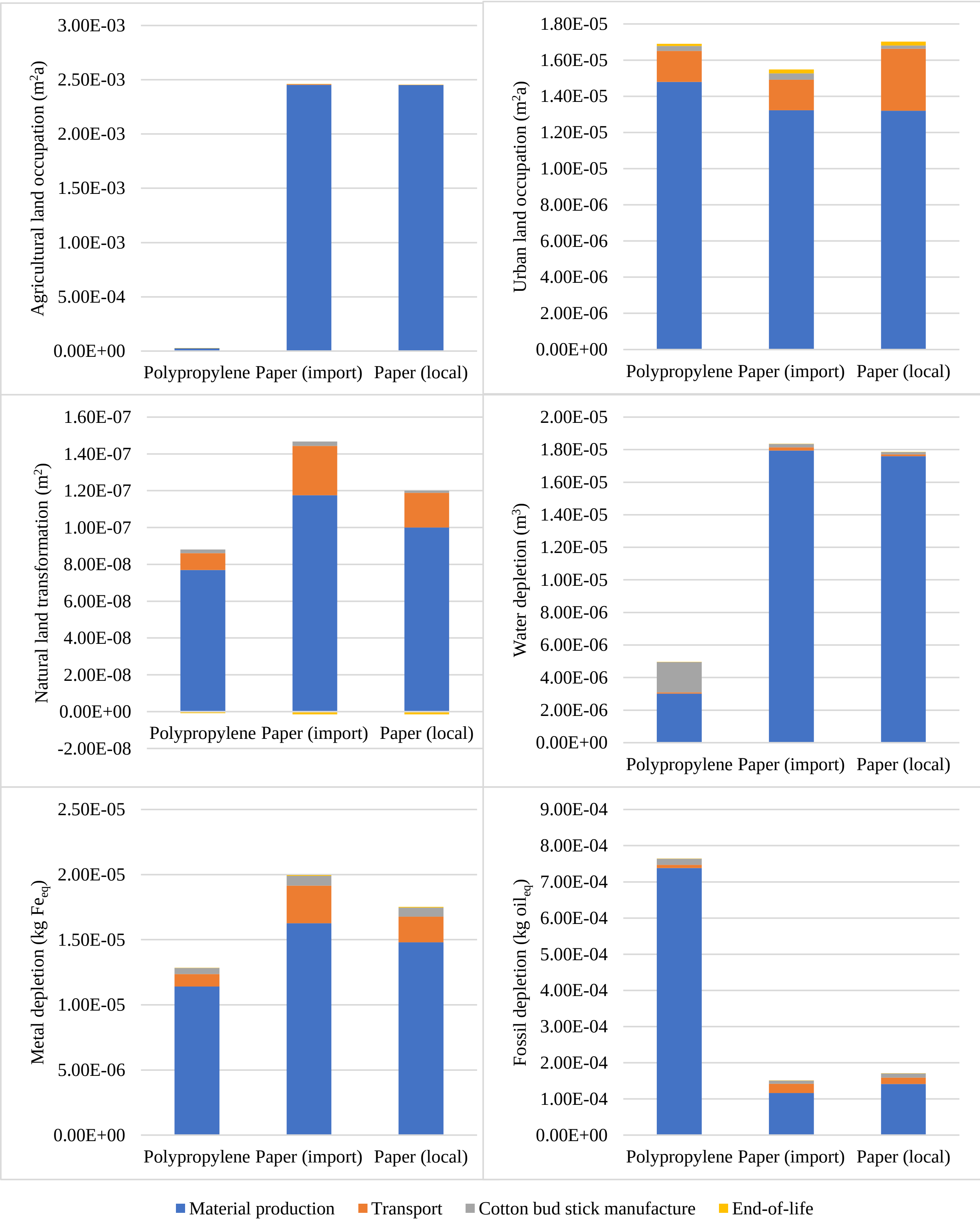

Figure 7-6: Cotton bud stick LCIA results for agricultural land occupation, urban land occupation, natural land transformation, water depletion, metal depletion and fossil depletion categories

7.3.2.2 Normalisation

Upon normalisation (shown in Figure 7-7), the most significant impacts were observed for human toxicity, freshwater and marine ecotoxicity as well as freshwater eutrophication. In each case, notably higher impacts were observed for polypropylene cotton bud sticks, whilst imported paper sticks had the least.

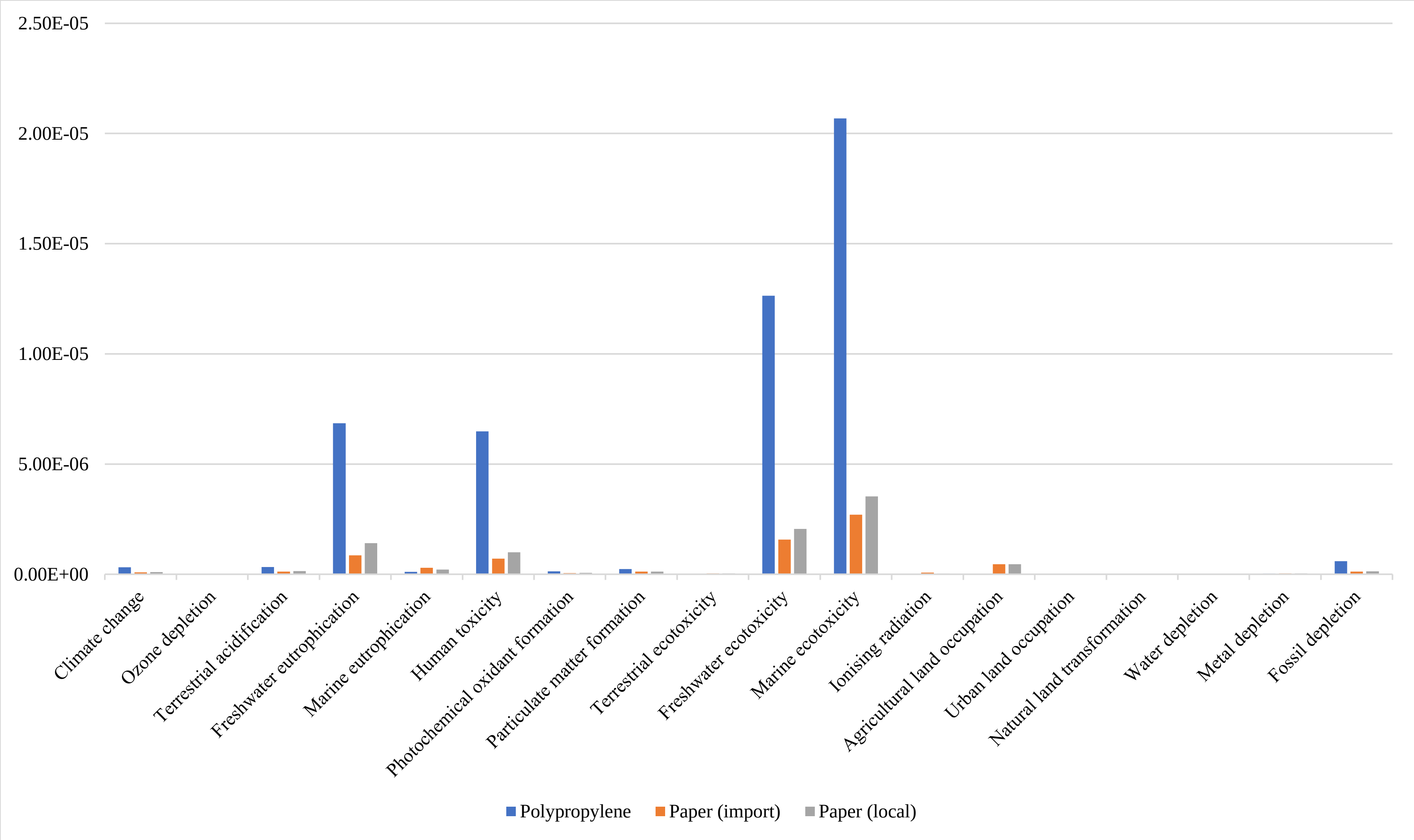

Figure 7-7: Cotton bud stick LCIA normalised results

7.3.3 Variation analyses

Variation analyses were conducted on the market share of the cotton bud stick manufacturers, which would directly affect the distances from material producers to cotton bud stick manufacturers (section 7.3.2.2).

7.3.3.1 Effect of cotton bud manufacturer market share

In South Africa, cotton bud manufacturers are based in the KwaZulu-Natal and Western Cape provinces. The market split for manufacturers and distributors was not available thus the average distance was considered. The effect of this assumption was explored via the variation of transport distances between material producers and cotton bud manufacturers.

In the case of paper, transport was a notable contributor to ozone depletion, urban land occupation, natural land transformation, terrestrial ecotoxicity, photochemical oxidant formation, and fossil and metal depletion. As such, a change in market shares had a greater influence in these categories (Figure 7-8), whereby the maximum distance was associated with production in Western Cape and the minimum with KwaZulu-Natal.

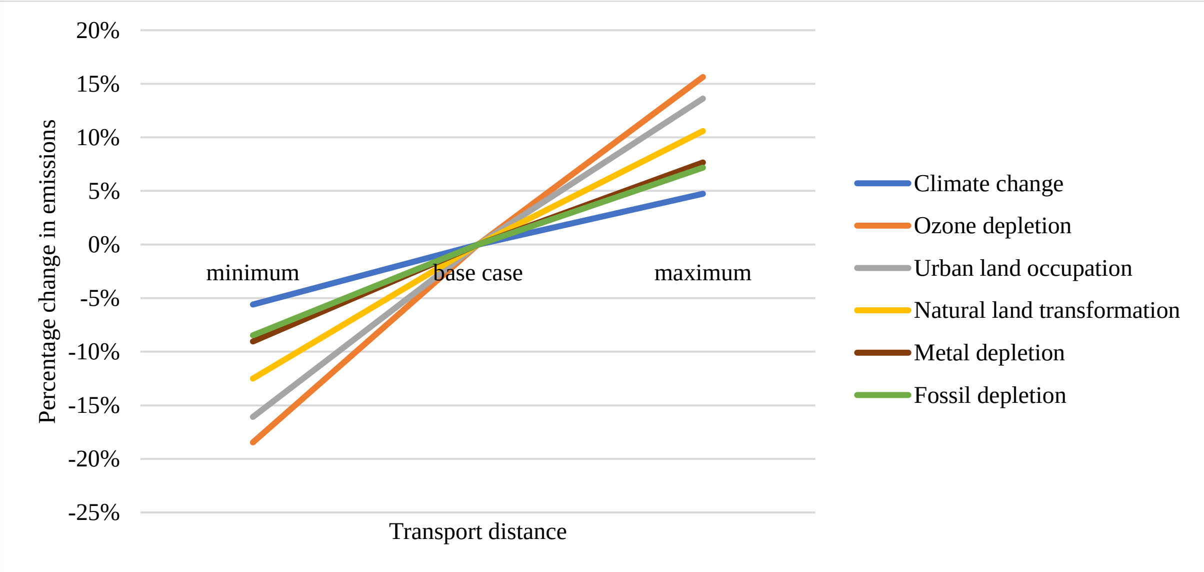

Figure 7-8: Effect of transport distance (i.e. market share) on local paper cotton bud stick emissions

For plastic, transport was a notable contributor to ozone depletion, terrestrial ecotoxicity, urban land occupation, natural land transformation and metal depletion. Thus, more notable variation in these categories were observed with varying transport distance (Figure 7-9). A sharp increase is observed from the base case as the majority of manufacturers are located relatively close to the propylene manufacturer (located in Mpumalanga), with one manufacturer located further afield in the Western Cape (maximum distance).

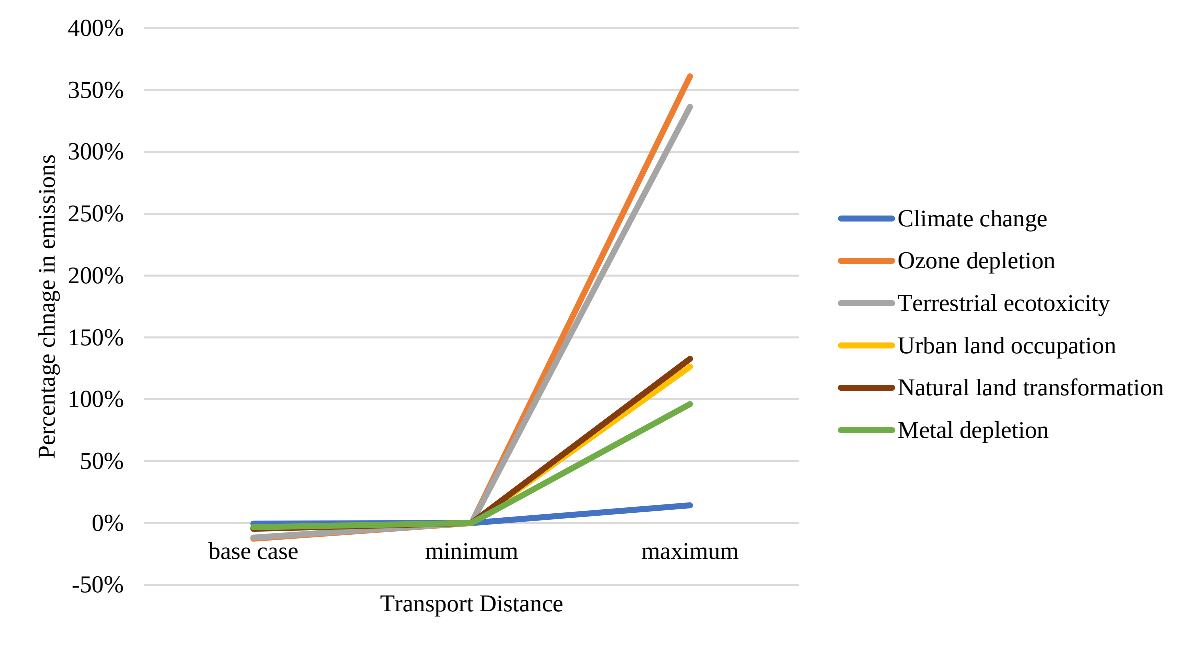

Figure 7-9: Effect of transport distance (i.e. market share) on plastic cotton bud stick emissions

Regardless of the market share the overall product comparisons within the impact categories were maintained. For example, if local paper was found to have the highest emissions in a category this was maintained regardless of the changes in transport distance.

7.4 Value-Chain Actor Responses

As mentioned in section 7.1, there are two potential interventions for cotton bud sticks: material substitution and improved removal at WWTPs. In South Africa, both options were under consideration and were explored via interviews with relevant value-chain actors.

7.4.1 Material substitution

In South Africa, there are two major cotton bud stick brand owners, Dove Beauty and Cherubs, of which the latter was already manufacturing paper cotton bud sticks in conjunction with a plastic option. However, there has been no official public response to the rising concern surrounding cotton bud sticks as a major contributor to marine pollution. In the retail space, in June 2018 major retailers Pick n Pay and Woolworths announced their intention to replace plastic cotton bud sticks with paper for their in-house brands, as part of a set of initiatives to combat plastic pollution (Pick n Pay, 2018; Woolworths Holdings Limited, 2018). There were no other official public responses by retailers in South Africa.

Of the retailers consulted, three were shifting from plastic to paper cotton bud sticks (Table 7-4). As mentioned in Chapter 5, Retailer C, had no official response to plastic marine issues due to the independence granted to store owners. Similar to straws, retailers cited consumer pressure as the driving force for material substitution.

"A lot of the changes that we made with regard to paper stemmed q-tips [cotton buds], straws, shopping bags was customer based" – Retailer A

Table 7-4: Consulted value-chain actor responses – cotton bud sticks

Participant	Response
Retailer A	Paper sticks
Retailer B	Paper sticks
Retailer C	No official response
Retailer D	Paper sticks

Unlike straws, paper was the only popular alternative to plastic cotton bud sticks. Thus, the only consideration mentioned by interviewees was cost. In this regard, Retailer D remarked that suppliers were raising prices in response to the rising popularity of paper sticks. Due to the need for quick action on the issue, the retailer described it as "a gun against the head situation in some ways". Similarly to the case of straws (section 5.3.2), the potential environmental impacts associated with the material change were not taken into consideration.

7.4.2 Intervention at wastewater treatment plants

As shown in section 7.2, WWTPs are a pathway for cotton bud sticks to enter the environment. Thus, WWTPs present a potential intervention point for cotton bud release into the marine environment. According to Engineer A, who works in wastewater treatment, current wastewater treatment infrastructure cannot effectively remove cotton bud sticks from the WWTP due to their specific size dimensions. Thus, they were investigating infrastructure improvements to increase stick removal during preliminary treatment, in the form of new screening technology. The engineer cited the operational risk posed by debris to the wastewater treatment unit processes in conjunction to improving the aesthetics of the effluent as the motivation for the improvements. Despite the identification of WWTPs as a pathway for cotton bud sticks into the marine environment, Engineer A, remarked that there had been no notable public pressure in this regard.

Cost was cited as the primary challenge to infrastructure upgrades. This was particularly prohibitive for plants where the process design did not allow for retrofitting, necessitating a complete rebuild of inlet works. The engineer also cited the potential impacts associated with increased waste removal, which would require an increase in trucks to transport the waste. This was viewed from a carbon footprint perspective as well as a social perspective in terms of visual and noise impacts on the surrounding residents.

7.5 Discussion

7.5.1 Cotton bud stick flow through wastewater treatment plants

Although WWTPs have been identified as a potential pathway for plastic into the marine environment, this is often explored within the context of microplastics (Carr, Liu & Tesoro, 2016; Murphy et al., 2016; Gatidou, Arvaniti & Stasinakis, 2019). This may be attributed to the fact the removal of large debris is integrated into the wastewater treatment process during primary treatment where the raw sewerage is screened. Theoretically, cotton bud sticks would be removed during this process, however, the removal efficiency is dependent on the size and type of the screens (Qasim, 1999; Templeton & Butler, 2010; Mourgkogiannis, Kalavrouziotis & Karapanagioti, 2018). Furthermore, plastic debris has the potential to not be captured based on their overall dimensions and orientation as they flow through the screen. This is exemplified by cotton bud sticks which have a length of 70 – 75 mm and a diameter of 2.0 – 2.5 mm, giving them the potential to pass through screens depending on their orientation. For example, they may pass through fine bar screen if flowing parallel to the bars. This was observed in the study whereby cotton bud stick concentrations decreased an average of 39 – 52 % after preliminary treatment where they passed through 6 mm screens. However, smaller screen sizes are associated with a higher cost of manufacturing (Mourgkogiannis, Kalavrouziotis & Karapanagioti, 2018). Furthermore, smaller sizes increase the likelihood of organic matter being captured by the screens which presents a technical constraint as organics are designed to be removed after primary treatment to facilitate proper disposal of the different types of waste (WEF & ASCE, 1998).

In Cape Town, cotton bud sticks were observed throughout the wastewater treatment process. This is similar to a study conducted by Mourgkogiannis, Kalavrouziotis & Karapanagioti (2018) across 101 WWTPS in Greece, whereby plant operators reported observing cotton bud stick throughout the plants, including the sludge. As mentioned in section 7.2.1, due to their low density, floating plastic items are also potentially removed during the primary and secondary treatment processes, in tanks which employ skimming of the surface (Cheremisinoff, 2002; Mourgkogiannis, Kalavrouziotis & Karapanagioti, 2018). This was evidenced by the presence of plastic debris in the sludge treatment which included scum skimmed from tank surfaces at Athlone (Figure 7-2A). This was also observed by Carr et al. (2016), whereby microplastics were observed to be relatively abundant in primary tank scum which is skimmed off the surface. In addition, Mourgkogiannis, Kalavrouziotis & Karapanagioti (2018) observed a sharp decrease in reported cotton bud sticks after secondary treatment which employed a scraper for surface collection. This was observed for the case of Mitchells Plain, which employs scrapers on the secondary sedimentation tanks, whereby a sharp decrease was observed in effluent cotton bud stick concentrations in comparison to the influent.

Although some WWTPs can achieve high removal efficiency, the high volumes of water processed result in large quantities of plastic being released into the marine environment (Murphy et al., 2016; Mourgkogiannis, Kalavrouziotis & Karapanagioti, 2018). Although Mitchells Plain had the lowest removal of stick during primary treatment, it had the lowest effluent flowrate and stick concentration and thus the lowest amount of potential sticks being released. Athlone had the highest effluent flowrates and was thus associated with the highest potential release of cotton bud sticks.

The influence of catchment area characteristics was evidenced by the varying influent cotton bud stick concentrations observed across the plants which ranged from. In addition, the results suggested that cotton bud stick concentrations were dependent on the time of day. This was evidenced by the cases of Athlone and Mitchells Plain which both had notable decreases in stick concentrations in the afternoon. This is to be expected as cotton bud sticks commonly form part of a person’s morning ablutions. However, this was not the case at Cape Flats where there was no significant difference ($p>.05$) between morning and afternoon concentrations. This may be attributed in the catchment area size resulting in morning flows arriving at the plant over a prolonged period of time.

7.5.2 Cotton bud stick life cycle assessment

Imported cotton bud sticks had the lowest emissions across the majority of impact categories, including those found to have notably higher significance during normalisation (i.e. human toxicity, freshwater and marine ecotoxicity and freshwater eutrophication. They had the highest emissions for ozone depletion, marine eutrophication, terrestrial ecotoxicity, ionising radiation, agricultural land occupation, natural land transformation and water and metal depletion for which plastic had the lowest emissions. However, these impacts were shown to have relatively lower significance during normalisation. Although plastic alternatives are often reported to perform better than paper products in terms of climate change emissions, this was not the case. As mentioned in Chapter 5, this is due to the use of coal as a primary feedstock in the production of propylene (unique to South Africa) and as a primary energy source for electricity production. The effect of the latter was also evident when comparing paper sticks, whereby locally manufactured sticks had higher climate change emissions.

Material production was the major contributor to emissions for all three sticks, contributing up to 99.5%. Stick manufacture was only a notable contributor (>10%) to ionising radiation and water depletion in the case of plastic, and freshwater and marine ecotoxicity for both paper scenarios. Transport of imported sticks was a significant (> 20%) contributor to ozone depletion, terrestrial acidification, photochemical oxidant formation and particulate matter formation and to a lesser extent natural land transformation and fossil depletion. However, the transport emissions for local paper were higher for most of these categories excluding ozone depletion and natural land transformation, which can be attributed to the use of road transport which is associated with higher emissions than freight shipping. Variations in market share for locally produced sticks had significant impacts on ozone depletion, urban land occupation and natural land transformation.

Impacts at end-of-life were only notable contributors to climate change (14% and 12%) and marine eutrophication (9% and 13%) for imported and locally manufactured paper sticks. These impacts can be attributed to the breakdown of paper in landfills and dumps. Similarly, to disposable straws, it can be assumed that paper cotton bud sticks will suffer a similar fate to plastic sticks due to similarities in characteristics. More specifically, they are just as likely to be flushed and enter wastewater treatment plants. Once they enter the WWTP, they can be assumed to have a similar capture rate as plastic sticks during screening due to similarities in dimensions. However, the separation mechanisms beyond screening will differ since the wet paper sticks will sink whereas the plastic sticks will float. Thus, paper sticks are likely to be removed via sedimentation processes including during grit removal, primary and secondary treatment. With regards to potential marine impacts, paper is marine degradable. Thus, it will pose a less significant physical threat to marine life in comparison to plastic, as it will not persist in the marine environment.

7.5.3 Value-chain actor responses

Similar to straws, responses to cotton bud sticks were driven by consumer pressure due to their contribution to marine pollution. As there was only one alternative material option available to retailers, the only factor they took into consideration was cost. However, the drive to make a swift change, left retailers vulnerable to price gouging by manufacturers.

From a wastewater treatment perspective, current infrastructure cannot effectively remove cotton bud sticks. Thus, interventions are being explored to install better screening technology to increase removal. However, cost was cited as a major constraint to infrastructure upgrades, particularly in cases where new plant inlet works would need to be built. The interventions are motivated by the operational risk plastic debris poses to plant equipment and a desire to improve the aesthetics of the discharged effluent. The increasing concern surrounding cotton bud stick contribution to marine pollution was not mentioned as a motivating factor. Unlike retailers, Engineer A took into consideration the environmental impacts associated with an intervention; increased waste removal would result in increased climate change emissions related to the transport of additional waste to disposal.

7.6 Conclusions

Wastewater treatment plants were confirmed to be a pathway for cotton bud sticks into the environment, whereby sticks were observed throughout the plant including the discharged effluent. Furthermore, this may be linked to the results of the beach surveys (Chapter 4) whereby more sticks were observed at beaches downstream from WWTPs (e.g. Paarden Eiland which is downstream from Athlone WWTP). Although debris is designed to be removed during preliminary treatment, the dimensions of the sticks makes them likely to pass through the screens depending on their orientation. This was demonstrated in the screen removal efficiencies which ranged from 39 – 52%. However, due to the limited nature of the study, variations in removal efficiencies and discharged stick amounts may be observed at other WWTPs with varying screening technologies as well as wastewater flowrates and catchment area characteristics.

From a life cycle assessment perspective, paper options were found to be favourable in comparison to plastic across the majority of categories including climate change emissions. The use of coal as a feedstock for polypropylene production coupled with coal-based energy resulted in significantly higher climate change emissions for plastic cotton bud sticks. The impact of the latter was also observed in the case of locally manufactured paper sticks which had higher climate change emissions in comparison to imported sticks. Material production was the major contributor to emissions for all material options. Variability in local manufacturer market share, and consequentially transport distance to stick manufacturers, was found to have a significant impact on ozone depletion, urban land occupation and natural land transformation. At end-of-life, paper and plastic sticks may be expected to behave differently in wastewater treatment plants as the former sinks whilst the latter floats. Thus, different plant removal rates may be observed. Upon entering the marine environment, paper was deemed to pose a lesser physical risk to marine life in comparison to plastic due to it biodegradability.

From a retailer perspective, substituting plastic cotton bud sticks with paper was viewed as a simple and quick way to appease consumers. Although, the potential environmental impacts were not a consideration during the decision-making process, the results of the LCA indicate paper as more favourable in comparison to plastic. Whilst wastewater treatment plants have been identified as a pathway for cotton bud stick flows into the marine environment, improvements to screening technology were motivated by the operational risk debris poses to plant equipment and a desire to improve the aesthetic of discharged effluent. In both cases, cost was the major consideration to differing extents. Whilst retailers are able to absorb the costs associated with material substitution, cost is a significant constraint to wastewater treatment plant upgrades.

Chapter 8 Plastic Product Life Cycle Management in South Africa

This chapter aims to meet the thesis objective to investigate the potential influence of providing specific knowledge on product leakage on the life cycle management of products including plastic as a material choice. As such, it explores approaches to plastic product life cycle management in South Africa and the influence of knowledge of plastic leakage in this regard. It begins with an exploration of approaches to plastic product LCM employed by fast-moving consumer goods (FMCG) companies and retailers based on publicly available information. In order to contextualise value-chain actor responses to the increasing concern surrounding plastic pollution, key packaging design criteria and their relative influence are explored based on a series of interviews. This includes the extent to which product fate at end-of-life is taken into consideration. Following this, value-chain actor perspectives surrounding the cause of plastic pollution and their knowledge on the extent of the problem are explored. The influence of plastic leakage on plastic product life cycle management is investigated through examining value-chain actor responses to plastic pollution, including the key drivers for intervention development as well as the associated challenges, barriers or opportunities. This consolidates the results of the functionality-defined case studies presented in Chapters 5 – 7 and expands on them by providing insights into company-wide strategies. The results are then discussed in relation to the key research questions presented in section 3.1:

a. *How is plastic product environmental management, and specifically LCM approached in South Africa?*
b. *What are the key criteria informing packaging design and what is their relative influence?*
c. *What is the influence of plastic pollution on plastic product LCM?*
d. *What are the key barriers, challenges and drivers for the development of strategies to mitigate plastic pollution?*

As mentioned in Chapter 3, two sets of interviews were conducted; in March 2017 and November 2018 – March 2019. This enabled the exploration of any shifts in perspectives. Thus, the results of the interviews from both sessions have been integrated allowing for the highlighting of any contrasts or similarities. Interviewed value-chain actors included employees of brand owners, industry associations, recyclers and retailers who each had in-house brands.

8.1 Life Cycle Management Approaches in South Africa

As described in the methodology (section 3.4), approaches to product life cycle management employed in South Africa were explored via a survey of publicly available information (including websites, reports and media releases), on fast moving consumer goods companies and retailers. More specifically, the application of any LCM tools, design concepts or strategies in South Africa was investigated (discussed in section 2.4). In addition, companies which operated in multiple countries were characterised according to their business strategies (described in Table 3-4).

As shown in Table 8-1, multinational companies were found to adopt a number of LCM concepts across their departments. More specifically, companies apply different life cycle concepts to the respective life cycle stages. Sustainable procurement is practised for materials sourcing, which often takes a socio-economic perspective. Many companies employ cleaner production principles with a focus on reductions in energy and water consumption as well as carbon emissions and waste production. However, this is often based on a gate-to-gate assessment of the manufacturing facilities directly owned by the company and does not necessarily extend to suppliers. Life cycle assessments are not commonly conducted; when they are it is usually for new products or to support significant product improvements. Furthermore, no evidence was found of any of the surveyed companies having employed LCC or SLCA. When it comes to packaging design, sustainable product design traditionally takes the form of packaging reduction and light-weighting. To a lesser extent, some companies (Coca-Cola Nestle, PepsiCo, Tiger Brands and Unilever) are exploring the use of compostable or plant-based material alternatives to plastic. Recent years have seen increasing emphasis on design for recycling and integration of recycled content, particularly for plastic packaging. As expected, these companies often practice green marketing based on the application of the aforementioned concepts.

In South Africa, extended producer responsibility (EPR) is not legislated in this sector. However, many companies practise EPR through voluntary membership of producer responsibility organisations (PROs) particularly in the packaging industry. Furthermore, membership of PROs may become mandatory as stipulated by the Industry Waste Management Plans (IWMP) submitted by the various packaging industries in response to a governmental call for industry waste management plans for paper and packaging (DEA, 2017). More specifically, the IWMP submitted by Packaging SA would require all producers, importers, brand owners and retailers to be members of relevant material associations (Packaging SA, 2018).

Unlike large multinationals, locally based South African companies which do not have investments in other countries, and are not listed on any stock exchanges, often do not employ any LCM concepts. Their public communications are centred around product marketing, via a company website and various social media platforms. It is also noteworthy that these brands were identified as the major contributors to marine litter during the beach surveys (section 4.1.5). For example, Unibisco Biscuits SA which was observed to be a major contributor of biscuit packaging, Richester Foods and Comestibles Aldor for lollipop wrappers, as well as Truda Foods and Frimax Foods when it came to snack packets.

Table 8-1: LCM concepts, strategies, tools and techniques employed by companies in South Africa

	Business Strategy	Headquarters	Stock Exchange Listing	Annual Report	Tools and Techniques				Design Concepts		Strategies	
					Life Cycle Assessment	Life Cycle Costing	Social Life Cycle Assessment	Materiality Assessment	Sustainable Product Design	Design for Recycling	Sustainable procurement	Cleaner Production
ABInBev	multinational	Belgium	✓	✓					✓	✓	✓	✓
Astral Foods	multinational	South Africa	✓									✓
AVI	international	South Africa	✓	✓				✓	✓	✓	✓	✓
Clover	multinational	South Africa	✓	✓							✓	✓
Coca Cola	multinational	United States	✓	✓	✓				✓	✓	✓	✓
Comestibles Aldor	global	Colombia										
Frimax Foods	national	South Africa										
IQ Foods	national	South Africa										
Jive	national	South Africa										
Nestle	multinational	Switzerland	✓	✓	✓			✓	✓	✓	✓	✓
Parmalat	multinational	Italy	✓	✓				✓	✓			✓
PepsiCo	multinational	United States	✓	✓				✓	✓	✓	✓	✓
Pick n Pay	*	South Africa	✓	✓					✓	✓	✓	✓
Pioneer Food	multinational	South Africa	✓	✓				✓			✓	✓
Premier	global	South Africa	✓									✓
Procter & Gamble	multinational	United States	✓	✓					✓	✓	✓	✓
RCL	global	South Africa	✓	✓					✓	✓	✓	✓
Rhodes Food Group	global	South Africa	✓									✓
Richester Foods	national	South Africa										
Shoprite Holdings Ltd	*	South Africa	✓	✓					✓	✓	✓	✓
The Lion Match Company	national	South Africa										
The SPAR Group Ltd	*	Netherlands	✓	✓				✓	✓	✓	✓	✓
Tiger Brands	multinational	South Africa	✓	✓	✓				✓	✓	✓	✓
Truda Foods	national	South Africa										
Twizza	national	South Africa										
Unibisco Biscuits SA	unknown	unknown										
Unilever	multinational	United Kingdom	✓	✓	✓				✓	✓	✓	✓
Woolworths Holdings Ltd	*	South Africa	✓	✓	✓			✓	✓	✓	✓	✓

*Retailers were not characterised due to their complex business models which included independently owned franchises

8.2 Key Criteria Influencing Packaging Design

A set of key design criteria taken into consideration during packaging design was compiled based on the series of interviews conducted in 2017. These addressed a number of aspects including:

- Functionality
- Technical requirements
- Economic implications
- Marketing
- Environmental impacts
- Fate at end-of-life

Value-chain actor perspectives on these criteria from both sets of interviews are presented in an integrated format (sections 8.2.1 – 8.2.5) to facilitate comparison between the two periods.

8.2.1 Functionality and technical requirements

Attributes related to functionality were cited as the most important metrics that determine product design. In particular, the ability of packaging to perform its primary function to protect and preserve was the most important criterion across the board. Brand owners and packaging designers are also limited by technology availability and capability, particularly in cases where a redesign may require the procurement of new technology which is associated with high financial implications. Retailer D did not deem technology availability to be relevant as they did not own any manufacturing facilities and were inherently bound by the options presented by their suppliers.

8.2.2 Economic

The importance of cost when determining viable alternatives in the design process was strongly emphasised by interviewees.

8.2.3 Consumer perception

The influence of consumer perception featured strongly as one of the factors influencing brand decisions. Interviewees emphasised that brands are motivated by image and perception and would like to be seen as "good citizens". Thus, products are designed with consumer convenience and perception in mind so as to promote choice.

During the first round of interviews, Brand Owner A pointed out that it would take an immense amount of pressure to motivate brands to make a change, particularly if such a change would potentially increase operational costs thus impacting their competitiveness. This was demonstrated in the cases of straws and cotton bud sticks, discussed in Chapter 5 and Chapter 7, whereby consumer pressure resulted in material substitution away from plastic despite the cost implications.

8.2.4 Environmental considerations

All brand owners and retailers appeared conscious of the environmental footprint of their products and paid close attention to the impacts of their products from raw material acquisition through to the manufacturing of the final product, i.e. a cradle-to-gate approach. Thus, when comparing alternatives, the impacts at end-of-life are not fully accounted for. Furthermore, as highlighted in section 8.1, environmental impacts considered are often limited to water and energy consumption, carbon emissions and waste production. These impacts are often only formally considered once cost-effective designs which meet the functional and technical requirements have been identified. The majority of value-chain actors were familiar with LCA and viewed it as a useful tool, both during the design of new products and to reduce the footprint of current products. However, as mentioned in section 8.1, very few companies conduct LCAs citing the cost as prohibitive.

Whilst Retailer D was personally aware of the need to take environmental impacts into consideration, the profit driven nature of their company meant that they are not taken into consideration.

8.2.5 End-of-life considerations

There was a shift observed in the extent to which end-of-life is taken into consideration. In 2017, value-chain actors reported that waste scenarios are rarely considered during the product design process. Furthermore, they seemed to have limited empirical knowledge regarding the fate of products at end-of-life particularly with regards to leakage. This was attributed to a lack of reliable evidence-based information. Despite acknowledging leakage as a reality, value-chain actors seemed to take an idealised approach to the end-of-life of their products which was often not based on evidence. More specifically, they seemed to only consider recycling and landfilling as possibilities at end-of-life. Thus, it seemed that leakage was viewed as an externality when it came to design decisions. However, the Packaging Designer recognised the importance of understanding the most likely life cycle of a product for consideration during the design process.

During the second round of interviews, there was increasing consideration of the possible fate of a product. Despite the limited information surrounding waste flows, value-chain actors are more cognizant of the potential for leakage. However, the extent to which leakage propensity is taken into consideration varies (discussed further in section 8.4.2). Retailers B and D did not consider it a consideration during packaging design; it did however influence decisions when coupled with consumer pressure.

Waste management infrastructure type and availability was cited as a consideration during product design. As mentioned in section 8.1, there has been an increasing focus on design for recycling. In this regard, brand owners and retailers were conscious of the potential capacity limitations of the recycling industry thus, some are taking more active roles in supporting recycling activities (discussed further in section 8.4.1). Only Retailer A and Brand Owner A take into consideration the recovery rate associated with different material options, using it as an indication of the likelihood for recycling at end-of-life. Biodegradable and/or compostable materials are not highly favoured by value-chain actors due to the lack of suitable infrastructure to treat them. In addition, value-chain actors were concerned about the potential for contamination of recycling streams by such materials.

8.2.6 Relative importance of packaging design criteria

During the second set of interviews conducted in 2018 – 2019, the relative importance of the different metrics was explored for retailers and brand owners with local decision-making power when it came to product design. This included ranking of the different criteria according to their importance during packaging design, whereby the most important was assigned a rank of 1 (Table 8-2). Participants often assigned equal rankings to multiple criteria, covering different aspects of packaging design, giving an indication of the complexity associated with packaging design. In addition, they highlighted that packaging is often an iterative process, due to the need to satisfy the range of different criteria.

Table 8-2: Value-chain actor rankings of packaging design criteria

Aspect	Criteria	Retailer A	Retailer B	Retailer C	Retailer D	Brand Owner A
Functionality	Protects and preserves	1	1	1	1	1
	Storage and transport	5	2	2	3	2
	Informs and instructs	3	3	3	3	1
	Packaged product wastage	6	1	4		2
Technical Requirements	Material properties (inertness)	3	1	3	3	2
	Material efficiency	5	2	2		1
	Technology availability	5	1	4		1
	Legislative requirements	3	1	1	1	1
Economic	Total cost	4	1	1	2	1
Marketing	Consumer perception	3	1	1	3	3
Environmental	Environmental impact	2	3	1		1
	Recycled content	2	4	2	3	1
End-of-Life	Recovery rate	4				1
	Recyclability	2	4	1	3	1
	SWM infrastructure availability	4	5	5		1
	Biodegradability	8	6	4		3
	Leakage propensity	3		3		1
	Reusability	7		2	3	1

8.2.7 Relative influence of packaging design criteria

As described in the methodology (section 3.4.1), the relative influence of the identified metrics was investigated through the completion of a preference elicitation exercise. The exercise required participants to rate and assign relative weights to the metrics using the “Max100” method, explored by Bottomley & Doyle (2001), whereby the most important metric is assigned 100 points and the rest assigned lower points relative to it.

When asked to weigh the criteria according to their relative performance, value-chain actors often assigned similar weights to the different metrics. More specifically, despite different rankings, the weighing exercise revealed that value-chain actors did not see much difference between the relative influences of criteria with different ranks. This is shown in the results of the normalised weights assigned to criteria in Figure 8-1. Moreover, they would at times assign the same weight to criteria they had ranked differently. This is further evidence of the complex nature of packaging design and the struggle value-chain actors face to balance different criteria.

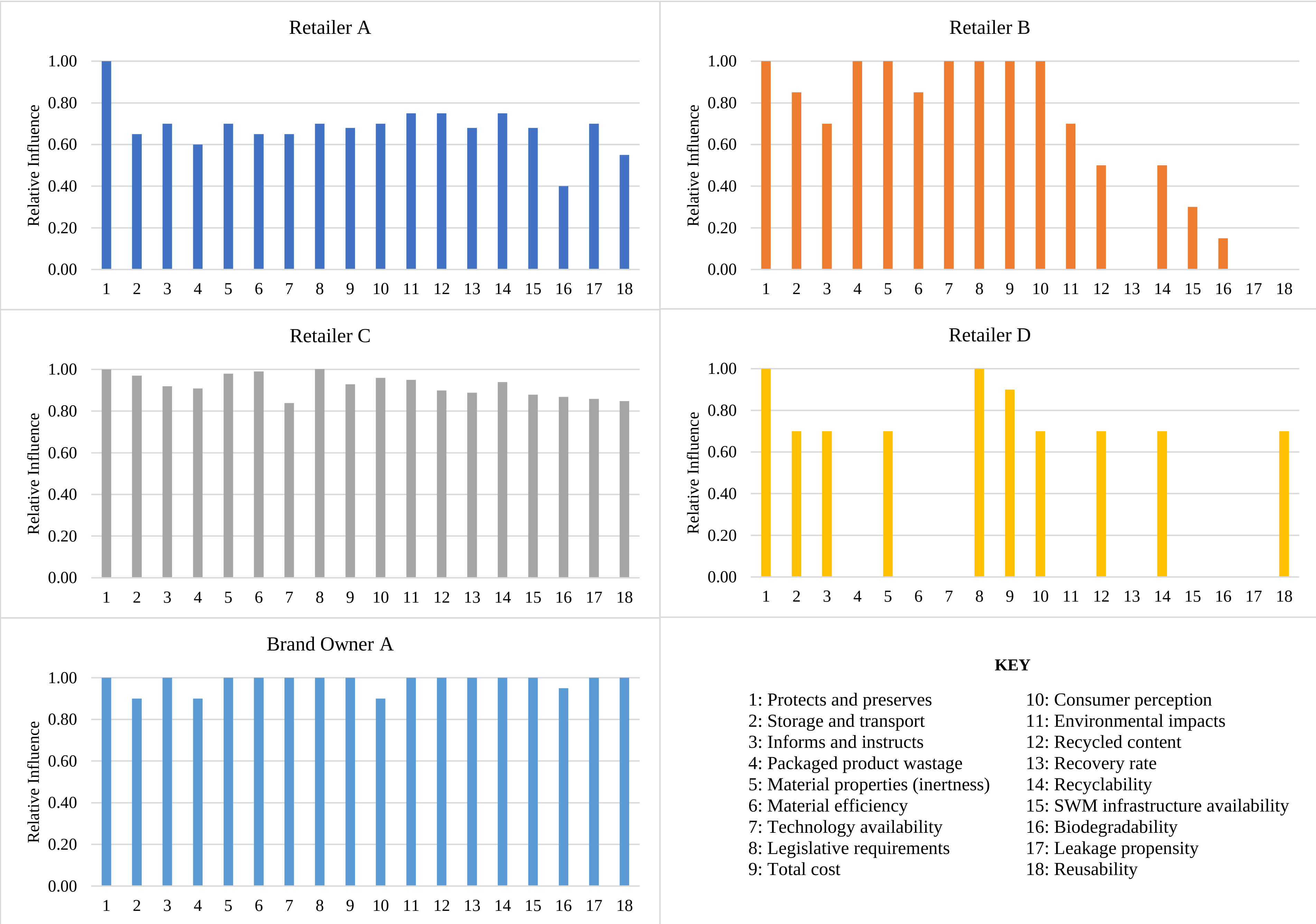

Figure 8-1: Relative influence of packaging design criteria

8.3 Perspectives of Plastic Pollution

Value-chain actor perspectives of plastic pollution were explored in order to gain insights on their understanding of the issue. This included their opinions on the causes of pollution and their knowledge regarding the extent of the problem.

8.3.1 Causes of plastic pollution

There were many differing perspectives as to the cause of plastic pollution (Table 8-3), including consumer behaviour, ineffective solid waste management infrastructure and practices and poor extended producer responsibility practices. Product design was also deemed as a contributing factor, in that the characteristics of the product and the intrinsic value at end-of-life influence the likelihood of escaping the value chain.

Table 8-3: Value-chain actor perspectives on plastic pollution causes

	Behaviour	Product Design	Extended Producer Responsibility	Waste management	Combination of All
2017					
Retailer A	✓				
Brand Owner A	✓				
Industry Association A					✓
Industry Association B	✓	✓		✓	
Packaging Designer					✓
2018/2019					
Retailer A					✓
Retailer B					✓
Retailer C					✓
Retailer D	✓		✓		
Brand Owner A					✓
Brand Owner B	✓		✓	✓	
Brand Owner C	✓				
Recycler A	✓	✓			
Recycler B					✓
Recycler C	✓				
Industry Association A					✓
Industry Association C					✓
Restauranteur A					✓
Restauranteur B					✓

Many of the value-chain actors viewed pollution causes as a complex combination of some or all factors, albeit to varying extents. Whilst they cited consumer behaviour as an integral element, they believed that it was no longer adequate to view the problem from this singular perspective and instead address the multifaceted nature of the problem. All of the retailers and brand owners acknowledged they held some responsibility for the products they put on the market, particularly from a product design perspective, and the subsequent fate of that product at end-of-life.

Retailer A – "There is a problem with plastic. It may not be the plastic itself. It may be management and human beings and lack of infrastructure or lack of whatever it is, but it's there. What we do with it and how we handle it and cope with it, is actually the challenge."

Although Brand Owner C acknowledged the responsibility of brand owners for the products they put on the market (as demonstrated in the case of straws in section 5.3), they viewed plastic pollution as a purely behavioural issue. This may be attributed to the fact that the value-chain actor is an active participant in voluntary EPR programmes and thus viewed themselves as responsible brand owners.

Whilst Recycler B attributed pollution to a combination of issues, they viewed brand owners and retailers as largely responsible, whilst consumers were being used as a convenient scapegoat. In their opinion, brand owners and retailers needed to take more responsibility for the nature of the products they put on the market and play a more active role in their management at end-of-life.

Recycler B – "It is my view a [sic] brand owners and retailers who don't give a shit!"

Recycler B qualified this using the case of PET bottles, which have built up a relatively high recycling rate, which they attributed to the active engagement of brand owners in supporting the recycling sector.

All the recyclers emphasised the importance of product design in the fate of products at end-of-life. This is to be expected as they present one of the options for waste treatment, thus they are familiar with the different design characteristics that may influence how that product is treated including likelihood of collection for recycling.

Recycler A – "The only hope we have is on engineering and design but bearing in mind that engineering and design doesn't stop at the statics and functionality. It's at value post life."

8.3.2 Perceptions of the extent of the problem

The majority of interviewees were either unwilling or unable to provide an estimate of how large they believed the plastic waste problem was, readily admitting their limited knowledge. They were aware that research that had been conducted surrounding the extent of the plastic pollution problem, but the level of engagement with such work varied widely. Industry Association A had actively worked on the issue of plastic pollution and thus was well versed on the matter. Retailer B and Industry Association C both demonstrated active engagement with this work. However, all three of interviewees expressed their scepticism surrounding the current knowledge. Retailer B also highlighted the limited information regarding plastic flows within the South African plastic industry in general. This was also expressed by Brand Owner A.

Retailer C – "We'd have to do a bit of research. There's been plenty of research done around it."

Whilst Retailer D and Brand Owner A were willing to hazard a guess, these were mostly based on anecdotes and their own personal experiences with litter in their daily lives. Although Restauranteur B, expressed a personal desire to mitigate plastic pollution, they demonstrated limited knowledge on the extent of the problem.

8.4 Responses to Plastic Leakage

As this thesis aims to investigate the feasibility and potential influence of integrating leakage into product LCM through the use of leakage rates, it is important to understand how value-chain actors are responding to the increasing concern surrounding plastic pollution. Thus, value-chain actor responses to plastic leakage were explored including key drivers and opportunities for strategy and intervention development, as well as challenges and barriers. This includes responses to products that have been identified as problematic as demonstrated in Chapters 5 – 7.

8.4.1 Value-chain actor strategies and initiatives

During the initial round of interviews conducted in 2017, the value-chain actors generally did not view themselves as playing a significant role in mitigating plastic pollution and tended to put the onus on consumers. Thus, the approaches of their employers were focussed on consumers in the form of consumer education on proper waste disposal and awareness raising campaigns. Whilst the value-chain actors supported recycling initiatives they did not view them as having a significant impact. There was a general sentiment that they were powerless when it came to the matter of plastic leakage and the associated impacts. Furthermore, the value-chain actors did not view themselves as responsible nor could they be held accountable for what happened to their products at end-of-life. However, the Packaging Designer and Brand Owner A postulated that the increasing global concern surrounding plastic pollution would result in consumer pressure on value-chain actors to take an active role in its mitigation.

Brand Owner A – "It will be foolhardy to expect us to police it. We've got no say in what the consumer does, but we do support initiatives to make sure it gets recycled."

As the plastic pollution has received increasing attention in recent years, there has been a shift observed in value-chain actor approaches to plastic product LCM. Retailers and brand owners now increasingly view their role in mitigating plastic pollution from both producer and EPR perspectives. More specifically, they recognise the role of product design in plastic pollution as well as their responsibility for the fate of their products at end-of-life. As such, they had expanded their activities beyond consumer education campaigns. Their EPR activities are often focussed on supporting recycling activities either directly or through memberships of voluntary PROs related to plastics collection and recycling. Through growing appreciation of EPR, value-chain actors are now changing their product design approaches to facilitate their activities at end-of-life. More specifically, value-chain actors are integrating design for recycling and/or circularity into the packaging design strategies (discussed further in section 8.4.2). Material substitution is an additional approach being implemented, as demonstrated in Chapter 5 and Chapter 7 for straws and cotton bud stick respectively. Furthermore, value-chain actors are now reviewing the effectiveness of their consumer education initiatives, in supporting their EPR activities. One example of this is the review on-pack recycling labels which do not have uniformity across producers resulting in confusion amongst consumers.

Retailer A did not believe that the focus on recycling would solve the plastic pollution problem and would instead require a suite of approaches including plastic reduction and elimination. A similar sentiment was also expressed by the Packaging Designer, who believed that whilst a focus on design for recycling would enable a circular economy it would not necessarily reduce littering.

Retailer A - "Plastic, we can't recycle ourselves out of the problem. We need to find other things to complement it."

Recyclers viewed themselves as integral to waste diversion. However, they considered themselves a "tool" to be utilised and the impetus was on retailers and brand owners to ensure that the product was designed with end-of-life in mind.

Retailer D – "Everybody does have a role to play and I don't think any specific role is watered down in any way. It's all relevant and of the same level of importance."

8.4.2 Influence of pollution on packaging design approaches

The growing concern surrounding plastic pollution has influenced value-chain actor approaches to product design to varying extents. Retailer D described their company as financially driven, but the concern surrounding plastic waste has led to the development of a packaging strategy which takes into consideration factors that were not traditionally considered including recyclability. Furthermore, the retailer has traditionally deferred to options offered by their suppliers but is now being more proactive regarding packaging specifications. In the case of Retailer C, they historically had a decentralised approach whereby individual store owners were given full decision-making power including product sourcing. However, the increasing public concern had seen a rise in store owners turning to head office for guidance, necessitating the formation of a packaging department to provide owners with more environmentally sustainable product options. Across the board, both brand owners and retailers are placing increasing emphasis on design for recycling principles in their packaging design strategies. In addition, many retailers and brand owners referred to following a circular economy approach, which was often interpreted as increasing recyclability.

Some of the value-chain actors have gone through the process of identifying priority products for redesign, however their approaches differed. For example, Retailer A described having identified a set of priority items based on items identified as being major contributors to marine pollution. Furthermore, they earmarked products with viable material alternatives to plastic for redesign. In comparison, Brand Owner A described taking a volume perspective, with the opinion that an intervention on such items would result in more impact industry wide. However, this has the potential to side-line products in their portfolio which had been identified as major contributors to marine pollution due to their relatively low production volumes. Retailer B has implemented a packaging design strategy to be implemented as products came up for regular design reviews.

Value-chain actors also prioritise items based on market and societal expectations, for example, the prioritisation of straws and cotton bud sticks for immediate intervention based on consumer pressure as demonstrated in Chapters 5 and 6. For multinational brand owners, prioritisation is also influenced by the company's global strategy. Retailers A and D also acknowledged the influence of foreign markets in their strategy development, viewing them as a form of guidance.

Retailer D – "We're looking at all the international stuff that's going on and we're trying to take our cues from there."

8.4.3 Key drivers for intervention development

As expected, value-chain actors cited a desire to maintain a competitive advantage as a key driver. Retailer A cited that consumers would commonly refer to competitor practices when lodging complaints. As such, value-chain actors maintain a keen eye on competitor practices. In addition, they take note of practices of their counterparts in developed markets viewing them as predictors of future local market expectations.

Retailer D – "If you're out of the space you might be seen as being counterproductive or unaligned."

As discussed in section 8.4.2 and demonstrated in Chapters 5 and 6, consumer pressure is a major driving force for intervention development. This is further evidenced by the shift in value-chain actor approaches from 2017 to 2019 (section 8.4.1). Increasing concern surrounding plastic marine pollution led to a global outcry resulting in societal pressure being placed on value-chain actors to take a more proactive role. As discussed in sections 2.3.1 and 5.3, this often takes the form of campaigns led by consumers or environmental groups, one example being the campaign by WWF-SA which advocated against the use of single-use plastics with a particular focus on items they considered to be the "worst offenders" including straws and cotton bud sticks (WWF-SA & Notten, 2018).

As mentioned in section 8.4.2, international legislation, particularly in Europe, influences practices in South Africa. For multinational companies, compliance with legislation may be integrated into global strategies. South African based companies which export to foreign markets are also driven by compliance in their target market. Some value-chain actors view international legislation as a precursor to similar legislations being enacted locally, thus they choose to comply pre-emptively. In addition, they are driven by voluntary global strategies including the New Plastics Economy Global Commitment (Ellen MacArthur Foundation, 2018).

Brand Owner A and Retailer D highlighted the increasing consideration of a company's sustainability efforts by investors. Thus, responding to the concern surrounding plastic pollution is seen to be imperative to a company's image. Furthermore, Retailer B noted that interventions are more readily approved by company executives for products that were in the public spotlight.

Retailer D – "Businesses spend millions on PR [public relations] to act or be perceived as a good corporate citizen. They'll do anything"

Job creation is viewed as the major opportunity to the development of strategies, particularly those with a focus on recycling. In South Africa, informal waste collectors play a vital role in waste diversion. Thus, an increase in recyclable waste would result in more opportunities for collectors. In addition, the increase in recycling capacity would create more formal job opportunities.

Recycler C – "One thing we have in our favour in Africa is we have an incredible opportunity to create employment."

8.4.4 Challenges and barriers to intervention development

Many of the challenges and barriers identified during the interviews are related to the design metrics (discussed in section 8.2), including functionality and technical requirements. Of particular concern is food packaging, whereby designers are faced with the challenge of finding alternative designs that would meet food safety requirements. Retailers without production facilities for their in-house brands are constrained by the technological capabilities of their suppliers.

As expected, cost is a major barrier to the design of product interventions, including material substitution and complete redesign. Interviewees pointed out that plastic was a favoured material due to its relatively low cost, thus material substitution would inevitably be associated with increased costs. They also highlighted the higher costs associated with new alternative products on the market due to the novelty associated with them. Value-chain actors have varying capacities to absorb this extra cost: Retailer A indicated that their company has funds set aside to absorb additional sustainability related costs whereas Retailer D indicated that the additional cost would need to be passed onto the consumer. Industry Association B also highlighted the socio-economic implications of designing out items that have been identified as problematic, specifically small format items. Some small format items provide an affordable option to populations who cannot afford to buy high volume items; thus, a product redesign would need to take this into consideration.

A lack of suitable solid waste management infrastructure to manage and process waste is viewed as a challenge to the efficacy of any design interventions implemented. Whilst value-chain actors are emphasising design for recycling, interviewees were acutely aware of the limited recycling infrastructure available in the country. In addition, the lack of solid waste services to separate and collect recyclables present an additional challenge. However, the interviewed recyclers all expressed confidence in their abilities to meet the additional required capacity. The lack of suitable infrastructure to process alternative materials, specifically biodegradable and/or compostable materials, was also cited as a deterrent for their adoption. Interviewees raised concerns of potential contamination of recycling streams by such materials which would impact the quality of plastic products downstream.

Retailer B – "I think retailers should still push to make everything recyclable even if there isn't a place to deal with that, but it is tricky."

Consumer misinformation and lack of understanding was a challenge reported by all retailers. A lack of understanding regarding the function of packaging (i.e. food safety and preservation) led to consumers attacking retailers on their use of plastic packaging whilst simultaneously praising them for the quality of the food contained within. Retailers also highlighted the increasing popularity of alternative products in popular media which results in consumers advocating for such items without a complete understanding of the material properties. For example, the marketing of compostable plastics as biodegradable (discussed in section 5.3.2), has reportedly led to a consumer base that views retailers as unwilling to act, by adopting what they viewed as a miracle product. Thus, retailers have had to take a more active role in combatting misinformation and consumer education.

Retailer D – "Honestly the level of understanding is very low… very, very low."

Stakeholder agendas present an additional level of complexity when it comes to balancing individual stakeholder priorities across the value chain. Retailer A highlighted the threat that initiatives aiming to reduce or eliminate plastic presents to their upstream suppliers, as this would effectively reduce their business throughput, making them "defensive". In addition, Recycler B accused producers of being unwilling to adopt sustainable practices, including incorporation of recycled content or exclusion of additives that decreased recyclability, due to a desire to cut costs. Furthermore, there was some contention amongst value-chain actors regarding their different roles. Retailers were commonly viewed as having the most power as they were the interface between suppliers and consumers. Brand Owner A viewed themselves as subject to the principles adopted by retailers as they are reliant upon them for product distribution. Whereas Retailer B described the relationship between retailers and brand owners as "co-dependent". In addition, Recycler B openly expressed their exasperation at retailers for seemingly not exerting enough pressure on their suppliers. As a result, there is reportedly some acrimony amongst stakeholders across the value chain resulting in multiple parallel initiatives.

Retailer A – "The biggest challenge is that there's so many organizations, with so many agendas, with so many viewpoints"

The broader environmental impacts associated with interventions are considered to a lesser extent, which was demonstrated in the cases of straws (Chapter 5) and cotton bud sticks (Chapter 7). Retailer D and Recycler A highlighted that the focus on mitigating plastic pollution could result in interventions that resulted in greater damages in other ecological spheres such as climate change. This was exemplified in the cases of straws and cotton bud sticks respectively, whereby the comparative life cycle assessments highlighted the potential for burden shifting associated with the different material alternatives (sections 5.4.1 and 7.5.2 respectively). However, many value-chain actors took into consideration the potential socio-economic impacts of bio-based plastics which were often made from food crops and thus presented a threat to food security.

8.4.5 Potential influence of product specific leakage rates on responses

As discussed in section 8.3.2, interviewees had limited knowledge regarding the extent of the leakage problem. During the interviews, interviewees were presented with the concept of leakage rates and how they can provide information on differences in leakage propensities for products (as shown in section 4.3). The majority of retailers and brand owners believed that the provision of more specific product information would be valuable for strategy development as they would have an enhanced understanding of the nature of the plastic pollution problem. In particular, leakage rates would provide an evidence base for the selection of priority products for intervention. Having a sound evidence base is viewed as particularly valuable when it comes to the justification of decisions to company executives and obtaining their buy-in. Retailer C also viewed leakage rates as a potential source of information for consumer education and combatting consumer misinformation regarding the extent of the plastic pollution problem.

Brand Owner A – "If I know that a certain percentage of this [plastic item] is contributing to the ocean, I mean, if one is in a rightful mind how could that not trigger some different thinking?"

Industry Association A did not believe that leakage rates would have any influence as they believed that the broader population "doesn't care". In their opinion, plastic pollution was not about the number but about the people receiving the information. Whilst Retailer D personally saw the potential value of leakage rates, they did not believe that the provision of more specific product information would alter their firm's practices. This is due to the emphasis on commercial gain underpinning strategy development within the firm. In addition, Retailer B highlighted that although leakage rates may be useful, in the absence of identifiable traits that can be linked back to the manufacturer/supplier (e.g. for the case of generic items such as straws), a value-chain actor may refute responsibility on this basis.

With regards to the provision of more product-specific information, Retailer B remarked that the provision of a list of quantified top offenders, for which the underpinning evidence can be demonstrated (such as that developed in section 4.1.5), is of great value as it can also be used as a reliable source of information. This was in reference to the multitude of lists being developed by environmental groups for which the underlying evidence was not necessarily specified, with the retailer specifically citing the list developed WWF-SA which had received a lot of attention on social media despite the lack of any data sources being cited (WWF-SA & Notten, 2018).

8.5 Discussion

8.5.1 Adoption of LCM concepts, tools and techniques in South Africa

LCM is not a term that is commonly used in South Africa, however there are a number of related techniques applied by FMCG companies and retailers operating locally. The extent to which LCM concepts are being adopted can be linked to a company's characteristics, including its business footprint and whether it is publicly traded. Multinational companies were found to adopt many LCM concepts including cleaner production principles, with a focus on water and energy consumption, carbon emissions and waste production. This is to be expected as larger companies are deemed to be subject to greater public scrutiny and are thus under more pressure to behave sustainably (Chih, Chih & Chen, 2010; Lourenço & Branco, 2013). Furthermore, ranking institutions are placing increasing emphasis companies' approaches to environmental and social sustainability as an indicator of overall performance, increasing its importance amongst investors (UNEP/SETAC, 2006). Hence companies listed on major stock exchanges are found to make greater efforts towards their corporate sustainability (Chih, Chih & Chen, 2010). Multinationals are also driven to employ an LCM based approach due to market requirements as well as regulations and legislation in the countries in which they operate (Hunkeler et al., 2004; UNEP/SETAC, 2007; Sonnemann et al., 2015). In comparison, locally based South African companies that are not publicly listed, often do not employ any LCM concepts. Furthermore, their communication is often limited to product sales. This may be attributed to their relatively smaller business footprint.

8.5.2 Influence of plastic leakage on value-chain actor approaches to product LCM

The increasing rhetoric surrounding plastic pollution has resulted in a shift in value-chain actor perspectives regarding their role in its mitigation, leading to a subsequent shift in their approaches to product LCM. This includes increases in the consideration of the fate of a product at end-of-life, the adoption of LCM concepts such as design for recycling and engagement in EPR activities.

Although the majority of interviewees viewed plastic pollution causes to be multifaceted, in 2017 value-chain actors located 'upstream in the value-chain' put the onus on consumers when it came to addressing it. However, during the second series of interviews value-chain actors reported taking a more active approach to mitigating plastic pollution. Retailers and brand owners now view their role in mitigating plastic pollution from both product design and EPR perspectives. From a product design perspective, more firms are adopting LCM techniques including design for recycling and/or design for circularity. Whilst South Africa has traditionally promoted design for recycling (Godfrey & Oelofse, 2017), it has gained in popularity in recent years with more companies deeming it necessary for survival. For example, Retailer D was traditionally cost-driven but has been forced to consider recyclability as part of their packaging design criteria. Furthermore, it has fundamentally altered business models as is the case of Retailer C, who previously had a decentralised retail model, has now found owners increasingly turning to head-office for guidance necessitating the formation of a packaging design division.

A shift was observed in the extent to which a product's fate at end-of-life is taken into consideration during product design. During the first round of interviews, value-chain actors took an idealised approach to waste scenarios and assumed their products would be properly disposed. 18 months later, during the second set of interviews, there was a more realistic consideration of the waste scenario associated with different products, including the possibility for leakage. In the absence of information regarding waste flows, value-chain actors use other criteria including material recovery rate for recycling and the presence of appropriate waste management infrastructure as indicators of the likelihood of a material being recycled. Ultimately interviewees were conscious of the fact that the design of a recyclable product does not mean this was guaranteed. Thus, through growing appreciation of EPR, upstream value-chain actors are increasingly supporting end-of-life activities that would facilitate proper disposal of their products. This is commonly done through supporting recycling initiatives either directly or through membership of voluntary PROs which have been found to play a significant role in growing the recycling landscape (Godfrey & Oelofse, 2017). The membership of voluntary PROs may also be in anticipation for the enactment of EPR policies based on governmental call for industry waste management plans for the paper and plastic industries, which would require producers to ensure proper disposal of their products. As mentioned in section 8.1, the proposed EPR plan submitted by Packaging SA in response to the call, cited all producers, converters, brand owners, retailers and importers as "obliged members" (Packaging SA, 2018).

Although there have been increasing conversations surrounding plastic pollution, interviewees presented a limited understanding of the extent of the problem. All of them were aware that research had been conducted in this regard however a minority have actively engaged with the work. This varied understanding of the problem may be linked to the varying approaches to the identification of products for intervention which are often based on anecdotes and logic and not empirical evidence. This includes prioritisation of high-volume items and those with readily available material alternatives, as well as looking towards foreign markets for guidance. Furthermore, value-chain actors also take their cues from consumers; prioritising items for immediate intervention as a response to consumer pressure. Only one retailer bases their prioritisation on "dirty dozen" lists compiled internationally. Whilst these lists generally share some commonalities (discussed in section 4.4.1), product contributions to plastic flows into the ocean are highly region dependent and can be influenced by a variety of factors including consumption rates, user behaviour and SWM infrastructure and practices (UNEP, 2018c). Two examples being the cases of plastic bags and bottles which are often cited as major contributors to marine pollution (Barnes et al., 2009; Galgani, Hanke & Maes, 2015; Eunomia, 2017); both were found to have a relatively low prevalence during both series of beach surveys conducted in Cape Town (section 4.1.4). Ultimately, the lack of evidence-based approaches for the identification of problematic items has the potential to result in strategies that do not effectively address marine pollution due to the prioritisation of items which are not major contributors in lieu of those that are. Thus, interviewees believed the provision of product specific leakage rates will enhance their own understanding of the nature of the plastic pollution problem, providing evidence for the selection of products for intervention. Furthermore, the availability of sound evidence is viewed as important for the justification of decisions to company executives and obtaining their buy-in when it comes to strategy development.

8.5.3 Key drivers and challenges for pollution mitigation strategy development

Key drivers for strategy and intervention development closely mirror those for adopting LCM based concepts and strategies including maintaining a competitive advantage, compliance with regulations and legislation, meeting investor expectations and meeting consumer expectations (Hunkeler et al., 2004; UNEP/SETAC, 2007; Sonnemann et al., 2015). Retailers and brand owners not only keep abreast of their competitors' practices, but also look towards their counterparts in developed markets for guidance. This may be attributed to institutional normative pressure, which is a key driver for environmental policy development, whereby companies will look towards what others are doing as an indication of their "moral" and "social" obligations (Ramus & Montiel, 2005). As a result, a company may not only copy another's policies but may also be more willing to endorse industry wide initiatives if they view their counterparts doing the same. Although there has not been any legislation or regulations aimed at mitigating plastic pollution enacted in South Africa, value-chain actors view European legislation as a precursor (including the EU agreement on single-use plastics (European Parliament, 2018)), choosing to comply pre-emptively. In addition, they are driven by global agreements including the New Plastics Economy Global Commitment (Ellen MacArthur Foundation, 2018),which has the additional benefit of increasing a company's image in society, portraying them as "good corporate citizens". This is in line with a suggestion by Stafford and Jones (2019) that the visibility associated with plastic pollution creates an opportunity for "environmental branding" of corporations.

Many of the challenges associated with intervention development are related to the packaging design criteria. A fundamental barrier is the design of alternative products that could effectively protect and preserve the contents. Cost is a major constraint to product redesign as plastic is an attractive option due to its relatively low cost in comparison with other options. Furthermore, interviewees reported that new alternative products are associated with higher costs due to the novelty. The extent to which cost affects value-chain actors differs according to their ability to absorb this extra cost.

A lack of suitable infrastructure is also a consideration for value-chain actors as it would directly impact the effectiveness of their interventions. In particular, the state of solid waste management practices and infrastructure is of concern with regards to their ability to collect the waste and divert it to the appropriate waste treatment. According to Stats SA (2018), 29.5% of South African households do not have access to waste removal services. Furthermore, source separation is not a prevalent practice in South Africa (Godfrey & Oelofse, 2017). The lack of suitable infrastructure is also a deterrent for the adoption of compostable materials due to the limited availability of industrial composting facilities in South Africa (DST, 2014).

Stafford and Jones (2019) highlight the potential for a single-minded focus on marine pollution to lead to a side-lining of other environmental threats. This was demonstrated during the interviews whereby the broader environmental impacts associated with the interventions are considered to a much lesser extents with only two interviewees highlighting the potential for trade-offs. Of particular concern were the potential impacts on climate change as previous studies comparing plastic and paper often found plastic to be the favourable option (James & Grant, 2005; Sevitz, Brent & Fourie, 2012; Kimmel et al., 2014). However, the converse was found in this study (Chapter 5 and Chapter 7) suggesting that this trade-off may be potentially negated in the South African context.

Consumer perception appears to be both a key driver and a challenge to strategy development. Value-chain actors are under increasing societal pressure to develop strategies to address plastic pollution. However, retailers highlighted consumer misinformation as a challenge they face in trying to meet consumer desires. According to interviewees, some consumers demonstrate a limited understanding of the function of packaging as well as the broader environmental impacts associated with alternative materials. This has led to consumers advocating for alternative materials based on a shallow understanding of the implications. This is in line with a study conducted in 2014, whereby Scott & Vigar-Ellis found that South African consumers had an incomplete understanding of what environmentally friendly packaging is, or the benefits it provided to themselves or the environment. In addition, some consumers relied on their "common sense" to evaluate whether packaging is environmentally friendly based on the material employed (Scott & Vigar-Ellis, 2014). A similar finding was made by Lindh, Olsson & Williams (2016) and Steenis et al. (2017) who found that Swedish and Dutch consumers respectively, based their perception of environmental impacts on the packaging material used leading to the belief that plastic and metal were least sustainable. Furthermore, Steenis et al. (2017) found that consumers perceived products that were deemed most environmentally sustainable from a LCA perspective as the least sustainable. This suggests that consumer perceptions have the potential to contradict their desire for sustainability (Lindh, Olsson & Williams, 2016; Steenis et al., 2017).

Differing stakeholder priorities across the value chain present an additional level of complexity to strategy development. In particular, value-chain actors reported plastic converters felt threatened by the rhetoric surrounding plastic pollution as it was commonly associated with the reduction of plastic products. Furthermore, there was some acrimony between value-chain actors surrounding stakeholder roles and responsibilities in mitigating plastic pollution. This has resulted in multiple parallel initiatives.

8.6 Conclusions

This chapter explored the influence of the growing concern surrounding plastic pollution on the life cycle management of plastic products in South Africa. This was achieved through two sets of interviews with key value-chain actors including brand owners, retailers, recyclers and industry associations, conducted in March 2017 and November 2018 – March 2019.

Over the 18 months between the two sets of interviews, a shift was observed in value-chain actors' perceptions of their locus of responsibility when it comes to plastic pollution; from being viewed as an externality, the issue and their role in its mitigation was more internalised. Thus value-chain actors are placing increasing emphasis on design-for-recycling. In addition, retailers and brand owners are also taking an EPR approach to product management through financial provisioning and/or support of recycling activities (e.g. via PROs) to facilitate the proper disposal and treatment of their products at end-of-life. Material substitution is also an option being explored for items with a readily available alternative, however there is a lot of uncertainty particularly when it comes to plastic alternatives (e.g. bio-based plastics). Of particular concern is the availability of suitable infrastructure for the treatment of these plastics, the validity of claims surrounding their biodegradability, and their potential to contaminate recycling streams.

The drivers for the development of strategies to address plastic pollution mirror those for adopting LCM based concepts including maintaining a competitive advantage, compliance with regulations and legislation, and meeting investor and consumer expectations. However, consumer expectations also present a challenge due to ill-founded consumer perceptions of sustainability coupled with a limited understanding of the function of packaging, which often leads to them advocating for alternatives that contradict their desire for sustainability. Cost is also a major challenge for stakeholders due to the relatively higher costs associated with material alternatives to plastic. The broader environmental impacts associated with intervention development are considered to a lesser extent increasing the potential of burden-shifting being made unwittingly. This was demonstrated in Chapters 5 & 7, which explored the life cycle impacts of material substitution for straws and cotton bud sticks.

Whilst value-chain actors are taking a more realistic perspective on the potential fate of product waste; the lack of reliable information is still a constraint. This is of particular concern for brand owners and retailers with a large product portfolio, when it comes to the prioritisation of products for intervention. This has led to a multitude of approaches to prioritisation, some of which have the potential to side-line products that may be major contributors to pollution. Consulted value-chain actors believed the provision of specific knowledge on product leakage rates would provide a much-needed evidence base for the selection of products for intervention. Thus, product-specific leakage rates have the potential to facilitate the development of targeted strategies to address plastic pollution, through the identification of items which are highly prone to leakage.

Chapter 9 Conclusions and Recommendations

This thesis investigated the feasibility and potential influence of using product-specific leakage rates as a proxy indicator for potential marine environmental impacts, to inform the life cycle management of products in which plastic is a material choice. This entailed the quantification of leakage rates for selected plastic items widely reported as being highly prone to leakage into the marine environment, based on a series of beach surveys coupled with waste generation data (Chapter 4). The potential influence of providing such specific knowledge on plastic leakage was investigated via the exploration of current approaches to the LCM of plastic products in Chapter 8. The evidence generated was grounded through the development of three product-specific case studies, for items identified as prone to leakage, whereby approaches to their life cycle management were investigated, and the sustainability performance of different interventions evaluated (Chapter 5 – 7).

This Chapter consolidates the results of Chapters 4 – 8 and concludes on the research findings in relation to the objective of the thesis.

9.1 Thesis Summary

This thesis was guided by two main research questions pertaining to the determination of product specific leakage rates and the potential influence of such knowledge on product life cycle management:

1. What are the leakage rates of plastic items which have been identified as prone to accumulation in the marine environment?
2. What is the feasibility and influence of providing specific knowledge on plastic leakage on the life cycle management of products in which plastic is a material choice?

To effectively address these questions the research was conducted in two stages, as described in Chapter 3.The first was the quantification of plastic flows into the marine environment so as to create specific knowledge on leakage rates for different items (reviewed in section 9.1.1). This was followed by investigating the integration of leakage into product life cycle management via the exploration of current approaches to product LCM in South Africa with a focus on the fast moving consumer goods (FMCG) sector, and how they have been influenced by the growing concern surround plastic leakage (reviewed in section 9.1.2).

9.1.1 Quantification of plastic flows and product leakage rates

Chapter 4 was focused on the quantification of plastic flows into the marine environment, so as to determine the leakage rates of items that have been identified as prone to leakage (research question 1). Beach accumulation rate surveys were utilised to quantify the flows of plastic items into the marine environment from Cape Town. Sampling was conducted at five beaches with varying catchment area characteristics, over two periods in 2017 and 2018 – 2019 respectively. Daily accumulation rates varied across all sites ranging from 38 – 2962 items.day^{-1}.100m^{-1} during the first sampling period and 305 – 2082 items.day^{-1}.100m^{-1} during the second. Plastic was the major contributor accounting for 85.6 – 98.9% of all items by count. Despite the variability in accumulation rates and composition, there was uniformity when it came to the major contributors. The top 12 most prevalent and abundant identifiable plastic items accounted for 43 – 66% during the first sampling period, and 41 – 73% during the second (Table 4-3). Ten of these items were prevalent during both periods, eight of which were associated with food consumed on-the-go including straws, polystyrene packaging, snack packets and beverage bottle lids. This was similar to findings of other marine litter studies whereby such items were identified as major contributors (Barnes et al., 2009; Andrady, 2011; Galgani, Hanke & Maes, 2015; Hanke, 2016).

Generally, items with relatively high accumulation rates were associated with higher leakage rates (as shown in section 4.3). The only exception was observed for the case of cigarette butts which had a high accumulation rate but a low leakage rate, suggesting that despite their abundance they had a low leakage propensity. However, this may also be attributed to their relatively higher density in comparison to water, reducing their visibility. Items associated with food consumed on-the-go, which were found to be top contributors, had leakage rates one order of magnitude higher than food items designed to be consumed in the home which were not prevalent during the beach surveys. This suggested that the purpose of the items inherently influenced their leakage propensity.

As discussed in section 4.4.3, the robustness of leakage rates was influenced by the uncertainty associated with the product accumulation rates coupled with the waste generation data. The development of marine accumulation rates was associated with high uncertainty due to the complexity associated with conducting and analysing beach accumulation surveys. More specifically, litter accumulation rates were influenced by a variety of factors including catchment area characteristics, weather patterns and ocean currents and tides. Furthermore, the regional variability associated with accumulation rates introduces an additional level of uncertainty regarding the geographical representativeness of the obtained rates. This thesis also highlighted the limitation presented by poor consumption data in developing countries. In this case, a variety of data sources were used including national surveys, market research and direct sales data. Whilst direct sales data may be deemed a reliable source, information was only available for major retailers and wholesalers and thus did not cover the entire market. Thus, the utilisation of unreliable waste generation data compounds the uncertainty associated with leakage rates.

9.1.2 Influence of leakage on plastic product life cycle management approaches

Approaches to product life cycle management in South Africa were investigated via a combination of desktop research using publicly available company data and interviews with relevant value-chain actors, including brand owners, retailers, recyclers, restauranteurs and industry associations (Chapter 8). In addition, case studies were conducted on key items that have been identified as problematic providing a practical basis for exploring value-chain actor approaches to the life cycle management of plastic products that are highly prone to leakage. More specifically, interventions for straws (Chapter 5), beverage bottle lids (Chapter 6) and cotton bud sticks (Chapter 7) were investigated including the underlying motivations and potential sustainability impacts.

LCM is not a term that is commonly used in South Africa, however there are a number of related concepts applied locally by FMCG companies and retailers including sustainable procurement, cleaner production and design for recycling. The extent to which they are employed may be linked to the characteristics of the company such as its business footprint and whether it is publicly listed on stock exchanges. More specifically, multinational brands are more likely to employ LCM concepts in comparison to locally based companies which are more focused on financial sustainability. Notably, the brands marketed by the latter were identified as major contributors to marine litter despite not being the market leaders.

The growing public concern surrounding plastic pollution has resulted in some companies assuming greater responsibility for the fate of their products at end-of-life. This has led to increasing emphasis on design for recycling coupled with increased EPR initiatives to support recycling activities to facilitate proper disposal of their products. The potential of a successful EPR scheme is evidenced by the case of PET bottles which saw a marked increase in recycling after the incorporation of PETCO, coupled with a decrease in their prevalence in the environment in comparison to lids. In addition, many companies have developed strategies focused on plastic packaging. These strategies are not necessarily focused on the mitigation of plastic pollution but on packaging sustainability at large. Instead, key drivers for strategy development mirrored those for adopting LCM concepts including maintaining a competitive advantage, compliance with regulations and legislation, meeting investor expectations and meeting consumer expectations (Hunkeler et al., 2004; UNEP/SETAC, 2007; Sonnemann et al., 2015).

When it comes to the prioritisation of products for intervention value-chain actors reported varied approaches. This may be attributed to a lack of reliable information surrounding the extent of the plastic pollution problem in South Africa, with value-chain actors often relying on anecdotes and logic instead of empirical evidence. Approaches include prioritisation of high-volume items and those with readily available material alternatives, as well as looking towards foreign markets for guidance. These approaches have the potential to result in the prioritisation of products which are not necessarily major contributors to marine pollution in lieu of those which are. Furthermore, value-chain actors also take their cues from consumers; prioritising items for immediate intervention as a response to consumer pressure. The influence of consumers was demonstrated in the cases of straws and cotton bud sticks whereby value-chain actors cited consumer pressure as the primary motivation for intervention development. Only one value-chain actor reportedly bases their prioritisation on "dirty dozen" lists compiled internationally.

When presented with the concept of leakage rates, value-chain actors believed they would provide a much-needed evidence-base for the selection of product for intervention. Furthermore, they cited a sound evidence base as integral to the justification of decisions to company executives and obtaining their buy-in for strategy development. However, despite their perspective on the potential value of leakage rates one retailer did not believe they would influence their firm's practices due to the emphasis on commercial gain in contrast to environmental issues.

The challenges associated with intervention development and product redesign are directly related to key packaging design metrics. Packaging functionality was cited as a major concern particularly when it comes to effective food protection and preservation. In addition, cost presents an additional constraint to the employment of alternative materials due to the relatively low cost of plastic. The broader environmental impacts associated with interventions are considered to a much lesser extent. This was exemplified in the cases of straws and cotton bud sticks, whereby value-chain actors relied on anecdotal evidence when comparing potential alternatives. Furthermore, the single-minded focus on plastic pollution resulted in a focus on biodegradability when considering the broader impacts of alternatives. This single minded-focus was also shown in the case of beverage bottle lids whereby value-chain actors were exploring the possibility of lid tethering to reduce lid leakage into the environment. Whilst this would increase the collection rate of lids, the lack of standardisation of lid materials would result in a mixed plastics stream (when separated during the PET recycling process) with limited recycling applications.

9.2 Conclusions

9.2.1 Plastic leakage into the marine environment from Cape Town

This thesis utilised beach accumulation surveys to estimate plastic flows into the ocean from five beaches in Cape Town over two sampling periods. Despite the variability associated with accumulation rates at different sites there was uniformity regarding the items which were found to be major contributors. More specifically, products associated with foods consumed on-the-go were found to be major contributors across catchment areas and sampling periods. Furthermore, these items were associated with relatively higher leakage rates, indicating the high leakage propensities of such items. Thus, strategies aimed at addressing these items could potentially reduce a significant proportion of plastic flows into the marine environment from Cape Town.

9.2.2 Influence of leakage on plastic product life cycle management

The increasing concern surrounding plastic pollution has pressured retailers and brand owners to review their approaches to the life cycle management of plastic products. More specifically, value-chain actors are increasingly focussing on the potential fate of the product waste. This may be attributed to the societal expectations, whereby value-chain actors are being viewed as responsible for their products throughout their entire life cycle including at end-of-life. As a result, they have developed strategies focused on plastic packaging. However, these strategies are not necessarily aimed at mitigating plastic pollution but instead focus on the responsible design of products, via design for recycling, and their management at end-of-life. Thus, although spurred by the concern surrounding marine pollution the extent to which these strategies address it is limited.

Interventions targeted towards products that were identified as prone to leakage, including straws and cotton bud sticks as explored in this thesis, were catalysed by consumer pressure and societal expectations at large. There was limited consideration of the broader environmental impacts associated with product interventions, increasing the potential for environmental burden-shifting to occur.

Significant overlap was observed between value-chain actors who employ LCM concepts in their companies and those who are actively responding to the plastic pollution challenge. There was no public response from smaller, locally based, brand owners whose products had been identified as major contributors to marine pollution during the beach surveys. This brings into question the potential effectiveness of initiatives aimed at mitigating plastic pollution which exclude this market segment.

9.2.3 Feasibility of leakage rates as a proxy indicator for potential marine environmental impacts

The feasibility of utilising leakage rates as a proxy indicator for potential marine environmental impacts to inform product life cycle management is dependent on data availability. More specifically, the availability of reliable data to inform waste generation is needed, in addition to reliable information regarding environmental accumulation. This is of particular concern in developing nations which are often characterised by poor data availability, as demonstrated in this thesis. In addition, litter accumulation rates are influenced by a variety of factors including weather patterns, water movements and catchment area characteristics. However, on a product level there was an element of consistency observed with regards to item prevalence and relative abundance across all sites for major contributors. Nonetheless, leakage ratios and ergo leakage rates provide valuable insights into the relative leakage propensity of different products as demonstrated in this thesis. This facilitates the identification of items that are prone to leakage into the environment for intervention development.

9.2.4 Inclusion of leakage into product life cycle management

This thesis demonstrated the need for specific knowledge of product leakage rates to facilitate responsible and effective plastic product life cycle management, particularly for products prone to leakage. The lack of product specific information has led to haphazard approaches to intervention development in some cases, and specifically the prioritisation of products, as value-chain actors are under increasing pressure to demonstrate their concern regarding plastic pollution. In addition, value-chain actors demonstrated a limited understanding of the extent of the plastic pollution problem and highlighted data unavailability as a key constraint. This has resulted in the development of strategies that would not necessarily mitigate plastic pollution. Consulted value-chain actors believed that product-specific leakage rates would provide a much-needed evidence base for the identification and prioritisation of items for intervention. Thus, the integration of leakage rates would facilitate the development of effective and targeted strategies, by enabling the identification of products which are highly prone to leakage.

9.3 Recommendations for Life Cycle Management Practise

This thesis has affirmed that the global concern surrounding plastic leakage has placed pressure on value-chain actors to develop strategies for its mitigation. However, in the absence of reliable data value-chain actors are taking varied approaches to the prioritisation of products. The inclusion of leakage rates into life cycle management practise could potentially play an important role for products where plastic is a material choice. Thus, retail and brand-owning corporations should consider employing the developed method for estimating specific leakage rates for products within their portfolios. Whilst access to reliable information is highlighted as a potential constraint, as producers, they would have access to sales figures in different markets and/or geographies to inform product waste generation. Furthermore, corporations may choose to collaborate with citizen-science organisations trained in beach accumulation survey methodology to obtain data on product flow rates into the marine environment; this may be incorporated into existing consumer awareness campaigns providing additional benefits from a public relations perspective.

Products related to foods consumed on-the-go were identified as highly prone to leakage. Thus, it is recommended that product design interventions be investigated for these items including the use of biocompatible materials to minimise harm when leaked into the environment or redesign for recyclability. Furthermore, brand owners and retailers should explore behaviour nudging approaches to reduce littering of such items or consider the viability of product elimination.

9.4 Recommendations for Future Research

Further research is required to improve the development of leakage rates, particularly for the estimation of product flows to the marine environment. Whilst beach accumulation surveys are currently accepted as a proxy for litter flows into the marine environment, research has shown that these flows are influenced by a variety of factors including weather patterns and ocean currents and tides. Thus, further research is required into the refinement of beach survey methodology in order to develop a more realistic representation of plastic flows into the marine environment. Furthermore, there is limited research on the flows of plastic in different environmental compartments including terrestrial, freshwater and ocean sub-compartments (i.e. surfaces, floors and the water column). An understanding of these flows would enable a more realistic understanding of the extent of the plastic pollution problem. In addition, more refined methods would enable the evaluation of the efficacy of implemented interventions.

Continued development of LCIA methods for the impacts associated with accumulation of non-biodegradable items in the marine environment is necessary. Whilst rudimentary indicators have been developed, these do not fully integrate the documented toxicity impacts associated with plastics in the environment. It is recognised that the impacts associated with plastic marine pollution are not fully understood however, some impacts have been well documented (i.e. entanglement and ingestion). These provide a springboard for the development of effect models for integration into LCA methodologies.

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Appendix A Life Cycle Impact Categories of Relevance

When conducting an LCA the selection of impact categories is directly linked to the environmental impacts associated with the product or system as well as the goals of the study. Quantifying impacts in these categories is underpinned by a variety of models which serve to interpret the results of the inventory analysis. There are a number of life cycle impact assessment methodologies which consider different impact categories dependent on the focus and scope of the methodology. However, there are several impact categories which are common across different methodologies and can thus be considered baseline categories when conducting an LCA (shown in Table A-1).

Table A-1: Life Cycle Assessment baseline impact categories (adapted from Guinée et al. 2002)

Impact Category	Focus Area
Depletion of abiotic resources	Related to extraction of minerals and fossil fuels
Climate change	Related to emissions of greenhouse gases to air
Ozone depletion	Output related and at a global scale
Human toxicity	Effects of toxic substances on the human environment
Ecotoxicity (freshwater, marine, terrestrial)	Impacts of toxic substances on ecosystems
Photochemical oxidant formation	Formation of harmful reactive substances (mainly ozone)
Acidification	Impacts of acidifying substances on the natural environment
Eutrophication	Impacts due to excessive macronutrients in the environment

Based on the environmental impacts outlined in section 2.2 it is clear that one major and tangible concern surrounding plastic pollution is its toxicity to humans, wildlife and ecosystems. These impacts may be considered under the LCA impact categories human toxicity and ecotoxicity. Impact on biodiversity, particularly the depletion of living organisms, is an area that is not routinely considered explicitly in life cycle impact assessment methodologies. Instead, it is considered in terms of drivers of biodiversity loss including land use, water use, ecotoxicity and climate change (Curran et al., 2011).

Human toxicity and ecotoxicity

In LCA the toxicity of a substance is assessed via two impact categories: human toxicity and ecotoxicity. The former models the impacts of toxic substances on human health whereas the latter is concerned with impacts on aquatic, terrestrial and sediment ecosystems. For both impact categories, fate, degradation and intermedia transport are of particular importance (Guinée et al., 2002). Many substances, particularly organic compounds, generally degrade into less toxic substances dependent on the conditions of the compartment. It is important to take into consideration the transportation of substances between compartments, as substances do not generally stay in one compartment. Furthermore, the toxicity of a substance may vary according to the media it is stored in.

In general, toxicity assessment models take into consideration four key aspects that affect the toxicity potential of a substance (Guinée et al., 2002):

- Fate - the residence time of a substance in an environmental compartment (air, water and soil), taking into consideration degradation mechanisms and transportation processes between compartments.

- Transfer – the proportion of a substance transferred to an exposure route from a given compartment.
- Exposure/intake – the intake of a substance by an organism which is dependent on the exposure route e.g. air, drinking water, crops.
- Effect – the impacts associated with the intake of a substance

The first three aspects are often modelled together as they are intrinsically linked. Depending on the toxicity model, several compartments and sub-compartments can be distinguished. Transfer between compartments and ultimately to exposure routes often takes place via natural environmental processes such as rainfall, degradation and sedimentation. The toxicity models then extend the environmental processes via exposure routes to relevant organisms and/or ecosystems (e.g. terrestrial, freshwater and marine).

Toxicity assessment models are used to develop characterisation factors which represent the toxicity of a substance in terms of a chosen indicator. These factors are used during the interpretation phase of LCA. Human toxicity and ecotoxicity characterisation factors have been determined for a range of inorganic and organic substances however they are yet to be developed for plastics (Guinée et al., 2002; Rosenbaum, 2008). As such it is not currently possible to evaluate the toxicity of plastics in LCA.

Appendix B Life Cycle Assessment Modelling Approaches

Straws

Data sources and modelling approach

The product life cycle stages, including relevant process descriptions, were informed by the combination of literature reviews as well as primary data sourcing via relevant actors along the value chain. In particular, value-chain actors were consulted in order to determine where the different life cycle stages took place as well as the associated manufacturing methods. A combination of primary and secondary data sourcing was used to inform the inventory foreground data. Primary data to inform the product life cycles was provided by local manufacturers and distributors. Secondary data was sourced from literature and the Ecoinvent v3.5 database. Background data was based on datasets available in the Ecoinvent v3.5 database. The life cycles were modelled using SimaPro LCA Software.

Material production

Limited information was available for paper and PLA straw manufacture beyond the geographical information supplied by local distributors due to confidential company information (i.e. importers). This included the specific location of the plants in the supply chain. The LCI for PLA production was based on an Ecoinvent dataset (Althaus et al., 2007). This dataset was based on the eco-profile for Ingeo PLA produced by NatureWorks^{TM} (Vink et al., 2007) and adapted to represent a general inventory by changing the energy sources to those of the relevant source country. This, coupled with the inclusion of capital goods, resulted in higher carbon emissions: 2.46 kg $CO_{2\ eq}$ vs 3.06 kg $CO_{2\ eq}$ per kg PLA resin. Furthermore, as a long-term perspective was taken, the temporary storage of CO_2 by biomass was not considered for both paper and PLA products (European Commission, 2010). The same approach was taken for paper straw manufacturer. Glass and steel straw manufacture inventory data was based on information provided by local manufacturers. The LCI for glass tube production was based on an Ecoinvent dataset for borosilicate production in the same region as specified by the straw manufacturer (Kellenberger et al., 2007). The steel tubes are predominantly sourced from China, thus relevant Ecoinvent datasets for stainless steel were adapted based on manufacturer specifications regarding steel type and production process. Propylene production was based on LCI data by Russo & von Blottnitz (2018).

Straw manufacture

Inventory data for the extrusion of PLA and plastic straw was based on Ecoinvent datasets which were then adapted based on manufacturer specifications. The glass and steel manufacturing inventory flows data were sourced from local manufacturers.

End-of-life

The end-of-life flows (Table A-2) were based on household surveys conducted on waste management practices (Stats SA, 2018b), coupled with industry recycling figures and estimates of beach accumulation rates as a proxy for flows into the marine environment (as found in Chapter 4).

Table A-2: Straw end-of-life flows

	Polypropylene	Polylactide	Paper	Glass	Stainless steel
Marine environment	38.0%	38.0%	38.0%	0.0%	0.0%
Open burning	0.3%	0.3%	0.3%	0.5%	0.5%
Dumps	19.9%	19.9%	19.9%	32.1%	17.6%
Landfills	41.8%	41.8%	41.8%	67.4%	15.9%
Recycling	0.0%	0.0%	0.0%	0.0%	66.0%

The landfilling, dumping and open burning inventories were based on models developed by Doka (2017). As there is currently no life cycle impact assessment indicator that allows for the consideration of the potential environmental impacts associated with leakage into the marine environment, leakage rate was used as a proxy indicator. Leakage rate was defined as: "*the fraction of consumed product that entered the marine environment.*"

There have been conflicting results regarding the degradation rate of PLA in landfills. A study into the anaerobic degradation of PLA under simulated accelerated landfill conditions at 35°C found amorphous PLA had degraded by 36% after 12 months, whereas no degradation was observed for semi-crystalline PLA. However, Krause & Townsend (2016) suggested that this was an underestimate of degradation rates as it did not take into account the influence of temperature, whereby they proposed that semi-crystalline PLA would be readily degradable under thermophilic conditions which are often observed in landfills. This has resulted in different assumptions being made when modelling landfilling of PLA, with Rossi et al. (2015) assuming a rate of 1% whereas Hottle et al. (2017) modelled low and high degradation scenarios with rates of 0% and 36% respectively. Thus, two scenarios were modelled for PLA; a "low" degradation rate of 1% and a "high" rate of 36%.

Transport

This study considered transport from the material producer to the straw manufacturer, and then to the distributor. In cases where the straws were locally manufactured (plastic, glass and steel) the straw manufacturer was also the distributor. The market split for manufacturers and distributors was not available thus the average distance was considered. This had potential implications for plastic, paper and steel life cycle impacts, which was explored via variation analyses of the market share.

Cut-off criteria

The impacts associated with distribution and retail of the straws were not included in the life cycle models. Transport from distributors to retailers and subsequently users was not taken into consideration. This was due to the variability of the distances and transportation modes involved. Furthermore, transport during the use phase was also excluded due to the increasing complexity associated with modelling consumer habits particularly when it comes to items consumed on the go. However, the cleaning burdens associated during the use phase were included as they are an integral element of reusable items. Transport to disposal sites was also omitted based on the aforementioned reasons. Transport to distributors was taken into consideration as many of the products are imported from other continents thus it was important to explore the associated impacts.

Primary and secondary packaging was omitted from the life cycle assessment due to the variability associated with both. The different straw materials are available with a range of packaging options. For example, plastic straws may be individually wrapped or sold unwrapped, then they may be further packaged in boxes or plastic sleeves. Whereas, reusable straws have the option of a hemp sleeve and they may be sold in paper sleeves, boxes or without any packaging.

Information on capital goods was not available across all production stages for the different life cycles. More specifically, information on capital goods for the straw manufacturing stage was not available for all the straw material types. Furthermore, the manufacture of reusable straws did not require the construction of a dedicated factory or specialised machinery resulting in increased complexity when allocating as the aforementioned may be utilised beyond straw making activities. Thus, only processes and transportation directly related to the production of the product were taken into consideration in the straw manufacturing life cycle stage.

Allocation

For this study, allocation was only necessary for the production of propylene, which is produced via Fischer-Tropsch synthesis, for which mass allocation was used. The cut-off method was used for recycling scenarios.

Cotton Bud Sticks

Data Sources and modelling approach

The product life cycle stages, including relevant process descriptions, were informed by the combination of literature reviews as well as primary data sourcing via relevant actors along the value chain. In particular, value-chain actors were consulted to determine where the different life cycle stages took place as well as the associated manufacturing methods. A combination of primary and secondary data sourcing was used to inform the inventory foreground data. Primary data to inform the product life cycles was provided by local distributors. Secondary data was sourced from literature and the Ecoinvent v3.5 database. Background data was based on datasets available in the Ecoinvent v3.5 database. The life cycles were modelled using SimaPro LCA Software.

Material production

Limited information was available for paper manufacture beyond the geographical information supplied by local distributors. Thus, the LCI was based on Ecoinvent data for paper production which were then adapted to be representative of the geographic region. The propylene production was based on LCI data by Russo & von Blottnitz (2018).

Cotton bud stick manufacture

Inventory data for the manufacture of cotton bud sticks was based on Ecoinvent datasets which were then adapted based on manufacturer specifications.

End-of-life

The end-of-life flows (Table A-3) were based on household surveys conducted on waste management practices (Stats SA, 2018b), coupled with industry recycling figures and estimates of beach accumulation rates as a proxy for flows into the marine environment (as found in Chapter 4).

Table A-3: Cotton bud stick end-of-life flows

	Polypropylene	Paper
Marine environment	84.7%	84.7%
Open burning	0.1%	0.1%
Dumps	4.9%	4.9%
Landfills	10.3%	10.3%

The landfilling, dumping and open burning inventories were based on models developed by Doka (2017). As there is currently no life cycle impact assessment indicator that allows for the consideration of the potential environmental impacts associated with leakage into the marine environment, leakage rate was used as a proxy indicator. Leakage rate was defined as: "*the fraction of consumed product that entered the marine environment.*"

Transport

The market split for manufacturers and distributors was not available thus the average distance was considered. This had potential implications for locally manufactured cotton buds, which was explored via variation analyses of the market share.

Cut-off criteria

The impacts associated with distribution and retail of the cotton buds were not included in the life cycle models. Transport from manufacturers to distributors then retailers and subsequently users' homes was not taken into consideration. This was due to the variability of the distances and transportation modes involved. Transport to disposal sites was also omitted based on the aforementioned reasons. For imported cotton buds, transport from the manufacturer to South Africa was considered so as to explore the associated impacts.

Primary and secondary packaging was omitted from the life cycle assessment due to the variability associated with both. Moe specifically, Cotton buds are sold in a variety of pack sizes and packaging types. Information on capital goods was not available across all production stages for the different life cycles. More specifically, information on capital goods for the cotton bud stick manufacturing stage was not available for both material types. Thus, only processes and transportation directly related to the production of the product were taken into consideration.

Allocation

For this study, allocation was only necessary for the production of propylene, which is produced via Fischer-Tropsch synthesis, for which mass allocation was used.

Appendix C Ethics Clearance

Application for Approval of Ethics in Research (EiR) Projects
Faculty of Engineering and the Built Environment, University of Cape Town

APPLICATION FORM

Please Note:
Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data.The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook**(available from the UCT EBE, Research Ethics **website**) prior to completing this application form: http://www.ebe.uct.ac.za/usr/ebe/research/ethics.pdf

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		Takunda Yeukai Chitaka
Department		Chemical Engineering
Preferred email address of applicant:		chttak002@myuct.ac.za
If a Student	Your Degree: e.g., MSc, PhD, etc.,	PhD
	Name of Supervisor (if supervised):	Prof H von Blottnitz
If this is a researchcontract, indicate the source of funding/sponsorship		Not applicable
Project Title		Inclusion of Leakage into Life Cycle Management of Products Involving Plastic as a Material Choice

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

SIGNED BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Takunda Yeukai Chitaka	Signature Removed	**20 Jan 2016**

APPLICATION APPROVED BY	Full name	Signature	Date
Supervisor (where applicable)	Harro von Blottnitz	Signature Removed	**20 Jan 2016**
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section1; and for all Undergraduateresearch (Including Honours).	J. Petersen Click here to enter text.	Signature Remove	21/1/2016 Click here to enter a date.
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.	G. Sithole Click here to enter text.	Signature Removed	27/02/2017 Click here to enter a date.

Page 1 of 1

APPLICATION FORM

Please Note:
Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form before collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form: http://www.ebe.uct.ac.za/ebe/research/ethics1

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		Takunda Yeukai Chitaka
Department		Chemical Engineering
Preferred email address of applicant:		chttak002@myuct.ac.za
If Student	Your Degree: e.g., MSc, PhD, etc	PhD
	Credit Value of Research: e.g., 60/120/180/360 etc.	360
	Name of Supervisor (if supervised):	Harro von Blottnitz
If this is a researchcontract, indicate the source of funding/sponsorship		
Project Title		Inclusion of Leakage into Life Cycle Management of Products Involving Plastic as a Material Choice

I hereby undertake to carry out my research in such a way that:
- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

SIGNED BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Takunda Yeukai Chitaka	signature Removed	20 Mar 2018

APPLICATION APPROVED BY	Full name	Signature	Date
Supervisor (where applicable)	Harro von Blottnitz	Signature Removed	20 Mar 2018
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section1; and for all Undergraduateresearch (Including Honours)	J. Petersen	Signature Removed	20-3-2018
Chair : Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.	R Behrens	Signature Removed	26 Apr 2018

Appendix D Interview Protocol

This section includes copies of the information sheet and informed consent form provided to participants. In addition, it includes the different questionnaires used which were tailored to the value-chain actors' activities and case study where relevant.

Information Sheet

Inclusion of Leakage into Life Cycle Management of Products Involving Plastic as a Material Choice

Information Sheet

This research aims to investigate the integration of plastic leakage into the life cycle management of products in which plastic is a material choice. Thus, I am interested in the current status quo regarding the decision-making process surrounding packaging design and the key metrics that are taken into consideration. I would also like to explore how leakage is currently approached during product life cycle management including product design, and the potential influence of providing specific knowledge on plastic leakage on current approaches.

As a major stakeholder in the plastics value chain, I believe you can provide some valuable insights.

To maintain anonymity no identifying participant information will be published. Instead participants will be identified using random numbers. Participants will be offered the opportunity to review a draft of the findings with the condition that they will not be published without their approval.

This research has been approved by the University of Cape Town Ethics in Research Committee.

Please feel free to contact me for any further information.

Takunda Chitaka

PhD Candidate
Department of Chemical Engineering
University of Cape Town

Informed Consent Form

Inclusion of Leakage into Life Cycle Management of Products Involving Plastic as a Material Choice

Informed Consent Form

I, the undersigned, confirm that (please tick box as appropriate):

1.	I have understood the objectives of the project, as explained by the researcher.	☐
2.	I have been given the opportunity to ask questions about the project and my participation.	☐
3.	I voluntarily agree to participate in the project.	☐
4.	The procedures regarding anonymity have been clearly explained to me.	☐
5.	I agree to the audio recording of this interview.	☐
6.	I understand that other researchers will have access to this data only if they agree to preserve the confidentiality of the data.	☐

Participant:

________________________	___________________________	________________
Name of Participant	Signature	Date

Brand Owners & Retailers

Influence of Plastic Leakage on Product Design

The aim of this interview is to ascertain the extent to leakage is taken into consideration when making design decisions for products involving plastic as a material choice. This includes the current status quo regarding the decision-making process surrounding packaging design and the key metrics that are taken into consideration.

Current approach to plastic leakage

1. What is your personal perspective on the issue of plastic litter?
    a. Is it a waste management issue, an Extended Producer Responsibility issue, a behavioural issue or potentially a design issue?

2. What is your understanding of the extent of the plastic leakage problem?

    a. Of all the plastic used in South Africa in a year, what % would you estimate ending up in the environment?

    b. Is this a wild guess, or have you done some reading / research on this?

    c. Do you have any indication of product-specific leakage rates? For example, 20% of plastic bags end up in the environment.

3. What role do you believe your organisation can/does play in addressing the issue of the increasing plastic accumulation in the marine environment?

    a. Do you have any programmes and/or initiatives targeted towards it?

4. Is Life Cycle Management a term you are aware of, and if so, do you employ this approach?

    a. Do you consider leakage during life cycle management?

Approach to product design decisions in which plastic is a possible material

1. Please give an overview of the decision-making approach to product design decisions in which plastic is a possible material, including the key metrics taken into consideration.

2. Does your organisation conduct or commission Life Cycle Assessments for environmental considerations?

    a. If not, what tools do you use to incorporate environmental considerations into your product design?

    b. What environmental impacts are taken into consideration during product design?

3. To what extent is the fate of product waste taken into consideration?

4. Trends say that consumers are increasingly valuing reusability and recyclability i.e. being green, is becoming increasingly important to consumers. How much of a role do you believe this plays during packaging design?

    a. However, recyclability doesn't necessarily mean the product will be recycled. To what extent is the possible fate of product waste (i.e. its waste scenario) taken into consideration?

Influence of leakage on product design

1. Is the potential for leakage taken into consideration during the design process and if so, to what extent?

2. What influence, if any, has the increasing focus on plastic marine litter had on your organisation's operations with regards to plastic products?

    a. Taking into consideration that as more litter surveys are generated the spotlight is getting brighter on specific items that seem to be prevalent in litter streams, do you feel there is increased consumer pressure to substitute/remove certain materials?

    b. Are there any particular products that have been identified as priority items in terms of plastic pollution? If so, how were they identified?

3. What influence do you think the provision of product specific leakage rates may have on product design? For example, if it was found that 20% of polystyrene food packaging ends up in the environment.

4. In light of growing spotlight on so-called priority items, what are the key barriers and/or challenges associated with product redesign?

5. Have you explored the option of material substitution for any products?

    a. If so, what approach was taken?

    b. What are any challenges or barriers you faced?

The New Plastics Economy

1. The New Plastics Economy vision for a circular economy advocates for the redesign of "problematic or unnecessary plastic packaging", and that all plastic packaging is reused, recycled and composted with none entering the natural environment. What are your thoughts on the vision from a developing country perspective?

What do you believe are some key barriers or challenges to achieving the vision?

Industry Associations

Influence of Plastic Leakage on Product Design

The aim of this interview is to ascertain the extent to leakage is taken into consideration when making design decisions for products involving plastic as a material choice. This includes the current status quo regarding the decision-making process surrounding packaging design and the key metrics that are taken into consideration.

Current approach to plastic leakage

5. What is your perspective on the issue of plastic litter?
    a. Is it a waste management issue, an Extended Producer Responsibility issue, a behavioural issue or potentially a design issue?

6. What is your understanding of the extent of the plastic leakage problem?

    a. Of all the plastic used in South Africa in a year, what % would you estimate ending up in the environment?

    b. Is this a wild guess, or have you done some reading / research on this?

    c. Do you have any indication of product-specific leakage rates? For example, 20% of plastic bags end up in the environment.

7. What role do you believe your organisation can/does play in addressing the issue of the increasing plastic accumulation in the marine environment?

    a. Do you have any programmes and/or initiatives targeted towards it?

Approach to product design decisions in which plastic is a possible material

5. What are the key design metrics taken into consideration during packaging design (e.g. cost, carbon emissions, light weighting)?

6. Trends say that consumers are increasingly valuing reusability and recyclability i.e. being green, is becoming increasingly important to consumers. How much of a role do you believe this plays during packaging design?

    b. However, recyclability doesn't necessarily mean the product will be recycled. To what extent is the possible fate of product waste (i.e. its waste scenario) taken into consideration?

Influence of leakage on packaging design

6. Is the potential for leakage taken into consideration during the packaging design process and if so, to what extent?

7. What impact do you think the increasing focus on plastic marine litter is having on the packaging industry?

8. Taking into consideration that as more litter surveys are generated the spotlight is getting brighter on specific items that seem to be prevalent in litter streams, do you feel there is increased consumer pressure to substitute/remove certain products?

9. What influence do you think the provision of product specific leakage rates may have on packaging design? For example, if it was found that 20% of polystyrene food packaging ends up in the environment.

    a. Do you think the provision of such information will be of value to the packaging industry e.g. in the development of strategies or interventions?

The New Plastics Economy

2. The New Plastics Economy vision for a circular economy advocates for the redesign of "problematic or unnecessary plastic packaging", and that all plastic packaging is reused, recycled and composted with none entering the natural environment. What are your thoughts on the vision from a developing country perspective?

    a. What do you believe would be some key barriers or challenges to achieving the vision in developing countries?

Recyclers

Influence of Plastic Leakage on Product Design

The aim of this interview is to ascertain the extent to leakage is taken into consideration when making design decisions for products involving plastic as a material choice. This includes the current status quo regarding the decision-making process surrounding packaging design and the key metrics that are taken into consideration.

Current approach to plastic leakage

8. What is your perspective on the issue of plastic litter?
    a. Is it a waste management issue, an Extended Producer Responsibility issue, a behavioural issue or potentially a design issue?

9. What is your understanding of the extent of the plastic leakage problem?

    a. Of all the plastic used in South Africa in a year, what % would you estimate ending up in the environment?

    b. Is this a wild guess, or have you done some reading / research on this?

10. Do you have any indication of product-specific leakage rates? For example, 20% of plastic bottles end up in the environment.

    a. Are you aware of the disparity that exists between the prevalence of lids vs bottles in the environment?

11. What role do you believe is the role of recyclers in addressing plastic pollution?

Potential influence of bottle redesign

7. Currently, do the PET bottles arrive with lids attached?

    a. If so, what fraction of the bottles do you estimate arrive with bottles attached?

8. What do you currently do with the bottle lids after they are separated out of the stream?

9. Is the price of the different material factored into what you pay for PET bottles?

10. Is there a point where the ratio of PP to PET will no longer be favourable? I.e. where you would no longer be willing to pay PET prices for what is essentially mixed recyclables?

11. What do you think is the potential influence of a beverage bottle redesign?

The New Plastics Economy

3. The New Plastics Economy vision for a circular economy advocates for the redesign of "problematic or unnecessary plastic packaging", and that all plastic packaging is reused, recycled and composted with none entering the natural environment. What are your thoughts on the vision from a developing country perspective?

    a. What do you believe would be some key barriers or challenges to achieving the vision?

Restauranteurs

Influence of Plastic Leakage on Product Design

The aim of this interview is to ascertain the extent of knowledge surrounding plastic pollution.

Current approach to plastic leakage

12. What is your personal perspective on the issue of plastic litter?
    a. Is it a waste management issue, an Extended Producer Responsibility issue, a behavioural issue or potentially a design issue?

13. What is your understanding of the extent of the plastic leakage problem?

    a. Of all the plastic used in South Africa in a year, what % would you estimate ending up in the environment?

    b. Is this a wild guess, or have you done some reading / research on this?

    c. Do you have any indication of product-specific leakage rates? For example, 20% of plastic bags end up in the environment.

14. What role do you believe your organisation can/does play in addressing the issue of the increasing plastic accumulation in the marine environment?

    a. Do you have any programmes and/or initiatives targeted towards it?

15. What influence, if any, has the increasing focus on plastic marine litter had on your organisation's operations with regards to plastic products?

    b. Taking into consideration that as more litter surveys are generated the spotlight is getting brighter on specific items that seem to be prevalent in litter streams, do you feel there is increased consumer pressure to substitute/remove certain materials?

    c. Are there any particular products that have been identified as priority items in terms of plastic pollution? If so, how were they identified?

16. In light of growing spotlight on so-called priority items, what are the key barriers and/or challenges associated with designing an intervention?

17. Have you explored the option of material substitution for any products?

    d. If so, what approach was taken?

    e. What are any challenges or barriers you faced?

Product Questionnaire – No intervention
Influence of Plastic Leakage on Product Design

The purpose of this interview is to ascertain the extent to which plastic leakage may influence design of items that have been identified as prone to leakage. Thus, the interview will be focused on one specific item, which may be considered a priority item in the context of its accumulation in the marine environment. In addition, the results of a performance assessment of the priority item will be presented for reflection.

Current Approaches and Perspectives

1. Are you aware of the current rhetoric surrounding this product regarding its contribution to marine pollution, and what is your perspective?

2. What fraction of this product do you estimate leaks into the environment?

3. What influence, if any, has the increasing focus on such products had on current and future operations?

4. In your opinion, what role do you believe your organisation can/does play in addressing the issue of the increased accumulation of this product in the marine environment?

    a. Is the extent of the problem significant enough to necessitate intervention, e.g. product elimination or redesign?

    b. Is your perceived contribution low enough to not necessitate action?

    c. Or do you believe current efforts are sufficient?

5. What would be the necessary drivers to initiate a significant intervention (e.g. product redesign)?

6. What are the challenges and barriers to designing an intervention (e.g. cost implications, procurement challenges)?

Review of Performance Assessment

1. Do you have an indication of the environmental impacts associated with this product in comparison to alternatives?

2. What do you think would be the key positives of this product over alternatives?

Product Questionnaire – Intervention in place

Influence of Plastic Leakage on Product Design

The purpose of this interview is to ascertain the extent to which plastic leakage may influence design of items that have been identified as prone to leakage. Thus, the interview will be focused on one specific item, which may be considered a priority item in the context of its accumulation in the marine environment. In addition, the results of a performance assessment of the priority item will be presented for reflection.

Current Approaches and Perspectives

1. What is your perspective on the current rhetoric surrounding this product regarding its contribution to marine pollution?

2. May you please walk me through the decision process that led to you selecting this product as a priority item and designing an intervention?

    a. What were the key drivers for the intervention?

    b. What were the key challenges and barriers to designing an intervention?

3. Were there any significant trade-offs you made, and what was your reasoning behind them?

Review of Performance Assessment

1. Do you have an indication of the environmental impacts associated with the selected intervention in comparison to alternatives?

2. What do you think would be the key positives and drawbacks of this intervention in comparison to alternatives?

Preference Elicitation Exercise

The purpose of the preference elicitation exercise is to ascertain the relative influence different issues have on decision making during product design. The short exercise will require you to rank a set of sustainability issues and assign scores to them according to their importance. As such the exercise has been split into three steps. Please may you fill in the results of each step in the table overleaf? An example of the completed exercise is available on the final page.

Step 1: Relevance

Based on background research a list of sustainability issues has been compiled. Which of these issues do you consider to be relevant when it comes to making decisions surrounding product design? If you feel that a pertinent issue has been overlooked please feel free to make additions to the list. Please indicated relevance with either "Y" for yes, or "N" for no.

Step 2: Ranking

Please may you rank the issues you consider relevant (marked "Y") in order of their relative importance when it comes to product design, particularly when it comes to plastic as a material choice? The purpose of this is to determine which issues you consider to be most important particularly as there is increasing global concern for plastic marine accumulation.

Step 3: Scoring

In order to ascertain the relative influence these issues have on decision-making it is necessary to score them. Starting with a score of 100 points for the most important issue, please assign scores to the rest of the issues relative to the most important issue.

Participant:

Date:

Aspect	Criteria	Relevance	Rank	Weight
Functionality	Protects & preserves			
	Storage and transport			
	Informs and instructs			
	Packaged product wastage			
Technical Requirements	Material properties (inertness)			
	Material efficiency			
	Technology availability			
	Legislative requirements			
Economic	Total cost			
Marketing	Consumer perception			
Environmental	Environmental impact			
	Recycled content			
End-of-Life	Recovery rate			
	Recyclability			
	Waste management infrastructure availability			
	Biodegradability			
	Leakage propensity			
	Reusability			

Participant: John Smith

Date: 2 January 2008

Aspect	Criteria	Relevance	Rank	Score
Functionality	Protects & preserves	Y	1	100
	Storage and transport	N		
	Informs and instructs	Y	3	75
	Packaged product wastage	Y	3	75
Technical Requirements	Material properties (inertness)	N		
	Material efficiency	N		
	Technology availability	Y	3	75
	Legislative requirements	Y	2	93
Economic	Total cost	N		
Marketing	Consumer perception	Y	4	65
Environmental	Environmental impact	N		
	Recycled content	Y	6	15
End-of-Life	Recovery rate	N		
	Recyclability	N		
	Waste management infrastructure availability	N		
	Biodegradability	N		
	Likelihood to be dumped or littered	N		
	Reusability	Y	5	50

Appendix E Interview Summaries

In order to maintain the anonymity of participants, interview transcripts were omitted in favour of interview summaries. These summaries report on the perspectives expressed by interviewees whilst maintaining anonymity through the omission of any identifying information.

Participant ID: Brand Owner A

Date: 13 March 2017

Communication Method: Face-to-face

Brand Owner A was actively engaged in their company's packaging design process and was well versed with company operations including sustainability goals. They viewed plastic pollution as being purely due to consumer behaviour. Throughout the interview, the brand owner expressed their lack of control over the fate of their products at end-of-life continuously expressing that they cannot "control" consumers. Whilst they invested in consumer education on proper waste disposal, they were sceptical about the effectiveness.

The brand owner highlighted that companies are increasing being evaluated according to their sustainability performance. This has resulted in greater consideration of the environmental impacts of their packaging, with an emphasis on carbon and water footprints. When it comes to the end-of-life of a product during design, material recyclability and biodegradation are considered.

Despite currently placing the onus on consumers for addressing plastic pollution, the brand owner acknowledged that rising consumer pressure would force firms to take a more active role. They emphasised that meeting consumer expectations was a key driver in the firm's decision-making process.

Whilst Brand Owner A exhibited great passion for sustainability, they did not believe that their firm currently had a meaningful role to play in plastic pollution mitigation.

Participant ID: Industry Association A

Date: 1 December 2016

Communication Method: Face-to-face

Industry Association A is active in the South African plastics industry. They viewed plastic pollution as caused by a combination of issues including behaviour, waste management, product design and extended producer responsibility. In addition, they highlighted that collection of plastics is a challenge including for widely recycled items which were supported via PROs.

Despite their affiliation with the plastics industry they were quick to admit that certain products were problematic, and solutions need to be found in this regard, including the possibility of a shift away from plastic. However, they highlighted that there were challenges associated with plastic alternatives including cost, functionality and technology availability.

Industry Association A exhibited great passion for the mitigation of plastic pollution and was actively involved in various initiatives in this regard.

Participant ID: Industry Association B

Date: 24 & 27 March 2017

Communication Method: Electronic

Industry Association B is active in the South African packaging industry. They believed that plastic pollution was largely a behavioural issue, whilst poor waste management exacerbated it. In their opinion, product design played a much smaller role. When it comes to EPR they believed that the various PROs were doing an "excellent job" but acquiesced that there was room for improvement.

Industry Association B described four key criteria for packaging design: functionality, economic, environmental and legal compliance. Environmental performance was evaluated in terms of light-weighting, recyclability and avoidance of harmful additives.

According to the industry association, plastic leakage was not taken into consideration during product design. The extent to which end-of-life was taken into consideration was constrained to the use of recyclable materials and did not consider the waste flows in reality. However, Industry Association B believed that the increasing concern surrounding plastic pollution would have a detrimental effect on the perception of plastic.

Participant ID: Packaging Designer

Date: 23 & 29 March 2017

Communication Method: Electronic & Telephonic

The packaging designer was experienced in the design of paper and plastic packaging. They attributed plastic pollution to a combination of issues including consumer behaviour, product design, extended producer responsibility and waste management practices. However, they believed that improvements in waste management coupled with behaviour change would have the most impact in reducing plastic pollution. They did not believe that EPR and design changes would necessarily minimize littering but acknowledged that they would enable a more circular plastics economy.

According to the designer, when designing packaging preservation and protection is a key factor in selecting a material. This includes material inertness to assess food safety. Following this, technology availability for the packaging was assessed including the associated cost. If viable material alternatives exist, which are similar in cost and availability, the environmental impacts are assessed using a "matrix of choice". Recyclability of the packaging design is also assessed at this stage. However, the extent to which recyclability is taken into consideration varies amongst firms; not all firms are willing to consider an increase in packaging costs for better environmental performance.

Whilst some firms consider recyclability as a key metric, they did not necessarily take into consideration the waste scenarios associated with the product in reality. Instead firms were content with the knowledge that the material was "technically recyclable" and not whether it will be recycled in practice. Furthermore, leakage is not taken into consideration during the design process with firms believing their role was limited to encouraging consumers to act responsibly. However, the packaging designer believed it was important to take a more realistic perspective to waste flows but remarked that "we are too far from it at this stage".

The designer highlighted that there has been constant pressure on plastic packaging however it was largely based on opinion and not on detailed studies. They postulated that the increasing concern surrounding marine plastic pollution would result in more consumer pressure on brands and organizations to take responsibility for it and be more active in its mitigation, including efforts to improve plastic collection and recycling rates.

Overall, the packaging designer was well aware of the sustainability issues associated with plastic packaging across its life cycle, including leakage, however expressed that in practice they are not always taken into consideration.

Participant ID: Retailer A

Date: 3 March 2017

Communication Method: Face-to-face

Retailer A was well versed with company operations and were at the forefront of packaging sustainability matters. The retailer took a number of criteria into consideration during product design including functionality, technology availability and consumer appeal. From an environmental perspective, the focus was on energy intensity and carbon and water footprints. In addition, the retailer highlighted that whilst they favoured materials that were recyclable, but this was not always possible due to technology limitations. The retailer did not consider plastic leakage in the design process as they did not believe that their clientele would litter. They believed the likelihood of their products being littered so low that it was not economically sound to invest in alternative packaging designs. Ultimately, they were trying to "find the lowest cost packaging to do the job".

In general, the retailer believed that plastic pollution was caused by consumer behaviour. Thus, they placed emphasis on consumer education and awareness campaigns.

Overall, Retailer A exhibited great passion for sustainability within the packaging industry. However, they were sceptical about their firm's contribution to the plastic pollution problem citing a desire for concrete evidence.

Participant ID: Brand Owner A

Date: 27 November 2018

Communication Method: Electronic & Telephonic

Brand Owner A was actively engaged in their company's packaging design and was well versed with company operations including sustainability goals. A number of factors were taken into consideration during packaging design. Key factors included packaging functionality, particularly relating to food preservation and consumer convenience during use, and consumer appeal. Once a suitable design was developed it was then evaluated according to a set of in-house sustainability metrics that were currently being finalised. A life-cycle perspective was employed when evaluating designs including sustainable sourcing of raw materials and recyclability at end-of-life.

The brand owner viewed plastic pollution as being caused by a combination of issues including behavioural, waste management infrastructure and management and product design. They also acknowledged their role as brand owners for the products they put on the market. As such there was increasing focus design for recycling across their brand portfolio. According to the brand owner, items were prioritised for redesign based on their production volumes. The motivation was that interventions for these items would result in the most favourable impact in terms of retaining plastics in the value chain and reducing flows to landfills. The brand owner also supported recycling activities and actively engaged with recyclers on their operations including desirable material types and capacity development. They believed that attaching value to waste would reduce the likelihood of leakage. Furthermore, the brand owner continually emphasised the importance of consumer education to mitigate plastic pollution and viewed as critical to the success of any interventions. Thus, they also ran consumer education initiatives. The brand owner also believed that everyone had a role to play in mitigating plastic pollution including converters, brand owners, consumers, recyclers and government.

The brand owner highlighted that a company's sustainability performance is increasingly being considered during valuations by investors. Thus, they viewed integrating sustainability into the business model as integral to maintaining their competitiveness. Furthermore, the brand owner highlighted the need to align themselves with the principles of their distributors (i.e. retailers); specifically, they referred to the sustainability commitments being made by retailers and the need to ensure that products aligned with these goals so that the retailers would continue to purchase them.

Cost was seen as a major constraint to the transition towards a circular economy; particularly the cost associated with new technologies and materials. In their opinion, the adoption of newer materials (e.g. biodegradables and compostables) would result in an increase in product costs potentially making them less accessible to people in lower income brackets. Increasing recyclability was viewed as a more realistic goal as South Africa already has recycling infrastructure in place. However, they acknowledged that there was a need for improvements to current infrastructure both in terms of capacity and capabilities to treat a greater range of materials.

Ultimately, Brand Owner A exhibited great passion for sustainability and viewed it as one of their own personal core principles.

Participant ID: Brand Owner B

Date: 7 February 2019

Communication Method: Telephonic

Brand Owner B was well versed with company operations including sustainability goals. They viewed plastic pollution as a combination of issues including consumer behaviour and waste management practices. Whilst they acknowledged their role as a producer, the brand owner expressed feeling of a lack of control over their waste once it was in the hands of consumers.

The brand owner highlighted that a company was under increasing global pressure to change their packaging. Thus, packaging redesign was currently a major priority and the company was exploring different options. This included increasing product recyclability, incorporating recycled content into packaging, and exploring biodegradable material options. Maintaining packaging functionality was viewed as a major challenge to food packaging redesign. In addition, they cited the technical difficulties associated with increasing recycled content.

Ultimately, Brand Owner B exhibited great passion for sustainability and emphasised the company's focus on continually making improvements across the value chain.

Participant ID: Brand Owner C

Date: 15 January 2019

Communication Method: Telephonic

Brand Owner C was well acquainted with their company's operations. In addition, they were actively involved in the recycling industry. They believed that plastic pollution was due to consumer behaviour. However, they believe they had a role in its mitigation from an EPR perspective. Thus, they were in favour of design interventions including material substitution and redesign. In addition, they believed that attaching value to waste would decrease the likelihood of leakage.

When it came to the matter of straws, the brand owner had switched to a paper alternative. They viewed it as the best disposable alternative in terms of cost, functionality and biodegradability. The brand owner was sceptical when it came to the widespread uptake of reusable straws.

Brand Owner C was in favour of tethering of lids to bottles. They viewed it as not only a way of mitigating plastic pollution but potentially increasing the recycling rate of discarded lids. They likened tethering of plastic lids to the tethering of metal tabs to beverage cans due to their propensity for leakage after they were detached from the can during opening. Consumer enjoyment was highlighted as a potential challenge. However, Brand Owner C was confident that this was an issue that could easily be overcome; citing that the same issue was faced when the can tabs were tethered but now consumers had become accustomed to the new design. In their opinion, the capabilities of recyclers to accommodate tethered closures was a more immediate concern. More specifically, whether PET bottle recyclers would have the operational capability to separate the polyolefin lids from the PET bottles. Overall, the brand owner believed the transition is necessary to mitigate plastic pollution and any challenges would be quickly overcome.

The brand owner highlighted that any interventions or strategies need to be financially sustainable. Furthermore, functionality and consumer enjoyment were major considerations. However, they also believed that whilst consumers may not always be in favour of certain changes it was important to prioritise the greater sustainability benefits that could be realised.

Overall Brand Owner C was very attuned to sustainability issues and exhibited great passion for ensuring their packaging was not only responsibly designed but was also well managed at end-of-life.

Participant ID: Engineer A

Date: 3 April 2019

Communication Method: Face-to-face

Engineer A was well versed with wastewater treatment in South Africa, including plant design and operations. According to the engineer, plastic products routinely enter wastewater treatment facilities with the wastewater. Whilst a wide array of items was observed entering the inlet works from the sewer network, they highlighted items such as personal hygiene products (including cotton bud sticks and sanitary wear), rags (textiles), condoms, plastic bags and bread packet closures as consistent offenders. These items were viewed as problematic as they interfered with and potentially damaged plant mechanical equipment. In addition, items which were not effectively removed negatively impacted the aesthetic of the released effluent. While larger items are easily removed in the inlet works, small items of a particular shape (e.g. cotton bud sticks and bread packet closures) tend to 'slip' through the inlet works screening infrastructure, and resurface on primary clarifiers, bioreactors and secondary clarifiers. If not manually removed from these process units, these items can exit the plants with the treated effluent.

The engineer acknowledged that current installed mechanical infrastructure cannot effectively remove cotton bud sticks due to their specific size dimensions. More specifically, all debris is meant to be removed during pre-treatment at the inlet works whereby the wastewater is screened. As cotton bud sticks have a dimension which is smaller than the screen size, they slip through the vertical screening bars depending on their orientation. Thus, new inlet works infrastructure improvements are required that could effectively remove debris of smaller dimensions (e.g. dual screening, one vertical bar type followed by perforated drum type). This is already being implemented as WWTWs are being upgraded. However, screening too finely is also not ideal, because the amount of organic material screened out increases significantly with decreasing screen sizes. This organic material is required in the biological treatment process to treat the wastewater.

Despite the rhetoric surrounding plastic pollution, Engineer A remarked that there had been no notable pressure on wastewater treatment plants as pathways for cotton bud sticks into the marine environment. Despite this, infrastructure upgrades had been explored due to the mechanical issues posed by debris within the process coupled with improving the aesthetic of the discharged effluent. Cost was cited as a majorly prohibitive to upgrades, particularly in cases where it was not possible to retrofit the inlet works necessitating a complete rebuild. In addition to cost, increased solid waste removal posed an additional challenge from both environmental and socio-economic perspectives. The increase in trucks to transport solid waste would result in additional carbon emissions, as well as increased noise and visual impacts on surrounding residents.

Participant ID: Industry Association A

Date: 6 November 2019

Communication Method: Face-to-face

Industry Association A is active in the South African plastics industry. Furthermore, they had years of experience working in the realm of plastic pollution and thus were well versed with the issue. They viewed plastic pollution as caused by a combination of issues including behaviour, waste management, product design and extended producer responsibility.

The industry association noted the increasing societal concern surrounding plastic pollution which had led to a lot of public outcry against products deemed as problematic, including plastic straws. They also highlighted that there was a lot of misinformation surrounding the topic leading to people problematizing products that were not necessarily contributors to pollution. According to the industry association, this extended to industry using the example of a firm that was recently established to chemically recycle marine plastic; however, the firm had a poor understanding of the extent of the problem and realistically it was not possible to attain the tonnages they had designed for. Furthermore, the industry association expressed scepticism surrounding the figures that were being reported for the extent of the plastic problem, viewing them as exacerbating the misinformation issue.

Industry Association A did not believe that plastic leakage rates would have any potential influence, citing a population which largely “doesn’t care”. In his opinion, “a very small group of people” would care. Ultimately, he believed that plastic pollution was not about the numbers but the people.

Industry Association A exhibited great passion for the mitigation of plastic pollution and was actively involved in various initiatives in this regard.

Participant ID: Industry Association C

Date: 10 December 2018

Communication Method: Electronic

Industry Association C is active in the South African recycling industry. They believed that plastic pollution was caused by a combination of issues including consumer behaviour, waste management practices and product design. They also viewed EPR as a key element in the management of products at end-of-life. However, they highlighted that the role of each factor and the extent to which it contributed was dependent on the context under consideration. The industry association viewed recyclers as playing a vital role in the circularity of products they not only diverted waste but also converted that waste into new products which at times were not always recyclable.

When it came to the disparity between the observed prevalence of bottles vs lids, the association believed that it may be attributed to a variety of factors including the behaviour of consumers when disposing their bottles (i.e. whether they close the lid or discard it separately), as well as the behaviour of collectors as to whether they remove attached lids during collection.

The industry association viewed lid tethering in a positive light as it would increase recovery of lids for recycling. They highlighted that PET recyclers may at first feel inconvenienced due to the increased influx of lids. Financially, the association anticipated that the pricing of PET bales would change to account for the presence of lids.

When it came to challenges to lid tethering, the association did not view capital costs associated with installing technology for redesign to be a legitimate impediment. Instead, they viewed brand owners as being too cost centric and disingenuous when it comes to striving towards sustainability within the industry. Furthermore, they highlighted that manufacturers commonly upgrade their production lines regularly and the switch could be made when a line came up for review.

Participant ID: Recycler A

Date: 26 March 2019

Communication Method: Face-to-face

Recycler A was an experienced PET recycler and was actively involved in the South African recycling industry. They believed plastic pollution was caused by a combination of issues including consumer behaviour and poor design. They believed that product design with end-of-life in mind was key to addressing plastic pollution. The recycler believed that their role was to divert waste and retain it in the value chain, but the extent of their impact was largely dependent on the recyclability of products.

When it came to the disparity between the observed prevalence of bottles vs lids, the recycler believed it was due to the lower value of lids for recycling, meaning they were unlikely to be collected and retained in the value chain. More specifically, the small size and light weight of the lids meant that a greater amount would need to be collected for it to make economic sense for the collector.

The recycler was in favour of lid tethering viewing it as a good way to increase material recovery. They believed the redesign was inevitable and brand owners who resisted would be risking their bottom line. From a technical perspective, their recycling process was already designed to separate PET from low density plastics and could accommodate the consequential influx of lids. Currently, they received PET bales with lids attached to varying extents. The recycler viewed this as a potential opportunity and chose to start recycling a fraction of the lids received. However, admittedly a majority of the lids were sent to landfill. Furthermore, as the recycler was accustomed to paying for bales with impurities (including lids, labels and dirt) they did not view tethering to result in major financial implications.

Overall, Recycler A was passionate about promoting a circular plastics economy. They kept abreast of developments in the plastic industry and as expected was a proponent of design for recycling. However, the recycler was conscious of the risk of inadvertent burden shifting when developing interventions. Thus, they advocated for a holistic approach to addressing plastic pollution.

Participant ID: Recycler B

Date: 20 February 2019

Communication Method: Face-to-face

Recycler B was an experienced recycler and was actively involved in the South African recycling industry. They believed plastic pollution was caused by a combination of issues including consumer behaviour and waste management practices. In addition, they believed brand owners played a large role from both design and EPR perspectives and consumers were being used as a convenient scapegoat. Thus, they believed that actions by brand owners in these spheres were essential to mitigating pollution. The recycler expressed great exasperation at retailers and brand owners, viewing them as impeding the transition to a more sustainable plastics industry.

When it came to the disparity between the observed prevalence of bottles vs lids, the recycler believed it was due to the lower value of lids for recycling. They attributed the low demand for lids due to the lack of standardisation of material types. In addition, manufacturers were not required to include a resin code which made it difficult to distinguish amongst different materials. Thus, lid recyclate was commonly relegated to low grade applications.

The recycler was in favour of lid tethering. They did not view it as a threat to their supply of lids but regarded it as a change in the flow of lids to the recycler whereby lids would now be sourced from bottle recyclers.

Overall, the recycler was passionate about promoting a circular plastics economy and viewed recycling as a key element of it. In addition, they believed that promoting a circular economy would result in more employment opportunities.

Participant ID: Recycler C

Date: 6 December 2018

Communication Method: Telephonic

Recycler C was well versed in their company's operations and the PET recycling industry at large. They believed plastic pollution was caused by poor consumer behaviour. Thus, they believed that education was essential in reducing plastic pollution. The recycler viewed themselves as a tool in the value chain. In their opinion, brand owners played a key role in product flows and it was their responsibility to ensure that products were designed to be recyclable.

When it came to the disparity between the observed prevalence of bottles vs lids, the recycler believed it was due to a combination of factors: the lids were less likely to be collected and retailed in the value chain due to their low value and they were also more visible in the marine environment due to their low density.

The recycler was in favour of lid tethering and viewed it as a way to increase recovery of lids. Furthermore, they viewed the resultant increase in material recovery as an opportunity to create more employment opportunities within the recycling industry. However, they highlighted consumer enjoyment as a concern. They did not anticipate the redesign to have any significant impacts on their recycling operations either technically or economically. They currently received PET bales with lids attached to varying extents. Thus, their recycling process included a sink-float tank for the separation of Pet from low-density plastics including polyolefins (e.g. lids). Financially, the bales were priced according to the total weight which was considered to be pure PET regardless of the presence of other materials in the form of lids and labels. Thus, the recycler did not consider the tethering of lids to have any major financial implications on purchasing as they were already purchasing "impure" bales. Furthermore, when considering the relatively low weight of the lid in comparison to the bottle they were comfortable absorbing the additional cost for purchase of unwanted material. The recycler also highlighted that the current waste management practices in Africa, which resulted in limited supply of materials at times, restricted how selective a recycler could be when purchasing materials.

Participant ID: Restauranteur A

Date: 18 February 2019

Communication Method: Face-to-face

Restauranteur A was driven by a personal desire to mitigate their contribution to plastic pollution. As such, they made the decision to substitute plastic food-ware with alternatives, including paper takeaway boxes and PLA straws. When selecting alternatives, they specifically sought out biodegradable options. As such, the restauranteur was under the assumption that PLA straws were biodegradable in the natural environment as this is how they had been marketed towards them. The restauranteur had considered paper straws, but they were not deemed suitable for the establishment due to the popularity of frozen drinks which raised concerns about the straws' structural integrity. Reusable straws were considered however the cost was prohibitive when coupled with the potential for theft by patrons.

Restauranteur A believed plastic pollution to be caused by a combination of issues including consumer behaviour and waste management. Whilst the restauranteur acknowledged their role in plastic pollution, they believed their efforts would have a small impact in comparison to large chain restaurants.

Participant ID: Restauranteur B

Date: 19 November 2018

Communication Method: Face-to-face

Restauranteur B was driven by a personal desire to combat plastic pollution and reduce their waste to landfill in general. They believed plastic pollution to be caused by a combination of issues including consumer behaviour and waste management and viewed it as their role to reduce the availability of plastic products. As such they made the decision to avoid plastic products in their establishment.

The restauranteur initially chose to eliminate all straws however this resulted in complaints from patrons. They then made the decision to offer paper straws for purchase which was also resulted in a backlash. Now the restauranteur only offers paper straws for takeaway purchases and opted for reusable glass straws for sit-in patrons. The decision to use reusable straws in-house was motivated by a desire to reduce their waste production. Hygiene was a major motivator for the choice of glass over other reusable options such as steel; it was important for them to be able to visually inspect the straw for cleanliness particularly in cases where the straws were used for allergens such as peanuts. In addition, the restauranteur was able to off-set the costs of the straws by partnering with a local manufacturer. When it came to the environmental impacts of the straws, the restauranteur admitted they had been motivated by the potential flows at end-of-life.

Ultimately, the restauranteur was very passionate about mitigating plastic pollution and environmental sustainability at large although their reasoning was often based on anecdotes. Furthermore, they exhibited a desire to learn more about how they could reduce their footprint.

Participant ID: Retailer A

Date: 28 March 2019

Communication Method: Face-to-face

Retailer A was actively engaged in their company's packaging design process. As such they were well versed with company operations and were at the forefront of packaging sustainability matters. The retailer employed an iterative process for packaging design, in order to balance the technical requirements and sustainability performance. Initially packaging would be designed according to the functional and technical requirements. Once these were met the sustainability of the proposed design was evaluated according to a set of in-house metrics. If necessary, the packaging would be redesigned to improve its sustainability performance. The retailer considered the potential fate of packaging waste using the performance of packaging PROs as a proxy; if the material was widely recycled and had an active PRO it was considered less likely to leak into the environment. The retailer also took into consideration the implication of actions such as light-weighting on likelihood of collection for recycling as lighter items were less likely to be collected as more units would need to be collected for it to be financially viable.

Whilst the retailer was a proponent of circular economy, they highlighted its limitations to addressing plastic pollution. Although they were moving towards increasing product recyclability and recycled content, they did not believe that recycling would solve the plastic pollution problem. More specifically, the technical limitations associated with recycling products and incorporating recycled content into new products would always necessitate the usage of some virgin material and there would always be some waste. Thus, they believed that a combination of approaches was necessary including plastic reduction and elimination.

The retailer highlighted that some stakeholders in the plastics industry were defensive when it came to the issue of plastic, stating "we feel the need to defend plastic". In particular he highlighted how plastic manufacturers view drives to reduce or eliminate plastic as a direct threat to their livelihoods. Plastic manufacturers were also reportedly reluctant to integrate recyclate into their operations due to concerns surrounding technical requirements. However, some manufacturers were open to conversations surrounding product redesign. The retailer also noted tensions amongst industry stakeholders across the value chain which resulted in varying parallel initiatives to address plastic pollution. They expressed concern that this splitting at resources would pose a threat to achieving the ultimate goal of a circular plastics economy.

When it came to the cause of plastic pollution, they viewed it as a combination of issues including behavioural and waste management infrastructure and management. Furthermore, they acknowledged the responsibility they have for the product they place on the market and its ultimate fate. The current plastic pollution rhetoric has resulted in the retailer developing a new plastic packaging strategy. Their strategy identified priority items for intervention based on their prevalence in the environment according to various reports including coastal clean ups and priority lists developed by other nations including the United Kingdom and the European Union. The retailer also prioritised plastic packaging that had readily available material alternatives. They viewed their role in mitigating plastic pollution as being a driver for recycling activities, through communication with the public and supporting recycling activities.

Retailer A acknowledged that consumer desires and expectations were a key driving force in their decision-making and considered them as holding “all power”. This was demonstrated for the cases of straws and cotton bud sticks whereby public outcry led to the retailer replacing them with paper alternatives throughout their stores. They emphasised that the company was driven by the voice of the consumer and personally made the effort to address any consumer packaging related complaints. However, the retailer highlighted that limited understanding of the function of packaging would at times result in consumers making complaints that were at odds with their desires. They gave the example of a consumer who praised the quality of their foods products whilst simultaneously complaining about the use of plastic packaging. Furthermore, the retailer highlighted that some consumers were not able to interpret the on-pack recycling information, including understanding of what a resin code represents with some assuming it was an indication of how many times it can be recycled. However, the retailer did acknowledge that some of the consumers were well informed and thus more open to having meaningful discussions surrounding packaging.

When it came to designing an intervention for straws the retailer initially considered elimination however, they were concerned about depriving a demographic that needed them such as the elderly. There were concerns raised surrounding the hygiene of reusable straws. The retailer was concerned about their liability wherein a consumer did not properly wash their straw, consequentially got sick, and attributed it to the retailer’s beverage instead of their own poor hygiene. Bio-based and compostable plastics were a concern due the risk of contaminating existing plastic recycling streams as they appear similar to traditional plastics. These materials were also a concern due to the use of food crops as a feedstock in some cases. In addition, the lack of suitable infrastructure to treat compostable materials made it unlikely they would be properly managed. Ultimately the retailer decided on paper straws however they were currently receiving customer complaints regarding the quality of the straws necessitating a search for a different supplier. In the case of cotton bud sticks the choice to switch to paper was simplified by the fact that it was the most readily available alternative.

Cost was cited as a major constraint to intervention development. However, the retailer indicated that they made the effort to not pass on the cost to consumers as there were specific resources allocated to sustainability related costs.

Overall, Retailer A exhibited great passion for sustainability within the packaging industry. The retailer had admittedly undergone a shift in mindset regarding their perspective on plastic. Instead of viewing conversations surrounding plastic pollution as an attack, they were now more open to engaging on the matter and having “robust arguments and debates”. As such, they were actively engaged in various initiatives to address plastic waste. Furthermore, they kept abreast of the rhetoric surrounding plastic pollution including taking note of international legislation and international retailer practices and watching documentaries in the media.

Participant ID: Retailer B

Date: 23 November 2018

Communication Method: Face-to-face

Retailer B was actively engaged in their company's packaging design. As such they were well versed with company operations and were at the forefront of packaging sustainability matters. The retailer had recently updated their packaging design strategy to incorporate a set of sustainability metrics. Most notably, there was now am emphasis on design for recycling. These metrics were intended to be incorporated when products came up for their regular packaging design review which happened after a set time period. The packaging strategy included specific product targets in terms of sustainability performance.

Whilst the retailer had adopted principles of design for recycling, they acknowledged the limitation presented by suitable waste management infrastructure availability. However, they believed that "retailers should still push to make everything recyclable even if there isn't a place to deal with it". Infrastructure availability was also cited as an inhibiting factor when it came to the adoption of compostable materials. In particular, the lack of industrial composting facilities for their treatment.

When it came to the cause of plastic pollution, they viewed it as a combination of issues including behavioural, waste management infrastructure and management and product design. Beyond packaging redesign, the retailer had consumer education initiatives. Furthermore, they were actively engaged in various industry and NPO driven initiatives to address plastic waste, with a focus on recycling. As the interface between brand owners and consumers they reported experiencing a lot of "back-lash" from consumers surrounding products perceived as being problematic. They did not perceive themselves as having any significant power to influence private brand-owners product design, as they were dependent on their products for sales.

Retailer B acknowledged that consumer desires and expectations were a key driving force when it came to the prioritisation of items for immediate intervention. This was demonstrated for the cases of straws and cotton bud sticks whereby public outcry led to the retailer replacing them with paper alternatives throughout their stores. The retailer highlighted that the publicity surrounding an item increased the likelihood of the executive readily supporting any interventions.

Consumer misinformation was cited as a challenge when it came to strategy development. They highlighted a poor understanding of on-pack recycling labels including the meaning of material resin codes whereby some consumers assumed they represented how many times the packaging can be recycled. Cost was also a major constraint to intervention development.

Overall, Retailer B exhibited a passion for sustainability within the packaging industry. They proactively sought out information surrounding plastic pollution from various sources including popular media and scientific research. The retailer also emphasised the need for more reliable information surrounding plastic waste flows to inform better strategy development.

Participant ID: Retailer C

Date: 6 March 2019

Communication Method: Telephonic

Retailer C was actively engaged in their company's packaging design. The rhetoric surrounding plastic pollution had resulted in a fundamental shift in the company's approach to packaging design. Historically the retailer had a decentralised approach whereby individual store owners operated autonomously from the head office. The concern surrounding plastic pollution had led to more store owners turning to head office for guidance necessitating the development of a national packaging division. The packaging strategy was focused on design for recyclability and circularity.

The retailer viewed plastic pollution as being caused by a combination of issues including behavioural, waste management infrastructure and management and product design. In terms of their response, the decentralised model meant that store owners were free to select their own interventions. For example, in the case of straws, the company had not released an official standpoint and retailers were free to offer material alternatives if they chose to do so.

Cost was seen as a major constraint to strategy development. The retailer highlighted that the novelty associated with new materials commanded a higher price. Although the retailer was focused on increasing recyclability, they were aware of the potential limitation presented by the lack of adequate infrastructure for its treatment. In addition, the lack of composting facilities was viewed as an inhibitor to the adoption of compostable materials.

Retailer C acknowledged that consumer desires and expectations were a key driving force when it came to decision-making. They viewed consumers are holding a lot of power and retailers as simply serving their demands. The retailer viewed popular media as being very influential regarding consumer perceptions, creating an emotional response to the issue of plastic pollution. They highlighted that this also led to a lot of misinformation regarding plastic packaging and material alternatives. In addition, they expressed concern surrounding the rise of misrepresentation of the technical capabilities and specifically degradability of alternative materials by suppliers.

Despite the relatively new focus on packaging sustainability, Retailer C was passionate about the development of packaging for a circular economy.

Participant ID: Retailer D

Date: 15 November 2018

Communication Method: Face-to-face

Retailer D was actively engaged in packaging design within the company. As such they were well versed with packaging design protocols. When it came to packaging design, the retailer was primarily cost driven, with packaging often viewed as the first port of call when looking for opportunities for cost reduction. The retailer does not own any manufacturing facilities thus they often deferred to the packaging options which were readily available via the supplier.

The retailer viewed plastic pollution as a behavioural issue but also acknowledged their responsibility as they provide the products to society. They believed that everyone has a role to play in addressing the problem and it should be approached as a "collaborative joint venture".

The current rhetoric surrounding plastic pollution has resulted in a shift within the business whereby they were forced to take into consideration the environmental impacts associated with packaging whereas they were previously purely cost driven. This resulted in the formulation of a packaging strategy underpinned by design for recycling principles which was then distributed to all suppliers for compliance. The retailer was also focused on consumer education via on-pack labelling and media communications. Despite this, Retailer D highlighted that the company remained cost driven, particularly if it came to interventions that increased costs. In such cases the company passed the cost to consumers. Furthermore, they highlighted that the firm was not particularly driven by a desire to mitigate plastic pollution but were instead driven by a desire to meet consumers' immediate expectations so as to maintain their market share. This was demonstrated by the case of cotton bud sticks and straws whereby they switched to paper alternatives due to wider societal pressures to eliminate the plastic products. Both items were viewed as a "quick win" in the eyes of consumers.

In the case of paper straws, the retailer called their supplier to initiate the conversation; coincidentally the supplier was already in the process of exploring alternative straw materials. However, the retailer expressed discontent at the fact that the supplier was not forthcoming about the specific construct of the straw such as the use of hydrophobic coatings. The decision to switch to paper as an alternate material for plastic cotton bud sticks was determined by the fact that paper was readily available. When it came to the environmental implications of material changes, there was emphasis on the fate at end-of-life and preventing harm to the marine environment.

When it came to the matter of compostables, the retailer viewed them with suspicion. The retailer was wary of the misinformation surrounding alternative materials and reported that some suppliers were misrepresenting the degradability of their materials. The retailer also expressed reservations about the drive for recyclable materials in the absence of adequate infrastructure for its collection and treatment.

Retailer D emphasised that companies were driven by a desire to be viewed as "good corporate citizens" and did not want to be viewed as "unaligned". Furthermore, they highlighted that investors are increasingly looking at companies' sustainability performance. Thus, they kept a keen eye on competitor practices and took cues from their counterparts in developed markets as a source of guidance.

Overall, Retailer D was very attuned to sustainability issues and expressed a personal desire to incorporate sustainability principles into his role. However, due to the commercial driven nature of the retailer he was limited with regards to the extent to which this could be achieved. Nonetheless, he was not deterred and actively engaged in industry led initiatives surrounding plastic waste.