Japan-UNIDO-CSIR-Wits project:
Supporting the transition from conventional plastics to more environmentally sustainable alternatives

Life Cycle Sustainability Assessment (LCSA) of material alternatives
for
take-out containers

Final report

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Executive summary

This Report covers "*Activity 1.2: Identify material substitution opportunities for identified product(s) with a Life Cycle Sustainability Assessment (LCSA).* It is a component of the Project titled **Supporting the transition from conventional plastics to more environmentally sustainable alternatives**, funded by the Government of Japan and the United Nations Industrial Development Organization (UNIDO) and carried out in collaborations by the Council on Scientific and Industrial Research (CSIR) and the University of Witwatersrand (WITS). The overall purpose of the project is to support South Africa's transition from conventional plastics to more environmentally sustainable alternatives; with the ultimate goal of reducing the amount of plastic leaking into the environment.

Polystyrene take-out containers and cups are used for take-out meals and perform a valuable function in containing and insulating hot meals and drinks. However, these single-use plastic items are also increasingly being found in the environment, contributing to the growing problem of marine litter. Polystyrene take-out containers and cups were identified (Activity 1.1) as products for which alternatives should be sought. However, the proposed alternatives should not only reduce the problem of material pollution and marine litter, but also not have any other unintended environmental impacts.

This study assessed the life cycle impacts of polystyrene take-out containers and cups and various alternatives using attributional life-cycle assessment (LCA) and the ReCiPe 2016 Midpoint(H) method, that considers 18 environmental impact categories. In addition, given the lack of a plastic pollution impact category in existing methods, we developed a Persistence and a Material Pollution Indicator for the pollution of plastic (and other materials) in the environment. The functional unit was based on the estimated consumption of take-out meals in South Africa and attention was placed in modelling the end-of-life stage to represent the South African context. Economic-based allocation was applied to ensure correct allotment of burdens to products and recyclate production was modelled using system expansion.

The main findings from the LCA study are that the raw material extraction and polymer production are responsible for the bulk of the environmental impact associated with meal kit use in South Africa and that polystyrene is the preferred option from this perspective, followed by paper/cardboard and bagasse. However, when adding persistence and material pollution indicators, biodegradable plastics, biobased plastics, bagasse and paper are less persistent in the environment than conventional plastics and polystyrene is at least four hundred times worse in terms of material pollution than paper

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Furthermore, comparing local production with import of finished products, local production of all investigated options performs worse from an environmental perspective in LCA, due to the use of fossil fuel generated electricity and Coal-to-Liquid production processes for monomer production. Alternatives to conventional plastic with lower environmental burdens are paper/cardboard (locally produced/manufactured), bagasse and PBS (both imported as finished products), with the latter showing potential for organic recycling in industrial composting facilities.

Increasing recycling rates of current available meal-kits will improve the overall environmental performance of all conventional plastic alternatives by about 30% over a 5-year period (as per EPR Regulations targets) whereas increased recycling of biodegradable and compostable alternative materials will improve the environmental performance by 40% over the same period.

Using different coating material than Polyethylene (PE) show a further improvement on the overall environmental performances of both the Bagasse and Paper meal-kit material alternatives. Although accounting only for 3-5% by mass of the whole meal-kit the choice of the right coating agent may positively impact on the production of the meal-kit (less resource intensive) and at the end-of-life when organic recycling can be implemented. When taking into account Persistence and Material Pollution in the environment, moving away from conventional plastic coating barriers can improve the natural biodegradability of the two alternatives.

Results align with those from international studies on single-use and re-usable cup and take-away container, which showed that single-use cups have similar environmental impacts regardless of the material they are made of, with paper to be preferred also to re-usable alternatives if recycling rates will increase (up to 80%). On single-use food-packaging made of polystyrene (PS), XPS and paper have often a better environmental performance than packaging alternatives of other materials (PET, PLA, PP and Aluminium) and packaging lightweight (without compromising its functionality) also show improvements on the environmental performance.

CONTENTS

List of Figures

List of Tables

1 INTRODUCTION

1.1 Project background

The overall aim of the project is to support South Africa's transition from conventional plastics to more environmentally sustainable alternatives; with the ultimate goal of reducing the amount of plastic leaking into the environment (including the marine environment) in South Africa. It aims to strengthen the local bioplastics and sustainable alternative material industry and build up capacities for plastics recycling through informal collection. This will be achieved through two distinct outputs, namely:

Output 1: An Action Plan to support sustainable transition to alternative material is developed, including strengthening of local industry (including the bioplastics industry).

Output 2: Capacity for plastics recycling is strengthened through encouraging waste separation at source and integration of informal collectors.

The aim of Output 1 is to support the identification and implementation of alternative materials for problem plastic products. More specifically, output 1 plans to evaluate and suggest alternative materials that provide the best social, economic, and environmental solution compared to traditional problem plastic product (s). To inform the action plan of Output 1, *Activity 1.2 was tasked to identify material substitution opportunities for identified product(s) using Life Cycle Sustainability Assessment (LCSA).* In a previous task (Activity 1.1 - Identification of single-use plastics with opportunity for replacement) polystyrene take-out containers and cups were identified as problematic plastics with low recycling rates and a high probability of leaking into the environment. Therefore, this study assessed the life cycle impacts of Polystyrene Take-out containers and cups and various alternatives using attributional life-cycle assessment (LCA). The impact assessment was carried out using the ReCiPe2016 method that considers 18 environmental impact categories. Two additional indicators, namely, Persistence and a Material Pollution were developed to address materials pollution and marine litter.

1.2 Why Take-out Containers?

Activity 1.1 concluded on a list of products as per **Table 1**, inclusive of criteria for selection. However, to understand to which extent the list and evaluation criteria were robust enough, the results were submitted to a panel of stakeholders for validation. Polystyrene cups and food container were added to the list due to the high probability of leaking into the environment and low recycling rates achieved. The new list of 17 products were then submitted to stakeholders for voting and polystyrene cups and take-out containers (clamshells) were selected for taking forward into Task 1.2.2, the LCSA study. The full range of alternatives for polystyrene cups and food container were assessed through Life Cycle Assessment.

2 LITERATURE REVIEW

Internationally there is a growing concern around food packaging and there are several LCA studies to assess both single-use take-away food packaging (UNEP, 2020) and beverages cups (UNEP, 2021). On beverage cup ten (10) LCA studies were compared which looked at both single-use and reusable cup for hot and cold drinks. Regarding take-away food packaging eleven (11) LCA studies were analysed which compared single-use plastic and other material alternatives, as well as reusable food packaging. Results showed that single-use cups have similar environmental impacts regardless of the material they are made of (whether bio-based plastic, fossil-based plastic or paper). Paper is the preferred alternative only if recycling rates increase (up to 80%), in which case this option is also preferable over reusable alternatives. On single-use food-packaging made of polystyrene (PS), XPS and paper have often a better environmental performance than packaging alternatives of other materials

(PET, PLA, PP and Aluminium). Light weighting of packaging (without compromising its functionality) also impact positively the environmental performance.

Table 1:Summary of Priority plastic products to be evaluated in terms of material replacement opportunities, inclusive of evaluation criteria.

Product	Application of criteria		Final List
	1,2,3: PRO screening (products marked with X are excluded as they are currently recycled or were not identified as candidates for replacement)	4: Availability of alternatives (commercially available)	
Candy wrappers	✓	✓	✓
Chip packs	✓	✓	✓
Biscuit wrapper	✓	✓	✓
Cling wrap (household)	✓	✓	✓
Polystyrene punnets	X		
Plastic punnets	X		
Plastic trays (meat)	X		
Plastic containers	X		
Plastic drinking bottles	X		
Plastic tops of bottles	X		
Grocery bags	X		
Straws	✓	✓	✓
Lollipop sticks	✓	✓	✓
Plastic cutlery	✓	✓	✓
Plastic lids on drinking cups	X		
Polystyrene cups	X		
Polystyrene food containers	X		
Plastic product bottles e.g. for shampoo	X		
Plastic pouches e.g. for washing powder, dog food, etc.	✓	X	
Other plastic bags such as sandwich bags, freezer bags, etc.	X		
Earbuds	✓	✓	✓
Condoms	✓	✓	✓
Nappies	✓	✓	✓
Sanitary pads and panty liners	✓	✓	✓
Blister packs for pills	X		
Syringes	✓	X	
Plasters	✓	✓	✓
Pallet wrap (industrial)	X		
Plastic pipes	X		
Plastic mulch (agriculture)	✓	✓	✓
Woven feed/fertiliser bags	X		
Cigarette butts	✓	✓	✓
Balloons	✓	✓	✓
Bin liners	✓	✓	✓

Regarding the other products identified in **Table 1** some Life Cycle based studies have been conducted to date in South Africa and internationally:

- *Cotton Bud Sticks:* Chitaka (2020) illustrates the potential environmental impacts associated with switching from plastic (polypropylene) to paper cotton bud sticks, via a comparative life cycle assessment. Both imported and locally manufactured paper cotton bud alternatives were investigated, and the study concluded on imported paper cotton bud sticks having the lowest emissions across most of the impact categories. This was mainly 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. Also from a retailer perspective, substituting plastic cotton bud sticks with paper was viewed as a simple and quick way to appease consumers.
- *Grocery Bags:* Russo et al. (2020) conducted a Life Cycle Sustainability Assessment of 16 carrier grocery bag material options potentially available in South Africa. Life Cycle Sustainability Impact Assessment results across all impact categories ranked fossil-based reusable bags as the best performing. Overall, re-usable bags were top ranked from an eCLA point of view; the reference bag of the study, HDPE 24 µm with 100% recycled content was the best fossil-based single-use bag, whereas among the biodegradable bags the best performing across all impact categories is the imported PBAT+Starch. Persistence indicator as a proxy to measure plastic pollution provides evidence on options (biodegradable bags) having the least potential impacts on environment due to their degradability, overtaking the re-usable alternatives.
- *Nappies:* Aumônier *et al.* (2008) conducted a comparative LCA for disposable and reusable nappies in UK. The study concluded that the manufacture of disposable nappies has greater environmental impact in the UK than their waste management by landfill; For reusable nappies the study showed that the impacts for reusable nappies are highly dependent on the way they are laundered.
- *Plastic drinking bottle and tops:* Chitaka (2020) investigated the Bottle Vs Lids issue when it comes to proneness of leakage into the environment. Although not an LCA study, she explored the challenges hindering the collection and recycling of lids and concluded that lid tethering as possible intervention would increase the collection rate of lids as they would remain attached to the widely recycled bottles.
- *Straw:* Chitaka et al. (2020) compared the environmental impacts associated with five straw material options available in South Africa. The study concluded that paper straws have the least impacts in most impact categories when compared with other disposable options and glass is favoured over steel as reusable option. In terms of marine pollution, reusable straws were deemed to pose the least risk due to their reusable nature. Paper was associated with the least potential impacts at disposal, due to its degradability.

It is worth to note that only two studies above mentioned tried to go beyond a conventional LCA: Chikata et al. (2020) which included a proxy indicator (called Leakage Rate) to account for marine pollution and Russo et al. (2020) which conducted a Life Cycle Sustainability Assessment developing a proxy indicator (called Persistence) to account for plastic, and more in general material, pollution in to the environment.

2.1 Polystyrene as a problem plastic

Polystyrene is a petroleum-based plastic made from styrene (ethenylbenzene) monomer. Polystyrene was first commercially produced in 1931 and is used in a wide range of commercial, packaging and building applications. Polystyrene products are produced through the polymerization of rigid plastic or expanded with a gas to create a foam prior to polymerisation. Rigid polystyrene is used in appliances such as television and computer cabinets, as well as disposable cutlery, and plates. Polystyrene foam has excellent insulating properties and is available in two forms. Expanded polystyrene (EPS) is used for cups for drinks, food storage and cushioning in packaging, while extruded closed-cell polystyrene foam (XPS) is used in building and construction, cushioning in packaging, and for food trays and take-out containers.

The use and indiscriminate disposal of plastics can create hazards to all biodiversity and ecosystems. Plastics have a potential to cause harm in two ways:

- Chemically when monomers, plasticisers and other hazardous additives leach from polystyrene products; and
- Physically, when plastic enters the environment and breaks down from macro-plastics to micro- and nano-plastics.

The composition of polystyrene products as well as context in terms of manufacture, use, disposal and fate in the environment is a critical aspect when determining the hazard (Liboiron, 2015). The monomer of polystyrene, styrene, is a known carcinogen and toxin and listed as Category 1 potential endocrine disruptors (European Commission 2016; Linther 2011). When the polymerization of styrene during manufacturing is complete, the resulting styrene is unlikely to be released, even following degradation in the environment. However, if styrene is not completely polymerised during the manufacture of polystyrene, residual styrene could leach into food and beverages- particularly hot food and beverages containing fats that will likely increase chemical leaching. The World Health Organization (WHO) lists the maximum permissible limit at 20 parts per billion (ppb) for styrene (World Health Organization, 2004). The reported amount of styrene that leaches from polystyrene into food and drinks varies in the literature (from about 1 to 300 ppb) depending on the experimental design , using various foods and/or solvents, varying time periods, and varying temperatures (Tawfik and Huyghebaert, 1998; Ahmad and Bajahlan, 2007; Sanagi *et al*., 2008). Many studies at *ambient temperature* indicate very low levels of leaching (nano-grams), that do not raise a safety concern for the consumer (EFSA CEF Panel, 2014; Bejgarn *et al*., 2015) However, leaching experiments from polystyrene with common foods at *relevant temperatures* (70 °C and 95°C) revealed that leaching from EPS does occur. The levels of leachate are very low and at the limits of current chemical detection methods, but bioassays have clearly demonstrated that this leachate is toxic to aquatic invertebrates (Thaysen *et al*., 2018; Aljaibachi and Callaghan, 2018). Furthermore, there is at least one study that identified volatile styrene monomers found in shells of eggs after they were stored for 2 weeks in polystyrene containers at supermarkets; with seven times more ethylbenzene and styrene compared to eggs not packaged in polystyrene (Matiella and Hsieh 1991).

As mentioned earlier if polymerization is complete, the biodegradation of polystyrene is unlikely to produce styrene. However, styrenes, have been detected in ocean water and sediments globally (Kwon *et al*., 2015; Kwon *et al*.,2017); and since man-made polystyrene plastic is thought to be one of the only sources of styrenes to the environment, the styrene is thought to be from the slow weathering of polystyrene in the environment.

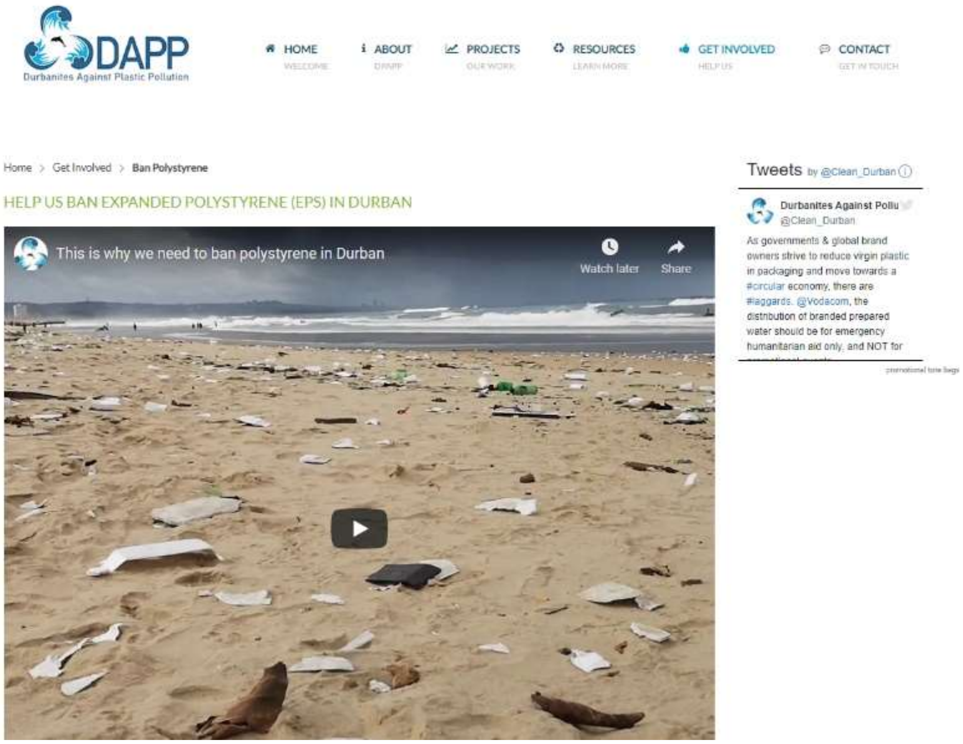
Plastics in the environment present physical hazards and polystyrene have been found to impact diverse biodiversity and ecosystems. Plastic pollution can cause entanglement, suffocation and reduced feeding ability of biota; resulting in reduced fitness, fecundity and lifespan. Hundreds of marine and freshwater species are known to have ingested or become entangled in plastics (Gall *et al*., 2015; Rochman *et al*., 2016; Huerta *et al*., 2017; de Souza *et al*., 2018). Plastic degrades in the environment extremely slow; taking decades (or longer) to break down physically and chemically. Even when a plastic item degrades under the influence of weathering, it first breaks down into smaller pieces of plastic debris or micro-plastics that are increasingly found in biota and the human food chain (Woodall *et al.,* 2014; Conkle *et al.,* 2018; Barnes *et al*., 2009; Gregory, 2009; Oehlmann *et al*., 2009; Ryan *et al*., 2009; Teuten *et al*., 2009; Thompson *et al*., 2009; Barboza *et al*., 2018; Peixoto *et al*., 2019).

Plastic pollution also has socio-economic impacts, by affecting fishing stocks, reducing the aesthetics of beaches and natural areas (Wyles *et al*., 2016), blocking drainage and wastewater treatment plants (Fobil *et al*., 2009), and providing a breeding ground for water-borne diseases (Wyles *et al*., 2016; Boelee *et al*., 2019; UNEP, 2014).

In addition to the physical hazards they pose, hydrophobic plastics such as polystyrene, have an ability to adsorb persistent organic pollutants (POPs) which can be released following ingestion of polystyrene microparticles by animals (e.g. fish). For example, seabirds that have consumed plastic waste have been found to have POPs in their tissues at 300% greater concentrations than in similar birds that have not eaten plastic. Polystyrene is particularly good at absorbing hydrophobic chemicals with concentrations of POPs adsorbed by polystyrene at up to a million times greater than in the surrounding water. Due to the known toxicity and persistence of POPs in organisms and food webs; these chemicals can disrupt key physiological processes and cause disease and reduce the fitness and reproductive ability of organisms. As a result of these risks, several scientists have recommended the reclassification of polystyrene and several other plastics as hazardous so that they could be more effectively regulated by environmental protection agencies (Rochman *et al.,* 2016).

Lastly, incomplete combustion of polystyrene at temperatures and aeration that is typical of household burning of wastes produces many toxic products; including styrene and other polyaromatic hydrocarbons that are probably carcinogenic (IARC, 2018).

Polystyrene is commonly reported as one of the top items of debris recovered from shorelines and beaches worldwide (Garrity and Levings, 1993; Bravo *et al*., 2009; Lee et al., 2013; Ocean Conservancy, 2017), including in Antarctica (Convey *et al.*, 2002) as well as South Africa (Chitaka and von Blottnitz, 2019). Polystyrene has also been found on the surface of the open ocean (Morét-Ferguson *et al*., 2010) and on the seafloor (Keller *et al.*, 2010). Currently, there is a global trend away from the use of polystyrene, particularly in food and single-use applications; with several towns Portland (Oregon, USA), Toronto (Canada), Muntinlupa (Philippines), Paris (France), and Tainan (Taiwan) prohibiting their use. The propensity for litter is locally highlighted by the Durban PAG that has lobbied for the ban on polystyrene (**Figure 1**).



Home > Get Involved > Ban Polystyrene

HELP US BAN EXPANDED POLYSTYRENE (EPS) IN DURBAN

This is why we need to ban polystyrene in Durban

Tweets by @Clean_Durban

Durbanites Against Pollu
@Clean_Durban

As governments & global brand owners strive to reduce virgin plastic in packaging and move towards a #circular economy, there are #laggards. @Vodacom, the distribution of branded prepared water should be for emergency humanitarian aid only, and NOT for

Figure 1: Web-page of a South African activist, education and outcome based programme driven by a group of experienced non-government implementation partners in Durban. Durbanites against Plastic Pollution (DAPP) https://dpapp.org/get-involved/ban-polystyrene

In summary, the high rates of polystyrene production and consumption, inadequate waste management and slow environmental degradation with the formation of microparticles and adsorption of hydrophobic toxic chemicals, has led to large quantities of polystyrene waste transporting adsorbed toxins and impacting terrestrial, aquatic and marine biodiversity and ecosystems.

2.2 Polystyrene take-out Containers

A Polystyrene take-out container is either a food tray (XPS) or a cup (EPS), as per **Table 1**.

Thus, for the purpose of comparing alternative material options to take-out container a **Meal-kit was defined as composed by clamshell food container and a cup**. The base line Meal-kit against with the other will be compared is the one made of expanded Polystyrene (EPS cup and XPS clamshell). A variety of meal-kit material type were considered as possible alternatives to the Polystyrene meal-kit as per **Table 2**.

Figure 2: PS take-out container (left) and cup (right)

3 METHODS

3.1 Cradle-to-grave life cycle assessment (LCA) of Polystyrene Take-out container and alternatives

Life Cycle Assessment (LCA), also known as environmental LCA (E-LCA), is a framework and standardised methodology for assessing the environmental impacts across the full life cycle of a product, i.e., “from raw material acquisition through production, use, end of life treatment, recycling and final disposal (i.e., cradle-to-grave)” (ISO 2006a). Application of LCA is guided by ISO standards 14040 (ISO 2006a) and 14044 (ISO 2006b) of 2006; which aim to ensure consistency in the application of the methodology and comparability of results. In line with the three ‘pillars’ of sustainability (environmental, social and economic); two additional approaches have also been developed, namely Social LCA (S-LCA), and Life Cycle Costing (LCC), aimed at assessing the social and economic impacts (respectively) of products across their life cycles. Life Cycle Sustainability Assessment (LCSA) is a fairly new approach that attempts to combine E-LCA, S-LCA and LCC, in order to provide a more comprehensive, ‘triple-bottom line’ assessment of products in terms of the three pillars of sustainability (UNEP 2011). In much of the early literature on LCSA (Kloepffer 2008; UNEP 2011), it was understood that conducting an LCSA required performing each type of assessment (E-LCA, S-LCA and LCC) in full; and synthesising the results. However, this type of approach fails to take into account the interactions and inter-dependencies between the three dimensions of sustainability (Gbededo *et al*., 2018); while also making it difficult to interpret the results for decision making (particularly when trade-offs exist between the economic, social and environmental dimensions). As such, a second, more integrative approach to conducting LCSA has emerged; in which a single, unified assessment is conducted, but based on an expanded set of indicators, encompassing environmental, social and economic impacts (Gloria *et al*., 2017; Guinee *et al*., 2011). The aim is to provide improved integration among the environmental, social and economic dimensions, through the adoption of a transdisciplinary approach. This study applies the second of these LCSA approaches, in that we incorporate additional environmental social, economic and governance indicators in order to achieve sustainable development objectives.

3.2 Goal of the Study

As per ISO 14044:2006 (ISO 2006b), the goal of the study is defined through a consideration of the following:

- **The intended application** is to identity material substitution opportunities for polystyrene take-out containers. The material alternatives should maintain product functionality and ensure that alternatives provide the best social, economic and environmental solution. Also, the recommendations of top alternative material options will be provided to project activity which need to demonstrate and test the technologies for final treatment of the material alternatives identified.
- **The reason for carrying out the study** is to understand – and quantify - the life cycle environmental and socio-economics impacts of alternative material options to polystyrene take-out containers in South Africa. Thus, the reason for the study is to evaluate and suggest alternative materials that provide the best social, economic and environmental solution compared to traditional plastic.
- **The intended audience** is primarily internal to the Project, since the LCSA results may influence another activity of the Project. Disclosing the full report with a wider audience the study will include peer review to ensure that the results are unbiased and conform with appropriate standards.

The goal of the study is to assess the environmental and socio-economic impacts of polystyrene take-out containers and various alternatives, throughout the products' life cycle. This will enable a comparison of the life cycle environmental and socio-economic impacts of the various material types (as per **Table 2**) by considering the whole life cycle of a product- from raw material to use and disposal. It can also aid in the identification of the "hotspots" in a product's life cycle that contribute to a substantial part of the overall impacts.

3.3 Scope, boundary, and functional unit of the study

The scope of the study covers decisions relating to the detail and accuracy of the study and related methodological decisions, including the choice of functional unit, system boundaries and data requirements. Scoping decisions may need to be revisited as the study progresses as more becomes known about the systems, and especially as more becomes known about their data availability.

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. In this study, the products to be studied are both take-out container and cup made of the material listed in **Table 2**.

The Meal-kits under consideration must have equivalent functionality. More specifically, the meal-kits have similar dimensions in terms of size and carrying capacity and would be suited in the carrying of hot meals or beverages. All Meal-kits considered in this study are single-use. The design should ensure adequate insulation from hot meals and beverages; with insulation in cups being particularly important. Therefore, aside from the Polystyrene and Bio-EPS cups, all cups are modelled as having a double wall in order to ensure that they are functionally equivalent.

Figure 2 and **Figure 3** provide example of some take-out container and cups investigated in this study.

Figure 3: Meal-kit alternative material.

Top left: paper/cardboard container; Top right: clear PET container; Bottom left: Bagasse container; Bottom right: PE-coated paper/cardboard cup

The **functional unit** for this study is the amount of meal-kit consumed in a year by one person, i.e. meal-kit×capita^{-1}×annum^{-1}. The national take-out container consumption is estimated from the fact that: "South Africans spend close to R2 billion a month on fast food, which represents more than 10% of total discretionary spend," (Business Tech, 2017). Population in 2017 was 57 million; therefore, R 35 per person per month. A burger and chips in 2017 were R 36.48[1]. **Therefore, the average per person take-out meal-kit is estimated at approximately one per month, or 12 meals per person per year.**

The reference meal-kit is the polystyrene take-out container and cup, which is used as the reference functional unit for the study. Information from major local producers determined the most common take-

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[1] https://inflationcalc.co.za/?date1=1991-01-01&date2=2017-01-01&amount=6.60

out container dimensions and shape (rectangular, 1400ml carrying capacity) and cup (250 ml carrying capacity) to be used as a reference.

Table 2 summarises the meal-kit options already available, their carrying capacity and functional unit with respect to the polystyrene meal-kit. Individual weight and carrying capacity have been measured, whenever possible (EPS, PET, Bagasse and Paper); and other material weights have been calculated using material density and functional unit in terms of volume. The last column lists the material used for each type of meal-kit to fulfil the functional unit- this is the Reference flows (gram of material per meal-kit×capita^{-1}×year^{-1}).

Table 2: Meal-kits mass, Functional Units and Reference Flows

	Material	**Container Type**	**Functional Unit in terms of Volume* (ml)**	**Individual weights (g)**	**Reference Flow (g)**
Commercially Available	**EPS/XPS**	Clamshell	1	10.47	125.64
		Cup	1	2.08	36
	Bagasse	Clamshell	1.12	36	483.84
		Cup	1	19.12	229.39
	Paper	Clamshell	1.12	31	416.64
		Cup	1	14	168
	PET	Clamshell	0.80	33	316.80
		Cup	1	9.42	113.06
Commercially Available Alternative Materials	**PP**	Clamshell	0.80	19.22	184.51
		Cup	1	9.42	113.04
	PLA	Clamshell	0.80	26	248.7
		Cup	1	12.6	151.2
	PBS	Clamshell	0.80	26.11	250.66
		Cup	1	17.06	204.72
	PBAT or PSM (Mater-bi)	Clamshell	0.80	25.28	242.67
		Cup	1	16.52	198.24
Prototypes	**PHB (used as proxy for the other materials: PHA, PHBV, PHBH)**	Clamshell	0.80	25.69 (25.07 – 26.11)	246.68 (240.67 – 250.7)
		Cup*	1	16.78 (16.38 – 17.06)	201.48 (196.56 – 204.72)
	Bio-foam (expanded PLA)	Clamshell	1	11.51	138.12
		Cup	1	4.5	54

****PS take-out container and cup were chosen as reference to which the other container and cups refers to. Their volumes are 1400 ml and 250 ml, respectively.***

The life cycle system is made up of all the life cycle stages (unit processes) making up the product system, enclosed by the system boundary. In this study, the system boundary for each of the material option investigated ends at the end-of-life of products, which then can be either recycled or disposed, consistent with the goal of a cradle-to-grave investigation.

Cradle-to-grave life cycle assessments were conducted for each of the meal-kit types. This included raw material extraction, product manufacturing and 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 (self-help disposal). Waste that is not properly managed also has the potential to enter the environment and we have developed persistence and materials pollution indicators to incorporate the impacts and extend the standard eLCA that covers 18 environmental indicators (ReCiPe, 2016).

3.4 Meal-kit materials value chain

Polystyrene cups and take-out containers are made by expanding/extruding polystyrene pellets and then thermoforming them into the desired shape-t cups are expanded polystyrene, EPS, and containers are extruded polystyrene, XPS. Manufacturing is done locally, whereas polystyrene pellets are imported from Singapore, Taiwan and Brazil [2]. The major polystyrene manufacturers are located in Gauteng, KwaZulu-Natal and Western Cape Provinces. The end-of-life options for polystyrene cups and take-out containers include landfill, open dumps and burning and the environment. Future scenarios include also some mechanical recycling using the EPR Regulation (2021) targets, however while recycling of PS items is happening is South Africa, recycling of EPS/XPS single-use items is hindered by its lightweight and price (see paper cups).

PET cups and take-out containers are made by thermoforming of PET resin[3]. PET is locally produced using imported terephthalic acid and locally produced ethylene (a combination of FT-synthesis and traditional oil refinery). There is 1 producer of PET in South Africa (Safripol (Pty) LTD, 3 PET manufacturers and 5 wholesalers, located around major cities in South Africa (Cape Town, Durban and Johannesburg)[4]. The end-of-life options for PET cups and take-out containers include landfill, open dumps and burning and the environment. Future scenarios include also some mechanical recycling using the EPR Regulation (2021) targets for thermoformed PET.

Polypropylene cups and take-out containers are made by thermoforming of PP resin both locally produced and imported. This study modelled the cups and take-out manufactured from locally manufactured polypropylene, due to lack of information regarding the amount of imported resin and the associated production sources. 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 by Safripol (Gauteng province) which is sold locally. The end-of-life options for PP cups and take-out containers include landfill, open dumps and burning, the environment (to model leaking and littering) and some recycling. Future scenarios include also increased mechanical recycling using the EPR Regulation (2021) targets for rigid polyolefins packaging.

Bagasse cups and take-out containers are currently imported from Southeast Asia (China, Taiwan, India)[5]. Bagasse is the sugarcane fibre waste left after juice extraction in the sugar industry, meaning the raw material for packaging is a waste product of another industry. Once the juice is extracted, the stalk is ground up and made into paper pulp, namely the bagasse. The processing mill extract the remaining moisture and press the dried bagasse into fiberboard sheets, which are then moulded into the desired shape (forming, hot pressing, drying). Often, a hydrophobic coating (PLA) is added to the container which increases their durability when in contact with wet food. The major distributors are based in Gauteng and Western Cape provinces[6]. The end-of-life options for bagasse cups and take-out containers include landfill, open dumps and burning and the environment. Future scenarios include also some organic recycling via industrial composting using the EPR Regulation (2021) targets for single-use compostable products.

Paper cups and take-out containers are mainly produced locally, with some imports occurring. For take-out containers food grade unbleached solid board is used[7], while for cups a combination of food

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[2] Personal communication with Valeska Cloete (Mpact).

[3] Personal communication with Cheri Scholtz (PETCO).

[4] Personal communication with Cheri Scholtz (PETCO).

[5] Personal communication with John Fox (EnviroMall).

[6] Personal communication with John Fox (EnviroMall).

[7] Personal communication with Calvin de Souza (CPT Cartons & Labels).

grade unbleached (exterior wall) and bleached (interior wall) solid board is used. Often, a hydrophobic coating (PE or PLA) is added to the container and cup which increases their durability when in contact with beverages. The double walling design is to ensure insulation from heat. A grease-proof coating barrier is added to the take-out food containers. For paper cups the solid bleached board is imported from overseas (Stora enso, North EU), and it comes in rolls already laminated (PE)[8]. The solid unbleached board for the take-out container and cups' outer layer is made of paper locally produced in South Africa. The end-of-life options for paper/cardboard cups and take-out containers include landfill, open dumps and burning and the environment.

Recycling of cups and take-out container could be done using the so-called liquid process recycling also used for liquid board carton. Thus, future scenarios include some recycling using the EPR Regulation (2021) targets for liquid board packaging. However, it is worth noting that recycling of paper cups is hindered mainly by two factors. The first is getting enough waste streams (as being an on-the-go item it is often disposed on the go, thus difficult to separate from general waste, unless it is done in a controlled environment – e.g. malls, airports. Also, to consider that recycling is done by waste pickers and fueled by price; Thus, if there is no price associated with cups/container, or if the price is too low, pickers don't collect.[9]

PLA or *Polylactide* is a starch-based polymer made from maize. PLA take-out containers are manufactured by the extrusion and thermoforming of PLA granulate into take-out with the required thickness; an edge trimming (optional) step cut them to the desired shape. There are currently no local manufacturers of PLA, thus the majority of take-out container are imported from China. The PLA is manufactured according to the NatureWorks™ production process (Vink & Davies, 2015). Major PLA container distributors are based in the Western Cape and Gauteng. Although PLA is biodegradable under industrial composting conditions, as BAU scenario 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 meal-kits were assumed to have the same fate at end-of-life as conventional single-use disposable items (disposed in landfill or open dumps). Future scenarios include also some organic recycling via industrial composting using the EPR Regulation (2021) targets for single-use biodegradable products.

Polymer Starch Materials (PSM), also known as thermoplastic starch, is obtained by processing raw starch by chemical, physical and mechanical methods with the addition of plasticisers such as sorbitol, glycerol and water. Blending it with other polymers (bio- and synthetic-based), fillers (clay), and natural fibres can improve the properties of PSM significantly. One of the most widely used commercially available thermoplastic starch is Mater-Bi® which mainly consists of corn starch blended with biopolymers and other compounds including natural plasticizers. A description of possible Mater-Bi® compositions have been described in **Global producers and potential of local production of alternatives** report for task 1.4. As BAU scenario it was assumed that PSM cup and container will not be composted due to the limited availability of industrial composting facilities. Thus, PSM meal-kit were assumed to have the same fate at end-of-life as conventional single-use disposable items (disposed in landfill or open dumps). However, PSM is biodegradable and compostable, thus future scenarios include some organic recycling via industrial composting using the EPR Regulation (2021) targets for single-use biodegradable products.

Polybutylene succinate (PBS) is a biodegradable polyester and is currently mostly fossil-based but can be 100% bio-based (e.g., from residues from the sugar industry). PBS is produced from 1,4-butane diol (BDO), succinic acid and often in combination with a third monomer. PBS can replace low- and high- density PE and PP in current packaging applications and PBS can be converted into finished products using conventional plastic processing techniques, including blown film extrusion, twin-screw extrusion, thermoforming, injection- and compression moulding. As BAU scenario it was assumed that

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[8] Personal communication with Carla Breytenbach (Detpak).

[9] Personal communication with Carla Breytenbach (Detpak).

PBS cup and container will not be composted due to the limited availability of industrial composting facilities. Thus, PBS meal-kit were assumed to have the same fate at end-of-life as conventional single-use disposable items (disposed in landfill or open dumps). However, PBS is biodegradable and compostable, thus future scenarios include some organic recycling via industrial composting using the EPR Regulation (2021) targets for single-use biodegradable products.

PBAT (Polybutylene adipate terephthalate) is a fossil-based biodegradable polyester and is produced by poly-condensation reaction between butanediol (BDO), adipic acid (AA) and terephthalic acid (PTA). PBAT resembles LDPE in its properties and typical applications are packaging (e.g. plastic films and bottles), coatings (e.g. of paper and cardboard) and foam. PBAT can be converted into finished products using conventional plastic processing techniques, including blown film extrusion, twin-screw extrusion, thermoforming, injection- and compression moulding. PBAT is biodegradable in soil (as per standards ISO 17556 and ASTM D5988) and home compostable, in contrast to polylactic acid (PLA), where industrial composting conditions (60ºC) are necessary. As BAU scenario it was assumed that PBAT cup and container will not be composted due to the limited availability of industrial composting facilities. Thus, PBAT meal-kit were assumed to have the same fate at end-of-life as conventional single-use disposable items (disposed in landfill or open dumps). Future scenarios include some organic recycling via industrial composting using the EPR Regulation (2021) targets for single-use biodegradable products.

PHB or Polyhydroxybutyrate, is a polyhydroxyalkanoate (PHA), a polymer belonging to the polyesters class that are of interest as bio-derived and biodegradable plastics. There are mainly three types of PHA's that are commercially available: poly-3-hydroxybutyrate (PHB), poly-3-hydroxybutyrate-co-4-hydroxybutyrate [P(3-HB-co-4-HB), poly-3-hydroxybutyrate-co-valerate (PHBV) and polyhydroxybutyrate-co-hexanoate (PHBH). PHA's exhibit thermoplastic properties, which make them suitable for biomedical and packaging applications, and they are certified to be biodegradable in marine conditions. Major producers are in China and Europe (Italy). As BAU scenario it was assumed that PHB cup and container will not be composted due to the limited availability of industrial composting facilities. Thus, PHB meal-kit were assumed to have the same fate at end-of-life as conventional single-use disposable items (disposed in landfill or open dumps). Future scenarios include some organic recycling via industrial composting using the EPR Regulation (2021) targets for single-use biodegradable products.

3.5 Life Cycle Inventory

This section provides an overview of the main data sources, modelling approach, allocation procedures, etc.; as well as assumptions and modelling choices relating to the life cycle stages of each meal-kit options (material production, manufacture, transport, end of life etc.).

The product life cycle stages, including relevant process descriptions, were informed by a combination of literature reviews, as well as data sourcing via relevant stakeholders along the value chain. In particular, stakeholders were consulted in order to determine where the different life cycle stages took place as well as the associated manufacturing methods, recycling rates for the different materials when relevant, as well as the proportions going to each disposal option, since this information is not readily available for South Africa in existing Life Cycle Inventory (LCI) databases.

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 v3.6 Database (Ecoinvent, n.d.) and background data was based on datasets available in the Ecoinvent v3.6 Database. The life cycles of the meal-kit options investigated were modelled using the SimaPro LCA Software 9.1.

Furthermore, wherever possible, background datasets from Ecoinvent v3.7 were adapted to the South African context by replacing the electricity and water input to match the South African energy mix and geography, as well as relevant sub-processes.

3.5.1 Allocation

The APOS (Allocation at the Point Of Substitution) system model was chosen (Ecoinvent, n.d.). The APOS system model follows the attributional approach in which burdens are attributed proportionally to specific process; the APOS system model incentives producers to assess recycling and reuse of material/products by allocating the environmental impacts according to the economic value of materials (raw material and/or recyclate).

3.5.2 Data sources

Specific datasets were used, either adapted from existing dataset or modelled as foreground datasets, for production of the raw materials (polymers) associated with each type of meal-kit options. Specifically:

Polystyrene pellets production occurs overseas and the granulate is imported from Singapore, Taiwan and Brazil, thus imports of PS pellets were modelled accordingly. Manufacture of PS meal-kit is done locally as expanded and extruded polystyrene (EPS and XPS respectively) with localised energy and water inputs.

Paper products are mainly manufactured locally from imported virgin bleached and locally produced unbleached paper/solid board, with some import of finished products occurring. Imports of PE laminated virgin reels from North Europe were modelled accordingly. However, since is no dataset representing South African forestry production in the Ecoinvent Database, nor dataset representing any paper product manufacturing, the production of unbleached solid boards is based on background datasets, with localised energy and water inputs.

PET bottle grade production was modelled as produced in South Africa using imported terephthalic acid and locally produced ethylene (a combination of Sasol production and imported oil). Manufacture of PET meal-kit is done locally via thermoforming of PET into the desired form, with localised energy and water inputs.

Polypropylene production was modelled as produced in South Africa using locally produced propylene. Manufacture of PP meal-kit is done locally via thermoforming of PP into the desired form, with localised energy and water inputs.

Bagasse from sugarcane production is provided as a background dataset in the ecoinvent v3.6 and bagasse products are all imported from Southeast Asia (China, Taiwan, India). The processing mill extracted the remaining moisture from the bagasse pulp and pressed the dried bagasse into fibreboard sheets, which are then moulded into the desired shape (forming, hot pressing, drying). Thus, imports of finished products manufactured in Asia were modelled.

Polylactide production is provided as a background dataset in the ecoinvent v3.6 and PLA products are all imported from Southeast Asia (China, Taiwan, India), thus production of PLA resin, manufacturing and imports of finished products were modelled accordingly.

PBS and **PBAT** materials are both modelled under the assumption that the PBS and PBAT components are fossil-based, rather than bio-based. When the polymers are locally produced (by SASOL), material (coal), energy and water inputs were added accordingly.

PSM (Mater-Bi®) material production is provided as a background dataset in the ecoinvent v3.6 and and PSM products are all imported from Europe and Asia (China), thus production of PSM resin, manufacturing and imports of finished products were modelled accordingly.

PHB material production was modelled using Harding *et al.* (2008) LCI, thus using the production of sugar from sugarcane as substrate. PHB products are all imported from Europe and Asia (China), thus production of PSM resin, manufacturing and imports of finished products were modelled accordingly.

Supporting datasets were modelled for meal-kit manufacturing, as relevant to each type of container; namely: expanded and extruded polystyrene (EPS and XPS respectively); extrusion of plastic sheet and thermoforming, inline; paper pulping, molding, etc. All scenarios of manufacturing occurring in South African and overseas were considered, with energy and water inputs adapted to the South African context.

Assembly datasets were modelled to represent meal-kit manufacturing. For each meal-kit type, a manufacturing step with specific energy and material requirements to make a single meal-kit was modelled. A life cycle stage for each meal-kit was also modelled, inclusive of distribution to retailers, and the disposal scenario (see End-of-life).

3.5.3 End-of-Life

The disposal scenario stage for each meal-kit was modelled to account for the different shares of disposed material that end up in recycling (when relevant), littering, sanitary and unsanitary landfill, open dumping and open burning. Since existing LCI databases do not have a category for plastic leakage to the environment; leakage is modelled as disposal to an open dump as the closest approximation; to account for at least some of the associated environmental impacts. In parallel, we have modelled the end-of-life of materials in South Africa in order to develop an indicator for persistence and Materials Pollution into the environment that impacts terrestrial, freshwater and marine ecosystems.

The end-of-life flows were modelled based on the Materials Flow Analysis (MFA) compiled by von Blottnitz *et al*. (2017). Based on the MFA, and contrary to perceptions, less than 1% of total plastic reaching end of life enters the environment directly through littering. The vast majority enters some form of formal or informal waste management system; although there is in turn significant leakage from such systems to the environment.

Only 65% of the population have regular waste collection services; so 35% of the population rely on self-help disposal (StatsSA 2018), i.e. open dumping. Self-help disposal can further be categorised as ‘burnt’ or ‘not burnt’. We assume that all open dumps are burnt annually, but only 60% of the waste actually burns (IPCC, 2006). Open dumping and open burning are new datasets in the Ecoinvent v3.6 database, which allowed for these options to be explicitly modelled. In terms of waste going to dedicated, official landfill sites, only a portion of such sites are fully compliant with legislative requirements, while the others can be described as non-compliant or ‘deficient’.

The MFA data suggests that, of the plastic entering these various disposal options, 32% goes to self-help disposal, 38% to non-compliant landfill, and 30% to compliant landfill.

In turn, leakage rates were estimated as 80% from self-help disposal (open dumping), 30% from non-compliant landfills, and 1% from compliant landfills (Von Blottnitz, 2019). Together with direct litter of 1%, there is a total of 275 Kilotonnes (Kt) of plastic leaking into the environment per annum – approximately 18% of the plastic that reaches end of life (see Figure 3).

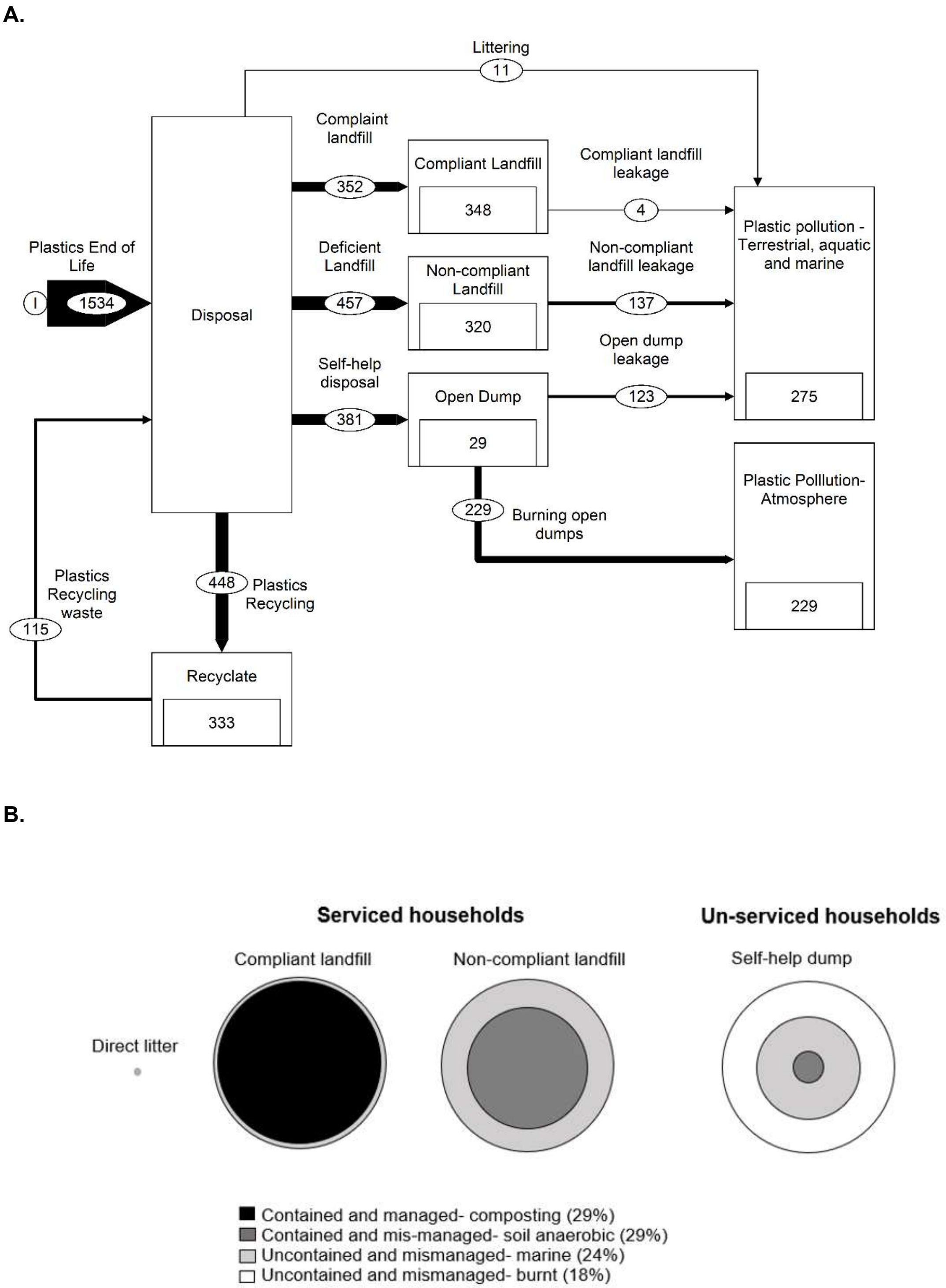

Figure 4: A: Plastics-end of-life in South Africa. Materials flow was carried out using STAN , based on data from von Blottnitz et al 2017). The values shown are in Kilotonnes (Kt). B. The End-of-life fate of materials as a result of waste (mis)-management and leakage into the environment. The waste disposed to various waste management systems in South Africa with the fate in the receiving environments in order to model biodegradation and assess material persistence indicator. Key shows the amount material in the receiving environment (% of total waste disposed).

Recycling: For each meal-kit type, output recycling rates were obtained or estimated from publicly available sources (EPR Regulation 2021; PlasticsSA 2019; PAMSA 2018, PolystyreneSA), as well as personal communications with experts (Pretorius 2020; Spangenberg 2021). The end-of-life recycling rates applied to each meal-kit type are presented in Table 3, as per the targets in the EPR legislation.

In modelling the end of life for each reference material flow, the recycling rates for each type of bag are applied and the fraction disposed to direct littering (before entering the waste management system) is accounted for. Thereafter, the waste enters either one of the above-mentioned disposal and waste management solutions; from which the associated leakage rates are then estimated (see Figure 3). The end-of-life modelling followed the EOL Recycling approach (Nordelöf *et al*., 2019; Weidema, 2000); where all the EOL steps, i.e., waste collection and sorting, recycling, as well as upgrading of the recycled material (i.e., recyclate production) are modelled explicitly (see Section 4.2). This means that credits should be awarded to production systems for providing waste streams containing materials that are recycled back into the same or other production systems as a secondary raw material. In the product system where those secondary materials are used as an input, the recycled material carries only the burdens caused by the recovery and upgrading processes.

Table 3: Targets recycling rate as per EPR Regulations (2021)

			EPR scheme projections (recycling rates targets, for mechanical recycling and/or industrial composting)				
	Material container type	Reference year (2021) Rec %	Y1	Y2	Y3	Y4	Y5
Baseline (BAU)	PS	12%	20%	25%	30%	36%	43%
	PET	0.00%	8%	12%	17%	24%	30%
	Bagasse	0.00%	15%	25%	50%	65%	80%
	Paper	5.00%	5%	10%	15%	20%	25%
Commercially available alternative materials	PP	19.67%	39%	42%	45%	48%	52%
	PLA	0.00%	5%	15%	40%	55%	70%
	PBS	0.00%					
	PBAT	0.00%					
	PSM (Mater-Bi®)	0.00%					
Biopolymers - Prototypes	Bio-foam (expanded PLA)	0.00%					
	PHB	0.00%					

3.5.3.1 Transport

This study considered transport from the raw material to the polymer producer; from the polymer producer to the meal-kit manufacturer; from the meal-kit manufacturer to the distributor; and at end of life, for modelling waste collection and transport to disposal sites (see Appendix A for assumptions on travel distances).

Transport to distributors/retailers is modelled in the Life Cycle datasets for each meal-kit according to the actual mass transported. No transport during the use phase was considered, to avoid allocating burdens associated with transporting the meal from place of purchase to consumption and disposal.

3.6 Impact assessment methods

3.6.1 Standard environmental LCA indicators

The ReCiPe 2016 method was used for environmental impact assessment at mid-point and end-point level, as well as Single Score (Huijbregts et al., 2016), as shown in Table 4.

Table 4: ReCiPe Mid-point, End-point and Single Score Indicators

Indicator		Unit	
GW	Global Warming	Kg CO2-eq	Kg of Carbon Dioxide equivalent
SOD	Stratospheric Ozone Depletion	Kg CFC11-eq	Kg of CFC-11 equivalent
IR	Ionizing Radiation	Kg Co-60-eq	Kg of Cobalt-60 equivalent
OF,HH	Ozone Formation, Human Health	Kg NOx-eq	Kg of Nitrogen Oxide equivalent
FPM	Fine Particulate Matter Formation	Kg PM2.5-eq	Kg of Particulate Matter <2.5µm
OF,TE	Ozone Formation, Terrestrial Ecosystem	Kg NOx-eq	Kg of Nitrogen Oxide equivalent
TA	Terrestrial Acidification	Kg SO2-eq	Kg of Sulphur Dioxide equivalent
FWE	Freshwater Eutrophication	Kg P-eq	Kg of Phosphorous equivalent
MarE	Marine Eutrophication	Kg N-eq	Kg of Nitrogen equivalent
TEcotox	Terrestrial Ecotoxicity	Kg 1,4-DCB-eq	Kg of 1,4- dichlorobenzene equivalent
FWEcotox	Freshwater Ecotoxicity	Kg 1,4-DCB-eq	Kg of 1,4- dichlorobenzene equivalent
MarEcotox	Marine Ecotoxicity	Kg 1,4-DCB-eq	Kg of 1,4- dichlorobenzene equivalent
HCTox	Human Carcinogenic Toxicity	Kg 1,4-DCB-eq	Kg of 1,4- dichlorobenzene equivalent
HNCTox	Human Non-Carcinogenic Toxicity	Kg 1,4-DCB-eq	Kg of 1,4- dichlorobenzene equivalent
LU	Land use	m^2/a crop-eq	Square metre per year crop equivalent
MRS	Mineral Resources Scarcity	Kg Cu-eq	Kg of Copper equivalent
FRS	Fossil Resource Scarcity	Kg oil-eq	Kg of oil equivalent
WU	Water Consumption	m^3	Cubic metre
HH	Human Health	DALY	Disability-Adjusted Life Years. One DALY represents the loss of the equivalent of one year of full health
Ecosys	Ecosystems	Species*yr	Actual species lost per year, based on species density and PDF (Potential Disappeared Fraction of species)
RES	Resources	USD2013	
SS	Single Score	Pt	Points

In addition to the standard environmental indicator used in the ReCiPe 2016 method, we developed additional indicators to assess other environment and socio-economic impacts.

3.6.2 Indicator for Materials Pollution

Plastic pollution, or more generally material pollution, is perceived as *'littering of the environment'* and is influenced by:

- The amount of material in terms of the products surface area, since many of the impacts to ecosystems and biodiversity relate to the area lost as a result of habitat degradation;
- The probability of a product being abandoned and released into the environment, which is a function of the product's value or material price;

- Dispersion of the bags on the environment by wind and water, which is a function of the products mass or density;
- Rate of biodegradation and hence the persistence of the product in the environment.

A model to incorporate influence of these variables and derive an indicator of material pollution or 'littering of the environment' is shown in Figure 5.

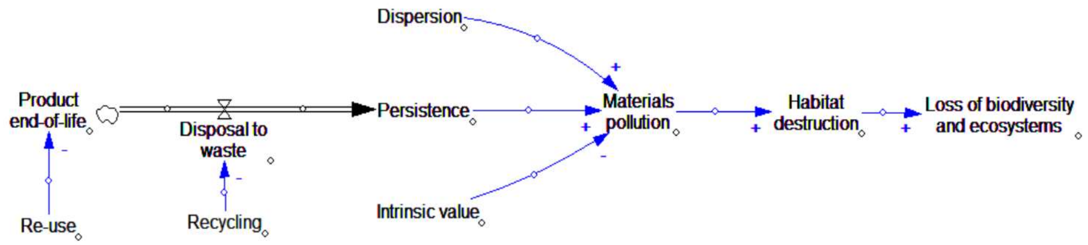

Figure 5: A model for an indicator of materials pollution or 'littering of the environment'. Model with the key variables and causality with arrows having reinforcing (+) or balancing (-) influence (Vensim PLE 8.2.1). Note that the Materials Pollution Indicator is a mid-point indicator for habitat destruction and the subsequent loss of biodiversity and ecosystems.

3.6.3 Persistence

A notable omission from all current impact assessment methods, including ReCiPe 2016, is an indicator to account for plastic pollution, specifically for the impacts of plastics and other materials leaking into the environment to impact biodiversity and ecosystems.

Based on the material flows and end-of-life waste management in South Africa, we calculated the amount of plastic or bioplastic material from the use and disposal of each product material type, which enters South Africa's waste management systems, and then leaks into the environment (see end-of-life modelling). The biodegradation data was sourced from simulated laboratory tests for compost at 58 °C (industrial composting); seawater at 30°C (marine environment); and anaerobic sludge at 37°C (landfill). The specific standards under which the tests were carried out were ASTM D5630 for landfill, D5338 for compost, and ASTM D7081 and ASTM D6691 for the marine environment; with the evolution of carbon dioxide used to determine the amount of carbon lost from the sample from biodegradation (Greene, 2018; Muniyasamy *et al*. 2017). The apparent biodegradation rate constant (k') for material type in the receiving environment (marine environment, landfill, and industrial composting) was calculated by assuming first order kinetics of exponential decay (Abu Qdais *et al*., 2016; Chem. Libretexts, 2019); as follows:

$$\frac{\partial N}{\partial t} = -k't$$

Where *N* is the amount of product material at time *t*, and *k'* is the apparent biodegradation rate constant.

If N_0 is the amount of product material at time 0, then integrating yields the following:

$$N = N_0 e^{-k' t}$$

Or, in a logarithmic form:

$$\ln\left(\frac{N}{N_0}\right) = -k't$$

Therefore, the apparent biodegradation rate constant is:

$$k' = -\frac{\ln\left(\frac{N}{N_0}\right)}{t}$$

The half-life, $T_{\frac{1}{2}}$ is the time taken for the material to biodegrade to half its original value:

$$T_{\frac{1}{2}} = \frac{\ln 2}{k'}$$

And the mean lifetime or average product material lifetime, τ, is:

$$\tau = \frac{1}{k'}$$

The weighted mean lifetime, τ_w, of a given amount (mass) of product material biodegrading in various receiving environments (m_1, m_2, m_3…) can be calculated as:

$$\tau_w = \tau_1 \frac{m_1}{m_1 + m_2 + m_3} + \tau_2 \frac{m_2}{m_1 + m_2 + m_3} + \tau_2 \frac{m_3}{m_1 + m_2 + m_3}$$

The product's material persisting in the environment over time is defined by the amount of material disposed of, and its rate of biodegradation in the environment. The Persistence indicator, P, is the product of *total amount* of material disposed of into the receiving environment(s), and the *weighted mean lifetime* of the material in the environment(s). The Persistence indicator has units with the product of mass and time; namely kilogram-years (kg.yr) or gram-seconds (g.s):

$$P = m_T \tau_w$$

Where m_T is the *total amount* of material disposed of into the receiving environment(s), $m_T = m_1 + m_2 + m_3 \ldots$

3.6.4 Intrinsic value

Aside from the material Persistence in the receiving environments, there are two other factors that describe the likelihood that a material will pollute the environment.

The intrinsic value of a product refers to the value of the material. The intrinsic value therefore reflects the probability of the product being abandoned in the environment, since a product made from a material with high value is likely to be collected or recovered for re-use and re-cycling. The intrinsic value, I, is the price of the material when recovered for recycling or the price of recyclate. Where product is recycled in a closed-loop without loss if intrinsic value of the recyclate for the manufacturing of the same product, the intrinsic value is equal to the polymer material price. However, where there is loss of material quality in recycling, a factor for loss of quality can be included. Therefore, Intrinsic value, it can be simply described:

$$I = R^q$$

Where:
I - Intrinsic value ($)
R - Price of polymer or raw material in the product ($)
q - Quality loss during recycling. For no loss in quality, q=1 and where there is a quality loss, q<1

3.6.5 Environmental dispersion

The environmental dispersion of a product refers to the likelihood of escaping waste management systems as a result of being easily wind-blown or buoyant in water. The mass of the product is a key aspect since heavy products are less likely to be dispersed. However, given that many products fragment into smaller pieces upon disposal, the density of the material from which the product is made is a more relevant parameter; and is being applied to assess marine impacts from plastics. Therefore, Dispersion, D, can be described as the reciprocal of density, ρ :

$$D = \frac{1}{\rho}$$

3.6.6 Material Pollution Indicator

A litter Indicator has been developed to relate littering or polluting the environment with the product biodegradability, surface area and the price (Civancik-Uslu *et al.,* 2019). The Litter Potential Indicator, LPI, is:

$$\mathrm{LPI} = \frac{\mathrm{p1}}{\mathrm{p2.\,p3.\,p4}}$$

Where:
p1- The material surface area of the product (m2)
p2- The price of the product ($/kg or R/kg)
p3- The mass of the product (kg)
p4- the rate of biodegradation (day^{-1})

A similar composite indicator, the Material Pollution Indicator, MPI, was developed in this as a mid-point indicator **describing the potential loss of niche space from material production and consumption that will impact biodiversity and ecosystems**. It incorporates the persistence in the environment (P), the intrinsic value lost from the materials economy (I) and dispersion to the environment (D) as:

$$MPI = \frac{P.D}{I}$$

Where: P- persistence (kg.yr), D- dispersion (m^3/kg) and I- Intrinsic value or price of recylate ($).

Since the Dispersion, D is determined by materials density, ρ (kg/m^3),

$$D = \frac{1}{\rho}$$

and the Intrinsic value, I is:

$$I = R^q$$

Then the Material Pollution Indicator:

$$MPI = \frac{P}{\rho.R^q}$$

The MPI therefore accounts for the mean lifetime of material pollution (yr), and incorporates the volume occupied by the material (m^3) in the environment and the loss and monetary value from inability to re-use or recycle material ($). The units of MPI are $\frac{m^3}{\$}.yr$. The Material Pollution Indicator therefore can be viewed as the impacts to niche volumetric space and the annual loss in economic value resulting from the material leaking into the environment after from the production and consumption of goods and associated packaging materials.

4 RESULTS

This section presents results for the ReCiPe2016 Single Score and the impacts on material pollution on the environment, namely the Persistence and Material Pollution indicators.

The results were modelled for the **Business as Usual (BAU) scenario** which depicts the following value chains:

- *Polystyrene*: polymer imported, manufacturing in South Africa, EoL in South Africa.
- *PET & PP*: polymer and manufacturing in ZA, EoL in South Africa.
- *Paper*: clamshell – both reels production and manufacturing in South Africa; cup – reels imported, manufacturing in ZA; for clamshell and cup EoL in South Africa.
- *Bagasse, PLA, PBS, PBAT, PSM, Biofoam, PHB*: finished product imported in ZA, EoL in South Africa.

A dedicated section, illustrate the Sensitivity Analysis on the following scenarios investigated: Local production vs imports of finished products; Future scenarios with increased recycling rates; and impacts of different coating agents.

In *Appendix B - Affordability* the analysis regarding the affordability/cost of the various meal-kit alternatives is presented.

ReCiPE environmental indicators of standard eLCA **Figure 6** show the Contribution Analysis Comparison of the ReCiPe2016 Single Score LCIA results for all the alternative materials available for the meal-kit, whereas Figure 8 and Figure 9 show the results for material persistence and material pollution in the environment, respectively.

From an environmental point of view using the standard eLCA indicators, the PS take-out performed the best by virtue of being extremely lightweight, when compared with all the other options (3-fold lighter on average compared to the other alternatives). The Raw Material Extraction and Polymer Production stage of the value chain (green bars **Figure 6)** accounts for the bulk of the environmental burden (71.2% on average across all the meal-kit alternatives); the Manufacturing stage accounts for 14.5% on average of the environmental burdens; followe by the Disposal (9.9%), Transport (5.7%). Recycling, when present (not all the alternative in the BAU scenario have material recycling) accounts for a -1.7% on average, meaning that it contributes to improve the overall performances by reducing the enviromental burdens associated with virgin material production.

Among biopolymers PLA and PHB resulted with the highest environmental impacts. This is due to the bio-based nature of the polymer: PLA is derived from various biomass residues (corn, sugar beet) by bacterial fermentation process; PHA's family, which PHB belongs to, are produced via bacterial fermentation of carbon substrates derived from renewable feedstocks. ReCiPe2016 Mid-point result (Appendix *Mid-point Indicators LCIA Results,* Figure 14 to Figure 31) show the mid-point impact categories in which PLA and PHB based meal-kit scored higher among the biopolymers, but still lower compared to conventional plastics. Specifically, PHB derived from sugar from sugarcane shows the highest environmental impacts in 15 out of 18 impact categories; PLA derived from maize scored as the second highest in 6 out of 18 impact categories. Impact categories in which all the bio-based meal-kit (PLA, PHB, PSM and Bio-foam) resulted worse than meal-kit made of other material (conventional plastics, bagasse and paper) are: Land Use, Water Use and Marine Eutrophication. *Appendix C – Mid- and End-point LCIA Results* presents the details regarding the LCIA Results Comparison for the ReCiPe2016 End- and Mid-point Indicators for all the meal-kit alternatives.

To understand the effect of recycling on all the material alternatives investigated for the meal-kit, a scenario analysis was performed using the EPR regulation targets (DFFE 2021) for each material. Section *Increasing recycling rates* and *Appendix D - Mid- and End-point LCA Results for the Scenario Analysis* show the ReCiPe2016 Single Score and End- and Mid-point LCIA results respectively.

However, when considering end of life impacts of material leaking into the environment and evaluating persistence in the environment and material pollution as additional indicators, the outcome is significantly different. In the next section, **Figure 7** shows how conventional plastics are very persistent in the environment when compared to biodegradable paper, bioplastics or bagasse; Figure 9 shows how the best option from an eLCA environmental point of view (PS) performs at least 400 times worse in terms of material pollution when compared to paper/cardboard alternatives. These results clearly indicate that the environmental benefits associated with plastics are dependent on proper the end-of-life management of these materials.

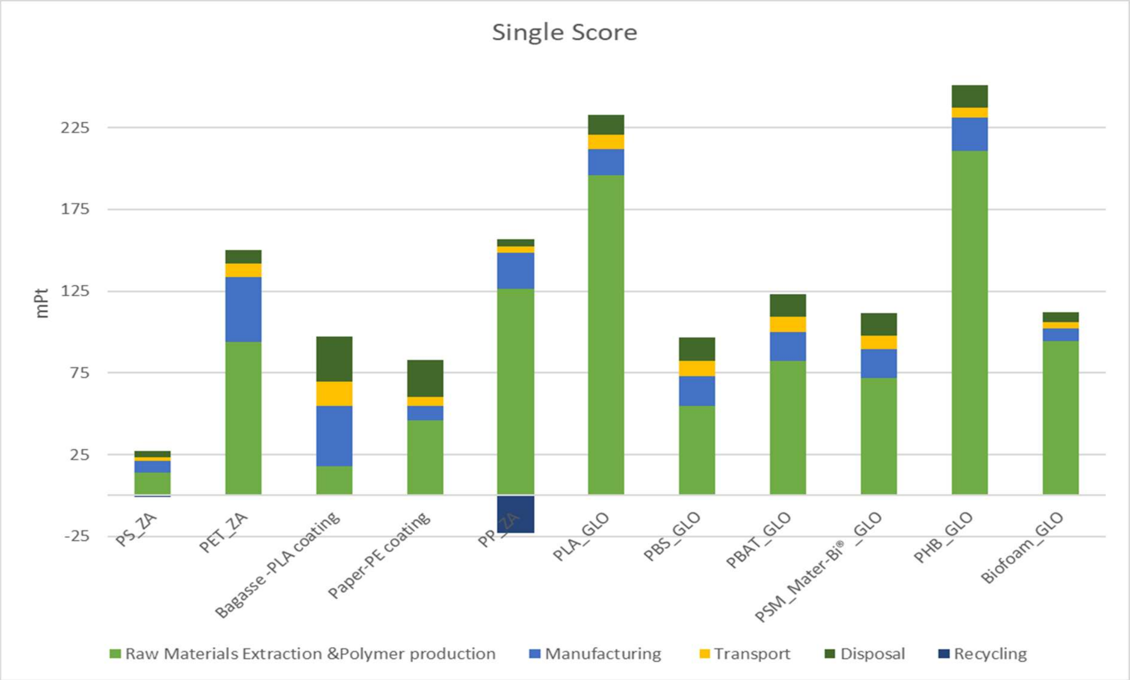

Figure 6: ReCiPe2016 LCIA Result Comparison (Single Score) for the 11 meal-kit alternatives considered in the study

4.1 Persistence and Materials Pollution Indicator

This section presents the results related to the impact of waste leaking into the environment. To account for it both Persistence and Material Pollution indicators were derived. **Table 5** reports all the calculation details, whereas **Figure 8** and **Figure 9** show the impacts of all the meal-kit alternatives in terms of material persisting in the environment (i.e. which does not degrades) and in terms of likelihood of littering of the environment.

The results show that PS has a reduced persistence compared to other plastics (PET, PP) due to the low density of XPS/EPS and mass of polymer in the product and reference flow results in persistence in the environment. The persistence of PS and other plastics (PET, PP) is substantially greater than several alternatives such as paper, PLA, PBS, PBAT, PSM (Mater-Bi®), and PHB. Furthermore, the low density of some plastics, particularly PS, results in a Materials Pollution Indicator for polystyrene that is 1284 times and 2456 times higher than that of the paper cup and clamshell, respectively.

These results do not include the various moisture-barrier coatings that are used on the cups and containers. Some of the alternatives to polystyrene, namely bagasse and paper, require a coating to improve reduce moisture permeability of cups and clamshells so that they can adequately perform the required function. The most common coating is no-biodegradable petroleum derived polymer, Polyethylene, that persists in the environment long after the paper component has degraded. The photo in Figure 7 shows a polyethylene coated cup 4-6 years after disposal to a home composting with the thin polyethylene plastics coating being only visible remains.

Figure 7: PE coated cup 4-6 years after disposal to a home composting

The standard coating polyethylene (PE) that amounts to 3%w/w of the cup or container, but various bio-plastics can also be used. PLA is increasingly being used at 5% w/w and other bio-plastics (PHB, PBS) could also serve the same purpose. The relatively small proportion of plastic/bio-plastic coating may have a significant influence on bio-degradation and hence persistence and material pollution. We therefore assessed various coatings in terms of persistence and materials, pollution (Table 6).

The coating (3%PE or 5% PLA/PBAT/PBS) will influence the persistence and Material Pollution Indicator of the (paper/bagasse) product. Therefore, carried out more detailed analysis of impact of different cup and clamshell coatings. Results show that non-biodegradable coatings, such as PE have a significant influence and can increase the persistence and MPI of paper/bagasse containers more than 580%. In contrast, use of all biodegradable coatings had a minimal effect (<10%) on persistence and MPI; with the biodegradable materials (PBS, PBAT, PHA) increasing Material Pollution Indicator by less than 6% and PLA by 9%.

Table 5: Persistence and Material Pollution Indicators' Results

Material type	Container Type	Reference Flow (g)	Mean material lifetime (yr)			Amount in receiving environment (g)			Weighted material lifetime (yr)	Persistence (kg.yr)	Material price ($/kg)	Price of polymer in material reference flow ($)	Density (kg/m^3)	MPI, Material Pollution Indicator (m^3/$).yr
			compost	marine	landfill	compost	marine	landfill						
EPS/XPS	Clamshell	125.64	24.41	246.33	172.18	36.07	29.01	36.69	140.94	17.708	1.20	0.15	20	**5.87254**
	Cup	36	24.41	246.33	172.18	10.34	8.31	10.51	140.94	5.074	1.20	0.04	30	**3.91503**
Bagasse	Clamshell	483.84	0.20	1.28	0.81	138.91	111.72	141.28	0.73	0.352	0.80	0.39	1200	**0.00076**
	Cup	229.39	0.20	1.28	0.81	65.86	52.97	66.98	0.73	0.167	0.80	0.18	1200	**0.00076**
Paper	Clamshell	461.64	0.20	1.28	0.81	132.54	106.59	134.80	0.73	0.336	0.80	0.37	1400	**0.00065**
	Cup	168	0.20	1.28	0.81	48.23	38.79	49.06	0.73	0.122	0.80	0.13	1400	**0.00065**
PET	Clamshell	316.8	24.41	246.33	172.18	90.95	73.15	92.51	140.94	44.650	1.00	0.32	1380	**0.10213**
	Cup	113.06	24.41	246.33	172.18	32.46	26.11	33.01	140.94	15.935	1.00	0.11	1380	**0.10213**
PP	Clamshell	184.51	24.41	246.33	172.18	52.97	42.60	53.88	140.94	26.005	1.50	0.28	920	**0.10213**
	Cup	113.04	24.41	246.33	172.18	32.45	26.10	33.01	140.94	15.932	1.50	0.17	920	**0.10213**
PLA	Clamshell	248.7	0.20	9.61	7.97	71.40	57.42	72.62	5.68	1.413	4.40	1.09	1240	**0.00104**
	Cup	151.2	0.20	9.61	7.97	43.41	34.91	44.15	5.68	0.859	4.40	0.67	1240	**0.00104**
PBS	Clamshell	250.66	0.20	0.82	0.48	71.96	57.88	73.19	0.48	0.120	5.50	1.38	1250	**0.00007**
	Cup	204.72	0.20	0.82	0.48	58.78	47.27	59.78	0.48	0.098	5.50	1.13	1250	**0.00007**
PBAT or PSM (Mater-bi)	Clamshell	242.67	0.21	0.82	0.48	69.67	56.03	70.86	0.48	0.117	4.20	1.02	1210	**0.00009**
	Cup	99.13	0.21	0.82	0.48	28.46	22.89	28.95	0.48	0.048	4.20	0.42	1210	**0.00009**
Bio-foam (expanded PLA)	Clamshell	138.12	0.20	9.61	7.97	39.65	31.89	40.33	5.68	0.785	4.40	0.61	80	**0.01615**
	Cup	54	0.20	9.61	7.97	15.50	12.47	15.77	5.68	0.307	4.40	0.24	80	**0.01615**
PHB etc	Clamshell	246.68	0.18	0.88	0.16	70.82	56.96	72.03	0.37	0.092	16.00	3.95	1200	**0.00002**
	Cup	201.48	0.18	0.88	0.16	57.84	46.52	58.83	0.37	0.075	16.00	3.22	1200	**0.00002**

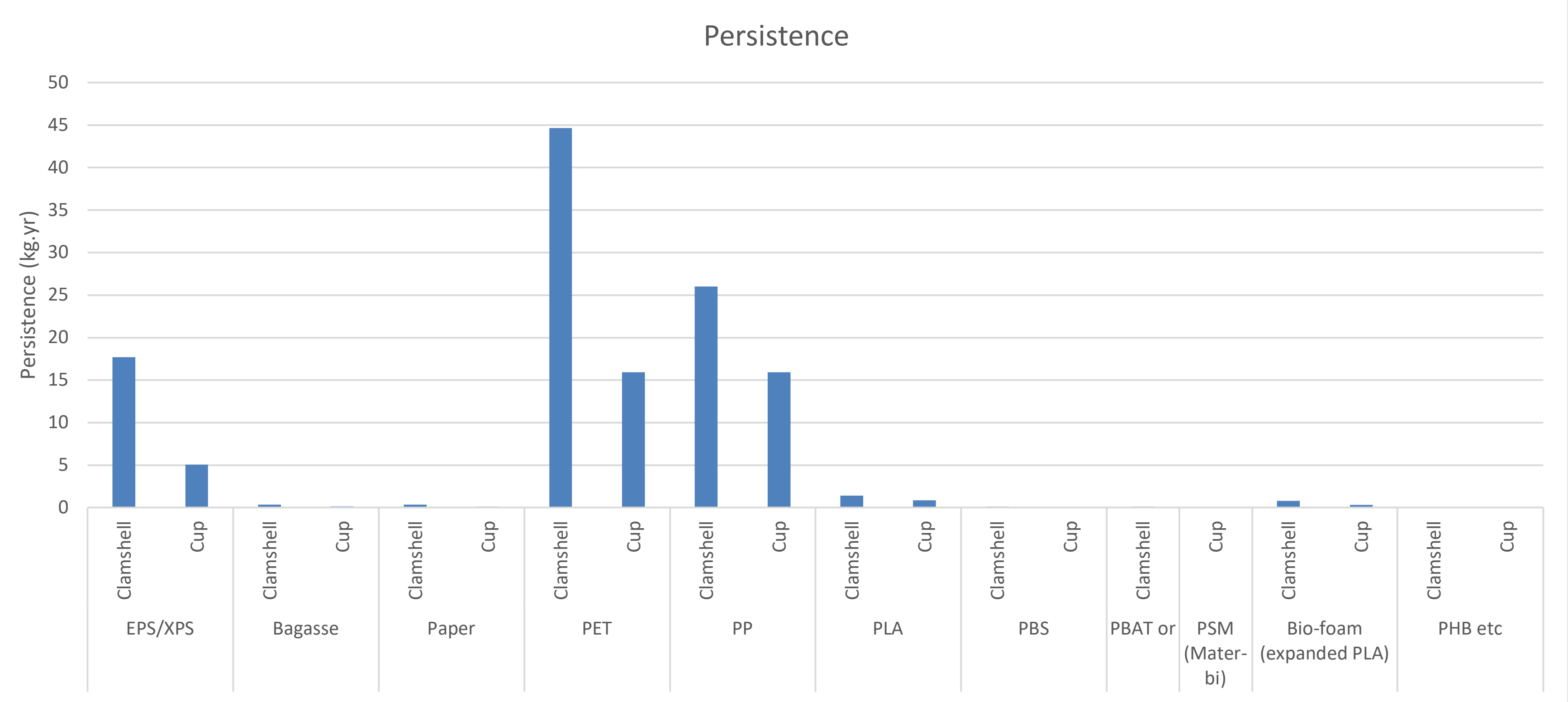

Figure 8: Persistence Indicator Results

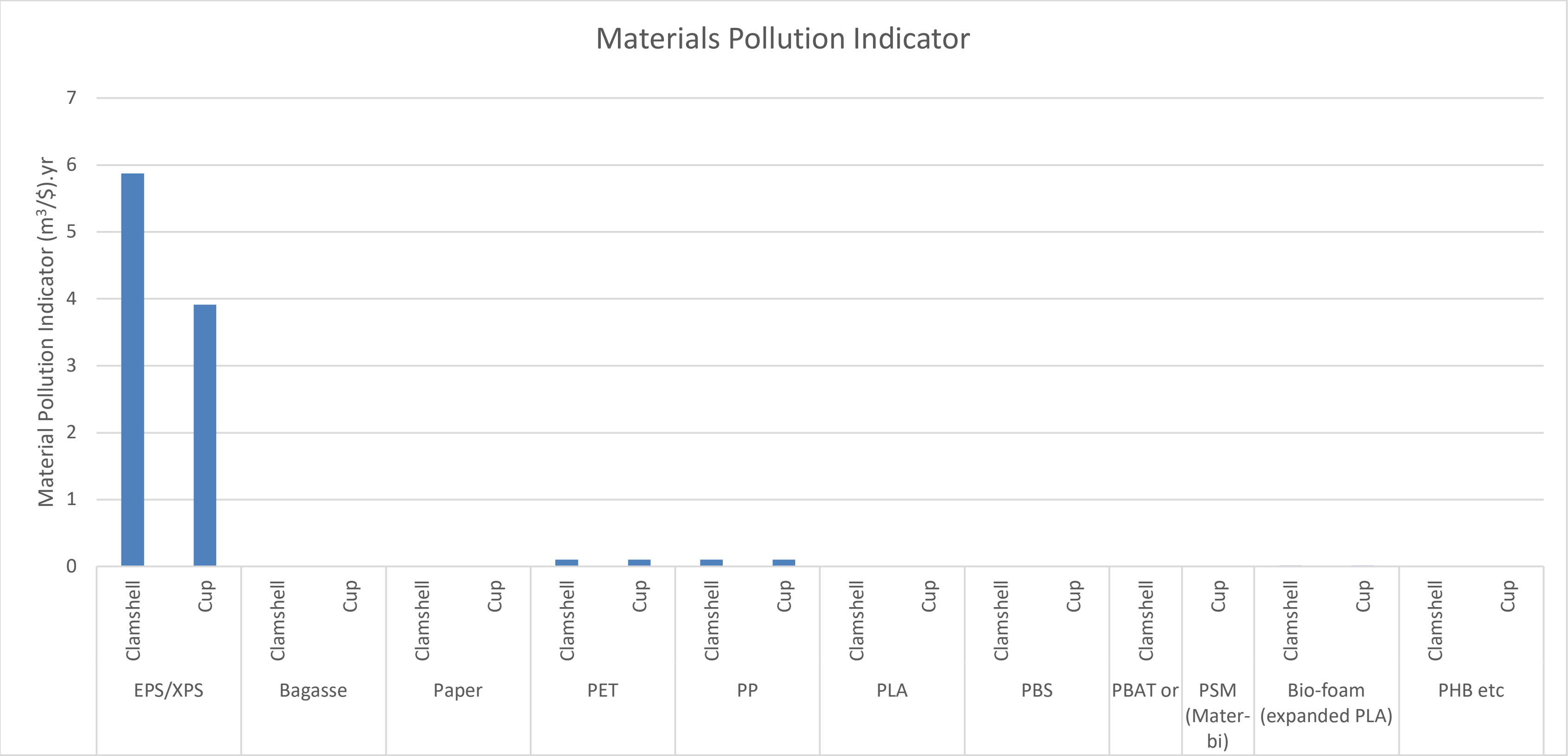

Figure 9: Material Pollution Indicator Results

Table 6: Persistence and Material Pollution Index, different material coating comparison

Material	Container Type & Coating	Functional Unit in terms of Volume	Individual weights (gr)	Reference Flow (g)	Persistence $(m^3/\$).yr$	Material price $/kg	Price of polymer or raw material in product/reference flow ($)	Density kg/m3	MPI, Material Pollution Index with coatings
Bagasse	Clamshell	1.12	36.00	483.84	0.35	0.80	0.39	1200	**0.001**
	_3%PE	1.12	1.08	14.5152	2.05	0.90	0.01	950	**0.165**
	_5%PLA	1.12	1.80	24.192	0.14	4.40	0.11	1240	**0.001**
	_5%PBS	1.12	1.80	24.192	0.01	5.50	0.13	1250	**0.000**
	_5%PBAT	1.12	1.80	24.192	0.01	4.20	0.10	1210	**0.000**
	_5%PHB	1.12	1.80	24.192	0.01	16.00	0.39	1200	**0.000**
	Cup	1	19.12	229.44	0.17	0.80	0.18	1200	**0.001**
	_3%PE	1	0.57	6.8832	0.97	0.90	0.01	950	**0.165**
	_5%PLA	1	0.96	11.472	0.07	4.40	0.05	1240	**0.001**
	_5%PBS	1	0.96	11.472	0.01	5.50	0.06	1250	**0.000**
	_5%PBAT	1	0.96	11.472	0.01	4.20	0.05	1210	**0.000**
	_5%PHB	1	0.96	11.472	0.00	16.00	0.18	1200	**0.000**
Paper	Clamshell	1.12	31.00	416.64	0.30	0.80	0.33	1400	**0.001**
	_3%PE	1.12	0.93	12.4992	1.76	0.90	0.01	950	**0.165**
	_5%PLA	1.12	1.55	20.832	0.12	4.40	0.09	1240	**0.001**
	_5%PBS	1.12	1.55	20.832	0.01	5.50	0.11	1250	**0.000**
	_5%PBAT	1.12	1.55	20.832	0.01	4.20	0.09	1210	**0.000**
	_5%PHB	1.12	1.55	20.832	0.01	16.00	0.33	1200	**0.000**
	Cup	1	14.00	168	0.12	0.80	0.13	1400	**0.001**
	_3%PE	1	0.42	5.04	0.71	0.90	0.00	950	**0.165**
	_3%PLA	1	0.70	8.4	0.05	4.40	0.04	1240	**0.001**
	_5%PBS	1	0.70	8.4	0.00	5.50	0.05	1250	**0.000**
	_5%PBAT	1	0.70	8.4	0.00	4.20	0.04	1210	**0.000**
	_5%PHB	1	0.70	8.4	0.00	16.00	0.13	1200	**0.000**

4.2 Sensitivity/Scenario Analysis

Some Scenarios were investigated to understand how the results were influenced by the following parameters w.r.t the BAU base case:

1. Local production VS Imported of finished goods;
2. Increasing recycling rates;
3. Different coating materials.

The results presented here refer to the ReCiPe2016 Single Score indicator only. *Appendix D - Mid- and End-point LCA Results for the Scenario Analysis* presents the results for all ReCiPe2016 End- and Mid-point Indicators.

4.2.1 Local production VS Imports of finished goods

Since the BAU Scenario included a mix of both locally produced meal-kit, imports of finished ones as well as alternatives where raw material were produced elsewhere and manufacturing occurred locally, we have investigated for all the meal-kits all the possible production routes.

Table 7 shows the comparison of the business as usual (BAU) scenario (highlighted in RED in **Table 7**) - which differs for the different material alternatives - with localising the production in South Africa (and importing raw materials), with the import of finished goods. It is evident that local production impacts on the overall environmental performance of the investigated options negatively. This is due to South Africa's reliance on coal-fired electricity and the Coal-2-Liquid production process (SASOL) for monomers, which impacts not only conventional plastic but also the fossil-based material options (PBS and PBAT).

Alternative options to consider when thinking of material replacement, which show a restrained increase in environmental burdens (~20% more, highlighted in GREEN in **Table 7**), are Paper, Bagasse and PBS, which also show potential to be organically recycled (industrial composting). Localising the manufacturing stage only translates in an increase in environmental burdens of 9.5% on average for Bagasse and all the biodegradable plastics and it may also preserve the manufacturing industry, since the biopolymers can be dropped into existing plastic manufacturing processes.

4.2.2 Increasing recycling rates

Using the EPR regulation (DFFE 2021) and the targets for increasing recycling rate for different material and single-use products (Table 3) the following Future scenarios were explored versus the BAU:

- Improved mechanical recycling for the conventional plastics alternative and Paper meal-kits;
- Industrial composting (as organic recycling) for the biopolymers alternative and Bagasse meal-kits.

Table 8 presents the results comparison relative to the ReCiPe Single Score for future waste treatment options results based on EPR regulation targets (**Table 3**) for the different material alternatives. It shows that increasing recycling rates, either as mechanical recycling or industrial composting, will improve the overall environmental performances of the investigated options, by up to ~30% for conventional Plastic and up to 40% for biodegradable/compostable alternatives materials over a 5-years period following the targets for both mechanical recycling and industrial composting in the EPR Regulations.

Table 7: ReCiPe2016 Single Score LCIA results comparing Local production VS Imports of finished products

	Unit	PS	PET	Bagasse	Paper	PP	PLA	PBS	PBAT	PSM (Mater-Bi®)	Bio-foam (expanded PLA)	PHB
ZA Production	mPt	41.5	**150**	119	**82.7**	**134**	380	114	256	183	182	342
	%	+57.8%		**+22.3%**			+63.1%	**+18%**	+108.1%	+61.9%	+62.5%	+36.3%
ZA Manufacturing Only	mPt	**26.3**	110	118	82.7	50.2	246	111	138	127	118	267
	%		-26.7%	+21.3%	0%	-62.5%	+5.9%	+14.9%	+12.2%	+12.4%	+5.4%	+6.4%
GLO Production	mPt	24.4	92.8	**97.3**	75.1	40.5	**233**	**96.6**	**123**	**113**	**112**	**251**
	%	-7.2%	-38.1%		-9.2%	-69.8%						

Table 8: ReCiPe2016 Single Score LCIA results comparing impacts of Increasing recycling rates

Meal-kit material type	**BAU Single Score (mPt)**	**Mechanical Recycling**					**Organic Recycling (Industrial Composting)**				
		Y1	**Y2**	**Y3**	**Y4**	**Y5**	**Y1**	**Y2**	**Y3**	**Y4**	**Y5**
PS	**26.3**	-4.2%	-6.8%	-9.5%	-12.5%	-16.4%					
PET	**150**	-4.7%	-8.0%	-11.3%	-15.3%	-19.3%					
Bagasse	**97.3**						-7.2%	-12%	-24%	-31.3%	**-38.5%**
Paper	**82.7**	-1.5%	-2.9%	-4.5%	-5.9%	-7.5%					
PP	**134**	-17.9%	-20.2%	-23.1%	-26%	**-29.7%**					
PLA	**233**						-0.4%	-1.7%	-4.3%	-5.6%	-7.3%
PBS	**96.6**						-1.6%	-4.5%	-11.6%	-15.9%	-20.2%
PBAT	**123**						-0.8%	-3.3%	-8.2%	-11.4%	-15.5%
PSM (Mater-Bi®)	**113**						-1.8%	-3.5%	-9.7%	-13.5%	-17%
Biofoam (expanded PLA)	**112**						-0.9%	-1.8%	-4.5%	-6.3%	-7.1%
PHB	**251**						-0.4%	-1.6%	-4.4%	-5.9%	-7.6%

Table 9: ReCiPe2016 Single Score results comparing the impact of different coating materials on overall LC and on coating production and meal-kit disposal

Meal-kit material type	**Coating type (5% by mass)**	**Single Score**					
		Overall LC		Coating Production		Disposal	
		mPt	%	mPt	%	mPt	%
Bagasse	**PLA (BAU)**	**97.3**		**17.3**		**27.8**	
	PE (3% by mass)	81.6	-16.1%	2.8	-83.9%	27.8	
	PBAT	86.7	-10.9%	6.7	-61.3%	27.8	
	PBS	84.3	-13.4%	4.3	-75.3%	27.8	
	PHB	96.8	-0.5%	16.8	-2.9%	27.8	
	PSM (Mater-Bi®)	86	-11.6%	6.0	-65.3%	27.8	
Paper	PLA (	94.6	14.4%	14.2	1265%	22.4	-0.44%
	PE (BAU; 3% by mass)	**82.7**		**1.04**		**22.5**	
	PBAT	85.9	3.9%	5.48	427%	22.4	-0.44%
	PBS	83.9	1.5%	3.51	238%	22.4	-0.44%
	PHB	94.2	13.9%	13.8	1227%	22.4	-0.44%
	PSM (Mater-Bi®)	85.3	3.1%	4.93	374%	22.4	-0.44%

4.2.3 Different coating materials

Only two meal-kit alternatives require coating materials as waterproof/grease barriers, namely the Bagasse and Paper options. As BAU the Bagasse meal-kit comes with a PLA coating, whereas the Paper meal-kit come with a PE (polyethylene) coating. Coating account for a 3-5% by mass of the total weight of the meal-kit (clamshell food container and cup).

The impact on the overall environmental performance, of the coating production as well as the impact on disposal were assessed. **Table 9** illustrate the results comparison for the ReCiPe2016 Single Score indicator.

The bagasse meal-kit show overall environmental improvements when other materials are used for coating the inner surface. To note that except for the PE option, all the other biopolymers can be organically recycled (via industrial and home composting), thus the bagasse meal-kit environmental performance can be improved by both increasing recycling rates and using less resource intensive and bio-degradable coating material.

The paper meal-kit with PE coating agent results show lower environmental impacts. Biodegradable options which may be considered as alternative materials and which show a restrained increase in environmental burdens (<5%) are PBS, PSM (Mater-Bi®) and PBAT.

5 DISCUSSION AND FUTURE IMPROVEMENT

The results showed that among the alternative materials currently in use, commercially available, and possible prototypes, the raw material extraction and polymer production stages of the value chain are responsible for the bulk of the environmental impact associated with meal- kit use in South Africa. Polystyrene performed the best (due to its extremely lightweight – 3-fold lighter on average compared to the other options), followed by Paper/Cardboard and Bagasse, scoring second and third best from an eLCA point of view. Among the biopolymers, PBS is the best alternative showing also potential for organic recycling in industrial composting facilities.

This is in line with UNEP (2020) and UNEP (2021) reports on a variety of single-use and re-usable cup and take-away container. Results showed that single-use cups have similar environmental impacts regardless of the material they are made of (whether biobased-plastic, fossil-based plastic, or paper), with paper to be preferred also to re-usable alternatives if recycling rates increase (up to 80%). On single-use food-packaging made of polystyrene (PS), XPS and paper showed a better environmental performance than packaging alternatives of other materials (PET, PLA, PP and Aluminium). Lightweight of packaging (without compromising functionality) also impact positively the environmental performance.

However, when adding persistence and material pollution indicators, biodegradable plastics, biobased plastics, bagasse and paper are less persistent in the environment than conventional plastics and polystyrene is at least four hundred times worse in terms of material pollution than paper due to its lightweight low intrinsic value (which hinders its collection/recovering for re-use and recycling) and thus making it prone to disperse greatly in the environment.

Other than the already in use options of Paper and Bagasse, a potential (commercially available) material replacement is represented by the PBS biopolymer, which scores good in terms of both material pollution and eLCA. Even when considering localising its production, keeping the fossil-based source (coal in the case of South Africa), it shows a restrained overall environmental burden increase (18%), which is the lowest among all the material alternatives considered. It also could easily replace the conventional PE coating barrier in both the Paper and Bagasse alternatives, the second and third best overall from an eLCA point of view. This could further increase their performances in both the Persistence and Material Pollution indicators, where they score poorly compared to the other biodegradable options due to the PE/PLA coating barriers which does not degrade in the environment (PE) or comes with a higher environmental burden (PLA).

Two bio-based meal-kits, namely those made of PLA and PHB, stand out among all bio-based options with the highest scores. This is due to the feedstock used in the production of the two biopolymers, which are maize and sugar from sugarcane, respectively. To improve the environmental performances, mainly related to the agricultural practices to produce the substrate for the fermentation process, it would be good to explore whether sugar-rich bio waste could be used instead of main feedstock (though renewable and abundant).

The report on Task 1.3 on Global producers and potential of local production of alternatives*,* also state that "*PBS can replace low- and high-density PE and PP in current packaging applications as films and as injection and blow-molded containers. There are also reports on the potential of PBS to replace polystyrene, particularly as foam, as property profiles are improved".*

Results of this study can easily be extended to other single-use items which show a potential for material replacement maintaining their functional equivalency.

Further development of the current study is aimed at integrating the results in one metric which will aggregate both the eLCA and the newly developed indicators to account for material pollution in the environment. However, to date, there is no consolidated methodology to attain that. We are exploring some normalisation methods such as the Min-Max Normalisation method, which is a technique used by well-known sustainability indices such as the HDI, SSI and EPI. Indicators are normalised to have an identical range (0-1 by default; but easily converted to any pre-determined scale), which then allows indicators to be compared and aggregated.

Also, to align with what emerged on the last PSC meeting of 8th Dec 2021 on the progress of Task 1.5 on *Demonstration of identified technologies/material,* where two possible biopolymers made of PHBH and different percentages of bagasse fiber content are currently under testing, a dedicated eLCA could be further exploring the environmental impact of those two prototype options not included in the study to date. Considering also the potential of PBS to replace polystyrene particularly as foam, a further prototype made of expanded PBS could be investigated from a LCA point of view.

6 References

Aljaibachi R, Callaghan A. Impact of polystyrene microplastics on Daphnia magna mortality and reproduction in relation to food availability. PeerJ. 2018 Apr 18;6:e4601. doi: 10.7717/peerj.4601. PMID: 29686944; PMCID: PMC5911131.

Abu Qdais, H. and Al-Widyan, M., 2016. Evaluating composting and co-composting kinetics of various agro-industrial wastes. Int J Recycl Org Waste Agricult 5, 273–280

Ahmad, M., and Bajahlan, A. S. (2007). Leaching of styrene and other aromatic compounds in drinking water from polystyrene bottles. J. Environ. Sci. 19, 421–426. doi: 10.1016/S1001-0742(07)60070-9

Aumônier S., Collins M. and Garrett P., (2008), An Updated Life Cycle Assessment Study for Disposable and Reusable Nappies, Science Report – SC010018/SR2, Environment Agency

Barboza, L. G. A., Vethaak, A. D., Lavorante, B. R. B. O., Lundebye, A. K., Guilhermino, L., (2018). Marine microplastic debris: An emerging issue for food security, food safety and human health. Mar. Pollut. Bull. 133, 336–348

Barnes D. K. A., Galgani F., Thompson R. C., Barlaz M., (2009).Accumulation and fragmentation of plastic debris in global environments. Phil. Trans. R. Soc. B 364, 1985–1998

Bejgarn, S., MacLeod, M., Bogdal, C., and Breitholtz, M. (2015). Toxicity of leachate from weathering plastics: an exploratory screening study with Nitocra spinipes. Chemosphere 132, 114–119.

Boelee, E., Geerling, G., van der Zaan, B., Blauw, A., Vethaak, A. D. (2019) Water and health: From environmental pressures to integrated responses. Acta Trop. 193, 217–226

Bravo, M., de los Ángeles Gallardo, M., Luna-Jorquera, G., Núñez, P., Vásquez, N., and Thiel, M. (2009). Anthropogenic debris on beaches in the SE Pacific (Chile): results from a national survey supported by volunteers. Mar. Pollut. Bull. 58, 1718–1726. doi: 10.1016/j.marpolbul.2009.06.017

BusinessTech (2017). https://businesstech.co.za/news/business/182033/how-much-south-africans-spend-on-takeaways/

Chem.libretexts, 2019. First order Reaction. Online. Available at: https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Kinetics/Reaction_Rates/FirstOrder_Reactions

Chitaka, T.Y., Russo, V. & von Blottnitz, H. In pursuit of environmentally friendly straws: a comparative life cycle assessment of five straw material options in South Africa. Int J Life Cycle Assess 25, 1818–1832 (2020)

Chitaka, T. Y. (2020), Inclusion of Leakage into Life Cycle Management of Products Involving Plastic as a Material Choice, University of Cape Town.

Civancik-Uslu D, Puig R, Hauschild M, Fullana-I-Palmer P. Life cycle assessment of carrier bags and development of a littering indicator. Sci Total Environ. 2019 Oct 1;685:621-630.

Conkle JL, Baez Del Valle CD and Turner JW. Are we underestimating microplastic contamination in aquatic environments. Environ Manage 2018; 61(1): 1–8.

Convey, P., Barnes, D., and Morton, A. (2002). Debris accumulation on oceanic island shores of the Scotia Arc, Antarctica. Polar Biol. 25, 612–617. doi: 10.1007/s00300-002-0391-x

DEA. 2018. South Africa state of waste. A report on the state of the environment. Pretoria, South Africa: Department of Environmental Affairs.

DFFE (2021), National Environmental Management: Waste Act: Regulations and notices regarding extended producer responsibility

de Souza Machado, A. A., Kloas, W., Zarfl, C., Hempel, S., Rillig, M. C. (2018). Microplastics as an emerging threat to terrestrial ecosystems. Glob. Change Biol. 24, 1405–1416

EFSA CEF Panel, 2014. (EFSA Panel on Food Contact Materials, Enzymes, Flavourings and Processing Aids). Scientific Opinion on the safety assessment of the substances Polystyrene as Hazardous Household Waste (butadiene, ethyl acrylate,methylmethacrylate, styrene) copolymer eithernotcrosslinked or crosslinked with divinylbenzene or 1,3-butanediol dimethacrylate, in nanoform, for use in food contact materials. EFSA Journal, 12(4):3635, 8 p. doi:10.2903/ j.efsa.2014.3635 http://dx.doi.org/10.5772/65865 59

Ecoinvent (n.d), ecoinvent

European Commission. Environment [Internet]. 2016. Available from: http://ec.europa.eu/environment/chemicals/endocrine/strategy/substances_en.htm

Fobil, J., Hogarh, J. (2009) The dilemmas of plastic wastes in a developing economy: Proposals for a sustainable management approach for Ghana. West Afr. J. Appl. Ecol. 10, 1

Franklin Associates. (2011). Life cycle inventory of foam polystyrene, paper-based, and PLA foodservice products. Prairie Village, United States: Franklin Associates.

Gall, S. C., and Thompson, R. C. (2015). The impact of debris on marine life. Mar. Pollut. Bull. 92, 170–179. doi: 10.1016/j.marpolbul.2014.12.041

Garrity, S. D., and Levings, S. C. (1993). Marine debris along the Caribbean coast of Panama. Mar. Pollut. Bull. 26, 317–324. doi: 10.1016/0025-326X(93)90574-4

GESAMP (2019). Guidelines or the monitoring and assessment of plastic litter and microplastics in the ocean (Kershaw P.J.,Turra A. and Galgani F. editors), (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP No. 99, 130p.M, Liyanage K and Garza-Reyes J (2018). Towards a Life Cycle Sustainability Analysis: A systematic review of approaches to sustainable manufacturing. Journal of Cleaner Production 184, 20: 1002-1015

Gloria T, Guinee J, Wei Kua H, Singh B and Lifset R (2017). Charting the Future of Life Cycle Sustainability Assessment: A Special Issue (Editorial). Journal of Industrial Ecology 21 (6): 1449 – 1453.

Greene, J., (2018). Biodegradation of Biodegradable and Compostable Plastics under Industrial Compost, Marine and Anaerobic Digestion. Ecology, Pollution & Environmental Science 1(1): 13-18

Gregory M. R. (2009). Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Phil. Trans. R. Soc. B 364, 2013–2025

Guinee J, Heijungs R, Huppes G, et al. (2011). Life Cycle Assessment: Past, Present, and Future. Environmental Science and Technology 45: 90–96

Häkkinen, T. & Vares, S. (2010). Environmental impacts of disposable cups with special focus on the effect of material choices and end of life. Journal of Cleaner Production. 18(14):1458–1463.

Harding, K.G., Dennis, J.S., von Blottnitz H., Harrison, S.T.L., Environmental analysis of plastic production process: Comparing pertroleum-based propylene and polyethylene with biologically-based poly-β-hydroxybutyric acid life cycle analysis. Journal of Biotechnology (2008), 130, pp: 57-66

van der Harst, E., Potting, J. & Kroeze, C. (2014). Multiple data sets and modelling choices in a comparative LCA of disposable beverage cups. Science of the Total Environment. 494–495:129–143. DOI: 10.1016/j.scitotenv.2014.06.084

Huerta Lwanga, E., Mendoza Vega, J., Ku Quej, V., Chi, J. L. A., Sanchez Del Cid, L., Chi, C., Escalona Segura, G., Gertsen, H., Salánki, T., van der Ploeg, M., Koelmans, A. A., Geissen, V. (2017). Field evidence for transfer of plastic debris along a terrestrial food chain. Sci. Rep. 7, 14071

Keller, A. A., Fruh, E. L., Johnson, M. M., Simon, V., and McGourty, C. (2010). Distribution and abundance of anthropogenic marine debris along the shelf and slope of the US West Coast. Mar. Pollut. Bull. 60, 692–700. doi: 10.1016/j.marpolbul.2009.12.006

Klugman, J., Rodreiguez, F. and Choi, H-J., The HDI 2010: New Controversies, Old Critiques. United Nations Development Programme Human Development Reports. 2011

IARC, 2018. International Agency for Research on Cancer, 2018 IARC Monographs Vol 121 Group (2018). “Carcinogenicity of quinoline, styrene, and styrene-7,8-oxide.” Lancet Oncology.

ISO (2006a). ISO 14040: Environmental Management – Life Cycle Assessment – Principles and Framework. Geneva: International Organization for Standardization.

ISO (2006b). ISO 14044: Environmental Management – Life Cycle Assessment – Requirements and guidelines. Geneva: International Organization for Standardization.

Kloepffer W (2008). Life Cycle Sustainability Assessment of Products. International Journal of Life Cycle Assessment 13 (2), 89–95

Kwon, B. G., Koizumi, K., Chung, S. Y., Kodera, Y., Kim, J. O., and Saido, K. (2015). Global styrene oligomers monitoring as new chemical contamination from polystyrene plastic marine pollution. J. Hazard. Mater. 300, 359–367. doi: 10.1016/j.jhazmat.2015.07.039

Kwon, B. G., Amamiya, K., Sato, H., Chung, S. Y., Kodera, Y., Kim, S. K., et al. (2017). Monitoring of styrene oligomers as indicators of polystyrene plastic pollution in the North-West Pacific Ocean. Chemosphere 180, 500–505. doi: 10.1016/j.chemosphere.2017.04.060

Lee, J., Hong, S., Song, Y. K., Hong, S. H., Jang, Y. C., Jang, M., et al. (2013). Relationships among the abundances of plastic debris in different size classes on beaches in South Korea. Mar. Pollut. Bull. 77, 349–354. doi: 10.1016/j.marpolbul.2013.08.013

Liboiron M. Redefining pollution and action: the matter of plastics. Journal of Material Culture. 2015, 21:87–110.

Lithner D, Larsson Å, Dave G. Environmental and health hazard ranking and assessment of plastic polymers based on chemical composition. Science of the Total Environment. 2011, 409:3309–3324.

Madival, S., Auras, R., Singh, S.P. & Narayan, R. 2009. Assessment of the environmental profile of PLA, PET and PS clamshell containers using LCA methodology. Journal of Cleaner Production. 17(13):1183–1194. DOI: 10.1016/j.jclepro.2009.03.015.

Matiella JE, Hsieh TC. Volatile compounds in scrambled eggs. Journal of Food Science. 1991, 56(2):387–390. doi:10.1111/j.1365-2621.1991.tb05286.x

Mater-Bi (n.d.), Mater-Bi - biodegradable and compostable bioplastics - Novamont

Morét-Ferguson, S., Law, K. L., Proskurowski, G., Murphy, E. K., Peacock, E. E., and Reddy, C. M. (2010). The size, mass, and composition of plastic debris in the western North Atlantic Ocean. Mar. Pollut. Bull. 60, 1873–1878.

Muniyasamy, S. and John, M.J, (2017). Biodegradability of Biobased Polymeric Materials. Chapter 21 in: Natural Environments - Handbook of Composites from Renewable Materials. pp 625-653. John Wiley & Sons, Inc. ISBN: 978-1-119-22379

Ocean Conservancy (2017). International Coastal Cleanup Report. Available online at: https://oceanconservancy.org/blog/2017/06/05/results-international-coastal-cleanup/

Oehlmann J., et al. 2009A critical analysis of the biological impacts of plasticizers on wildlife. Phil. Trans. R. Soc. B 364, 2047–2062

Plastics Today 2021. Accessed 12/03/2021. https://www.plasticstoday.com/resin-pricing

Peixoto, D., Pinheiro, C., Amorim, J., Oliva-Teles, L., Guilhermino, L., Vieira, M. N. (2019). Microplastic pollution in commercial salt for human consumption: A review. Estuar. Coast. Shelf Sci. 219, 161–168.

Ryan P. G., Moore C. J., van Franeker J. A., Moloney C. L. (2009). Monitoring the abundance of plastic debris in the marine environment. Phil. Trans. R. Soc. B 364, 1999–2012

Rochman, C. M., Browne, M. A., Underwood, A. J., van Franeker, J. A., Thompson, R. C., Amaral-Zettler, L. A. (2016). The ecological impacts of marine debris: Unraveling the demonstrated evidence from what is perceived. Ecology 97, 302–312

Russo V., Stafford W. and Nahman A., (2020), *Comparing Grocery Carrier Bags in South Africa from an Environmental and Socio-Economic Perspective,* Waste Research Development and Innovation Roadmap Research Report; Department of Science and Innovation: Pretoria, South Africa

Saisana M, Filippas D. *Sustainable Society Indicator (SSI): Taking societies` pulse along social, environmental and economic issues*. The Joint Research Centre audit on the SSI. EUR 25578 EN. Luxembourg (Luxembourg): Publications Office of the European Union; 2012. JRC76108

Sanagi, M. M., Ling, S. L., Nasir, Z., Ibrahim, W. A. W., and Abu Naim, A. (2008). Determination of residual volatile organic compounds migrated from polystyrene food packaging into food simulant by headspace solid phase microextraction–gas chromatography. Malays. J. Anal. Sci. 12, 542–551.

Suwanmanee, U., Varabuntoonvit, V., Chaiwutthinan, P., Tajan, M., Mungcharoen, T. & Leejarkpai, T. 2013. Life cycle assessment of single use thermoform boxes made from polystyrene (PS), polylactic acid, (PLA), and PLA/starch: Cradle to consumer gate. International Journal of Life Cycle Assessment. 18(2):401–417.

Tawfik, M. S., and Huyghebaert, A. (1998). Polystyrene cups and containers: styrene migration. Food Addit. Contam. 15, 592–599.

Teuten E. L., et al. (2009). Transport and release of chemicals from plastics to the environment and to wildlife. Phil. Trans. R. Soc. B 364, 2027–2045

Thaysen Clara, Stevack Kathleen, Ruffolo Ralph, Poirier David, De Frond Hannah, DeVera Julieta, Sheng Grace, Rochman Chelsea M. (2018) Leachate From Expanded Polystyrene Cups Is Toxic to Aquatic Invertebrates (Ceriodaphnia dubia). Frontiers in Marine Science 5, 71

Thompson R. C., Moore C. J., vom Saal F. S., Swan S. H. (2009). Plastics, the environment and human health: current consensus and future trends. Phil. Trans. R. Soc. B 364, 2153–2166

UNEP (2014). United Nations Environment Programme, "Valuing plastics: the business case for measuring, managing and disclosing plastic use in the consumer goods industry" (United Nations, 2014).

UNEP (2011). Towards a Life Cycle Sustainability Assessment. Nairobi, Kenya: UNEP/SETAC Life Cycle Initiative

UNEP (2020). Single-use plastic take-away food packaging and its alternatives - Recommendations from Life Cycle Assessments.

(UNEP 2021). United Nations Environment Programme (2021). Single-use beverage cups and their alternatives - Recommendations from Life Cycle Assessments.

Wyles, K. J., Pahl, S., Thomas, K., Thompson, R. C. (2016). Factors that can undermine the psychological benefits of coastal environments: Exploring the effect of tidal state, presence, and type of litter. Environ. Behav. 48, 1095–1126

Woodall, L. C., Sanchez-Vidal, A., Canals, M., Paterson, G. L., Coppock, R., Sleight, V., et al. (2014).

The deep sea is a major sink for microplastic debris. R. Soc. Open Sci. 1:140317.

World Health Organization (2004). Guideline for Drinking-Water Quality[M], 3rd Edn. World Health Organization

Appendix A – Transport distances

Import from overseas in both ZA_manufactured (assembly level) and GLO_ZA_imported (LC level).
Road transport in ZA_produced, ZA_manufactured and GLO_ZA_imported (LC level)

Table 10: Modelling of transportation

Transportation stage	Assumptions
PET pellets from producers to meal-kit manufactures (CT, Durban or JHB)	1300, 650 and 84km for CT, Durban and JHB; average 680km from Safripol to either Berri Astrapack, Mpact Versapck and Zibo Containers
PS pellets from overseas	5600 nm* on average from Singapore, Taiwan, India, Europe and Brazil
PP from overseas	India and South Korea, 6200 nm on average (11500 km)
Bagasse container from overseas	China, Taiwan, India 6100 nm on average (11300 km)
PLA container from overseas	China 7000 nm on average (13000 km)
PLA resin from oversea	China and US 7000 nm on average (13000 km)
PSM (e.g MaterBi)	Europe and China 6800 nm on average (12600 km)
PBAT	Europe and China 6800 nm on average (12600 km)
PBS	Thailand and China 6550 nm on average (12200 km)
PHA's	US, Europe and China 7150 nm on average (13200 km)
Home/collection point to landfill/dump	For most serviced households the distance to landfill is 20 km, while self-help dump is within 2 km. Weighted average 6 km
From recycling plant (MRF) to manufacturer	50 km, 3-7 t truck
Solid bleached paper (already laminated) for cup from North Europe	15700 km * on average

*converted from nautical miles; 1 nm equates to 1.852 km; sea distances retrieved from SEA-DISTANCES.ORG - Distances

Appendix B - Affordability

The affordability of packaging containers is largely a function of material price and therefore the material price (FOB materials market price, $/tonne, Plastics today 2021) was used to estimate the cost of materials used in each meal kit (cup and take-out container) of polystyrene and the various alternatives.

Polystyrene EPS/XPS material in the cup or clamshell has a very low material price and the alternatives such as paper (as well as bagasse and bioplastics) are at least twice as costly. PLA, PBAT and PBS material cost about five times more than polystyrene, while PHA, PHBH is about forty times the cost of polystyrene. Polystyrene XPS/EPS cup and clamshell is clearly more affordable, and this is also partly attributable to low material weight of expanded polystyrene products (>95% air).

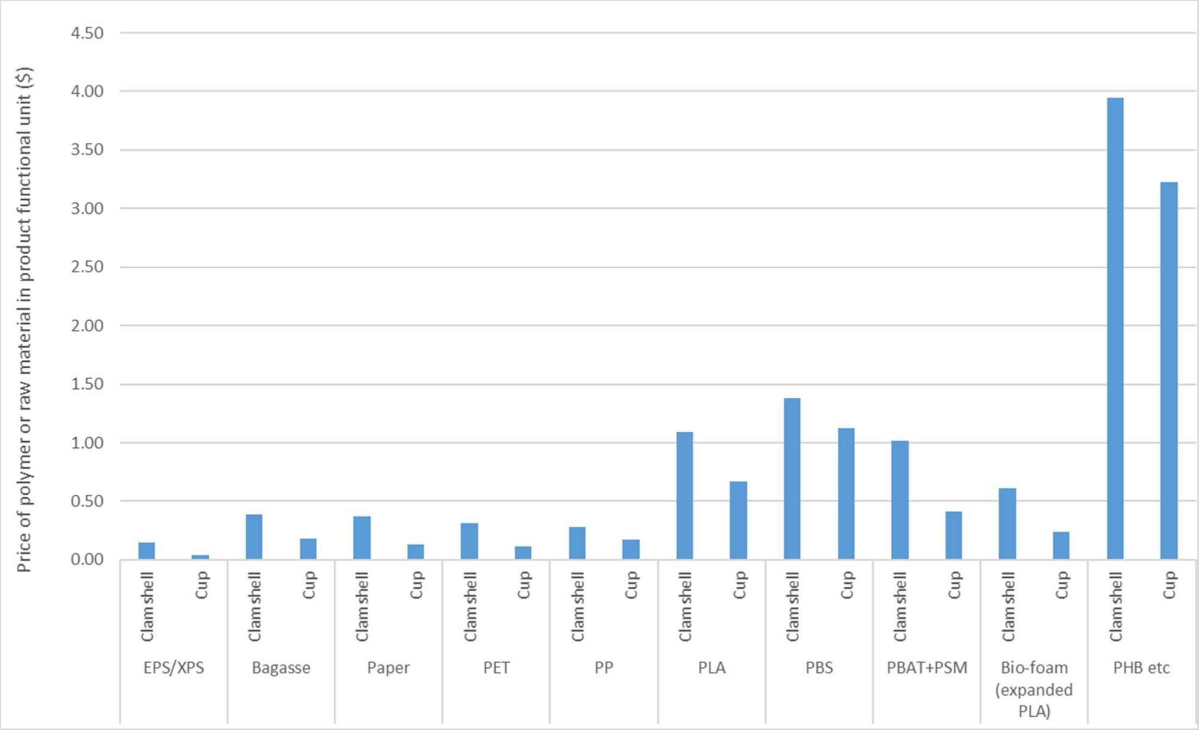

Figure 10: Affordability Results Comparison

Appendix C – Mid- and End-point LCIA Results

This section presents the ReciPe2016 LCIA results comparison regarding the Contribution Analysis, for all the mid- and end-point indicators of the RecCiPe2016 LCIA method as described in Table 4.

End-point Indicators LCIA Results

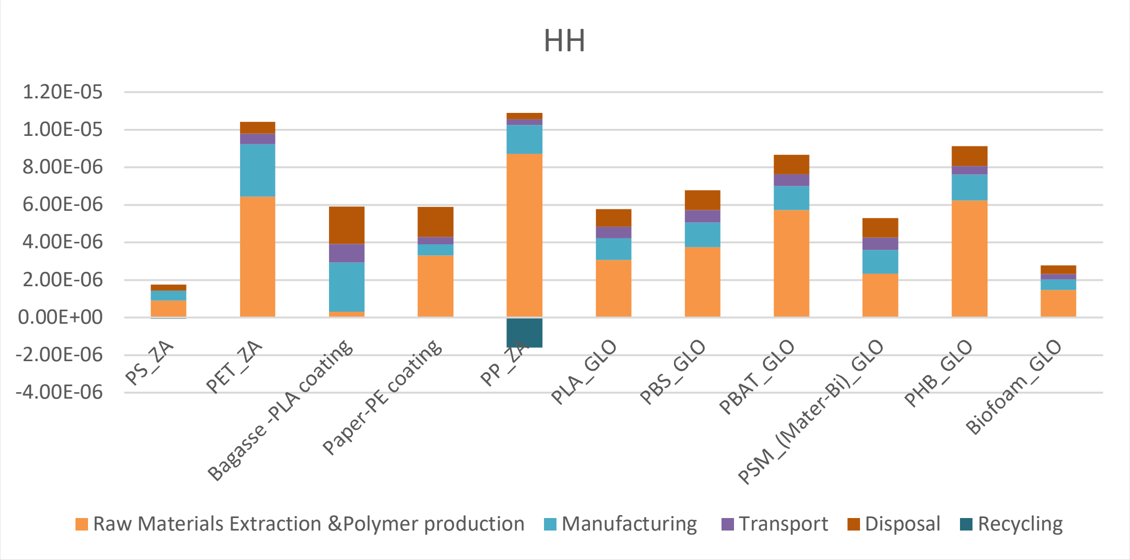

Figure 11: Human Health LCIA results comparison

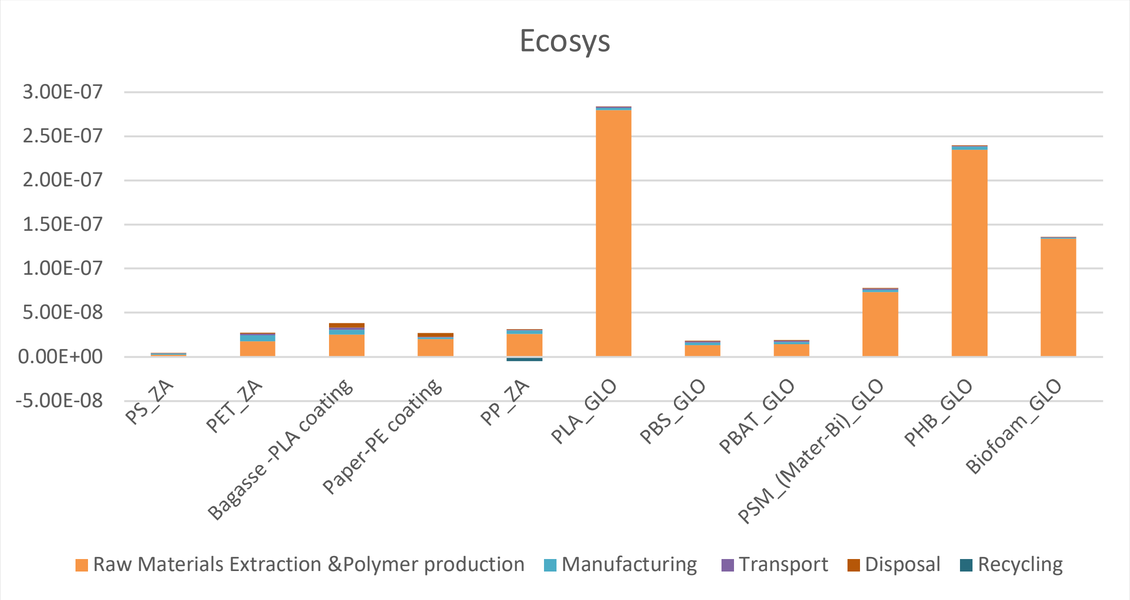

Figure 12: Ecosystems LCIA results comparison

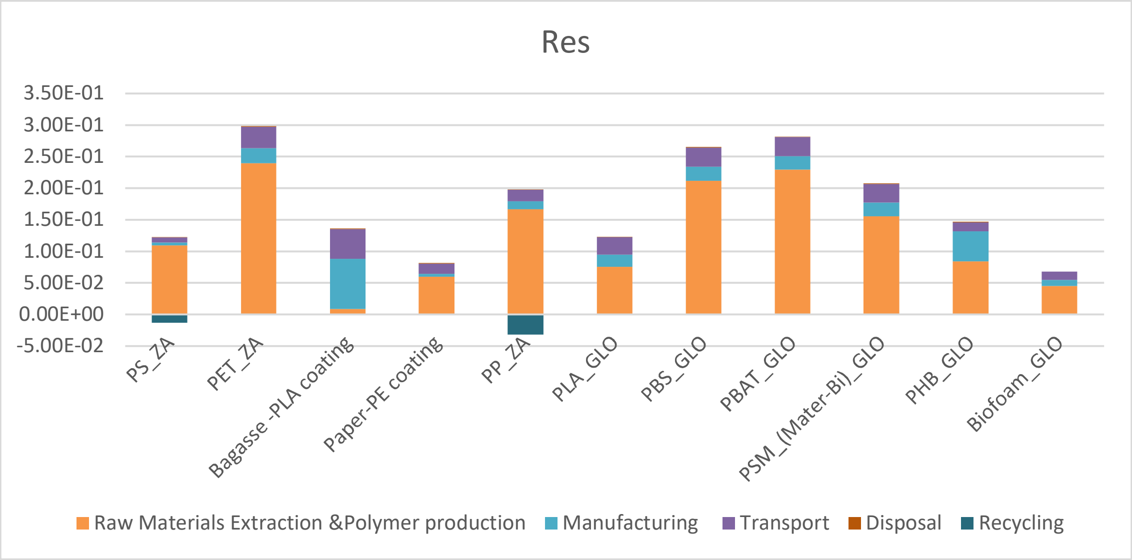

Figure 13: Resources LCIA results comparison

Mid-point Indicators LCIA Results

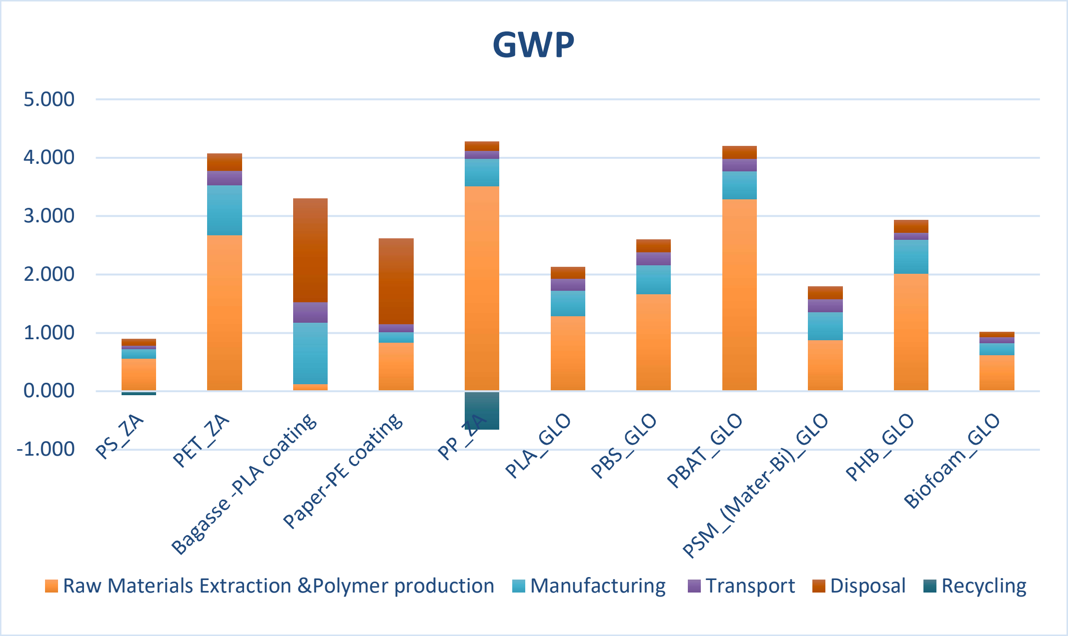

Figure 14: Global Warming Potential LCIA results comparison

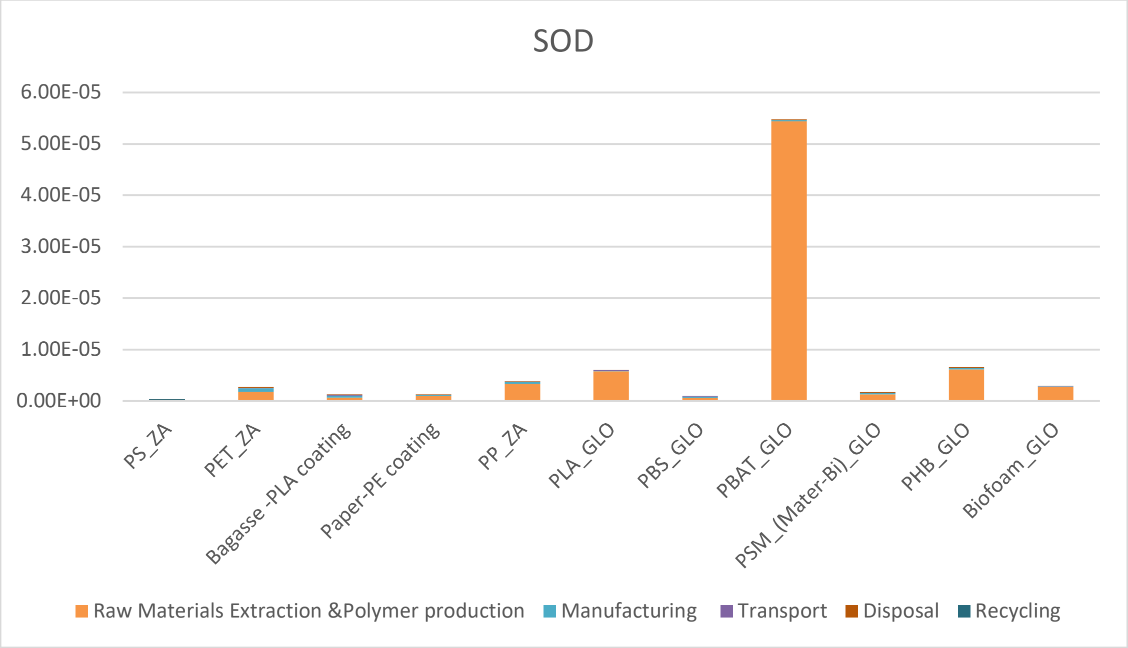

Figure 15: Stratospheric Ozone Depletion LCIA results comparison

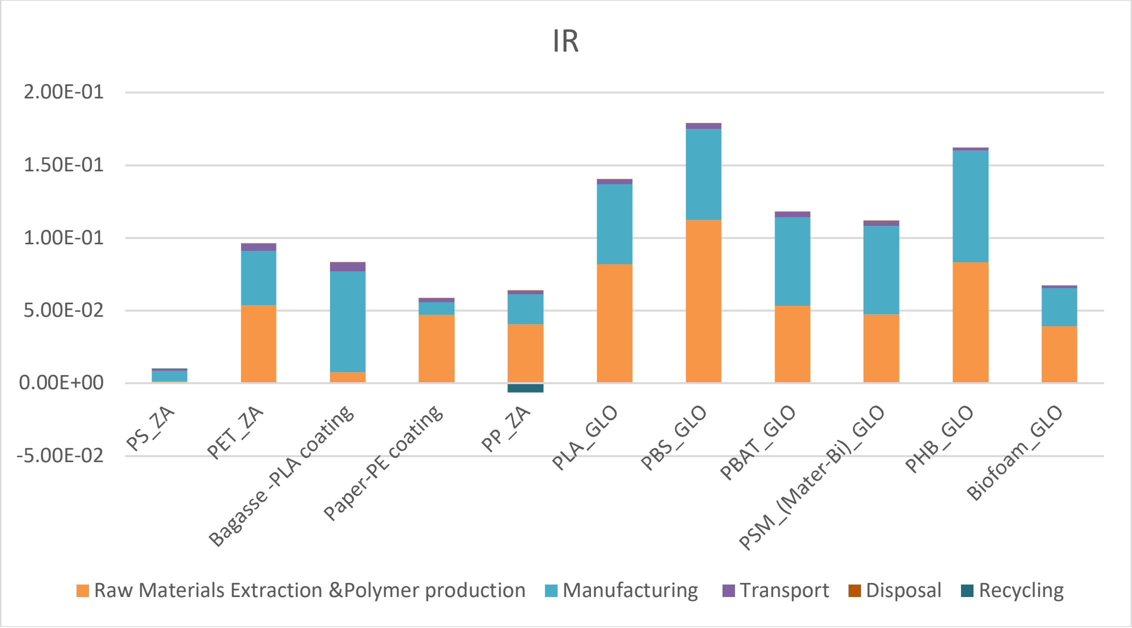

Figure 16: Ionizing Radiation LCIA results comparison

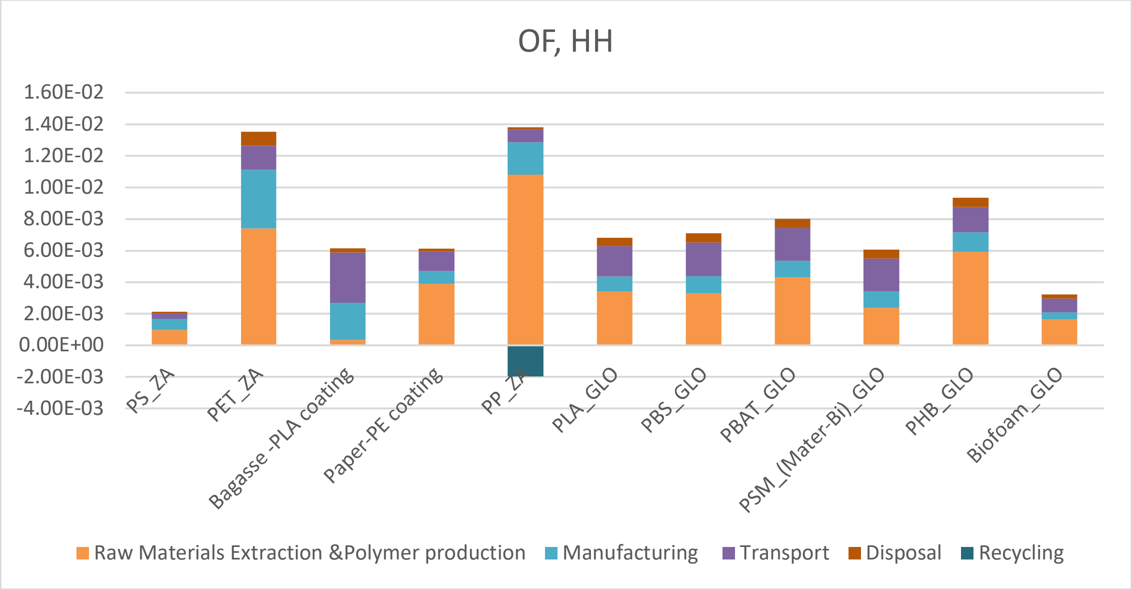

Figure 17: Ozone Formation, Human Health LCIA results comparison

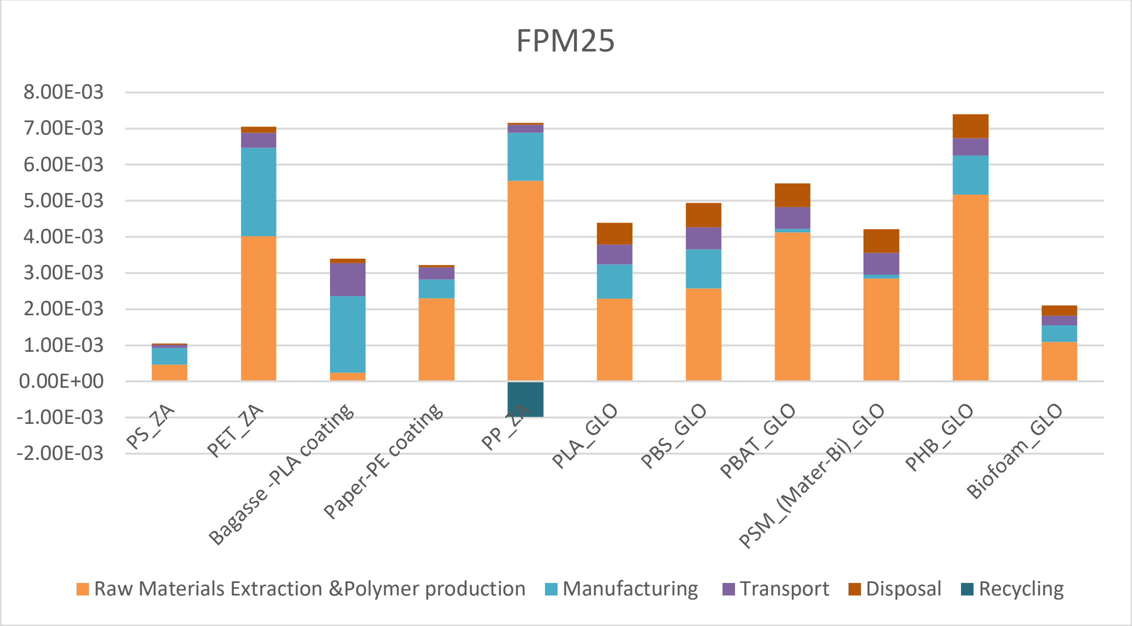

Figure 18: Fine Particulate Matter LCIA results comparison

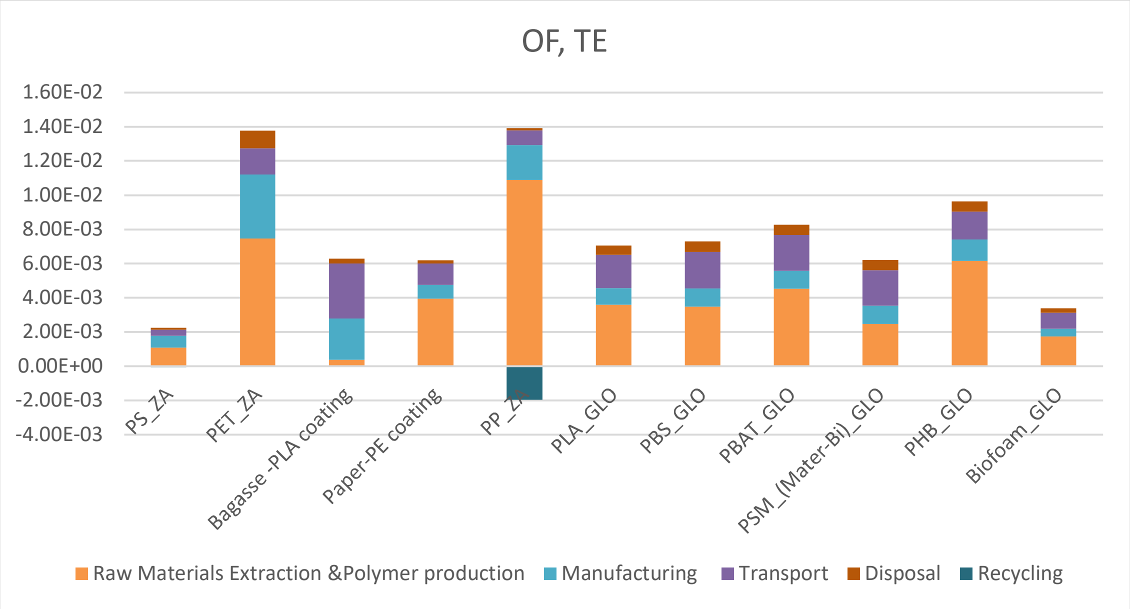

Figure 19: Ozone Formation, Terrestrial Ecosystem LCIA results comparison

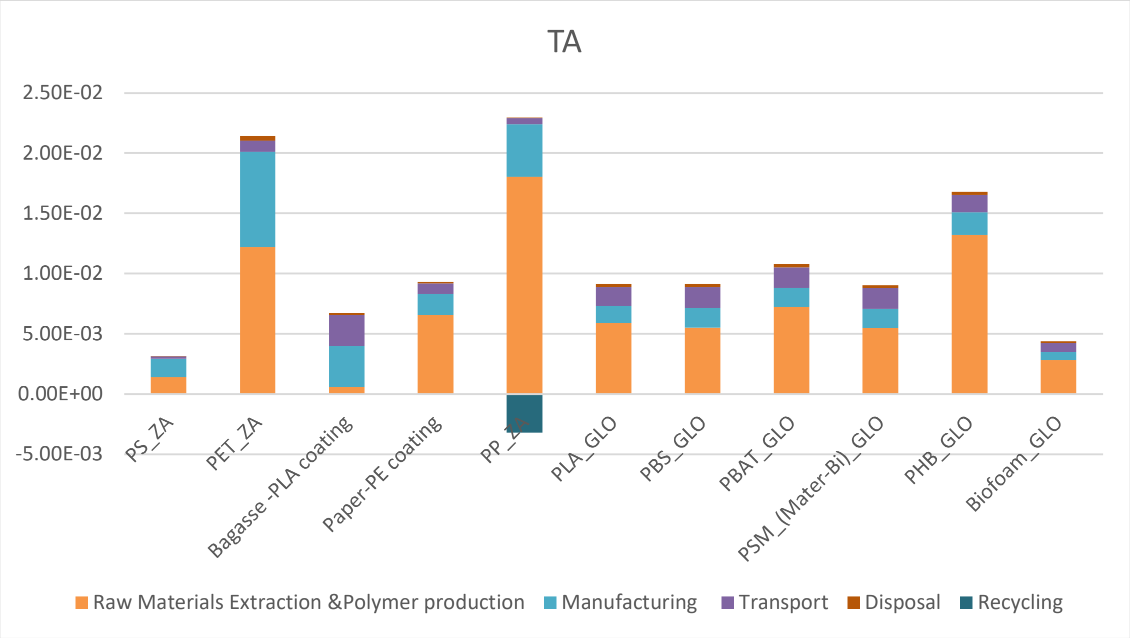

Figure 20: Terrestrial Acidification LCIA results comparison

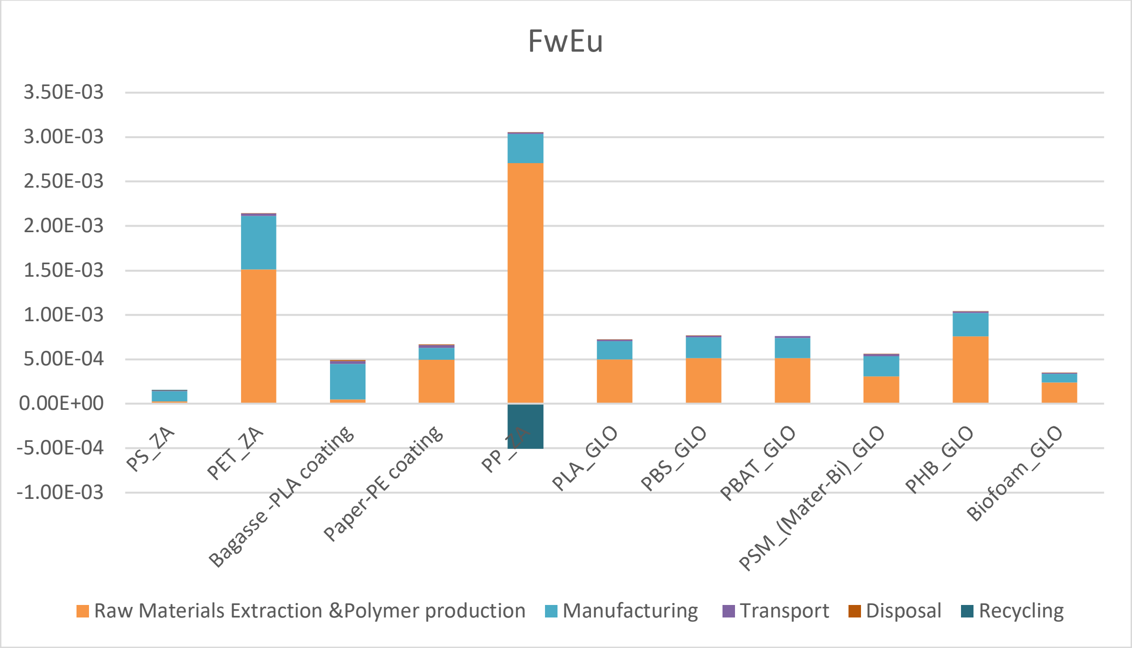

Figure 21: Freshwater Eutrophication LCIA results comparison

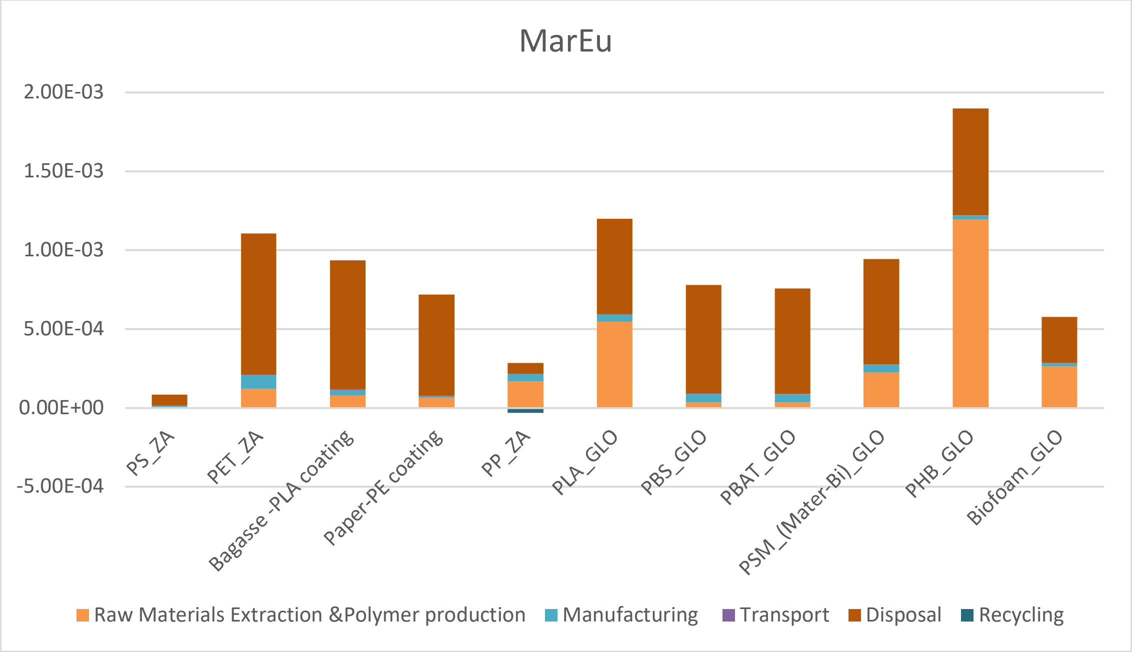

Figure 22: Marine Eutrophication LCIA results comparison

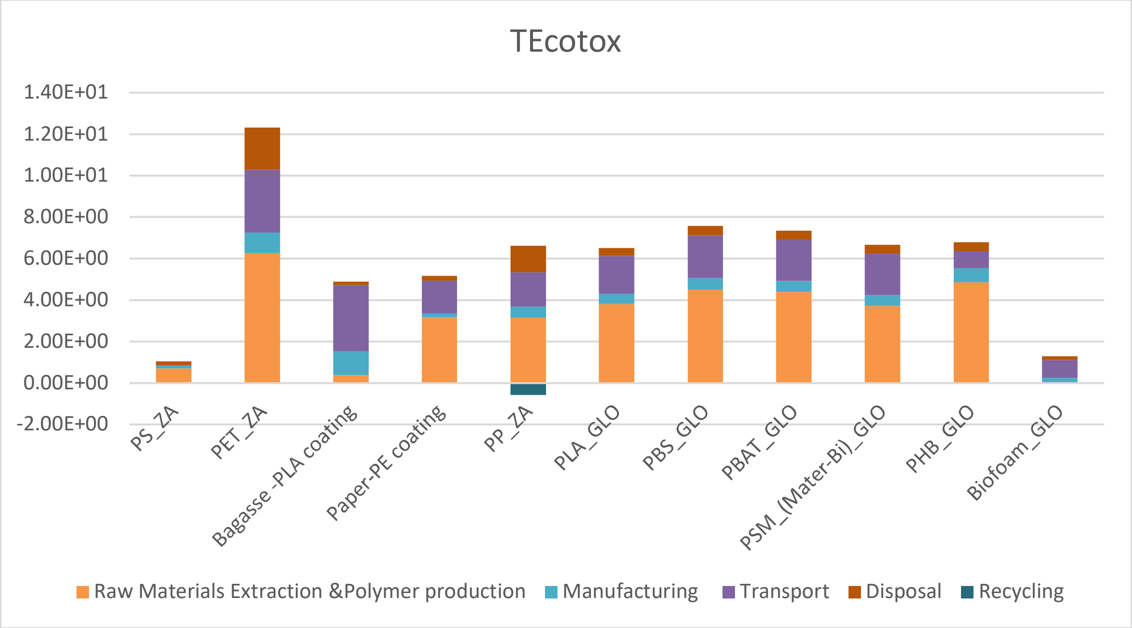

Figure 23: Terrestrial Ecotoxicity LCIA results comparison

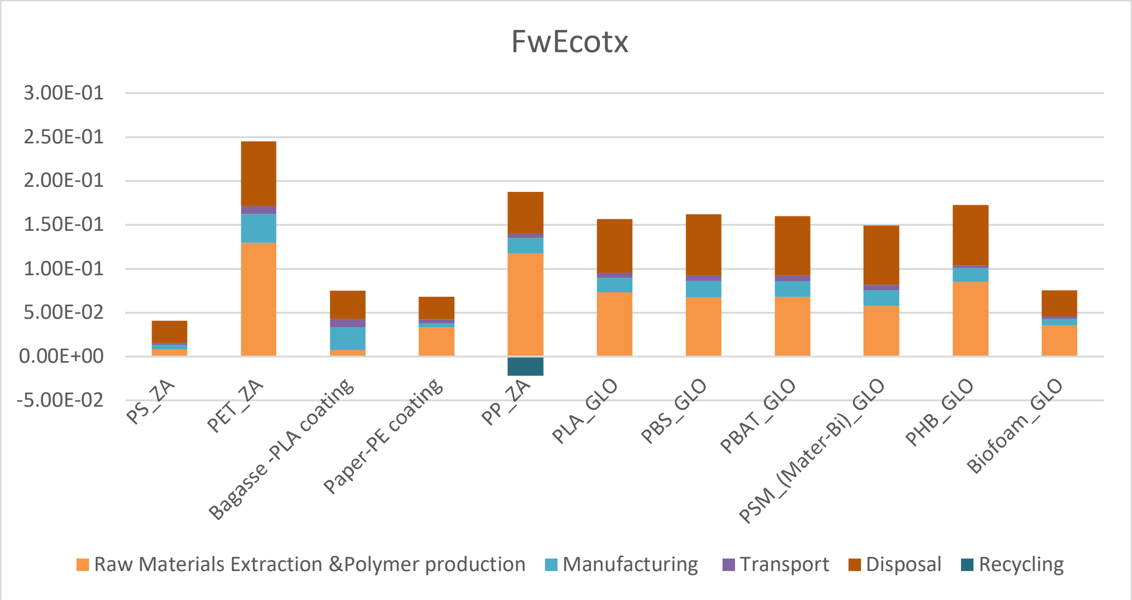

Figure 24: Freshwater Ecotoxicity LCIA results comparison

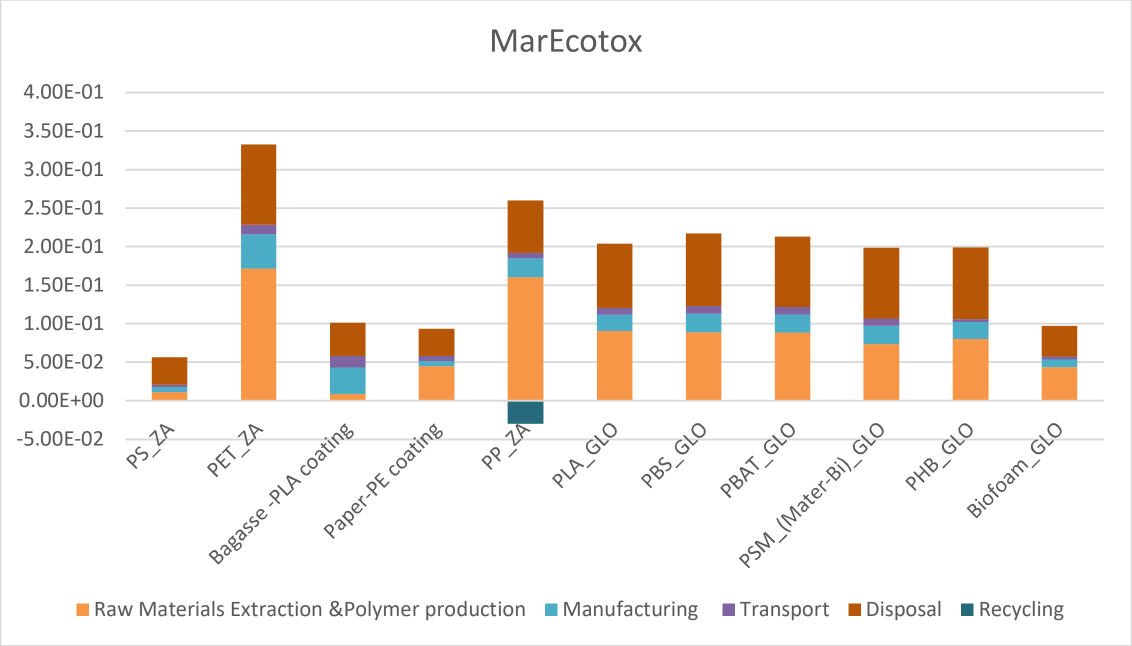

Figure 25:Marine Ecotoxicity LCIA results comparison

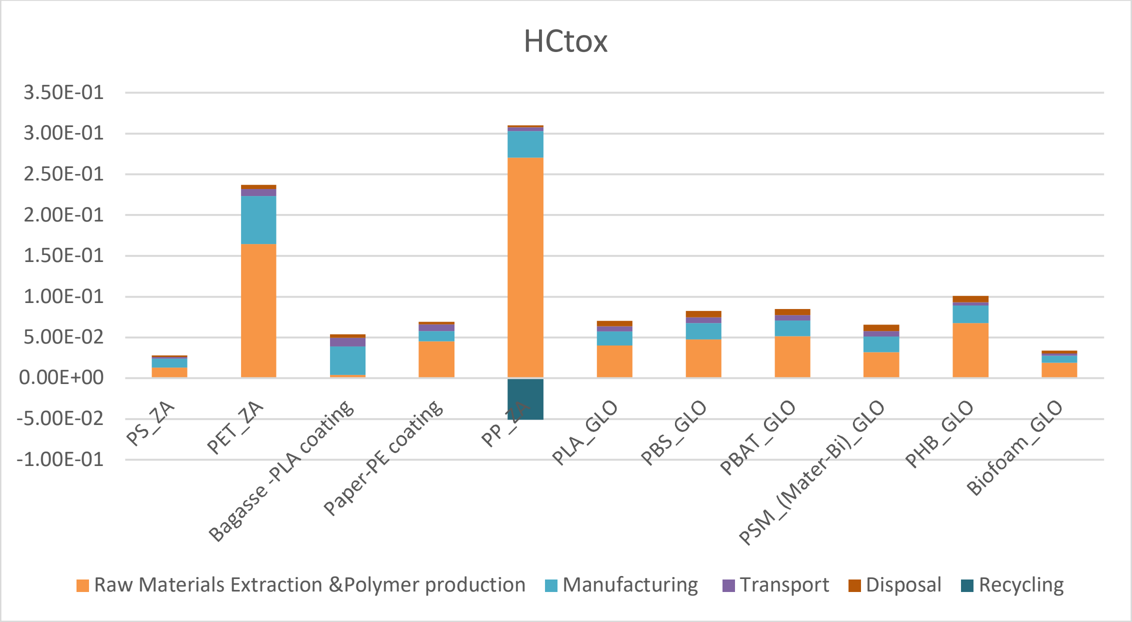

Figure 26: Human Carcinogenic Toxicity LCIA results comparison

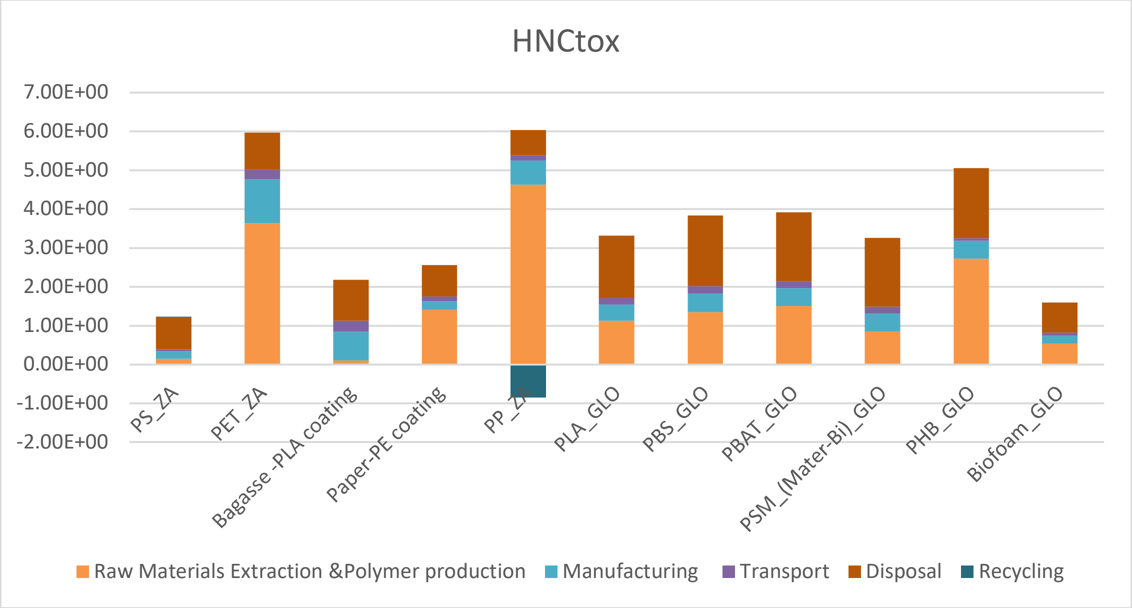

Figure 27: Human Non-Carcinogenic Toxicity LCIA results comparison

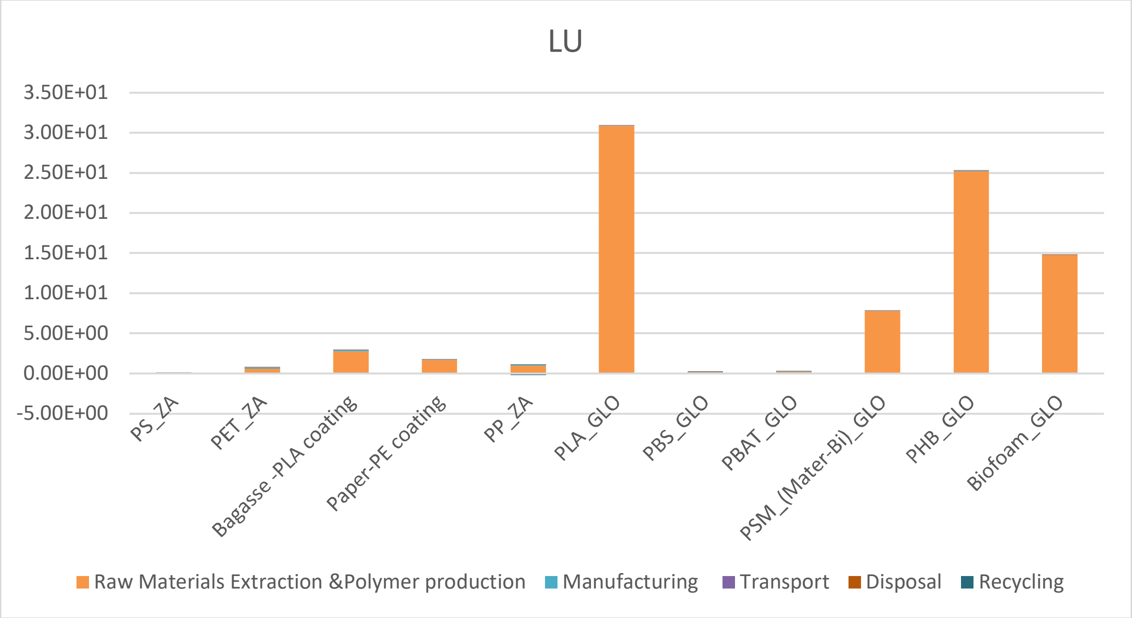

Figure 28: Land Use LCIA results comparison

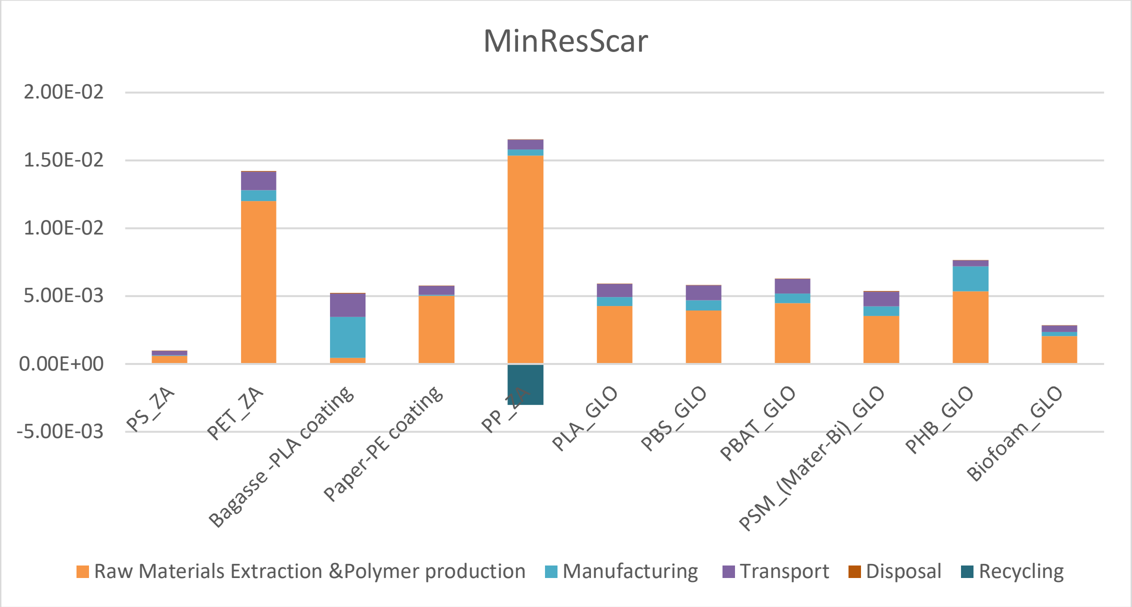

Figure 29: Mineral Resource Scarcity LCIA results comparison

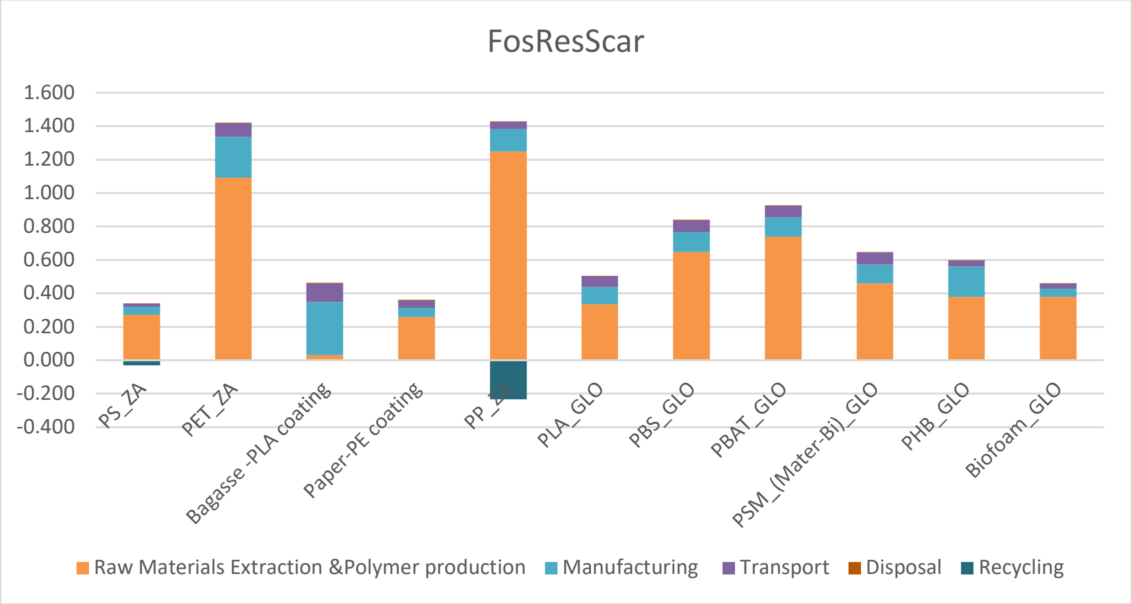

Figure 30: Fossil Resource Scarcity LCIA results comparison

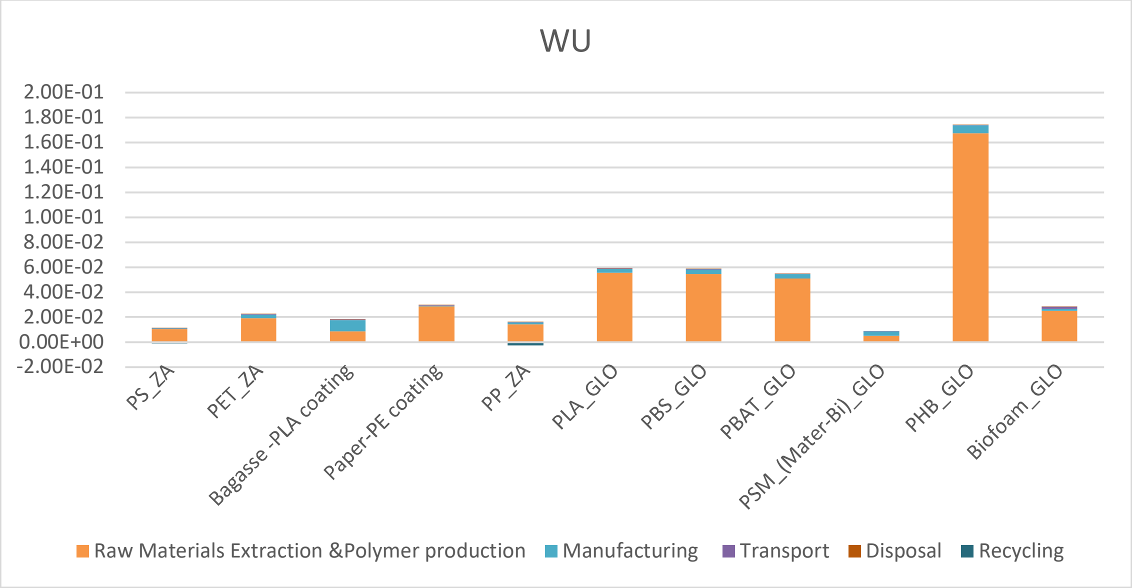

Figure 31: Water Use LCIA results comparison

Appendix D - Mid- and End-point LCA Results for the Scenario Analysis

This section presents the details of the Scenario Analysis at Mid- and End-point level obtained with the ReCiPe2016 LCIA method.

End-Point LCIA Results

Table 11: ReCiPe2016 End-point LCIA results comparing Local production VS Imports of finished goods

	Unit	**PS**	**PET**	**Bagasse**	**Paper**	**PP**	**PLA**	**PBS**	**PBAT**	**PSM (Mater-Bi®)**	**Biofoam (expanded PLA)**	**PHB**
ZA Production	DALY	**2.9e-06**	1.1e-05	6.9e-06	5.3e-06	9.3e-06	6.7e-06	8e-06	1.8e-05	7e-06	3.8e-06	1.1e-05
	%	+58.6%		+17.3%			32.9%	+17.7%	+106.5%	+32.5%	35.7%	+19.5%
	Species*yr	**7e-09**	2.7e-08	5.5e-08	2.7e-08	2.6e-08	5.1e-07	1.8e-08	4.8e-08	1.7e-07	2.4e-07	2.8e-07
	%	+70.1%		+42.3%			+78.5%	+29.3%	+148.2%	+122.6%	+77.9%	+17.1%
	USD 2013	0.12	0.33	0.12	0.08	0.17	0.13	0.25	0.35	0.12	**0.06**	0.13
	%	+12.8%		-13.1%			-9.1%	-4.5%	+24.8%	-3.9%	-9.2%	-14.3%
ZA Manufacturing Only	DALY	**1.8e-06**	7.6e-06	7.4e-06	5.3e-06	3.4e-06	6.7e-06	7.8e-06	9.7e-06	6.3e-06	3.2e-06	1.03e-05
	%		-26.7%	+24.6%	0.6%	-63.1%	+15.8%	+15.2%	+11.5%	+18.7%	+15.5%	+12.9%
	Species*yr	**4.1e-09**	1.8e-08	4.3e-08	2.6e-08	8.2e-09	2.9e-07	1.7e-08	2.2e-08	8.1e-08	1.4e-08	2.4e-07
	%		-34.1%	+13.3%	-4.4%	-68.8%	+1.1%	+23.6%	+16.1%	+4.1%	+1.5%	+1.7%
	USD 2013	0.11	0.38	0.13	0.10	0.12	0.14	0.26	0.28	0.21	**0.07**	0.15
	%		+15.4%	-4.4%	+26.8%	+17.5%	-2.1%	-0.8%	-1.1%	-0.9%	-1.6%	-1.4%
GLO Production	DALY	**1.7e-06**	6.4e-06	5.8e-06	4.8e-06	2.8e-06	5.8e-06	6.8e-06	8.7e-06	5.3e-06	2.8e-06	9.1e-06
	%	-7.2%	-38.5%		-9.3%	-70.3%						
	Species*yr	**3.6e-09**	1.4e-08	3.9e-08	2.5e-08	6.1e-09	2.8e-07	1.4e-08	1.9e-08	7.8e-08	1.4e-07	2.4e-07
	%	-13.8%	-48.4%		-9.9%	-76.7%						
	USD 2013	0.11	0.38	0.14	0.09	0.12	0.14	0.27	0.28	0.21	**0.07**	0.15
	%	+2.8%	+16.3%		+15.5%	+18.7%						

Table 12: ReCiPe2016 End-point LCIA results comparing impact of increasing recycling rates

		Meal-Kit Types																																
		PS			PET			Bagasse			Paper			PP			PLA			PBS			PBAT			PSM (Mater-Bi®)			Bio-foam (expanded PLA)			PHB		
BAU	***Indicator (Units*)***	***HH***	***ES***	***RES***	***HH***	***ES***	***RES***	***HH***	***ES***	***RES***	***HH***	***ES***	***RES***	***HH***	***ES***	***RES***	***HH***	***ES***	***RES***	***HH***	***ES***	***RES***	***HH***	***ES***	***RES***	***HH***	***ES***	***RES***	***HH***	***ES***	***RES***	***HH***	***ES***	***RES***
	Value	**1.8e-06**	**4.2e-09**	**0.11**	**1.1e-05**	**2.7e-08**	**0.33**	**5.9e-06**	**3.8e-08**	**0.14**	**5.3e-06**	**2.7e-08**	**0.08**	**9.3e-06**	**2.6e-08**	**0.17**	**5.8e-06**	**2.8e-07**	**0.14**	**6.9e-06**	**1.4e-08**	**0.27**	**8.7e-06**	**1.9e-08**	**0.28**	**5.3e-06**	**7.8e-08**	**0.21**	**2.8e-06**	**1.4e-07**	**0.07**	**9.1e-06**	**2.4e-07**	**0.15**
Mechanical Recycling	***Y1***	-4.4%	-3.4%	-8.3%	-4.4%	-4.8%	-6.4%				-1.3%	-1.8%	-0.4%	-17.7%	-18.6%	-18.7%																		
	Y2	-6.6%	-5.6%	-13.2%	-7.7%	-8.1%	-11.0%				-2.8%	-3.7%	-0.9%	-20.4%	-21.2%	-21.7%																		
	Y3	-9.4%	-7.8%	-18.3%	-11.0%	-11.4%	-15.6%				-4.4%	-5.5%	-1.4%	-23.2%	-24.2%	-24.7%																		
	Y4	-12.2%	-8.0%	-24.5%	-15.5%	-16.1%	-22.1%				-5.7%	-7.4%	-1.8%	-26.0%	-26.9%	-27.7%																		
	Y5	-16.0%	-13.1%	-31.7%	-19.3%	-20.1%	-27.6%				-7.2%	-8.8%	-2.3%	-29.6%	-30.7%	-31.3%																		
Organic Recycling (Industrial Composting)	***Y1***							-5.3%	-15.1%	-0.7%							-0.9%	-0.4%	-0.7%	-0.9%	-8.6%	0.0%	-0.6%	-6.2%	0.0%	-1.1%	-1.4%	0.0%	-1.1%	0.0%	-0.1%	-0.5%	-0.4%	0.0%
	Y2							-8.6%	-25.1%	-0.7%							-2.6%	-1.1%	-0.7%	-2.6%	-25.0%	0.0%	-2.0%	-17.6%	-0.4%	-3.2%	-4.2%	0.0%	-2.9%	-0.7%	-0.3%	-1.9%	-1.2%	-0.7%
	Y3							-17.1%	-49.9%	-1.5%							-7.1%	-2.8%	-0.7%	-6.9%	-66.4%	-0.4%	-5.2%	-47.2%	-0.4%	-8.7%	-11.5%	-0.5%	-7.2%	-2.9%	-0.7%	-5.0%	-3.8%	-0.7%
	Y4							-22.2%	-65.0%	-2.2%							-9.7%	-3.9%	-1.4%	-9.6%	-91.4%	-0.4%	-7.2%	-64.5%	-0.7%	-11.9%	-15.9%	-0.5%	-9.7%	-3.7%	-0.9%	-6.9%	-5.0%	-1.4%
	Y5							-27.5%	-79.9%	-2.2%							-12.5%	-4.9%	-1.4%	-12.1%	-116.4%	-0.8%	-9.1%	-82.0%	-11.0%	-14.9%	-20.1%	-1.0%	-12.6%	-5.1%	-1.2%	-8.8%	-6.7%	-1.4%

*** HH (Human Health): DALY, ES (Ecosystems): species*yr; RES (Resources): USD2013**

Table 13: ReCiPe2016 End-point LCIA results comparing the impact of different coating materials on overall LC and on coating production and meal-kit disposal

Meal-kit material type	**Coating type (3-5% by mass)**	**Human Health (DALY)**						**Ecosystems (species*yr)**						**Resources (USD 2013)**					
		Overall LC		Coating Production		Disposal		Overall LC		Coating Production		Disposal		Overall LC		Coating Production		Disposal	
		DALY	%	DALY	%	DALY	%	species*yr	%	species*yr	%	species*yr	%	UDS 2013	%	UDS 2013	%	UDS 2013	%
Bagasse	**PLA (BAU)**	5.9E-06		2.7E-07		1.98E-06		3.8E-08		2.5E-08		5.09E-09	-3.2%	1.4E-01		8.1E-03		1.24E-03	
	PE (3% by mass)	5.7E-06	-2.9%	1.1E-07	-59.2%	1.97E-06	-0.5%	1.4E-08	-64.0%	2.7E-10	-98.9%	5.18E-09	1.8%	1.4E-01	3.6%	1.4E-02	73.5%	1.24E-03	
	PBAT	6.1E-06	3.2%	4.6E-07	73.0%	1.98E-06		1.5E-08	-61.9%	1.2E-09	-95.3%	5.09E-09	0.0%	1.5E-01	7.3%	1.9E-02	130.5%	1.24E-03	
	PBS	5.9E-06	0.3%	2.9E-07	9.7%	1.98E-06		1.4E-08	-63.2%	7.1E-10	-97.1%	5.09E-09	0.0%	1.5E-01	5.8%	1.7E-02	105.7%	1.24E-03	
	PHB	6.1E-06	3.9%	5.0E-07	85.4%	1.98E-06		3.2E-08	-16.2%	1.9E-08	-24.9%	5.09E-09	0.0%	1.4E-01	-1.5%	6.7E-03	-17.2%	1.24E-03	
	PSM (Mater-Bi®)	5.8E-06	-1.2%	2.0E-07	-24.0%	1.98E-06		1.9E-08	-49.6%	6.0E-09	-76.1%	5.09E-09	0.0%	1.4E-01	2.9%	1.2E-02	49.9%	1.24E-03	
Paper	PLA	5.4E-06	1.5%	2.2E-07	236.9%	1.6E-06	-0.6%	4.7E-08	72.1%	2.0E-08	11491%	4.1E-09	-2.4%	7.2E-02	-7.4%	6.6E-03	-40.5%	9.9E-04	-0.4%
	PE (BAU - 3% by mass)	5.3E-06		6.5E-08		1.6E-06		2.7E-08		1.8E-10		4.2E-09		7.8E-02		1.1E-02		1.0E-03	
	PBAT	5.5E-06	4.5%	3.8E-07	483.1%	1.6E-06	-0.6%	2.7E-08	0.4%	9.6E-10	444%	4.1E-09	-2.4%	8.1E-02	3.6%	1.5E-02	36.9%	9.9E-04	-0.4%
	PBS	5.4E-06	2.1%	2.4E-07	270.8%	1.6E-06	-0.6%	2.7E-08	0.7%	5.8E-10	231%	4.1E-09	-2.4%	7.9E-02	1.5%	1.4E-02	22.5%	9.9E-04	-0.4%
	PHB	5.6E-06	5.1%	4.1E-07	524.6%	1.6E-06	-0.6%	4.2E-08	53.3%	1.5E-08	8593%	4.1E-09	-2.4%	7.1E-02	-8.8%	5.5E-03	-50.6%	9.9E-04	-0.4%
	PSM (Mater-Bi®)	5.3E-06	0.6%	1.7E-07	155.4%	1.6E-06	-0.6%	3.1E-08	14.7%	4.9E-09	2667%	4.1E-09	-2.4%	7.6E-02	-3.2%	9.9E-03	-10.9%	9.9E-04	-0.4%

Mid-Point LCIA Results

Table 14 presents the ReciPe2016 LCIA Mid-point results when comparing locally produced meal-kit (including of raw material production), with manufacturing of products in South Africa from imports of raw materials, with imports of finished goods. BAU Scenario Results for each meal-kit material option are in **BOLD RED font**. **BAU scenarios** are those whom the percentages compare with.

Table 14: ReCiPe2016 Mid-Point Results Comparison for Local production Vs Manufacturing VS Imports of finished goods

ZA Production																																								
	GWP		**SPD**		**IR**		**OF, HH**		**FPM25**		**OF, TE,**		**TA**		**FwEu**		**MarEu**		**TEcotox**		**FwEcotoc**		**MarEcotox**		**HCTox**		**HNCTox**		**LU**		**MRS**		**FRS**		**WU**	
	Kg CO$_2$ eq	%	Kg CFC11 eq	%	Kg Co60 eq	%	Kg NOx eq	%	Kg PM2.5 eq	%	Kg NOx eq	%	Kg SO$_2$ eq	%	Kg P eq	%	Kg N eq	%	Kg 1,4DCB eq	%	Kg 1,4DCB eq	%	Kg 1,4DCB eq	%	Kg 1,4DCB eq	%	Kg 1,4DCB eq	%	m2a crop eq	%	Kg Cu eq	%	Kg oil eq	%	m^3	%
PS	1.16	40.3%	4.9E-07	109.4%	2.5E-02	141.7%	4.2E-03	101.0%	2.0E-03	92.2%	4.7E-03	115.1%	6.2E-03	98.1%	3.9E-04	147.5%	1.1E-04	36.1%	2.07	25.5%	5.3E-02	29.5%	7.1E-02	25.2%	5.0E-02	-31.5%	1.65	34.1%	0.147	134.4%	1.3E-03	28.7%	4.2E-01	34.5%	1.1E-02	11.1%
PET	**4.07**		**2.7E-06**		**9.7E-02**		**1.4E-02**		**7.1E-03**		**1.4E-02**		**2.1E-02**		**2.1E-03**		**1.1E-03**		**12.3**		**2.5E-01**		**3.3E-01**		**2.4E-01**		**5.97**		**0.84**		**1.4E-02**		**1.4E+00**		**2.3E-02**	
Bagasse	3.57	8.2%	1.7E-06	29.9%	6.5E-02	-22.2%	7.7E-03	24.6%	4.2E-03	22.9%	7.8E-03	23.7%	1.3E-02	95.8%	9.5E-04	92.9%	8.6E-04	-8.4%	5.01	2.7%	8.3E-02	10.8%	1.1E-01	12.9%	1.0E-01	88.4%	2.8	28.4%	4.49	52.2%	5.1E-03	-3.4%	5.7E-01	23.3%	3.1E-03	-82.9%
Paper	**2.61**		**1.3E-06**		**6.0E-02**		**6.0E-03**		**3.2E-03**		**6.0E-03**		**9.4E-03**		**6.8E-04**		**7.2E-04**		**4.59**		**6.8E-02**		**9.3E-02**		**6.7E-02**		**2.57**		**1.81**		**5.8E-03**		**3.6E-01**		**3.0E-02**	
PP	**3.63**		**3.2E-06**		**5.8E-02**		**1.2E-02**		**6.2E-03**		**1.2E-02**		**2.0E-02**		**2.6E-03**		**2.5E-04**		**6.03**		**1.7E-01**		**2.3E-01**		**2.6E-01**		**5.17**		**0.943**		**1.4E-02**		**1.2E+00**		**1.3E-02**	
PLA	2.56	20.2%	8.5E-06	39.8%	8.3E-02	-41.1%	1.0E-02	46.4%	6.0E-03	36.8%	1.0E-02	44.7%	1.8E-02	100.4%	1.3E-03	77.9%	1.1E-03	-8.3%	6.9	6.0%	1.8E-01	15.3%	2.4E-01	15.7%	1.3E-01	87.5%	4.56	37.3%	55.4	79.3%	8.7E-03	45.6%	6.7E-01	31.6%	2.1E-02	-62.1%
PBS	2.91	11.5%	1.4E-06	42.0%	1.1E-01	-37.4%	8.8E-03	23.9%	6.1E-03	23.7%	9.0E-03	23.2%	1.5E-02	61.9%	1.1E-03	38.2%	8.1E-04	3.1%	7.63	0.9%	1.7E-01	-71.9%	2.3E-01	7.4%	1.2E-01	45.6%	4.45	15.9%	0.423	56.7%	5.6E-03	-4.8%	9.4E-01	12.2%	5.6E-02	-5.9%
PBAT	7.73	84.0%	5.9E-05	6.8%	1.2E-01	-1.7%	2.0E-02	143.8%	1.2E-02	109.5%	2.0E-02	139.1%	3.3E-02	202.8%	3.8E-03	404.6%	9.5E-04	25.5%	10	36.1%	2.8E-01	76.9%	3.8E-01	79.0%	3.9E-01	361.2%	9.1	132.7%	1.45	370.8%	2.2E-02	249.7%	2.1E+00	123.1%	6.3E-02	15.1%
PSM (Mater-Bi®)	2.21	23.5%	3.4E-06	103.0%	6.5E-02	-42.3%	9.2E-03	51.4%	5.7E-03	36.0%	9.3E-03	50.2%	1.6E-02	77.2%	9.8E-04	74.6%	8.5E-04	-9.6%	6.51	-2.4%	1.7E-01	10.7%	2.2E-01	11.1%	1.1E-01	66.7%	4.28	31.7%	17.4	121.4%	6.1E-03	13.4%	7.7E-01	19.2%	1.0E-02	17.4%
Bio-foam (expanded PLA)	1.23	20.6%	4.1E-06	39.7%	4.0E-02	-41.2%	4.8E-03	46.2%	2.9E-03	37.0%	4.9E-03	45.0%	8.8E-03	100.5%	6.2E-04	77.6%	5.3E-04	-8.5%	3.31	6.1%	8.7E-02	15.2%	1.1E-01	15.7%	6.3E-02	88.1%	2.18	37.1%	26.5	79.1%	4.2E-03	45.6%	3.2E-01	31.3%	1.0E-02	-62.1%
PHB	3.42	16.7%	6.9E-06	6.3%	8.7E-02	-46.0%	1.2E-02	31.6%	8.9E-03	20.7%	1.3E-02	29.7%	2.6E-02	53.6%	1.6E-03	56.7%	1.8E-03	-4.7%	6.65	-2.1%	2.0E-01	13.3%	2.3E-01	12.5%	1.6E-01	61.4%	6.15	21.8%	29.4	16.2%	7.6E-03	-1.6%	7.6E-01	26.1%	1.9E-01	10.3%
ZA Manufacturing Only																																								
	GWP		**SPD**		**IR**		**OF, HH**		**FPM25**		**OF, TE,**		**TA**		**FwEu**		**MarEu**		**TEcotox**		**FwEcotoc**		**MarEcotox**		**HCTox**		**HNCTox**		**LU**		**MRS**		**FRS**		**WU**	
	Kg CO$_2$ eq	%	Kg CFC11 eq	%	Kg Co60 eq	%	Kg NOx eq	%	Kg PM2.5 eq	%	Kg NOx eq	%	Kg SO$_2$ eq	%	Kg P eq	%	Kg N eq	%	Kg 1,4DCB eq	%	Kg 1,4DCB eq	%	Kg 1,4DCB eq	%	Kg 1,4DCB eq	%	Kg 1,4DCB eq	%	m2a crop eq	%	Kg Cu eq	%	Kg oil eq	%	m^3	%
PS	**0.827**		**2.3E-07**		**1.0E-02**		**2.1E-03**		**1.0E-03**		**2.2E-03**		**3.1E-03**		**1.6E-04**		**8.0E-05**		**1.65**		**4.1E-02**		**5.6E-02**		**7.3E-02**		**1.23**		**0.0627**		**9.9E-04**		**3.1E-01**		**1.0E-02**	
PET	3.04	-25.3%	1.3E-06	-52.1%	1.0E-01	7.8%	1.1E-02	-22.1%	5.4E-03	-23.7%	1.1E-02	-21.0%	1.5E-02	-30.4%	1.0E-03	-53.4%	1.0E-03	-6.3%	12.1	-1.6%	2.1E-01	-14.7%	2.8E-01	-15.1%	1.3E-01	-46.4%	4.18	-30.0%	0.417	-50.4%	8.9E-03	-37.2%	1.2E+00	-17.6%	2.2E-02	-2.2%
Bagasse	3.66	10.9%	1.8E-06	44.9%	6.9E-02	-17.4%	9.2E-03	49.4%	4.7E-03	38.5%	9.3E-03	48.4%	1.5E-02	118.1%	9.3E-04	89.6%	9.4E-04	0.7%	5.33	9.2%	8.5E-02	13.1%	1.2E-01	13.9%	1.0E-01	86.6%	2.81	28.9%	3.15	6.8%	5.2E-03	-0.8%	5.9E-01	27.0%	1.7E-02	-5.5%
Paper	2.64	1.1%	1.1E-06	-13.4%	5.4E-02	-9.2%	6.6E-03	11.3%	3.3E-03	3.7%	6.7E-03	11.5%	7.8E-03	-16.8%	4.9E-04	-27.5%	7.1E-04	-1.3%	5.43	18.3%	6.4E-02	-5.4%	8.3E-02	-10.7%	5.0E-02	-25.5%	2.32	-9.7%	1.72	-5.0%	6.3E-03	9.3%	3.5E-01	-2.0%	3.1E-02	0.3%
PP	1.38	-62.0%	6.2E-07	-80.4%	3.7E-02	-36.2%	4.9E-03	-58.9%	2.5E-03	-59.6%	5.0E-03	-58.3%	7.4E-03	-62.8%	4.7E-04	-81.5%	1.3E-04	-49.8%	4.27	-29.2%	8.8E-02	-47.3%	1.2E-01	-47.2%	5.7E-02	-78.1%	1.75	-66.2%	0.185	-80.4%	2.6E-03	-80.7%	6.0E-01	-49.3%	6.9E-03	-48.3%
PLA	2.33	9.4%	6.4E-06	5.1%	1.1E-01	-19.3%	8.6E-03	26.6%	5.3E-03	19.5%	8.9E-03	25.5%	1.4E-02	49.0%	9.6E-04	32.6%	1.2E-03	1.7%	6.75	3.7%	1.7E-01	5.1%	2.2E-01	5.4%	9.7E-02	37.2%	3.73	12.3%	31	0.3%	5.9E-03	-0.7%	5.8E-01	15.2%	5.5E-02	-2.0%
PBS	2.83	8.4%	1.4E-06	35.0%	1.5E-01	-17.3%	9.2E-03	28.9%	5.9E-03	19.8%	9.4E-03	28.1%	1.4E-02	55.4%	1.0E-03	30.7%	8.0E-04	2.7%	7.84	3.7%	1.7E-01	-72.3%	2.3E-01	6.0%	1.1E-01	35.9%	4.31	12.2%	0.392	45.2%	5.8E-03	-0.7%	9.3E-01	10.3%	5.7E-02	-3.9%
PBAT	4.42	5.2%	5.5E-05	0.5%	8.8E-02	-25.3%	1.0E-02	24.8%	6.4E-03	17.3%	1.0E-02	24.4%	1.6E-02	44.4%	1.0E-03	34.0%	7.8E-04	2.8%	7.61	3.5%	1.7E-01	5.6%	2.3E-01	5.6%	1.1E-01	34.1%	4.37	11.8%	0.426	38.3%	6.3E-03	-0.8%	1.0E+00	8.8%	5.4E-02	-2.2%
PSM (Mater-Bi®)	2.01	12.3%	2.0E-06	20.1%	8.2E-02	-26.6%	8.1E-03	32.8%	5.2E-03	22.3%	8.2E-03	31.8%	1.4E-02	53.9%	8.2E-04	46.4%	9.7E-04	2.1%	6.94	4.0%	1.6E-01	6.0%	2.1E-01	6.6%	9.4E-02	44.0%	3.7	13.8%	7.98	1.5%	5.3E-03	-0.7%	7.3E-01	13.0%	7.6E-03	-14.1%
Bio-foam (expanded PLA)	1.12	9.8%	3.1E-06	4.8%	5.4E-02	-19.3%	4.1E-03	26.3%	2.5E-03	19.4%	4.2E-03	25.4%	6.5E-03	48.4%	4.6E-04	32.5%	5.9E-04	1.6%	3.24	3.8%	7.9E-02	5.2%	1.0E-01	5.4%	4.6E-02	37.4%	1.79	12.6%	14.9	0.7%	2.8E-03	-0.7%	2.8E-01	14.8%	2.6E-02	-1.9%
PHB	3.19	8.9%	6.9E-06	5.8%	1.2E-01	-25.9%	1.2E-02	23.0%	8.5E-03	15.0%	1.2E-02	22.4%	2.2E-02	31.0%	1.3E-03	25.0%	1.9E-03	1.1%	7.12	4.9%	1.8E-01	5.2%	2.1E-01	6.0%	1.3E-01	29.7%	5.52	9.3%	25.4	0.4%	7.7E-03	0.1%	6.9E-01	15.5%	1.7E-01	-0.6%
Global Production (and Import of finished goods)																																								
	GWP		**SPD**		**IR**		**OF, HH**		**FPM25**		**OF, TE,**		**TA**		**FwEu**		**MarEu**		**TEcotox**		**FwEcotoc**		**MarEcotox**		**HCTox**		**HNCTox**		**LU**		**MRS**		**FRS**		**WU**	
	Kg CO$_2$ eq	%	Kg CFC11 eq	%	Kg Co60 eq	%	Kg NOx eq	%	Kg PM2.5 eq	%	Kg NOx eq	%	Kg SO$_2$ eq	%	Kg P eq	%	Kg N eq	%	Kg 1,4DCB eq	%	Kg 1,4DCB eq	%	Kg 1,4DCB eq	%	Kg 1,4DCB eq	%	Kg 1,4DCB eq	%	m2a crop eq	%	Kg Cu eq	%	Kg oil eq	%	m^3	%
PS	0.8	-3.3%	1.6E-07	-31.2%	1.3E-02	21.4%	1.9E-03	-6.7%	9.3E-04	-9.3%	2.1E-03	-6.0%	2.3E-03	-26.4%	9.5E-05	-39.7%	7.7E-05	-4.0%	1.62	-1.8%	3.9E-02	-4.4%	5.4E-02	-4.6%	2.1E-02	-71.4%	1.13	-8.1%	0.0352	-43.9%	1.0E-03	4.4%	3.0E-01	-4.5%	1.0E-02	2.1%
PET	2.77	-31.9%	8.6E-07	-67.7%	1.4E-01	46.1%	8.2E-03	-39.8%	4.2E-03	-40.1%	8.6E-03	-37.4%	8.9E-03	-58.5%	6.8E-04	-68.3%	1.0E-03	-8.1%	11.8	-4.1%	2.0E-01	-19.2%	2.7E-01	-19.6%	9.1E-02	-61.5%	3.62	-39.4%	0.271	-67.7%	9.0E-03	-36.8%	1.1E+00	-24.6%	2.4E-02	4.9%

Bagasse	**3.3**		**1.3E-06**		**8.3E-02**		**6.2E-03**		**3.4E-03**		**6.3E-03**		**6.7E-03**		**4.9E-04**		**9.3E-04**		**4.88**		**7.5E-02**		**1.0E-01**		**5.4E-02**		**2.18**		**2.95**		**5.2E-03**		**4.6E-01**		**1.8E-02**	
Paper	2.5	-4.2%	9.7E-07	-24.0%	6.0E-02	0.5%	5.2E-03	-13.1%	2.8E-03	-12.1%	5.2E-03	-13.0%	5.7E-03	-39.1%	4.1E-04	-39.9%	7.1E-04	-1.9%	4.47	-2.6%	6.1E-02	-10.1%	8.3E-02	-10.7%	3.9E-02	-40.9%	2.15	-16.3%	1.67	-7.7%	6.1E-03	4.7%	3.0E-01	-15.4%	3.1E-02	0.7%
PP	1.23	-66.1%	3.9E-07	-87.6%	5.7E-02	-1.2%	3.5E-03	-70.3%	1.9E-03	-70.0%	3.6E-03	-69.6%	4.1E-03	-79.4%	3.0E-04	-88.4%	1.1E-04	-55.3%	4.09	-32.2%	8.2E-02	-50.9%	1.1E-01	-50.7%	3.7E-02	-85.6%	1.44	-72.1%	0.105	-88.9%	2.7E-03	-80.5%	5.5E-01	-54.1%	7.8E-03	-41.9%
PLA	**2.13**		**6.1E-06**		**1.4E-01**		**6.8E-03**		**4.4E-03**		**7.1E-03**		**9.1E-03**		**7.3E-04**		**1.2E-03**		**6.51**		**1.6E-01**		**2.0E-01**		**7.0E-02**		**3.32**		**30.9**		**5.9E-03**		**5.1E-01**		**5.6E-02**	
PBS	**2.61**		**1.0E-06**		**1.8E-01**		**7.1E-03**		**4.9E-03**		**7.3E-03**		**9.1E-03**		**8.0E-04**		**7.8E-04**		**7.56**		**6.2E-01**		**2.2E-01**		**8.2E-02**		**3.84**		**0.27**		**5.8E-03**		**8.4E-01**		**6.0E-02**	
PBAT	**4.2**		**5.5E-05**		**1.2E-01**		**8.0E-03**		**5.5E-03**		**8.3E-03**		**1.1E-02**		**7.6E-04**		**7.6E-04**		**7.35**		**1.6E-01**		**2.1E-01**		**8.5E-02**		**3.91**		**0.308**		**6.3E-03**		**9.3E-01**		**5.5E-02**	
PSM (Mater-Bi®)	**1.79**		**1.7E-06**		**1.1E-01**		**6.1E-03**		**4.2E-03**		**6.2E-03**		**9.0E-03**		**5.6E-04**		**9.5E-04**		**6.67**		**1.5E-01**		**2.0E-01**		**6.5E-02**		**3.25**		**7.86**		**5.4E-03**		**6.5E-01**		**8.9E-03**	
Bio-foam (expanded PLA)	**1.02**		**2.9E-06**		**6.7E-02**		**3.3E-03**		**2.1E-03**		**3.4E-03**		**4.4E-03**		**3.5E-04**		**5.8E-04**		**3.12**		**7.5E-02**		**9.8E-02**		**3.4E-02**		**1.59**		**14.8**		**2.9E-03**		**2.4E-01**		**2.7E-02**	
PHB	**2.93**		**6.5E-06**		**1.6E-01**		**9.4E-03**		**7.4E-03**		**9.6E-03**		**1.7E-02**		**1.0E-03**		**1.9E-03**		**6.79**		**1.7E-01**		**2.0E-01**		**1.0E-01**		**5.05**		**25.3**		**7.7E-03**		**6.0E-01**		**1.7E-01**	

Table 15: ReCiPe2016 Mid-point LCIA results comparing the impact of different coating materials on overall LC and on coating production and meal-kit disposal

			Meal-kit Type	**Bagasse**						**Paper**					
			Coating type (3-5% by mass)	**PLA (BAU)**	PE (3% by mass)	PBAT	PBS	PHB	PSM (Mater-Bi®)	PLA	**PE (BAU; 3% by mass)**	PBAT	PBS	PHB	PSM (Mater-Bi®)
Impact Category	Value Chain stage	Units													
Global Warming Potential	Overall	Kg CO_2 eq		**3.3**	3.27	3.45	3.31	3.34	3.26	2.61	**2.61**	2.73	2.62	2.65	2.58
		%			-0.91%	4.55%	0.30%	1.21%	-1.21%			4.60%	0.38%	1.53%	-1.15%
	Coating Production	Kg CO_2 eq		**0.113**	0.0549	0.266	0.13	0.16	0.0763	0.0924	**0.0359**	0.218	0.107	0.101	0.0625
		%			-51.42%	135.40%	15.04%	41.59%	-32.48%	157.38%		507.24%	198.05%	181.34%	74.09%
	Disposal	Kg CO_2 eq		**1.77**	1.81	1.77	1.77	1.77	1.77	1.43	**1.46**	1.43	1.43	1.43	1.43
		%			2.26%					-2.05%		-2.05%	-2.05%	-2.05%	-2.05%
Stratospheric Ozone Depletion	Overall	Kg CFC11 eq		**1.27E-06**	7.72E-07	5.16E-06	8.05E-07	1.25E-06	8.61E-07	1.65E-06	**1.27E-06**	4.84E-06	1.28E-06	1.64E-06	1.32E-06
		%			-39.21%	306.30%	-36.61%	-1.57%	-32.20%	29.92%		281.10%	0.79%	29.13%	3.94%
	Coating Production	Kg CFC11 eq		**5.09E-07**	1.17E-08	4.4E-06	4.75E-08	4.88E-07	1.04E-07	4.17E-07	**5.34E-09**	3.61E-06	3.89E-08	3.92E-07	8.49E-08
		%			-97.70%	764.44%	-90.67%	-4.13%	-79.57%	7708.99%		67503.00%	628.46%	7240.82%	1489.89%
	Disposal	Kg CFC11 eq		**4.09E-08**	4.02E-08	4.09E-08	4.09E-08	4.09E-08	4.09E-08	3.28E-08	**3.24E-08**	3.28E-08	3.28E-08	3.28E-08	3.28E-08
		%			-1.71%					1.23%		1.23%	1.23%	1.23%	1.23%
Ionizing Radiation	Overall	Kg Co-60 eq		**0.0834**	0.0784	0.0806	0.085	0.0829	0.0789	0.0605	**0.0597**	0.0582	0.0618	0.06	0.0568
		%			-6.00%	-3.36%	1.92%	-0.60%	-5.40%	1.34%		-2.51%	3.52%	0.50%	-4.86%
	Coating Production	Kg Co-60 eq		**0.00718**	0.00216	0.00432	0.00879	0.00662	0.0027	0.00588	**0.0038**	0.00354	0.00721	0.00532	0.00221
		%			-69.92%	-39.83%	22.42%	-7.80%	-62.40%	54.74%		-6.84%	89.74%	40.00%	-41.84%
	Disposal	Kg Co-60 eq		**0.000188**	0.000187	0.000188	0.000188	0.000188	0.000188	0.000151	**0.000151**	0.000151	0.000151	0.000151	0.000151
		%			-0.53%										
Ozone Formation, Human Health	Overall	Kg NOx eq		**0.00615**	0.00597	0.00621	0.00612	0.00634	0.00606	0.0603	**0.00595**	0.00608	0.00601	0.00618	0.00595
		%			-2.93%	0.98%	-0.49%	3.09%	-1.46%	913.45%		2.18%	1.01%	3.87%	
	Coating Production	Kg NOx eq		**0.00269**	0.00013	0.000348	0.00026	0.000471	0.000192	0.000233	**0.00517**	0.000285	0.000213	0.000357	0.000157
		%			-95.17%	-87.06%	-90.33%	-82.49%	-92.86%	-95.49%		-94.49%	-95.88%	-93.09%	-96.96%

	Disposal	Kg NOx eq		**0.000269**	0.000239	0.000269	0.000269	0.000269	0.000269	0.000216	**0.000193**	0.000216	0.000216	0.000216	0.000216
		%			-11.15%					11.92%		11.92%	11.92%	11.92%	11.92%
Particulate Matter 2.5 Formation	Overall	Kg PM2.5 eq		**0.0034**	0.00322	0.00346	0.0034	0.00361	0.00337	0.00333	**0.00322**	0.00338	0.00333	0.00351	0.00331
		%			-5.29%	1.76%	0.00%	6.18%	-0.88%	3.42%		4.97%	3.42%	9.01%	2.80%
	Coating Production	Kg PM2.5 eq		**0.000199**	6.85E-05	0.000258	0.000202	0.000412	0.00017	0.000163	**3.35E-05**	0.000211	0.000165	0.000296	0.00014
		%			-65.58%	29.65%	1.51%	107.04%	-14.57%	386.57%		529.85%	392.54%	783.58%	317.91%
	Disposal	Kg PM2.5 eq		**0.000127**	8.01E-05	0.000127	0.000127	0.000127	0.000127	0.000102	**6.47E-05**	0.000102	0.000102	0.000102	0.000102
		%			-36.93%					57.65%		57.65%	57.65%	57.65%	57.65%
Ozone Formation, Terrestrial Ecosystem	Overall	Kg NOx eq		**0.00628**	0.00609	0.00634	0.00625	0.000646	0.00617	0.0061	**0.00602**	0.00615	0.00607	0.00625	0.00602
		%			-3.03%	0.96%	-0.48%	-89.71%	-1.75%	1.33%		2.16%	0.83%	3.82%	
	Coating Production	Kg NOx eq		**0.000301**	0.000143	0.000366	0.000271	0.000488	0.000199	0.000247	**8.54E-05**	0.0003	0.000222	0.00037	0.000164
		%			-52.49%	21.59%	-9.97%	62.13%	-33.89%	189.23%		251.29%	159.95%	333.26%	92.04%
	Disposal	Kg NOx eq		**0.000276**	0.000246	0.000276	0.000276	0.000276	0.000276	0.000222	**0.000198**	0.000222	0.000222	0.000222	0.000222
		%			-10.87%					12.12%		12.12%	12.12%	12.12%	12.12%
Terrestrial Acidification	Overall	Kg SO_2 eq		**0.00674**	0.00637	0.00681	0.00666	0.00728	0.0067	0.00953	**0.00936**	0.00959	0.00946	0.00997	0.00949
		%			-5.49%	1.04%	-1.19%	8.01%	-0.59%	1.82%		2.46%	1.07%	6.52%	1.39%
	Coating Production	Kg SO_2 eq		**0.000512**	0.000156	0.000588	0.000434	0.00105	0.000472	0.00042	**9.28E-05**	0.000482	0.000356	0.000746	0.000387
		%			-69.53%	14.84%	-15.23%	105.08%	-7.81%	352.59%		419.40%	283.62%	703.88%	317.03%
	Disposal	Kg SO_2 eq		**0.00016**	0.000148	0.00016	0.00016	0.00016	0.00016	0.000128	**0.000119**	0.000128	0.000128	0.000128	0.000128
		%			-7.50%					7.56%		7.56%	7.56%	7.56%	7.56%
Freshwater Eutrophication	Overall	Kg P eq		**0.000492**	0.000461	0.000489	0.000488	0.000508	0.000473	6.91E-05	**0.000676**	0.000688	0.000687	0.000704	0.000675
		%			-6.30%	-0.61%	-0.81%	3.25%	-3.86%	-89.78%		1.78%	1.63%	4.14%	-0.15%
	Coating Production	Kg P eq		**4.41E-05**	1.28E-05	4.14E-05	4.01E-05	0.0000602	2.56E-06	3.61E-05	**8.91E-06**	0.000034	3.29E-05	3.95E-05	0.000021
		%			-70.98%	-6.12%	-9.07%	36.51%	-94.20%	305.16%		281.59%	269.25%	343.32%	135.69%
	Disposal	Kg P eq		**8.79E-06**	8.93E-06	8.79E-06	8.79E-06	8.79E-06	8.79E-06	7.09E-06	**7.24E-06**	7.09E-06	7.09E-06	7.09E-06	7.09E-06
		%			1.59%					-2.07%		-2.07%	-2.07%	-2.07%	-2.07%
Marine Eutrophication	Overall	Kg N eq		**0.000934**	0.000862	0.000888	0.000888	0.000981	0.000904	0.000774	**0.00072**	0.000736	0.000736	0.000812	0.000749
		%			-7.71%	-4.93%	-4.93%	5.03%	-3.21%	7.50%		2.22%	2.22%	12.78%	4.03%
	Coating Production	Kg N eq		**4.86E-05**	1.25E-06	2.95E-06	2.82E-06	0.0000955	1.81E-05	3.98E-05	**9.1E-07**	2.41E-06	2.31E-06	7.77E-05	1.49E-05
		%			-97.43%	-93.93%	-94.20%	96.50%	-62.76%	4273.63%		164.84%	153.85%	8438.46%	1537.36%
	Disposal	Kg N eq		**0.000817**	0.000792	0.000802	0.000802	0.000802	0.000802	0.00066	**0.000644**	0.00066	0.00066	0.00066	0.00066
		%			-3.06%					2.48%		2.48%	2.48%	2.48%	2.48%

	Overall	Kg CO_2 eq		**4.88**	4.79	4.94	4.94	4.97	4.83	4.61	**4.59**	4.66	4.66	4.68	4.57
		%			-1.84%	1.23%	1.23%	1.84%	-1.02%	0.44%		1.53%	1.53%	1.96%	-0.44%
Terrestrial Ecotoxicity	Coating Production	Kg 1,4 DCB eq		**0.296**	0.101	0.354	0.353	0.386	0.248	0.243	**0.0558**	0.291	0.289	0.288	0.203
		%			-65.88%	19.59%	19.26%	30.41%	-16.22%	335.48%		421.51%	417.92%	416.13%	263.80%
	Disposal	Kg 1,4 DCB eq		**0.156**	0.26	0.156	0.156	0.156	0.156	0.126	**0.211**	0.126	0.126	0.126	0.126
		%			66.67%					-40.28%		-40.28%	-40.28%	-40.28%	-40.28%
Freshwater Ecotoxicity	Overall	Kg 1,4 DCB eq		**0.075**	0.0702	0.074	0.0738	0.0753	0.0731	0.071	**0.068**	0.0702	0.0701	0.0713	0.0695
		%			-6.40%	-1.33%	-1.60%	0.40%	-2.53%	4.41%		3.24%	3.09%	4.85%	2.21%
	Coating Production	Kg 1,4 DCB eq		**0.00647**	0.00166	0.00549	0.00528	0.00679	0.00458	0.0053	**0.00124**	0.0045	0.00433	0.00516	0.00376
		%			-74.34%	-15.15%	-18.39%	4.95%	-29.21%	327.42%		262.90%	249.19%	316.13%	203.23%
	Disposal	Kg 1,4 DCB eq		**0.0318**	0.318	0.0318	0.0318	0.0318	0.0318	0.0257	**0.0259**	0.0257	0.0257	0.0257	0.0257
		%			900.00%					-0.77%		-0.77%	-0.77%	-0.77%	-0.77%
Marine Ecotoxicity	Overall	Kg 1,4 DCB eq		**0.101**	0.096	0.101	0.1	0.1	0.0994	0.0965	**0.0933**	0.0959	0.0957	0.0953	0.0948
		%			-4.95%	0.00%	-0.99%	-0.99%	-1.58%	3.43%		2.79%	2.57%	2.14%	1.61%
	Coating Production	Kg 1,4 DCB eq		**0.00794**	0.00217	0.00719	0.00691	0.00643	0.00585	0.00651	**0.00161**	0.0059	0.00567	0.0047	0.0048
		%			-72.67%	-9.45%	-12.97%	-19.02%	-26.32%	304.35%		266.46%	252.17%	191.93%	198.14%
	Disposal	Kg 1,4 DCB eq		**0.0432**	0.0435	0.0432	0.0432	0.0432	0.0432	0.0349	**0.0354**	0.0349	0.0349	0.0349	0.0349
		%			0.69%					-1.41%		-1.41%	-1.41%	-1.41%	-1.41%
Human Carcinogenic Toxicity	Overall	Kg 1,4 DCB eq		**0.0536**	0.0514	0.0543	0.0539	0.0556	0.0527	0.0676	**0.0667**	0.0682	0.0678	0.0692	0.0669
		%			-4.10%	1.31%	0.56%	3.73%	-1.68%	1.35%		2.25%	1.65%	3.75%	0.30%
	Coating Production	Kg 1,4 DCB eq		**0.00345**	0.00157	0.00416	0.00375	0.00541	0.00257	0.00283	**0.000974**	0.00341	0.00307	0.00372	0.00211
		%			-54.49%	20.58%	8.70%	56.81%	-25.51%	190.55%		250.10%	215.20%	281.93%	116.63%
	Disposal	Kg 1,4 DCB eq		**0.00392**	0.00359	0.00392	0.00392	0.00392	0.00392	0.00316	**0.0029**	0.00316	0.00316	0.00316	0.00316
		%			-8.42%					8.97%		8.97%	8.97%	8.97%	8.97%
Human Non-Carcinogenic Toxicity	Overall	Kg 1,4 DCB eq		**2.18**	2.07	2.2	2.19	2.3	2.15	2.63	**2.57**	2.65	2.63	2.72	2.6
		%			-5.05%	0.92%	0.46%	5.50%	-1.38%	2.33%		3.11%	2.33%	5.84%	1.17%
	Coating Production	Kg 1,4 DCB eq		**0.0983**	0.0336	0.121	0.106	0.217	0.0697	0.0805	**0.0224**	0.0996	0.0866	0.157	0.0571
		%			-65.82%	23.09%	7.83%	120.75%	-29.09%	259.38%		344.64%	286.61%	600.89%	154.91%
	Disposal	Kg 1,4 DCB eq		**1.05**	1	1.05	1.05	1.05		0.85	**0.813**	0.85	0.85	0.85	0.85
		%			-4.76%					4.55%		4.55%	4.55%	4.55%	4.55%
Land Use	Overall	m2a crop eq		**2.95**	0.215	0.228	0.225	2.22	0.839	4.01	**1.81**	1.78	1.77	3.41	2.28
		%			-92.71%	-92.27%	-92.37%	-24.75%	-71.56%	121.55%		-1.66%	-2.21%	88.40%	25.97%
		m2a crop eq		**2.74**	0.00451	0.0183	0.0145	2.01	0.629	2.25	**0.00268**	0.015	0.0119	1.64	0.515

	Coating Production	%			-99.84%	-99.33%	-99.47%	-26.64%	-77.04%	83855%		459.70%	344.03%	61094%	19116%
	Disposal	m2a crop eq		**0.00287**	0.00286	0.00287	0.00287	0.00287	0.00287	0.00231	**0.00232**	0.00231	0.00229	0.00229	0.00229
		%			-0.35%					-0.43%		-0.43%	-1.29%	-1.29%	-1.29%
Mineral Resource Scarcity	Overall	Kg Cu eq		**0.00524**	0.00499	0.00524	0.00519	0.0053	0.00514	0.0059	**0.0058**	0.00589	0.00585	0.00594	0.00582
		%			-4.77%	0.00%	-0.95%	1.15%	-1.91%	1.72%		1.55%	0.86%	2.41%	0.34%
	Coating Production	Kg Cu eq		**0.000369**	0.000111	0.000363	0.00031	0.000425	0.000268	0.000302	**7.38E-05**	0.000297	0.000254	0.000338	0.00022
		%			-69.92%	-1.63%	-15.99%	15.18%	-27.37%	309.21%		302.44%	244.17%	357.99%	198.10%
	Disposal	Kg Cu eq		**3.59E-05**	3.59E-05	3.59E-05	3.59E-05	0.0000359	3.59E-05	2.88E-05	**2.89E-05**	2.88E-05	2.88E-05	2.88E-05	2.88E-05
		%								-0.35%		-0.35%	-0.35%	-0.35%	-0.35%
Fossil Resource Scarcity	Overall	Kg oil eq		**0.463**	0.471	0.494	0.485	0.464	0.471	0.347	**0.357**	0.372	0.364	0.0348	0.353
		%			1.73%	6.70%	4.75%	0.22%	1.73%	-2.80%		4.20%	1.96%	-90.25%	-1.12%
	Coating Production	Kg oil eq		**0.0289**	0.0365	0.0598	0.0507	0.0301	0.037	0.0237	**0.0277**	0.049	0.0415	0.0192	0.0303
		%			26.30%	106.92%	75.43%	4.15%	28.03%	-14.44%		76.90%	49.82%	-30.69%	9.39%
	Disposal	Kg oil eq		**0.00326**	0.00325	0.00326	0.00326	0.00326	0.00326	0.00261	**0.00262**	0.00261	0.00261	0.00261	0.00261
		%			-0.31%					-0.38%		-0.38%	-0.38%	-0.38%	-0.38%
Water Use	Overall	m^3		**0.0183**	0.0144	0.0178	0.0179	0.027	0.014	0.0329	**0.0304**	0.0324	0.0325	0.04	0.0293
		%			-21.31%	-2.73%	-2.19%	47.54%	-23.50%	8.22%		6.58%	6.91%	31.58%	-3.62%
	Coating Production	m^3		**0.00467**	0.000695	0.00412	0.00428	0.0133	0.000331	0.00383	**0.000605**	0.00338	0.00351	0.0109	0.000271
		%			-85.12%	-11.78%	-8.35%	184.80%	-92.91%	533.06%		458.68%	480.17%	1701.65%	-55.21%
	Disposal	m^3		**2.89E-05**	2.81E-05	2.89E-05	2.89E-05	0.0000289	2.89E-05	2.32E-05	**2.27E-05**	2.32E-05	2.32E-05	2.32E-05	2.32E-05
		%			-.2.77%					2.20%		2.20%	2.20%	2.20%	2.20%

Table 16: ReCiPe2016 Mid-point LCIA results comparing impact of increasing recycling rates (Mechanical Recycling)

			GWP	SOD	IR	OF, HH	FPM25	OF, TE	TA	Fw Eutr	Mar Eutr	Terr Ecotox	Fw Ecotox	Mar Ecotox	HC Tox	HNC Tox	LU	MinRes Scar	FosRes Scar	WU
Meal-kit type		**Units**	Kg CO_2 eq	Kg CFC11 eq	Kg Co-60 eq	Kg NOx eq	Kg PM25 eq	Kg NOx eq	Kg SO_2 eq	Kg N eq	Kg P eq	Kg 1,4-DCB eq	Kg 1,4-DCB eq	Kg 1,4-DCB eq	Kg 1,4-DCB eq	Kg 1,4-DCB eq	Kg CO_2 eq	Kg Cu eq	Kg oil eq	m^3 eq
PS	**BAU**		**0.827**	**2.3E-07**	**0.0103**	**0.00208**	**0.00103**	**2.2E-03**	**0.00314**	**0.000158**	**8E-05**	**1.65**	**0.0407**	**0.0563**	**0.073**	**1.23**	**0.0627**	**0.000987**	**0.31**	**0.00999**
	Y1	**%**	-5.68%	0.85%	2.91%	-2.40%	-0.97%	-2.29%	-1.27%	2.53%	-7.62%	-1.21%	-5.65%	-5.86%	-63.29%	-5.69%	3.03%	-0.41%	-6.77%	-7.61%
	Y2	**%**	-9.31%	1.28%	4.85%	-3.85%	-1.94%	-3.67%	-1.91%	3.80%	-12.48%	-2.42%	-9.09%	-9.41%	-63.70%	-9.76%	4.94%	-0.71%	-10.65%	-12.31%
	Y3	**%**	-12.82%	1.71%	6.80%	-5.29%	-3.30%	-5.50%	-2.87%	5.70%	-17.23%	-3.03%	-12.78%	-12.97%	-64.11%	-13.01%	6.70%	-1.01%	-14.84%	-17.02%
	Y4	**%**	-17.17%	2.56%	9.71%	-6.73%	-4.47%	-7.34%	-3.82%	7.59%	-22.97%	-4.24%	-16.95%	-17.41%	-64.66%	-17.89%	9.09%	-1.32%	-19.68%	-22.72%
	Y5	**%**	-22.13%	3.85%	12.62%	-8.65%	-5.73%	-9.17%	-4.78%	10.13%	-29.71%	-5.45%	-21.87%	-22.38%	-65.21%	-22.85%	11.64%	-1.72%	-25.48%	-29.33%
PET	**BAU**		**4.07**	**2.7E-06**	**0.0965**	**0.0136**	**0.00705**	**0.0138**	**0.0214**	**0.00214**	**0.00111**	**12.3**	**0.245**	**0.332**	**0.237**	**5.97**	**0.84**	**0.0142**	**1.42**	**0.0226**
	Y1	**%**	-4.91%	-4.87%	-3.21%	-4.41%	-3.55%	-4.35%	-3.27%	-4.67%	-6.31%	-4.88%	-6.12%	-6.02%	-5.06%	-5.36%	-4.76%	-6.34%	-5.63%	-6.64%
	Y2	**%**	-8.60%	-8.61%	-5.49%	-7.35%	-6.24%	-7.25%	-6.07%	-7.94%	-11.26%	-8.13%	-10.20%	-10.24%	-8.44%	-9.21%	-8.21%	-11.27%	-9.15%	-11.06%
	Y3	**%**	-12.29%	-11.99%	-7.77%	-9.56%	-8.79%	-10.14%	-8.41%	-11.68%	-15.77%	-12.20%	-14.69%	-14.46%	-12.24%	-13.07%	-11.67%	-16.20%	-13.38%	-15.93%

	Y4	%	-17.44%	-16.85%	-10.98%	-13.97%	-12.48%	-13.77%	-12.15%	-16.36%	-22.16%	-17.07%	-20.41%	-20.18%	-17.30%	-18.43%	-16.43%	-23.24%	-19.01%	-22.12%
	Y5	%	-21.87%	-20.97%	-13.78%	-17.65%	-15.60%	-17.39%	-14.95%	-20.56%	-27.57%	-21.22%	-25.71%	-25.30%	-21.52%	-24.79%	-20.60%	-28.87%	-23.94%	-27.88%
Paper	**BAU**		**2.61**	**1.3E-06**	**0.0597**	**0.00595**	**0.00322**	**0.00602**	**0.00936**	**0.000676**	**0.00072**	**4.59**	**0.068**	**0.0933**	**0.0667**	**2.57**	**1.81**	**0.0058**	**0.357**	**0.0304**
	Y1	%	-2.30%	-0.79%	-0.50%	-0.67%	-0.31%	-0.66%	-0.32%	-0.15%	-3.47%	-0.87%	-2.06%	-2.14%	-0.60%	-1.56%	-1.66%	-0.34%	-0.28%	-1.32%
	Y2	%	-4.60%	-0.79%	-1.17%	-1.34%	-0.62%	-1.33%	-0.53%	-0.30%	-7.08%	-1.74%	-4.12%	-4.18%	-1.05%	-3.11%	-3.87%	-0.69%	-0.56%	-2.96%
	Y3	%	-6.90%	-0.79%	-1.68%	-2.02%	-1.24%	-1.99%	-0.85%	-0.59%	-10.69%	-2.40%	-6.18%	-6.32%	-1.50%	-4.67%	-5.52%	-1.03%	-0.84%	-4.28%
	Y4	%	-9.20%	-1.57%	-2.18%	-2.69%	-1.55%	-2.66%	-1.07%	-0.74%	-14.17%	-3.27%	-8.24%	-8.36%	-1.95%	-6.23%	-7.18%	-1.38%	-1.12%	-5.92%
	Y5	%	-11.49%	-1.57%	-2.85%	-3.36%	-2.17%	-3.32%	-1.39%	-1.04%	-17.78%	-4.14%	-10.44%	-10.40%	-2.55%	-7.78%	-9.39%	-1.55%	-1.40%	-7.24%
PP	**BAU**		**3.63**	**3.2E-06**	**0.0578**	**0.0118**	**0.00617**	**0.0119**	**0.0198**	**0.00255**	**0.000253**	**6.03**	**0.166**	**0.229**	**0.259**	**5.17**	**0.943**	**0.0136**	**1.19**	**0.0134**
	Y1	%	-18.73%	-19.87%	-10.73%	-16.19%	-15.88%	-16.30%	-16.16%	-19.61%	-18.58%	-14.43%	-19.88%	-19.65%	-19.31%	-19.54%	-19.30%	-22.06%	-19.24%	-19.40%
	Y2	%	-21.76%	-22.71%	-12.46%	-18.81%	-27.00%	-18.91%	-18.69%	-22.35%	-21.34%	-16.75%	-22.89%	-23.14%	-22.39%	-22.63%	-22.27%	-25.00%	-22.27%	-22.39%
	Y3	%	-24.52%	-25.87%	-14.01%	-21.36%	-20.75%	-21.43%	-21.21%	-25.49%	-24.51%	-18.91%	-26.51%	-26.20%	-25.48%	-25.53%	-25.24%	-28.68%	-25.21%	-25.60%
	Y4	%	-27.55%	-29.02%	-15.74%	-23.98%	-23.18%	-24.03%	-23.23%	-28.63%	-27.27%	-21.23%	-29.52%	-29.26%	-28.57%	-28.63%	-28.31%	-32.06%	-28.24%	-28.66%
	Y5	%	-31.40%	-33.12%	-17.99%	-27.37%	-26.58%	-27.48%	-26.77%	-32.55%	-31.23%	-24.21%	-33.73%	-33.19%	-32.43%	-32.69%	-32.24%	-36.54%	-32.27%	-32.76%

Table 17: ReCiPe2016 Mid-point LCIA results comparing impact of increasing recycling rates (Organic Recycling - Industrial Composting)

			GWP	**SOD**	**IR**	**OF, HH**	**FPM25**	**OF, TE**	**TA**	**Fw Eutr**	**Mar Eutr**	**Terr Ecotox**	**Fw Ecotox**	**Mar Ecotox**	**HC Tox**	**HNC Tox**	**LU**	**MinRes Scar**	**FosRes Scar**	**WU**
Meal-kit type		**Units**	Kg CO_2 eq	Kg CFC11 eq	Kg Co-60 eq	Kg NOx eq	Kg P eq	Kg NOx eq	Kg SO_2 eq	Kg N eq	Kg P eq	Kg 1,4-DCB eq	Kg 1,4-DCB eq	Kg 1,4-DCB eq	Kg 1,4-DCB eq	Kg 1,4-DCB eq	Kg CO_2 eq	Kg Cu eq	Kg oil eq	m^3 eq
Bagasse	**BAU**		**3.3**	**1.3E-06**	**0.0834**	**0.00615**	**0.0034**	**0.00628**	**0.00674**	**0.000492**	**0.000934**	**4.88**	**0.075**	**0.101**	**0.0536**	**2.18**	**2.95**	**0.00524**	**0.463**	**0.0183**
	Y1	**%**	-7.88%	-5.51%	-2.40%	-0.98%	-0.88%	-1.11%	-1.34%	-0.81%	-14.03%	-1.02%	-6.80%	-6.24%	-1.49%	-7.80%	-18.64%	-6.11%	-0.22%	-6.56%
	Y2	**%**	-13.03%	-8.66%	-3.96%	-1.63%	-1.76%	-1.75%	-2.37%	-1.22%	-23.34%	-98.05%	-68.16%	-67.95%	-2.43%	-12.84%	-31.53%	-10.31%	-0.43%	-11.48%
	Y3	**%**	-26.36%	-16.54%	-7.91%	-3.25%	-3.24%	-3.34%	-4.60%	-1.63%	-46.68%	-3.28%	-22.53%	-21.88%	-5.04%	-25.69%	-63.05%	-20.42%	-1.08%	-22.95%
	Y4	**%**	-33.94%	-21.42%	-10.31%	-4.23%	-4.41%	-4.30%	-6.08%	-3.25%	-60.71%	-4.30%	-29.33%	-28.61%	-6.53%	-33.03%	-82.00%	-26.72%	-1.51%	-29.51%
	Y5	**%**	-41.82%	-26.30%	-12.71%	-5.20%	-5.29%	-5.25%	-7.42%	-4.07%	-74.73%	-5.33%	-36.00%	-35.35%	-8.02%	-40.83%	-99.05%	-32.82%	-1.73%	-36.61%
PLA	**BAU**		**2.13**	**6.1E-06**	**1.4E-01**	**6.8E-03**	**4.4E-03**	**7.1E-03**	**9.1E-03**	**7.3E-04**	**1.2E-03**	**6.51**	**1.6E-01**	**2.1E-01**	**7.1E-02**	**3.32**	**3.1E+01**	**5.9E-03**	**5.1E-01**	**5.6E-02**
	Y1	**%**	-0.47%	-0.16%	0.00%	-0.44%	-0.91%	-0.57%	-0.22%	-0.14%	-2.50%	-0.31%	-1.91%	-1.96%	-0.57%	-2.41%	-0.32%	-1.18%	0.00%	-0.36%
	Y2	**%**	-1.41%	-0.66%	-0.71%	-1.32%	-2.27%	-1.42%	-0.77%	-0.28%	-8.33%	-1.08%	-6.37%	-6.37%	-1.70%	-7.53%	-0.97%	-3.20%	-0.20%	-1.25%
	Y3	**%**	-4.23%	-1.97%	-2.14%	-3.52%	-6.14%	-3.55%	-2.19%	-0.55%	-22.00%	-3.07%	-15.92%	-16.67%	-4.55%	-20.18%	-2.91%	-8.59%	-0.40%	-3.56%
	Y4	**%**	-5.63%	-2.63%	-2.86%	-31.28%	-8.41%	-4.96%	-3.07%	-0.83%	-93.03%	-4.15%	-22.29%	-23.04%	-6.11%	-27.71%	-3.88%	-11.95%	-0.59%	-4.80%
	Y5	**%**	-7.04%	-3.45%	-3.57%	-6.31%	-10.45%	-6.24%	-3.94%	-0.97%	-38.58%	-5.38%	-28.03%	-29.41%	-7.81%	-35.24%	-4.85%	-15.15%	-0.79%	-6.23%
PBS	**BAU**		**2.61**	**1E-06**	**0.179**	**0.0071**	**0.00494**	**0.0073**	**0.00914**	**0.000796**	**0.000781**	**7.56**	**0.162**	**0.217**	**0.0824**	**3.84**	**0.27**	**0.00584**	**0.841**	**5.9E-02**
	Y1	**%**	11.88%	-1.60%	0.00%	-0.56%	-0.61%	-0.55%	-0.33%	-3.52%	-4.87%	-0.26%	-1.85%	-2.30%	-0.49%	-2.60%	-46.67%	-1.20%	0.00%	-2.18%
	Y2	**%**	-1.53%	-4.90%	-0.56%	-1.55%	-2.23%	-1.51%	-0.98%	-3.64%	-14.60%	-1.06%	-6.79%	-6.91%	-1.58%	-7.55%	-139.3%	-3.60%	-0.12%	-3.02%
	Y3	**%**	-3.83%	-13.40%	-2.23%	-3.94%	-6.07%	-3.97%	-2.63%	-4.02%	-38.67%	-2.91%	-17.90%	-17.97%	-4.25%	-19.79%	-371.5%	-9.93%	-0.36%	-5.36%

	Y4	**%**	-5.36%	-18.50%	-2.79%	-5.35%	-8.30%	-5.34%	-3.50%	-4.27%	-53.14%	-4.10%	-24.07%	-24.88%	-5.95%	-27.34%	-511.1%	-13.53%	-0.48%	-6.87%
	Y5	**%**	-6.90%	-23.50%	-3.35%	-6.90%	-10.53%	-6.85%	-4.49%	-4.52%	-67.73%	-5.16%	-30.86%	-31.34%	-7.52%	-34.64%	-648.2%	-17.29%	-0.59%	-8.21%
PBAT	**BAU**		**4.2**	**5.5E-05**	**0.118**	**0.008**	**0.00549**	**0.00828**	**0.0108**	**0.000761**	**0.000757**	**7.35**	**0.16**	**0.214**	**0.085**	**3.91**	**0.308**	**0.00632**	**0.928**	**5.5E-02**
	Y1	**%**	-0.24%	0.00%	0.00%	-0.38%	-0.73%	-0.48%	0.00%	-0.13%	-4.76%	-0.41%	-2.50%	-2.34%	-0.59%	-2.30%	-39.29%	-1.11%	0.00%	-0.36%
	Y2	**%**	-0.71%	0.00%	-0.85%	-1.25%	-2.00%	-1.33%	-0.93%	-0.26%	-14.40%	-1.09%	-6.88%	-7.01%	-1.53%	-6.91%	-118.2%	-3.48%	-0.11%	-1.46%
	Y3	**%**	-2.14%	-0.18%	-2.54%	-3.38%	-5.28%	-3.38%	-1.85%	-0.66%	-38.57%	-2.99%	-17.50%	-17.76%	-4.12%	-18.67%	-315.3%	-9.02%	-0.32%	-3.83%
	Y4	**%**	-3.10%	-0.36%	-4.24%	-4.63%	-7.29%	-4.59%	-2.78%	-0.79%	-52.97%	-4.08%	-24.38%	-24.30%	-5.65%	-25.83%	-434.4%	-12.34%	-0.43%	-5.28%
	Y5	**%**	-4.05%	-0.36%	-5.08%	-5.88%	-9.29%	-5.80%	-3.70%	-1.05%	-67.50%	-5.31%	-30.63%	-30.84%	-7.18%	-32.99%	-551.3%	-15.66%	-0.54%	-6.92%
PSM (Mater-Bi®)	**BAU**		**1.79**	**1.7E-06**	**0.112**	**0.00607**	**0.00422**	**0.00622**	**0.00903**	**0.00056**	**0.000945**	**6.67**	**0.149**	**0.198**	**0.0654**	**3.25**	**7.86**	**0.00536**	**0.647**	**8.9E-03**
	Y1	**%**	-0.56%	-1.18%	0.00%	-0.49%	-0.95%	-0.64%	-0.33%	-0.18%	-3.92%	-0.45%	-2.01%	-2.02%	-0.61%	-2.77%	-1.53%	-1.31%	-0.15%	-3.05%
	Y2	**%**	-1.68%	-2.96%	-0.89%	-1.65%	-2.61%	-1.61%	-0.89%	-0.36%	-11.64%	-1.20%	-6.71%	-7.07%	-1.99%	-8.62%	-4.58%	-3.92%	-0.15%	-9.26%
	Y3	**%**	-5.03%	-7.69%	-2.68%	-4.45%	-6.87%	-4.50%	-2.55%	-0.89%	-31.01%	-3.30%	-18.79%	-18.69%	-5.35%	-22.77%	-12.34%	-10.45%	-0.46%	-24.60%
	Y4	**%**	-7.26%	-10.65%	-4.46%	-6.10%	-9.48%	-6.11%	-3.43%	-1.07%	-42.54%	-4.50%	-25.50%	-25.76%	-7.34%	-31.08%	-16.92%	-14.37%	-0.62%	-33.75%
	Y5	**%**	-9.50%	-13.61%	-5.36%	-7.74%	-12.09%	-7.72%	-4.32%	-1.43%	-54.18%	-5.70%	-32.89%	-32.83%	-9.33%	-39.69%	-21.63%	-18.28%	-0.77%	-43.00%
Bio foam (expanded PLA)	**BAU**		**1.02**	**2.9E-06**	**0.0672**	**0.00327**	**0.00211**	**0.00338**	**0.00438**	**0.000348**	**0.000576**	**3.12**	**0.0752**	**0.0977**	**0.0337**	**1.59**	**14.8**	**0.00285**	**0.243**	**0.0269**
	Y1	**%**	0.00%	-0.34%	-0.30%	-0.61%	-0.95%	-0.59%	-0.23%	-0.29%	-2.78%	-0.32%	-1.99%	-2.05%	-0.30%	-2.52%	0.00%	-1.05%	-0.41%	-0.37%
	Y2	**%**	-0.98%	-1.03%	-0.74%	-1.53%	-2.37%	-1.48%	-0.91%	-0.29%	-8.33%	-0.96%	-5.98%	-6.24%	-4.45%	-7.55%	-0.68%	-3.51%	-0.41%	-1.12%
	Y3	**%**	-4.02%	-2.05%	-2.23%	-3.67%	-6.16%	-3.55%	-2.28%	-0.86%	-22.05%	-2.88%	-16.09%	-16.79%	-4.45%	-20.13%	-2.70%	-8.77%	-0.82%	-3.35%
	Y4	**%**	-5.59%	-2.74%	-3.12%	-5.20%	-8.53%	-5.03%	-3.20%	-0.86%	-30.38%	-4.17%	-22.21%	-23.13%	-5.93%	-27.67%	-4.05%	-11.93%	-0.82%	-4.83%
	Y5	**%**	-7.16%	-3.42%	-3.87%	-6.42%	-10.43%	-6.21%	-3.88%	-1.15%	-38.72%	-5.45%	-28.32%	-29.38%	-7.72%	-35.22%	-4.73%	-15.09%	-0.82%	-5.95%
PHB	**BAU**		**2.93**	**6.5E-06**	**0.162**	**0.00935**	**0.0074**	**0.00964**	**0.0168**	**0.00104**	**0.00190**	**6.79**	**0.173**	**0.20**	**0.101**	**5.05**	**25.3**	**0.00768**	**0.601**	**0.174**

Y1	**%**	-0.34%	-0.15%	0.00%	-0.32%	-0.54%	-0.41%	0.00%	0.00%	-1.58%	-0.44%	-2.31%	-2.50%	-0.99%	-1.78%	-0.79%	-0.91%	0.00%	0.00%
Y2	**%**	-1.02%	-0.77%	-0.62%	-1.07%	-1.49%	-1.14%	-0.60%	0.00%	-5.79%	-1.33%	-6.36%	-7.50%	-1.39%	-5.54%	-1.58%	-2.86%	-0.17%	0.00%
Y3	**%**	-3.07%	-1.99%	-1.85%	-2.89%	-3.92%	-2.90%	-1.19%	0.00%	-15.26%	-3.24%	-16.18%	-19.50%	-3.56%	-14.65%	-3.95%	-7.42%	-0.50%	-1.15%
Y4	**%**	-4.44%	-2.76%	-3.09%	-3.96%	-5.54%	-4.05%	-1.79%	-0.96%	-21.05%	-4.57%	-22.54%	-26.50%	-4.85%	-20.20%	-5.53%	-10.29%	-0.67%	-1.72%
Y5	**%**	-5.80%	-3.52%	-3.70%	-5.88%	-7.03%	-5.08%	-2.38%	-0.96%	-27.37%	-5.74%	-28.90%	-33.50%	-6.24%	-25.94%	-6.72%	-13.02%	-2.50%	-1.72%