Plastic Packaging in the Circular Economy

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i) Abstract

Plastic waste in the natural environment is a global concern, leading to calls for the adoption of a circular economy for plastics. Whilst attempts to achieve this have primarily focused on recycling, the work presented in this thesis asks: *'What is required to make reusable packaging systems mainstream?'* for consumer goods, and *'Is going packaging-free the answer to the plastics waste problem?'* for fruit and vegetables.

First, an online survey was used to investigate the factors that influence what people are willing to reuse, and an LCA was conducted on different food takeaway options. Building on this, behavioural analysis, environmental assessment and materials technology were integrated to assess the viability of a real-world returnable takeaway bowl system. Using yogurt as a case study, semi-structured interviews were then analysed to examine the socio-technical transition from single-use to return systems. Finally, progress in the removal of single-use packaging from fruit and vegetables was investigated, alongside an analysis of plastic packaging and food waste policies.

Key findings are:

1) Container and system design, customer acceptance of wear, and the return rate of the containers all affect the viability of a returnable packaging system. 2) Plastic is a good material choice for reuse as it is lightweight and inexpensive, although further work to understand contamination and the generation of microplastics is recommended. 3) The transition from single-use to reuse is currently at a standstill; cost and convenience are key. 4) A tension exists between plastic and food waste policies, with food waste policies taking precedence. 5) Going packaging-free is only part of a wider solution for plastic packaging waste from fresh produce.

Finally, legislation will drive change, however any future initiatives to reduce single-use plastic packaging should be implemented using an evidence-based approach to ensure progress on other sustainability goals is not compromised.

ii) Acknowledgements

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The papers that form the basis of Chapters 2 and 3 are from multi-disciplinary studies with contributions from many colleagues to whom I am incredibly grateful: Thank you - Harriet Baird, Stuart Walker, Maryam Hoseini, Saima Eman, Paul Mattinson, Rorie Beswick-Parsons, Andrew Slark, Seth Mehl, Thomas Webb, Anthony Ryan, Rachael Rothman, and Patrick Fairclough.

Heartfelt thanks to the Many Happy Returns project investigators, researchers, support staff and stakeholders, especially Thomas Webb. Many thanks to Peter Anstess and his team for introducing and operating the reusable scheme in the university cafés, and Vytal for their enthusiasm. Thank you also to the anonymous industry representatives interviewed as part of the work in Chapter 4, and to Peter Jackson for his assistance with the ethics application.

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In loving memory of Joan Pamela Dobson and Thomas Fred Dobson.

iii) Statement of contribution

This thesis by publication comprises four research chapters. Three of these chapters (Chapters 2, 3, and 5) are adapted from published articles, while Chapter 4 constitutes the initial draft of a manuscript intended to be developed for publication. The corresponding references are provided below:

Chapter 2: Greenwood, S.C., Walker, S., Baird, H.M., Parsons, R., Mehl, S., Webb, T.L., Slark, A.T., Ryan, A.J., Rothman, R.H., 2021. Many Happy Returns: Combining insights from the environmental and behavioural sciences to understand what is required to make reusable packaging mainstream. Sustain. Prod. Consum. 27, 1688–1702. https://doi.org/10.1016/j.spc.2021.03.022

Chapter 3: Hoseini, M., Greenwood, S.C., Eman, S., Mattinson, P., Baird, H.M., Beswick-Parsons, R., Fairclough, J.P.A., Webb, T.L., Ryan, A.J., Rothman, R.H., 2024. Integrating behavioural, material and environmental science to inform the design and evaluation of a reuse system for takeaway food. Resour. Conserv. Recycl. 209, 107815. https://doi.org/10.1016/j.resconrec.2024.107815

Chapter 5: Greenwood, S., Reynolds, C., 2024. Fresh produce on the loose: examining the coherence between plastic packaging and food waste policy using the case study of fruit and vegetables in the UK. Environ. Res. Food Syst. 1, 025008. https://doi.org/10.1088/2976-601X/ad7ff3

The contribution from SG to the work in each chapter is detailed below:

Chapter 2 - Many Happy Returns: Combining insights from the environmental and behavioural sciences to understand what is required to make reusable packaging mainstream

This is an output from a proof-of-concept study on reusable packaging led by SG as part of the project Plastics: Redefining single-use, EP/S025278/1. She contributed to both studies described in the paper, devised the single-use to reuse scale, and set the questions and facilitated the discussions in co-creation workshops. In the behavioural work, she advised on reuse types, packaging and product characteristics, and contributed to the coding and interpretation of the results. SG

set the research question for the lifecycle assessment: How does the environmental impact of takeaway food containers change as a result of different use models (single-use vs. refill vs. return) and different container materials (various types of plastics and non-plastics)? She compiled the first draft of the paper, wrote the common sections, edited the specialist sections, supervised the revisions and was the corresponding author.

Author Contributions: **Sarah C. Greenwood**, Chemistry, study lead, lead and corresponding author, investigation (see above); **Stuart Walker**, Chemical and Biological Engineering (CBE), investigation (LCA); **Harriet M. Baird**, Psychology, investigation; **Rorie Parsons**, Geography and Planning, project team; **Seth Mehl**, the Digital Humanities Institute, input on linguistics; **Thomas L. Webb**, Psychology, supervision; **Andrew T. Slark**, Chemistry, project team; **Anthony J. Ryan**, Chemistry, PI and supervision; **Rachael H. Rothman**, CBE, supervision

Chapter 3 - 'Integrating behavioural, material and environmental science to inform the design and evaluation of a reuse system for takeaway food'

This chapter is the output from the first of two cross-work package studies within the project Many Happy Returns, NE/V010638/1, for which Greenwood was co-Principal Investigator.

SG led the study, chaired project meetings, and researched and interviewed prospective system providers. She contributed to the provision of data for the LCA and, following the initial results, initiated a sensitivity analysis on weight and the energy mix for washing. SG derived the formulae for the calculations in 3.4.6 and performed the analysis on the cost of the scheme. She wrote sections of the first draft and contributed to the responses to the reviewers' comments.

More detailed analysis performed by SG has been added to this chapter; 3.5.1 on the performance of the trial in the university cafés, 3.5.2.3 and 3.5.5.4 comparing the heavy and light testing regimes, and 3.6.3 on the importance of return rate.

Full author list: **Maryam Hoseini**, Chemical and Biological Engineering, first author and LCA analysis; **Sarah C. Greenwood**, Chemistry, study lead, project co-

PI, investigation (see above for contribution); **Saima Eman**, Psychology, investigation; **Paul Mattinson**, Mechanical Engineering, materials testing; **Harriet M Baird**, Psychology, investigation and supervision; **Rorie Beswick-Parsons**, Human Geography, project team; **J. Patrick A. Fairclough**, Mechanical Engineering, supervision of materials testing; **Thomas L Webb**, Psychology, PI and supervision; **Anthony J Ryan**, Chemistry, co-PI and supervision; **Rachael H Rothman**, CBE, supervision and corresponding author.

Chapter 4 - Establishing the barriers and enablers to the introduction of reusable packaging using a hypothetical model of yogurt supplied via UK retailers in returnable pots

The work presented in this chapter is the output of the second of the two cross-work package studies conducted as part of Many Happy Returns. SG led the study, which included the chairing of online co-creation workshops with the project's industrial stakeholders and the Sheffield academic team. She conducted and analysed the anonymous stakeholder interviews.

This chapter is authored by SG with supervision from **Rorie Beswick-Parsons** in Geography and Planning. It is a preliminary draft intended for journal publication. For academic rigour, RB-P and SG intend to combine their analyses before submitting for publication.

Chapter 5 - Fresh produce on the loose: examining the coherence between plastic packaging and food waste policy using the case study of fruit and vegetables in the UK

This chapter is an augmented version of the published paper. Greenwood was the lead and corresponding author with supervision by **Christian Reynolds**, Principal Investigator of the NERC-funded project NE/V010654/1 'Reducing plastic packaging and food waste through product innovation simulation'.

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Plastic Packaging in the Circular Economy

1 Introduction

Of the 9 billion tonnes of plastic ever produced, only 10% has been recycled, 14% has been incinerated and the remainder still exists in landfill or the natural environment (Geyer, 2020). Plastic waste in the Earth System is a cause for concern - accumulation in the Great Pacific Garbage Patch and the harm done to wildlife through entanglement or ingestion are well documented. Plastic debris has even been found on the deep-sea floor of the Arctic (Bergmann et al., 2022), and is so abundant that researchers have suggested using it as a stratigraphic indicator for the current geological epoch (Zalasiewicz et al., 2016). Human health is also at risk - the open burning of plastic waste is common, especially in the global south, causing respiratory problems (Pathak et al., 2023), and there is growing public concern about the effects of microplastics (Lim, 2021).

Packaging accounts for 46% of global plastics manufacture (Basel Convention, 2020). Reducing the amount of plastic used for packaging therefore has the potential to have a significant impact on the amount of plastic polluting the environment. One way of achieving this is through the introduction of reusable packaging systems (EMF, 2019), where containers are used multiple times for the same purpose, keeping the plastic in the economy for as long as possible before being treated as waste (ideally closed-loop recycling), another is to remove consumer packaging altogether.

This thesis is a result of work performed on reusable packaging and packaging reduction in the project “Plastics: Redefining single-use”, UKRI Plastics Research and Innovation Fund EP/S025278/1, the UKRI Smart Sustainable Packaging Challenge projects “Many Happy Returns: Enabling reusable packaging systems” NE/V010638/1 and “Reducing plastic and food waste through product innovation simulation” NE/V010654/1, and work funded by the University of Sheffield Knowledge Exchange Impact Fund.

1.1 Plastics

The term plastic covers hundreds of materials, a small fraction of which are used for packaging applications. A useful working definition of *plastic* is used by the UK Government: a polymer material to which additives or substances may have

been added (HM Revenue and Customs, 2021). The word *polymer* comes from Greek, meaning many parts, and is defined as 'any of a class of natural or synthetic substances composed of very large molecules, called macromolecules, that are multiples of simpler chemical units called monomers' (Britannica.com, 2024). The average molecular weight of different plastics typically varies between 20,000 and 200,000 (libretexts.org, 2024), and can be an order of magnitude higher for ultra-high molecular weight PE, UHMPWE, used in medical implants (Kurtz, 2004).

Plastics are classified as either thermoplastic, those that can be reheated and remoulded after initial manufacture, or thermosetting, crosslinked materials that cannot be reshaped after initial manufacture. Some definitions include rubbers and elastomers under the generic term of plastics (which is the convention in this thesis), which is useful for newer materials like thermoplastic elastomers, that sit between the two (Young and Lovell, 1991). For the purpose of this thesis, 'plastic' is generally used when describing the bulk material and 'polymer' when discussing its base. As in the commercial world, the two terms are also used interchangeably.

Naturally occurring polymers include proteins, where amino acids are linked by amide bonds e.g. keratin and collagen, and polysaccharides (carbohydrates) e.g. chitin and cellulose, the fibrous matter in plants (Numata, 2020). Humans have been utilising and adapting naturally sourced polymers for millennia; Animal horn (keratin), and latex from the sap of the Hevea Brasiliensis tree, containing cis-1,4-polyisoprene, (Bottier, 2020) are good examples.

The 19th century saw innovators adapting natural polymers to produce higher performance materials. Vulcanised rubber was developed by cross-linking natural latex using sulphur. Cellulose nitrate, made from cotton was adapted first as Parkesine, then as Celluloid to produce early thermoplastics (Blank, 2013; Plastics Historical Society, 2024). Significant in the development of packaging, Cellophane, a clear film produced from regenerated cellulose using the viscose process, was first made in 1908 and used commercially from the 1920s (Hisano, 2017).

The first fully synthetic plastic was the thermoset Bakelite, phenol formaldehyde resin filled with wood flour, patented in 1909 (Baekeland, 1909). Rapid development followed; all of the plastics commonly used today in packaging i.e. that have been allocated a resin identification code as shown in Figure 1.1, were first synthesised between 1913 and 1957.

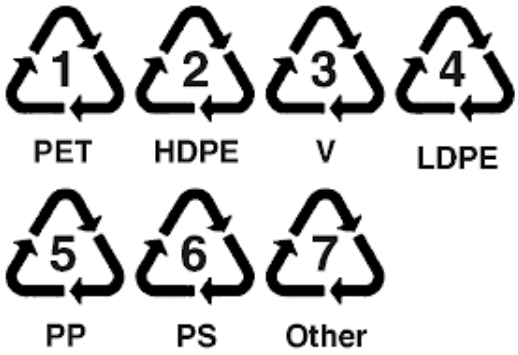


Figure 1.1 *Resin identification codes for plastics commonly used in packaging, adapted from (ASTM, 2022).*

These are polyethylene terephthalate (PET), high density polyethylene (HDPE), polyvinyl chloride (V), low density polyethylene (LDPE), Polypropylene (PP) and Polystyrene (PS). 'Other' covers any other plastics used in packaging including multi-material laminates, e.g. a PE/EVOH/PE co-extrusion.

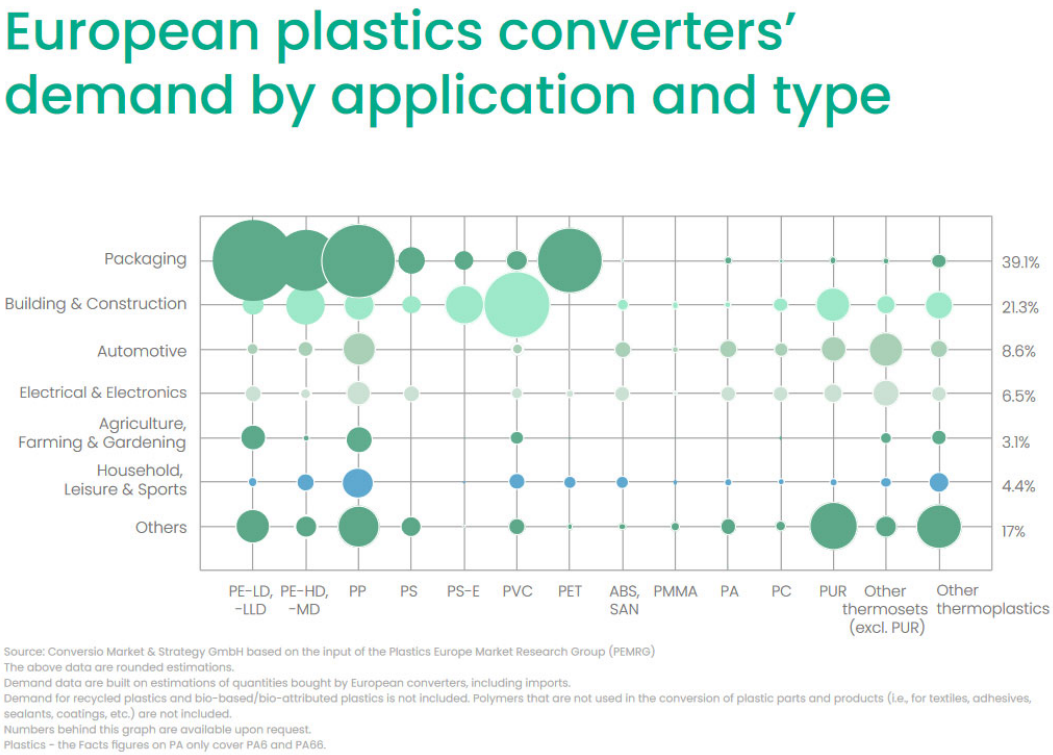


Figure 1.2 *European plastics converters' demand by application and type (Plastics Europe, 2022).*

Global plastics production, for all applications, has grown from 2 million tonnes per year in 1950 to 460 million tonnes in 2019 (Hannah Ritchie et al., 2023).

Figure 1.2, reproduced from Plastics Europe, shows European plastics converters' demand for plastics by application and type. Packaging is by far the biggest application, and the polyolefins are the biggest volume plastics.

1.2 Packaging

Packaging can be described as 'a coordinated system of preparing goods for transport, distribution, storage, sale and use' (Soroka et al., 1996). Beyond its most basic purpose of containment (Yam, 2009), packaging's functions can be divided into three main areas: those that 1) protect the product, 2) facilitate the handling of the product through the supply chain, and 3) communicate (Lindh et al., 2016b). In other words, packaging's functions are to *contain*, *protect* and *preserve*, *inform* and *sell* to the consumer, and provide a level of *convenience*, within *economic* and *environmental* constraints (Soroka et al., 1996). By these definitions, packaging has been in existence for as long as people have traded goods, and as trade has grown has developed with it to become a multi-billion dollar global industry, predicted to have a turnover as large as $1.4 trillion by 2030 (Singh, 2022).

Packaging is divided into three main levels - primary, secondary, and tertiary. Primary, or consumer packaging comprises all components that are sold with a single product (or multi-pack) to the consumer, secondary or collation packaging is what is used to group the primary packs for distribution (e.g. a 'corrugate' box, or a returnable plastic crate), and tertiary packaging is what groups the secondary packaging, e.g. a pallet, stretch wrap and pallet labels. Shipping containers or tankers are not considered as packaging in EU/UK legislation. In addition, postal packaging is becoming increasingly important with the rise of home delivery and e-commerce (often just called e-commerce packaging), and also foodservice packaging - containers used for fresh food and drink, usually filled at the point of sale, e.g. a single-use coffee cup or burger clamshell. The majority of consumer packaging is single-use, often with a short use time (George, 2020), foodservice packaging in particular, which in some cases can be just moments. Only 2% of consumer packaging is thought to be reusable.

1.2.1 Modern packaging materials

For context, this section discusses the major current packaging materials, including raw materials, manufacturing methods, applications and recycling methods.

Plastic is the most common material used for packaging. Flexible plastics (films) and rigid plastics (everything else) account for over 44% by sales of the global market, followed by paper and paperboard (cardboard) (33%), metal (12%), glass (6%), and the remaining 5% covering all other materials (e.g. wood and ceramics) (Statista, 2022). These are listed below in chronological order of application in the field of packaging.

1.2.1.1 Paper

Used as long as 2000 years ago in China to protect precious items (Harford, 2017), paper is made from cellulose fibres pressed and held together through hydrogen bonding. Cellulose is a natural biopolymer, $(C_6H_{10}O_5)_n$, and is the main substance in plant cell walls. For modern paper, it is sourced from wood, which comprises of bundles of cellulose fibre bound with lignin and hemicellulose. The fibres are extracted by pulping, either mechanically or chemically, where the lignin is removed. The fibres are then treated further in water, and additives are included to control the final properties of the paper. This mixture, which is 98% water, is then processed in machines which separate the pulp from the water, compress the paper through a series of rollers and dry it. This process makes paper one of the most water-intensive of the basic packaging materials to manufacture (Ashby, 2013).

Coatings can then be applied, e.g. clay for smoothness (Atkinson, 2023). The finished substrate is then sold to packaging companies, which print and convert it into packaging, such as cartons or labels.

Waste paper and card are recycled by being re-pulped, de-inked and used as a percentage in new paper or a 100% recycled material. There is a noticeable difference in quality between recycled and virgin grades. This is because the strength of paper is related to the length of the cellulose fibres, and each time a fibre is recycled it is exposed to conditions that could damage it. The resulting substrate is usually grey in colour from ink residue. It is a common belief in the paper industry that a paper fibre can be recycled up to 7 times (MM Group, 2022).

1.2.1.2 Glass

Glass bottles have been used for wine since at least the 4th century (Wheeler, 2024). Soda-lime-silica glass, soda glass, is used for making bottles, jars and window glass. It is made from silica, SiO_2 in the form of high purity sand (68-73%), sodium carbonate, Na_2CO_3 (10-15%), lime added as limestone, $CaCO_3$ (10-13%), Alumina Al_2O_3 (1.5-2%) and other compounds in smaller amounts. These raw materials are fused in a furnace at a temperature of 1500°C in a continuous process. The molten glass is moulded immediately into containers. Unlike pure silica, which has a crystalline structure (e.g. quartz), the sodium ions act as a network modifier, breaking up the regularity making it amorphous; the lime is added to decrease the water solubility of the sodium ions. This produces a material of high clarity and chemical resistance, but that is heavy and fragile when compared to other materials used for packaging. It is impervious to gas and liquids (Anderson et al., 1990; Soroka et al., 1996).

Glass is recycled into new containers by being crushed into cullet and added to the furnace with the raw materials. Advances in collection and sorting technologies mean that glass with recycled content can be as good a quality as virgin glass. Although proponents of glass claim it is 'infinitely recyclable', much of post-consumer glass packaging ends up as aggregate or is spun into glass fibre for insulation (British Glass, 2024).

1.2.1.3 Metals

Steel

Steels used in packaging are low-carbon steels plated with either tin or chromium. Canisters made from tin-plated steel were used for tobacco as early as the 18th Century. Pig iron is extracted from iron ore, containing iron oxides, in a blast furnace at a temperature of up to 1300°C, is converted into low-carbon steel in a second furnace, cast into slabs and hot-rolled into coils, which are then processed further to tailor the finished properties for the intended application. Steel is used in food cans, beverage cans, jar lids, paint cans and gift tins (Arcelor Mittal, 2024). Food canning, developed in the early 1800s, is its most important application, making it possible to preserve food which can then be stored at ambient temperatures for a number of years (Soroka et al., 1996).

Aluminium

Because of its high reactivity, aluminium is extracted from its ore, bauxite, using electrolysis, which is an extremely energy-intensive process. Once the metal is extracted from the ore, the processing is similar to that of steel.

Aluminium is used for drinks cans, ovenable food trays, screw caps and collapsible tubes. Its high ductility means that it can be rolled into very thin foils (9 to 20 µm), which can then be used to provide a high gas and water vapour barrier in laminated flexible packaging (see 1.2.1.4). It is also used as a nano-scale coating on metallised plastic films, used extensively for snack food packaging.

Steel and aluminium are both easily sorted for recycling. Steel is magnetic and can be separated with magnets, while aluminium is extracted using eddy current separation. Food and drink cans from both metals have a lacquer (plastic) coating that acts as a barrier to prevent the metal from tainting the contents. They are recycled by being melted back down, any lacquers or inks burning off in the process. Because they are metals, steel and aluminium can be recycled repeatedly without any loss of quality.

Aluminium has the highest embedded energy of all of the basic packaging materials, and its extraction is water-intensive (Ashby, 2013). It is considerably more energy-efficient to recycle aluminium than it is to extract it from raw materials.

1.2.1.4 Plastic

Although there is a growing industry in bioplastics, 99.5% of plastic currently placed on the market is derived from oil (European Bioplastics, 2024). Plastic has distinct advantages over other materials, being cheap, lightweight, and easy to process. Different types of plastic have desirable properties such as high moisture vapour barrier, high gas barriers, and low sealing temperature. Films made from different plastics are often laminated or co-extruded together to create a composite material with superior properties to a mono-material equivalent, for example, the lightweight flexible pouches which have replaced cans for pet food.

All of the most commonly used plastics in packaging apart from PET are vinyl polymers, LDPE and HDPE, PVC and PS. These have a carbon backbone with hydrogen atoms attached and different pendant groups depending on the monomer (see Figure 1.3).

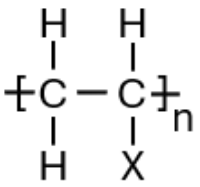


Figure 1.3 *Vinyl polymer formula: X is H for PE, Cl for PVC, CH_3 for PP and styrene for PS*

The chemical structure of PET is shown in Figure 1.4 below.

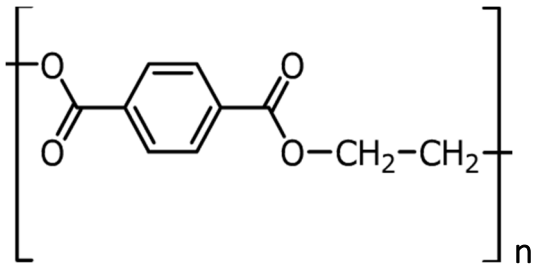


Figure 1.4 *Formula for PET*

PET, $(C_{10}H_8O_4)_n$, a polyester, is synthesised from two monomers, ethylene glycol and terephthalic acid.

EVOH, another vinyl polymer and nylon, a polyamide (PA) are used in coextrusions with PE to enhance barrier properties. PVDC and acrylic have also been used as barrier coatings. All of these are thermoplastics. Thermosets are rarely used in packaging applications, although they have been used as lids and screwcaps in the past (S. Greenwood, 2018).

Plastics are used to make carbonated drinks bottles, milk bottles, ready meal trays, fruit punnets, shrink-films, stretch-wraps, overwraps, gas-flushed packs for fresh meat and crisp packets, and are an integral component of many composite packaging materials (see below).

The recyclability of plastic is discussed in 1.5.1.

1.2.1.5 Composites

In a packaging materials context, composites are multi-material components where the individual components can't be easily separated. Examples include beverage cartons, and cans made from a laminated fibre tube attached to a metal base.

1.3 Food waste

Although the primary aim of this work is to investigate the reduction of single-use plastics waste, it is impossible to do so without considering the relationship between packaging and food waste. On a global scale one third of food produced for human consumption is lost or wasted (Gustavsson et al., 2011). The narrative that 'packaging prevents food waste', whilst true at the most basic of levels, is an oversimplification. The relationship between the two is beginning to be examined in an academic context (Brennan et al., 2021), and Chapter 5 examines this in detail in the context of the removal of packaging from fresh produce.

1.4 The problem with plastic

1.4.1 Recycling

Thermoplastics are mechanically recycled by being shredded, heated to above their melting point, and then formed back into pellets to be used again. However individual plastic types have different melting temperatures and are immiscible once molten. This immiscibility can be explained using the Flory-Huggins theory, which uses thermodynamics to determine whether a polymer and a solvent, or a polymer and another polymer will mix. It is based on the Gibbs energy of mixing (Equation 1.1). The Flory-Huggins equation (1.2) recast the Gibbs energy of mixing for two polymers, 1 and 2.

$$\Delta G_{mix} = \Delta H_{mix} - T\Delta S_{mix} \qquad \textit{Equation 1.1}$$

$$\frac{\Delta G_{mix}}{RT} = \frac{\Phi_1 ln\Phi_1}{N_1} + \frac{\Phi_2 ln\Phi_2}{N_2} + \Phi_1\Phi_2\chi \qquad \textit{Equation 1.2}$$

Where:

R is the gas constant

T is absolute temperature

Φ is the volume fraction, $\Phi_1 + \Phi_2 = 1$

N is the molecular weight

χ is the interaction parameter, and typically ≤ 0.5 in value

For mixing to occur spontaneously, ΔG_{mix} must be negative. The entropy of mixing, the first two terms on the right of 1.2, are very small and negative, so the equation is dominated by the third term, the enthalpy of mixing. χ is the Flory-Huggins interaction parameter. It can be determined through calculation or experiment and is typically ≤ 0.5 in value (Ronald Koningsveld et al., 2001), making ΔG_{mix} positive and therefore mixing not possible. Whilst it might be expected that two very different polymers, say PE and PET, won't mix, the effect is so strong that even isomeric polymers, PE and PP, which are both alkanes, won't mix either.

Chemical compatibilisers are available and it is possible to create a mixed recycled material, but this generally has much lower functional properties than the original polymers in isolation. A typical application is for use as an alternative to wood for benches and decking. In order to extract the maximum value from waste plastic packaging by recycling, the plastic components therefore have to be sorted and processed separately. Furthermore, the presence of coloured plastic, and additional components such as caps and labels can affect the quality (and hence the commercial value) of the recycled material, either through pigment and ink, or by being a different material which acts as a contaminant (RECOUP, 2021). The presence of pigment can also impair the sorting process - carbon-black pigment is opaque to the near-infrared of the sorting lines in materials recovery facilities (MRFs).

Even once post-consumer plastic items are sorted into material types, there are then differences in material grades and compounds that are included to improve the original materials' performance: antioxidants, processing aids, slip or antistatic additives. A plastic's formulation can be tailored exactly to requirements when virgin polymer is used, but when recycled content is introduced, there is an increased level of variability.

There is the added complication that thermal processing causes polymers to degrade. In the polyolefins (PE and PP) this is by bond scission of the polymer backbone and cross-linking, decreasing the molecular weight and altering its physical properties. The ester linkage in PET makes it susceptible to degradation (Schyns et al., 2023). This however can be reversed by employing solid-state polycondensation which increases the molecular weight (Cruz and Zanin, 2006;

Polymetrix, 2024). This is one of the reasons PET recycling rates and post-consumer recyclate inclusion rates are so high compared to HDPE (it is possible to make a bottle from 100% rPET; the maximum rHDPE inclusion rate is less than 50% (Gaduan et al., 2023).

The complexities of the sorting and recycling process, the fact that the resulting resins often must be downcycled, and that virgin resin is usually cheaper than recycled materials, have done little to encourage growth in the plastics recycling industry. Plastics are the least recycled of all the common packaging materials. This is reflected in the domestic waste recycling rates for different packaging materials in the UK - Glass, Metal, and Paper, which are (relatively) easier to sort and process, have recycling and recovery rates of 66%, 68%, and 74% respectively, while Plastic sits at 51%. According to the plastics recycling charity RECOUP, only one third of 'pots, tubs and trays' and just 7% of plastic film were collected from households for recycling in 2018. This compares to 59% for plastic bottles, used for Milk and Soft Drinks. Some of the UK's plastic waste is sent abroad for processing, resulting in concern among NGOs and the public that it is not being processed properly. What is not collected for recycling is sent to landfill or incineration with general household waste.

1.4.2 Foodservice and food-to-go packaging

The amount of takeaway packaging placed on the market in the UK was 1.2M tonnes in 2019, 220kT of which was plastic (Burrows, 2022). Only a tiny fraction of takeaway food packaging is recycled. This is because the food is often consumed and the packaging disposed of on the go, and any food residue contaminates the recycling stream (Smithers, 2019; Wilson et al., 2022). Food containers and cutlery account for 9 % of all litter items found across aquatic ecosystems worldwide (50% of all litter items are plastic packaging, e.g. bags, bottles ancccd bottle caps) (Morales-Caselles et al., 2021).

1.5 Waste management of post-consumer packaging

The default option only a quarter of a century ago was to design single-use items to be thrown away and forget about them - at the time of the introduction of the UK landfill tax in 1996 (Seely, 2009), 90% of household waste was sent to landfill and only 5% was recycled (Hughes et al., 1996). Two years previously, in 1994, the

European Parliament and Council Directive 94/62/EC on Packaging and Packaging waste was published. The resulting legislation meant each member state of the EC (of which the UK was one) was given targets for the recycling of waste packaging, and it is these targets and the introduction of the Doorstep Recycling Act of 2003 that have driven recycling rates to the present levels.

1.5.1 The European Waste Framework Directive and the Waste Hierarchy

The European Waste Framework Directive 75/442/EEC was first introduced in 1975, (Commission regulation, 2006).

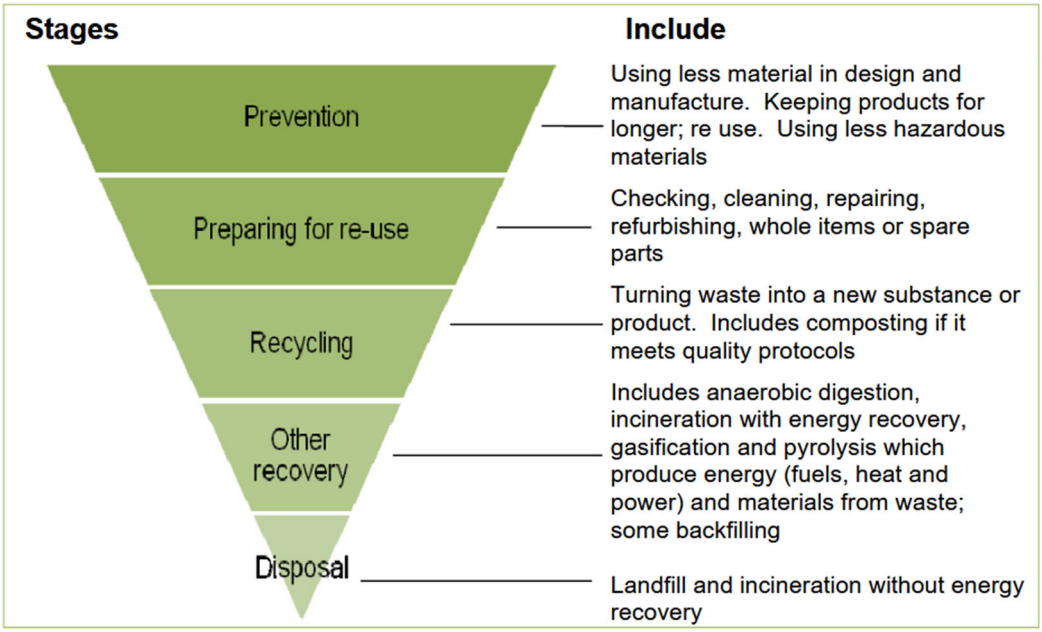


Figure 1.5 *The Waste Hierarchy, showing waste treatment options in order of preference: prevention, preparing for reuse, recycling, other recovery and disposal. Source - Guidance on applying the Waste Hierarchy, Defra (Crown, 2011).*

It wasn't until a major revision in 2008 that the concept of the Waste Hierarchy was introduced in a legislative context for Europe (C. Zhang et al., 2022). Figure 1.5 shows the waste hierarchy as included in the UK government's guidance for application. The waste hierarchy is intended for application to all sources of waste, so there are some incongruencies when applied to packaging: 1) Preparing for reuse in terms of packaging requires a whole new infrastructure to allow for new containers and the reverse logistics to allow them to be washed and used again (although sadly now so does the reconditioning of, say a washing machine, and the introduction of 'right to repair' regulations). 2) For compostable plastic packaging,

composting merely converts the material into CO_2, H_2O, and a small amount of heat and biomass (BSI, 2000a) so it is difficult to justify this as recycling. 3) For some packaging there is also a tension between prevention and recycling - combining materials into a composite or laminate can minimise the amount of resources needed, but also render it unrecyclable. If considering CO_2 emissions as well as solid waste, there is now also an argument that incineration, rather than landfill, should be at the bottom of the hierarchy (Stallard et al., 2024).

1.5.2 The circular economy

The concept of a circular economy has been growing in popularity over recent years and is, like the waste hierarchy, now embedded in EU legislation. The transition to circularity is recognised as a route to a thriving economy within the Earth's planetary boundaries. Instead of the traditional linear model where materials are extracted, turned into products and then disposed of ('take, make, waste'), a number of strategies can be employed, including sharing, repair, reuse, remanufacturing, and recycling to keep material in circulation for as long as possible, thus saving resources (Stahel, 2016). Although definitions of the circular economy differ, they almost all take the form of 'Reduce, Reuse, Recycle' (Kirchherr et al., 2017).

The Ellen MacArthur Foundation has been instrumental in communicating the concept (see Figure 1.6), particularly in the field of plastic pollution. Their New Plastic Economy initiative (EMF, 2018a) has resulted in the New Plastics Economy Global Commitment and a series of country-specific Plastics Pact commitments, beginning with the UK Plastics Pact introduced in May 2018. These are voluntary agreements; signatories include large actors across the plastic packaging value chain.

Early efforts to move to a circular economy for plastics have focussed on recycling (Ghisellini et al., 2016), with recycling targets for all materials introduced for all EU states. Prevention, or reduction, has been encouraged to a lesser extent - the 1994 regulations have a rather vague statement that the 'minimum amount' of packaging should be used, and the original UK Courtauld commitment from 2005-2009 set targets for weight reduction of packaging of all materials on a voluntary basis.

It is worth noting that the circular economy principle as presented by the EMF (Figure 1.6) does not explicitly take into account social or economic factors, rather

it is assumed that these are taken care of by circularity. In a global context, social and economic factors are covered by the UN's definition of sustainable development.

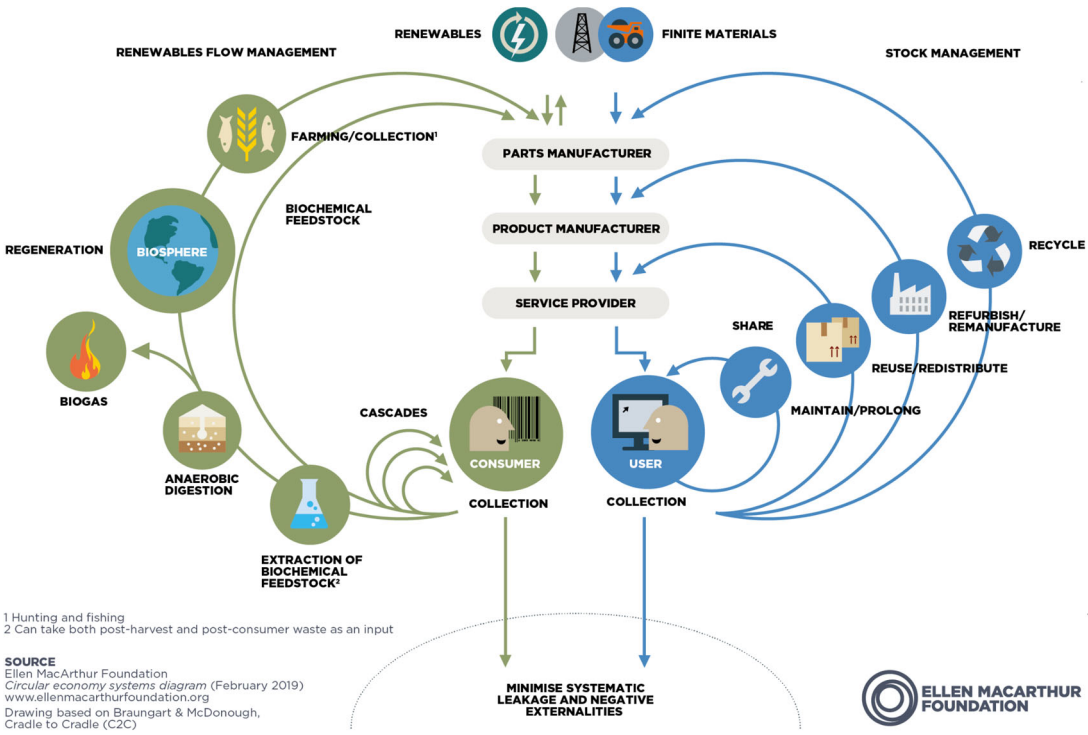


Figure 1.6 *The EMF circular economy systems diagram, showing renewable processes on the left and finite materials on the right (Ellen MacArthur Foundation, 2019).*

1.5.3 Sustainable development

The United Nations define sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." (UN, 2024). It is often described as having 3 components - social, environmental and economic sustainability, which all need to be satisfied, and is represented as a Venn diagram (Figure 1.7). This concept is also known as the three pillars of sustainability, the triple bottom line, or simply 'people, planet, profit', (Purvis et al., 2019).

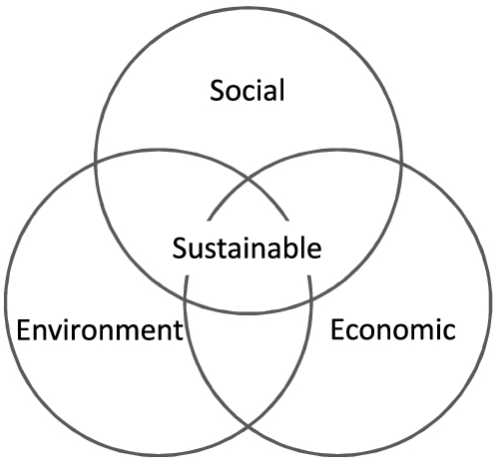


Figure 1.7 *taken from* (Purvis et al., 2019). *Typical representation of sustainability as three intersecting circles.*

This definition provides a useful lens through which to understand a situation from a general point of view. The 17 UN sustainable development goals that followed are much more specific (United Nations, 2024).

1.6 Legislation and voluntary agreements

The most significant legislation relating to plastic packaging in the UK currently is the Packaging Essential Requirements Regulations (PER) (legislation.gov.uk, 2015) and the Producer Responsibility Regulations (Packaging Waste) (legislation.gov.uk, 2007) which both originate from the EU's Packaging Essential Requirement Regulations of 1994 (European Union, 1994).

The former sets out what is acceptable under law for the composition of packaging materials (e.g. the exclusion of heavy metals, ensuring that materials are recyclable or recoverable) and the latter obliges companies to be (partially) responsible for the recycling of the packaging they place on the market in order for country-wide recycling targets to be set, originally via the EU and now through the Resources and Waste Strategy. The UK Landfill tax was introduced in 1996 in order to help achieve these targets (Seely, 2009).

These laws are no longer seen as fit for purpose as household recycling rates have plateaued, so legislation is currently being updated both in the EU and the UK in once-in-a-generation reviews. In 2018, the EU adopted a European Strategy for Plastics (European Commission, 2022a) and the UK Government launched both its 25-year environment plan (gov.uk, 2018a) and the Resources and Waste Strategy

for England (gov.uk, 2018b). Equivalent strategies exist or are in development for all UK nations (Scottish Government, 2016; UK Governments, 2020; Welsh Government, 2021). Following the announcement of the 25-year environment plan, consultations have subsequently taken place on several proposed regulations which would help the drive towards a circular economy. These include a plastics packaging tax (implemented in April 2022) (HM Revenue and Customs, 2022), a deposit return scheme (DRS) for drinks bottles, Extended Producer Responsibility ('the producer pays'), an overhaul of the producer responsibility regulations (DEFRA, 2022), standards for bio-based, biodegradable and compostable plastics, and consistent collection of waste packaging from households across the UK (now revised as 'Simpler Recycling' (Defra, 2023)). The 25-year plan has the specific target of **ending all avoidable plastic waste by 2042**.

The UK Environment Bill was announced in 2018 to replace EU environmental legislation post-Brexit and as a vehicle to implement the 25-year plan (Harvey, 2021), becoming law as the Environment Act in November 2021 (gov.uk, 2021). In March 2022, the United Nations Environment Assembly (UNEA-5) adopted a mandate calling for the development of a global treaty on plastics with a target for adoption of 2024 (UNEP, 2022) and in November 2022 the EU issued a draft update of the 1994 Packaging and Packaging Waste Directive (European Parliament, 2022; European Union, 1994) which was adopted in March 2024 (European Parliament, 2024). The legislative landscape relating to packaging waste is therefore complex and multi-faceted to say the least.

Running in parallel to the work on legislation, there have been several voluntary commitments to reduce packaging and food waste led by WRAP:

1.6.1 The UK Plastics Pact

The UK Plastics Pact (WRAP, 2018) was introduced in May 2018. A voluntary commitment with the aim of making plastic packaging more circular, signatories agree to aim for the following targets by the end of 2025:

1. Eliminate problematic or unnecessary single-use packaging through redesign, innovation or alternative (reuse) delivery model.
2. 100% of plastics packaging to be reusable, recyclable or compostable.
3. 70% of plastics packaging effectively recycled or composted.
4. 30% average recycled content across all plastic packaging.

1.6.2 Courtauld 2030

Courtauld 2030 (WRAP, 2022a) is focused on reducing food waste, cutting carbon and protecting critical water resources. It has built on previous voluntary agreements since the Courtauld Commitment, or Courtauld 1, named after the art gallery where its launch event was held in July 2005. Courtauld 1 covered both food and packaging waste, the packaging component focussed solely on weight reduction of primary packaging and included all materials (WRAP, 2024a). The food waste target of Courtauld 2030 is aligned with the United Nations Sustainable Development Goal 12.3 on food waste (UN, 2022a). The full set of targets are:

> For food waste: To deliver against UN SDG 12.3: a 50% per capita reduction in food waste by 2030 vs the UK 2007 baseline (covering manufacture, retail, hospitality and food service, and household).
>
> For GHG emissions: To deliver a 50% absolute reduction in GHG emissions associated with food and drink consumed in the UK by 2030 (against a 2015 baseline).
>
> For water: With an overall target by 2030 that: 50% of fresh food is sourced from areas with sustainable water management (WRAP, 2022a).

Courtauld 2030 does not include packaging, instead this is covered by the UK Plastics Pact (see 1.7.1).

1.7 Work presented in this thesis - the elimination of single-use plastic packaging

The work presented in this thesis looks at the reduction of single-use packaging through the introduction of reusable packaging systems and by selling products with the consumer packaging eliminated altogether, rather than the conventional approach of increasing the recyclability of plastics.

1.7.1 Reuse

Reuse is defined in EU regulations as ‘any operation by which products or components that are not waste are used again for the same purpose for which they were conceived’ (European Union, 1994). This can cover consumer goods such as reconditioned electrical goods and furniture, and reclaimed construction materials.

There is a nascent industry in the provision of the logistics for the reuse of consumer goods at scale (SUEZ, 2023).

The amount of raw material utilised, and the effort required to convert it into containers make the case that there has always been an element of commercial packaging reuse. Evidence for this includes clay amphorae found in a Mediterranean shipwreck showing signs of previous use (Twede, 2005), and that 19th-century manufacturers employed various tactics to retrieve bottles and jars used for their products (Tom Licence, 2020).

Whilst in the 20th century, milk and fizzy drinks were delivered to doorsteps, and beer was supplied to pubs in returnable glass bottles, the majority of packaging placed on the market today is single-use; in the 1970s, 94% of milk was supplied in this way, but this declined to less than 3% in 2018 (Parsons in Greenwood et al., 2020). Reuse is limited to business-to-business packaging (such as beer kegs or returnable plastic crates used for fresh produce), beverages (e.g. in Germany and Denmark for beer and carbonated drinks), a few consumer refill packs (e.g. instant coffee and cleaning products), and bring-your-own container options in 'zero waste' stores or for takeaway hot drinks.

However, there is increased interest in reuse models as an option to save both solid waste and carbon emissions. Numerous brands have signed up to voluntary schemes like the New Plastics Economy Global Commitment (EMF, 2018b) and national Plastics Pacts (USPP, 2020; WRAP, 2018), which include targets to investigate and implement reusable packaging systems by the end of 2025. A multitude of different schemes have been trialled or are operating at a niche level, documented by EMF, (2019), Coelho et al. (2020), and online platforms such as the Reuse Portal and Planet Reuse (Planet Reuse, 2024; The Reuse Portal, 2024). Despite the number of formats, all of these schemes can be divided into either *Refill*, where a container stays in the possession of one individual for its service lifetime, or *Return* (also known as *Reuse* or *Prefill*), where a container is returned, washed, refilled and used by multiple individuals over its lifetime.

However, the implementation of reuse schemes is low (George, 2020). For the schemes to be successful, they must be something that consumers are willing to engage with and be viable both financially and environmentally. Multidisciplinary research at the University of Sheffield led by the Grantham Centre for Sustainable

Futures investigated the barriers and enablers to making reusable packaging mainstream, part of which is included in chapters 2, 3 and 4 of this thesis.

1.7.2 Packaging elimination

By law, packaging should already use the minimum amount of material - the UK Packaging Essential Requirements Regulations state:

> *"Packaging shall be so manufactured that the packaging volume and weight be limited to the minimum adequate amount to maintain the necessary level of safety, hygiene and acceptance for the packed product and for the consumer."*

This was supported by the first voluntary Courtauld Commitment (2005) administrated by WRAP, which had a target for packaging weight reduction for components of ALL materials, not just plastic.

More recently, Target 1 of the UK Plastics Pact (2018) is for the elimination of 'Problem Plastics' where WRAP ask signatories to:

> *"Eliminate problematic or unnecessary single-use [plastic] packaging through redesign, innovation or alternative (reuse) delivery model[s]"*

Examples of these include components made of PVC and PS, which are not recyclable in the UK, plastic wrapping for multi-sales of tins, bottles and cartons, and plastic packaging for uncut fresh fruit & vegetables.

The work presented in Chapter 5 of this thesis investigates the removal of packaging from fresh produce, including past trials and a policy analysis.

Combined, the chapters presented here investigate alternatives to the default scenario of recycling as a waste management strategy for plastic packaging, looking towards a more circular future.

1.8 Summary of chapters, research questions and methods used

Chapter 2 includes an LCA which is used to answer the questions 'Does the material used to make the container make a difference in a reuse system for takeaway food?', 'Is reuse better than single-use?', and 'Is return better than refill?'. A survey was used to determine what products people are willing to reuse the

packaging for and which aspects of packaging containers influence whether people will want to reuse them.

Chapter 3 uses a real-world example as a living lab to examine how much wear and staining people will accept on containers used for a takeaway food bowl borrowing scheme and applies an LCA methodology to determine the break-even points for carbon and water for the containers vs single-use.

Chapter 4 addresses the barriers and enablers to there being a national infrastructure for the sale, collection and reuse of returnable pots for multi-serving yogurt. These were investigated via a stakeholder workshop to co-create a hypothetical model, semi-structured interviews and the application of a socio-technical framework, the Multi Level Perspective (MLP).

Chapter 5 addresses the questions 'ls going packaging-free the answer to the UK's plastic waste problem for fresh fruit and veg?' and 'How well aligned are supermarket packaging policies on food waste and packaging waste with the UKPP and the Courtauld 2030 voluntary agreements?'. A literature review of traditional and non-traditional sources is used alongside a policy coherence analysis. Alternatives to selling fresh produce loose (and reuse) are discussed.

Chapter 6 includes an overall discussion. The results and conclusions from the 4 original research chapters are discussed in more depth and recommendations made for future research to work towards eliminating single-use plastic packaging in the UK.

2 Many Happy Returns: Combining insights from the environmental and behavioural sciences to understand what is required to make reusable packaging mainstream

2.1 Background and Summary

2.1.1 Background

This chapter is based on the paper 'Many Happy Returns: Combining insights from the environmental and behavioural sciences to understand what is required to make reusable packaging mainstream' for which the candidate was the lead author (Greenwood et al., 2021). It was a main output from the Reuse proof of concept study that was part of the project 'Plastics: Redefining single-use' EP/S025278/1 funded by the Plastics Research and Innovation Fund, running for two years from January 2019. The aim of the PRIF was 'to explore novel ideas and innovations with the potential to make the plastics sector more circular and address the challenge of persistent plastic pollution.' (UKCPN, 2020).

There were 38 co-investigators from all faculties of the university, 7 post-doctoral research associates, a packaging technologist (Greenwood) and support staff. People were divided into four Competency and Capability Teams (CCTs): 1) Technological feasibility, 2) Environmental and Techno-economic Assessment, 3) Understanding Social Change, and 4) Promoting Behavioural, Organisational and Social Change irrespective of their own discipline, and worked on their own research. At the start of the project in January 2019 a two-day workshop was held with all Co-Investigators, the project PDRAs, representatives from the PRIF projects from other universities, and stakeholders from industry and the third sector. This first workshop was used to identify seven possible topics for proof-of-concept studies, which the university team rationalised over the next few weeks to three. The final chosen topics addressed the issues of 1) single-use plastics used in dentistry, 2) in Agriculture, and 3) Reusable Plastic Packaging. Researcher time in Psychology (CCT 4), Social Science (CCT3), Environmental Assessment (CCT2), and Polymer Science (CCT1) was made available to each of the proof-of-concept studies. A further two workshops, in March and July 2019, again with participants from the university, industry and the third sector were used to develop our

overarching research question '**How do we facilitate reuse as mainstream?**' and expand on this.

The work presented in this chapter combines the Environmental Assessment and Psychology aspects of the work, with additional input from a Linguistics colleague. SG led the Reuse proof of concept study and contributed to both studies used in the paper. She devised the single-use to reuse scale, and set the questions and facilitated the discussions in the workshops. In the behavioural work, she advised on reuse types, packaging and product characteristics, and contributed to the coding and interpretation of the results. SG set the research question for the lifecycle assessment: how does the environmental impact of takeaway food containers change as a result of different use models: single-use, refill (the customers' own) or return (borrowed from the restaurant), and different materials (different kinds of plastics and non-plastics)? She compiled the first draft of the paper, wrote the common sections, edited the specialist sections, supervised the revisions and was the corresponding author.

The paper was published in 2021. The team won the 2022 Institute of Chemical Engineers (IChemE) Hutchison Medal, which is awarded for 'a contribution to the literature that has stimulated debate within the chemical engineering community'. Further output from the Reuse POC included 1) the PRIF conference paper 'Buy the product but rent the packaging - making reusable plastic packaging mainstream' (Greenwood et al., 2020) which included short versions of the Environmental Assessment and Psychology POC work, with further work from Human Geography, a socio-technical (social and technical) analysis of the decline of doorstep milk delivery in the UK, and a discussion of the technical challenges associated with the repeated washing of plastic containers. 2) A technical report on existing commercial washing technology (Naomi Brown, unpublished, but used within the project). 3) The Understanding Social Change CCT produced the paper 'Understanding plastic packaging: the co-evolution of materials and society' (Evans et al., 2020) which included a case study on the use of refill for personal care products by the retail chain The Body Shop, drawing on a blog by SG (S. Greenwood, 2018), and 4) the successful application to the Smart Sustainable Plastics Packaging Challenge for the project 'Many Happy Returns: Enabling reusable packaging systems' NE/V010638/1 (See Chapters 3 and 4).

Author Contributions: **Sarah C. Greenwood**, Chemistry, study lead, lead and corresponding author, investigation (see above); **Stuart Walker**, Chemical and Biological Engineering (CBE), investigation (LCA); **Harriet M. Baird**, Psychology, investigation; **Rorie Parsons**, Geography and Planning, project team; **Seth Mehl**, the Digital Humanities Institute, input on linguistics; **Thomas L. Webb**, Psychology, supervision; **Andrew T. Slark**, Chemistry, project team; **Anthony J. Ryan**, Chemistry, PI and supervision; **Rachael H. Rothman**, CBE, supervision

2.1.2 Summary

The introduction of reusable packaging systems (both refill and return) has the potential to significantly reduce waste from single-use plastic packaging. However, for these schemes to be successful, both the environmental impact and the willingness of consumers to engage with such systems need to be carefully considered. This chapter combines and discusses two complementary studies: (i) a life cycle assessment comparing the environmental impacts of single-use, refillable, and returnable containers for a takeaway meal, and (ii) a large online survey of UK adults exploring what types of product and packaging consumers are willing to reuse, how, and why. The findings of the life cycle assessment indicate that reusable containers outperform single-use plastic containers on most measures of environmental impact. The survey found that given the choice of disposal, reuse or recycling, that recycling is the preferred method of dealing with packaging once empty in the UK, and that people's decisions regarding what types of packaging they are willing to reuse are largely driven by the aspects of the packaging itself (e.g. material and type) rather than the nature of the product inside of the packaging (e.g. the state of matter of the contents). The survey also showed that people were more willing to engage in reuse systems with which they were already familiar. Additionally, the language used to describe these schemes and the term 'reuse' needs to be considered. Combined, these factors can be used to determine the best packaging reuse system for a given product and situation.

2.2 Introduction

An estimated 1.53 million tonnes of plastic primary packaging for consumer goods was placed on the UK market alone in 2017, with just 30% of this being recycled (Thomson et al., 2018). Mismanagement of plastic waste worldwide has contributed to significant pollution and is expected to continue to rise unless action is taken. If current trends continue, 12 billion tonnes of plastic waste is likely to be in landfills or the natural environment by 2050 (Geyer et al., 2017). Through its lifetime, packaging transitions from a position of use, with value and worth, to a position of waste without any of these (Langley et al., 2011); identifying routes to maintain the use, value and worth (e.g. by introducing a monetary deposit for containers, or finding an economically sustainable market for recyclate) is key to reducing plastic packaging waste. One potential way to reduce plastic waste is the implementation of reusable packaging systems. It has also been estimated that replacing 20 per cent by weight of single-use plastic packaging with returnable or refillable systems presents a business opportunity of $10bn globally (EMF, 2019). However, in implementing such benefits (if in fact they are achievable), it is important to ensure that unintended negative impacts do not arise and that consumers are willing to engage with and use a reuse system. There is little point in creating a scheme with low environmental impact if consumers are not willing to engage with the system, and vice versa, a reuse system that consumers are willing to engage with that brings no environmental benefit. It is therefore critical when considering reuse systems to take an interdisciplinary approach considering both environmental impacts and willingness to engage. At the time of this study, there was little available literature on this. The closest is Wever et al., (2013) who balanced the ecological costs of additional packaging features (e.g. the addition of a sports cap to bottled mineral water) with product price into an eco-costs/value ratio (EVR). Whilst this doesn't measure willingness to engage in reuse behaviour, acceptability to the customers is measured by what they are willing to pay.

The work presented here combines insights from the environmental and behavioural sciences to start to understand what is required to make reusable packaging mainstream. For any given reuse system, it is important to identify a suitable material, packaging format, and reuse model; The first study in this chapter uses Life Cycle Assessment (LCA) to consider the environmental impact of a range

of possible reusable packaging options for takeaway containers. On-the-go food packaging is seen as a problem area for packaging waste due to a lack of recycling infrastructure (S. C. Greenwood, 2018) and the level of contamination from leftover food (Smithers, 2019). It is difficult to establish an accurate figure for the total weight of global takeaway and food-to-go packaging; anything that is reported is normally the market value in dollars. In the USA, however, over 7.5 billion single-use extruded polystyrene (EPS) containers are used annually (58,500 tonnes) and over 1.8 billion single-use aluminium containers in the UK (13,680 tonnes) (Gallego-Schmid et al., 2019). Whilst the life cycle of refillable (customer-owned) takeaway containers has been compared to single-use plastic in the past (e.g. Gallego-Schmid et al., (2019)), when this study took place, the comparison with returnable (company-owned) and bagasse single-use food containers was novel. Although the technology and materials to produce durable alternatives to single-use packaging exist, little research has explored which types of packaging consumers are willing to reuse, again at the time of the study, no research had considered which methods of reuse consumers prefer for different products and packaging. The second study in this chapter is therefore a large online consumer survey with the aim of understanding what types of packaging people are willing to reuse (and how) and explore factors that influence people's decisions with respect to packaging that they are willing to reuse. The balance between the potential environmental impact of various packaging systems (as identified by LCA) and users' willingness to engage with those systems is then discussed.

2.2.1 Literature review

Reusable packaging systems have been part of EU packaging legislation since 1994 when the European Union stipulated that packaging should be recyclable, reusable or recoverable (European Union, 1994). However, unlike recycling, there were no quotas set by the EU for member states to comply with and no legislative drivers at the EU level. Consequently, up to the current time, reuse has been limited to business-to-business packaging (such as returnable plastic crates used for fresh produce), beverages, a few consumer refill packs (e.g. instant coffee and cleaning products) and bring-your-own container options in, to date, niche 'zero waste' stores. However, there is increased interest in reuse models and numerous brands have signed up to voluntary schemes like the New Plastics Economy Global

Commitment (EMF, 2018b) and national Plastics Pacts (USPP, 2020; Wrap, 2020), which include targets to investigate and implement reusable packaging systems by the end of 2025. New EU legislation now includes targets for reuse (see 6.2.4).

2.2.1.1 Formats of (re)use

There are many different kinds of reusable packaging systems (Coelho et al., 2020; Lofthouse et al., 2009), which can be broadly divided into two main categories - (i) *return*, where the container is owned and cleaned by a business (or group of businesses) and (ii) *refill*, where the container is owned by the consumer after the first purchase and then refilled with auxiliary products (at home) or taken to a refill station (on the go) (EMF, 2019; Greenwood et al., 2020). Figure 2.1 illustrates the different forms of product delivery, ranked in decreasing order of anticipated packaging waste from left to right. Note that the EU definition of reusable packaging is packaging that '*has been conceived and designed to accomplish within its life cycle a minimum number of trips or rotations in a system for reuse*' (BSI, 2004).

Single-use and Repurpose

Single-use refers to packaging which is intended to be used once and is then recycled or disposed of; it is also referred to as 'one way' in the context of reusable packaging systems (Golding, 1999). Repurpose is when packaging is used for a secondary purpose (e.g. a biscuit tin used to keep wood screws in). Research has indicated that consumers often find secondary uses for nominally single-use packaging (Haws et al 2014; Price & Ridgway, 1983), and how it is executed is largely unpredictable (Shipton, 2007), meaning that there is not a clear line between single-use and repurpose.

Refill models

Refill systems are gaining in popularity (Fuentes et al., 2019), especially since the advent of 'zero-waste shopping' (arguably a rebrand of the 'Weigh and Save' style shops popular in the 1980s and 1990s) and could be more appropriate and easier to implement for some products than a return system.

Refill at home (EMF, 2019) is possibly the simplest reuse option to implement for a manufacturer. There is still waste from the single-use packaging used to refill the original pack, but less packaging overall and reverse logistics are not required. A

disadvantage, however, is that the refill packaging is often made from multilayer film which cannot currently be recycled (Coelho et al., 2020).

Refill on-the-go (EMF, 2019) is where the consumer takes the original packaging, or their own container, to a sales point to be filled or refill themselves. In many cases, there is still the issue of packaging waste at the store level (e.g. bag in box containers for the dispensing of liquids, such as Ecover bulk retail packs, use single-use cardboard boxes with hard-to-recycle inner bags (Ecover, 2021)). Reusable coffee cups are a good example of refill on-the-go and although the Covid-19 pandemic in 2020 put a temporary halt to their use, 'contactless' serving techniques were quickly developed to enable their use once again (City to Sea, 2020).

Return models

In return systems the packaging is effectively rented by the consumer and then returned. Various return models have been developed for primary packaging, mainly for drinks bottles (Golding, 1999). A review of the environmental impact of returnable packaging systems across the life cycle (WRAP, 2010a) identified a number of factors that influence the environmental viability of a return model including the burden of manufacture of the containers, the number of cycles that a container will complete in its lifetime, transportation distances, the size of the container pool (i.e. the number of containers in circulation in the system), vehicle utilisation and recycled content/post-consumer recycling. These factors imply that the most efficient return model will utilise containers that: contain recyclable material, are recyclable themselves, are tough enough to have a long life in the system and are nestable when empty to optimise vehicle utilisation. These containers can also be shared between multiple manufacturers of different products to create a collective return model. This type of system has been in operation for a number of years in some European countries, where generic bottles are used (WRAP et al., 2008), and for transit crates e.g. for factory-made bakery products (Bakers Basco, 2021).

In a collective return model, standard types and sizes of containers are delivered to the product manufacturer, or a co-packer (in returnable transit packaging) who fills and labels the containers and distributes them to the retailers. Once the consumer has finished the product, they return the empty container either via a return station or through doorstep collection. A network of local facilities clean and recondition

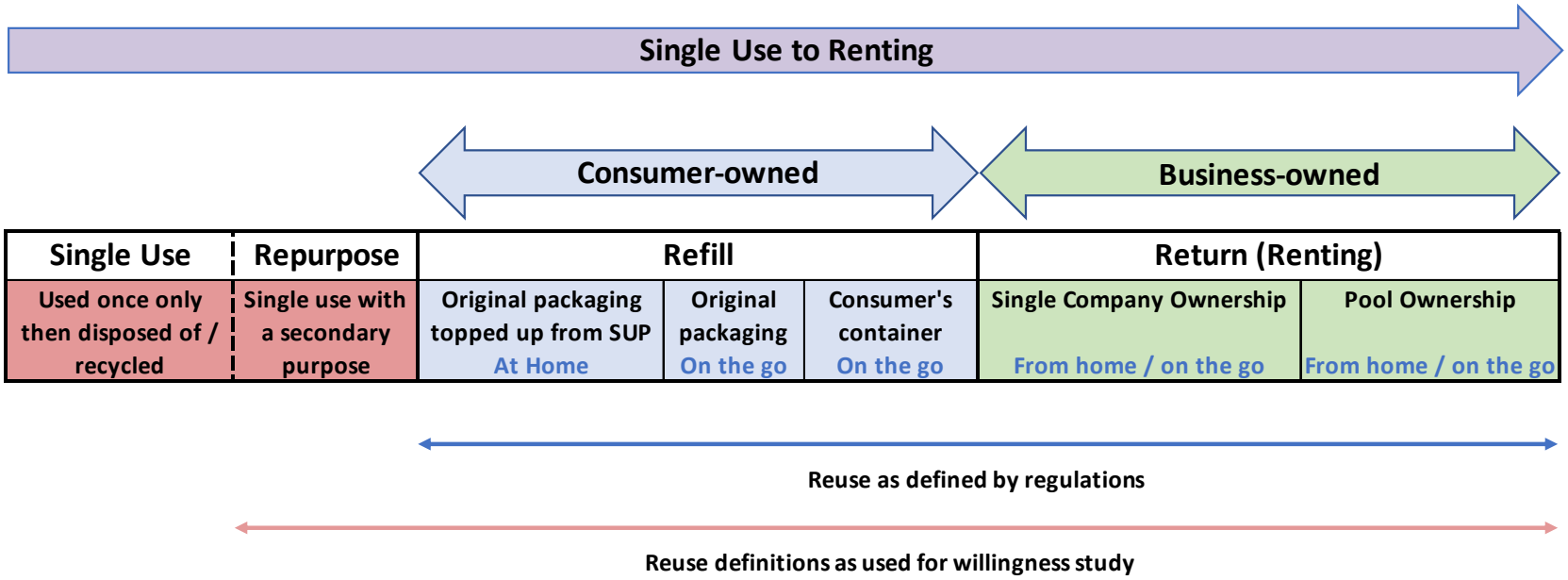


Figure 2.1 *Scale showing single-use to reuse, ordered in decreasing levels of anticipated packaging waste from left to right showing definitions (including the EMF's taxonomy shown in blue) based on (Greenwood et al., 2020).*

the containers and deliver them to the closest of the co-operative of manufacturers ready for the next duty cycle. The use of standard pool containers minimises the length of the journeys the containers make. Inventory control is simplified and peaks and troughs in demand can be smoothed (WRAP, 2010a).

A simple collective model has been applied to food service (Caulibox, 2020; Ecobox, 2020); Consumers buy a freshly prepared meal in a returnable container, which they take back to a participating outlet or collection point once finished. The container is then washed, either by the outlet themselves or at a central facility, and then used again by one of the collective businesses. For fast-moving consumer goods, however, it is unlikely that brands will be willing to engage with collectively-owned consumer packaging as bespoke packaging is considered important for brand equity (see 4.4.4 'Brand is Packaging'). A system that uses a brand's own packaging ('Loop') has been on trial in locations worldwide (Smithers, 2020). Whilst the packaging is owned by the individual brands, the operator is responsible for the logistics and washing of multiple brands' containers.

2.2.2 Life cycle assessment of reusable packaging

It is essential when considering new products and processes to assess their environmental impacts to avoid unintended consequences. Life cycle assessment (LCA) considers the environmental impacts associated with all stages of a product's life cycle. In the context of reusable plastic packaging containers, the environmental impact of raw materials used to make the product, the energy used in processing and transport throughout all stages of the cycle, the number of reuses and the eventual end of life of the product are all important.

The environmental impacts of reusable packaging have been considered by a number of authors, e.g. for milk. Stefani et al. (2020) considered a centralised milk supply chain, finding that reusable glass milk bottles had significantly higher environmental impacts than their lighter-weight reusable PET counterparts due to the much higher transport emissions from moving the heavier packaging between consumer and refilling locations. Meyhoff Fry, J., et al. (2010) considered doorstep delivery of a local milk supply chain, finding that the impacts due to packaging production (raw materials and processing) were the most significant. Accorsi et al. (2014) evaluated the life cycle impacts of secondary packaging (i.e. crates and boxes), finding that reusable containers had lower environmental impacts, however

higher economic cost than single-use alternatives. At the time of the study presented in this chapter, the environmental impacts of takeaway food containers had been considered previously, but only for single-use and refill options and not return. Gallego-Schmid et al. (2019) evaluated the environmental impact of single-use Aluminium, polypropylene and extruded polystyrene (EPS) containers and compared them to reusable polypropylene. Extruded polystyrene containers were found to have the lowest impact across impact categories, due to the lower volume of raw materials required for a container and the lower energy required for processing. However, the recycling rates of EPS are negligible due to its low density and therefore poor cost-effectiveness, and the problems posed by its low degradability and impact as marine litter are significant, though it should be noted that marine litter is not included as a specific impact category in Life Cycle Assessment. When this study was conducted, there had not been any analysis published comparing the life cycle impacts of refill and return options with single-use takeaway packaging. The return loop for takeaway containers is simpler than that for some other returnable packaging, such as Loop (Smithers, 2020), but the case study presented here serves as a starting point for the understanding of larger systems.

2.2.3 Consumer willingness to engage with reuse models

Technical solutions, infrastructure, and opportunities interact with individuals' and organisations' beliefs, skills, and motivation to determine their behaviour that, in turn, shape outcomes like a reduction in plastic waste (Khan et al., 2020). An example of this could be a Local Authority spending £2 million on new cycle lanes and expecting to observe an increase in the number of people cycling to work. The infrastructure may well help, but its success also depends on people's attitudes toward cycling (and other modes of transport), normative beliefs (that is what people think i) others do or ii) what others think they should do), motivation, perceptions of risk and so on that dictate whether the cycle lanes are actually used. A successful reuse packaging system requires people to be willing to engage with that system, which depends on attitudes toward reuse, normative beliefs, motivation, perceptions of contamination etc.

Consumer research has indicated that 85% of people want to buy products in packaging that they can reuse; however, less than one in five people actually engage

with reuse systems (Poole, 2019). These findings suggest that, although people have positive attitudes towards reuse and are motivated to reuse, they often struggle to translate these intentions into behaviour. Considerable research has studied what has been termed 'the intention-behaviour gap' in other domains (e.g. for a review with respect to health behaviours, see Sheeran and Webb, (2016)) and identified a multitude of reasons why people struggle to translate intentions into action. However, one factor that might be important to consider is whether people actually have the opportunity to engage in a reuse system. Given that reuse models are currently far from the norm, even the best intentions may be thwarted by a lack of opportunity (e.g. a supermarket does not allow a consumer to use their own container for products from the deli counter because of hygiene concerns). Therefore, this research focuses on understanding what people might be willing to do, rather than their current intentions, as intentions are likely constrained by the current (lack of) availability of reuse systems. Behavioural willingness refers to how willing a person would be to perform a behaviour if given the opportunity to do so (Gibbons et al., 1998). Although willingness is a cognitive construct, research has indicated that willingness to engage in a behaviour is a key predictor of that behaviour in the future (e.g. Hukkelberg and Dykstra (2009)). Research has also shown that as people's experiences of engaging in a behaviour increases (e.g. experience of using an in-store refill station), then people's intentions replace willingness as the key predictor of that behaviour (Pomery et al., 2009). Exploring what people might be willing to reuse can also provide useful directions for where a new model of reuse might prove successful.

Despite the important role of consumers in the success of reuse models, very little research has considered the factors that might influence whether consumers use reusable packaging or engage with reuse systems. One exception is a study conducted by Ertz et al. (2017) who found that contextual factors, such as legislation and pricing, and psychological factors, such as attitudes and subjective norms predicted consumers' intentions to use reusable packaging. However, at the time of our study it was not possible to find research that had explored how aspects of the product or packaging could influence a consumer's willingness to engage in reuse of the packaging.

2.3 Methods

2.3.1 Life cycle assessment (LCA) methodology

The LCA was carried out in accordance with the Product Environmental Footprint (PEF) method (Manfredi et al., 2012) as well as ISO14040 and ISO14044 guidelines, and is composed of four main steps: goal and scope definition, inventory analysis, impact assessment and results interpretation. The LCA was carried out using SimaPro9.0 software. The outcomes will be of interest to packaging manufacturers and those involved in the packaging supply chain, policy makers, packaging wholesalers and consumers. The LCA was perfomed by SW with the research question set by SG, supervised by RR.

2.3.1.1 Goal and scope

The goal of the study was to evaluate and compare the cradle-to-grave environmental impacts of 8 different takeaway containers used within the UK to assess the "best" container on an environmental basis. The 8 cases (see Figure 2.2) represent various options for single-use, refill, and return. In each category, the most commonly used packaging was selected, and in some categories, multiple types of packaging were analysed to represent a range of material options. The extruded polystyrene clamshell is of particular interest as this has previously been shown to have the lowest carbon impact when compared with alternatives (Gallego-Schmid et al., 2019), the PBT (polybutylene terephthalate) container was chosen for one of the return options, as this is in use for that purpose in Luxembourg (Ecobox, 2020). PBT is an engineering plastic used in food contact applications and not a typical single-use packaging material. The same Tupperware-style box was included in both the return and refill cases in order to allow a comparison of these cases independent of the container.

The functional unit is the reference unit on which the data is normalised. Here the functional unit is 'the production and use of an item of packaging that can hold 300 g of takeaway food, used to take away food from a restaurant to a nearby home in Sheffield, UK'. To compare reuse and single-use cases, the life cycle impacts were first calculated for all cases for 200 takeaways (uses), then the average of those uses calculated to give the functional unit. 300g is a typical size of a food-to-go portion. A location was chosen to enable accurate transport calculations; the impact

of transport (and therefore the exact location) is discussed in the results section. The focus of this study is the packaging, and as such the impact of the food contained within the packaging is excluded from the study. The food is likely to have a very significant impact on the total environmental impacts of the takeaway meal, but due to the wide variation between food types and the fact that the packaging impact is independent of the food, the food is not included in the analysis. Transport between the takeaway and the consumer location is assumed to be on foot, and to have no energy consumption or environmental impacts attached to it. This is a reasonable assumption if the takeaway and home are close to each other. When takeaway food is ordered, it is very common for additional packaging, e.g. plastic or paper bags, to be used. This additional packaging was not included in this study, since it is assumed that such packaging would be required regardless of the takeaway container used.

Expanded polystyrene tray with attached lid	Polypropylene Takeaway container with lid	Aluminium foil Takeaway tray with cardboard lid	Bagasse tray with attached lid
“EPS Clamshell”	“PP Microwave Tray”	“Aluminium Tray”	“Bagasse Clamshell”
Single-use			Eco single-use

Polybutylene tere-phthalate (PBT) bowl with Polyethylene lid	Tupperware-style Polypropylene box with lid	Steel tin with lid	Tupperware-style Polypropylene box with lid
“Luxembourg Box”	“Return Tupperware”	“Mess Tin”	“Refill Tupperware”
Return		Refill	

Figure 2.2 *Packaging options considered in the LCA, including an EPS clamshell, PP container with lid, Al tray with cardboard lid and bagasse clamshell for single-use, and PBT bowl with PE lid, PP bowl with lid and steel tin with lid for reuse systems.*

Figure 2.3 shows the flowcharts for the three cases considered. Across all cases, the processes of manufacturing and distributing each container are fundamentally the

same: Raw materials are transported, processed and manufactured into the container, which is then transported to a supplier. Additional packaging which may be used for the bulk transport of containers is not considered in this study.

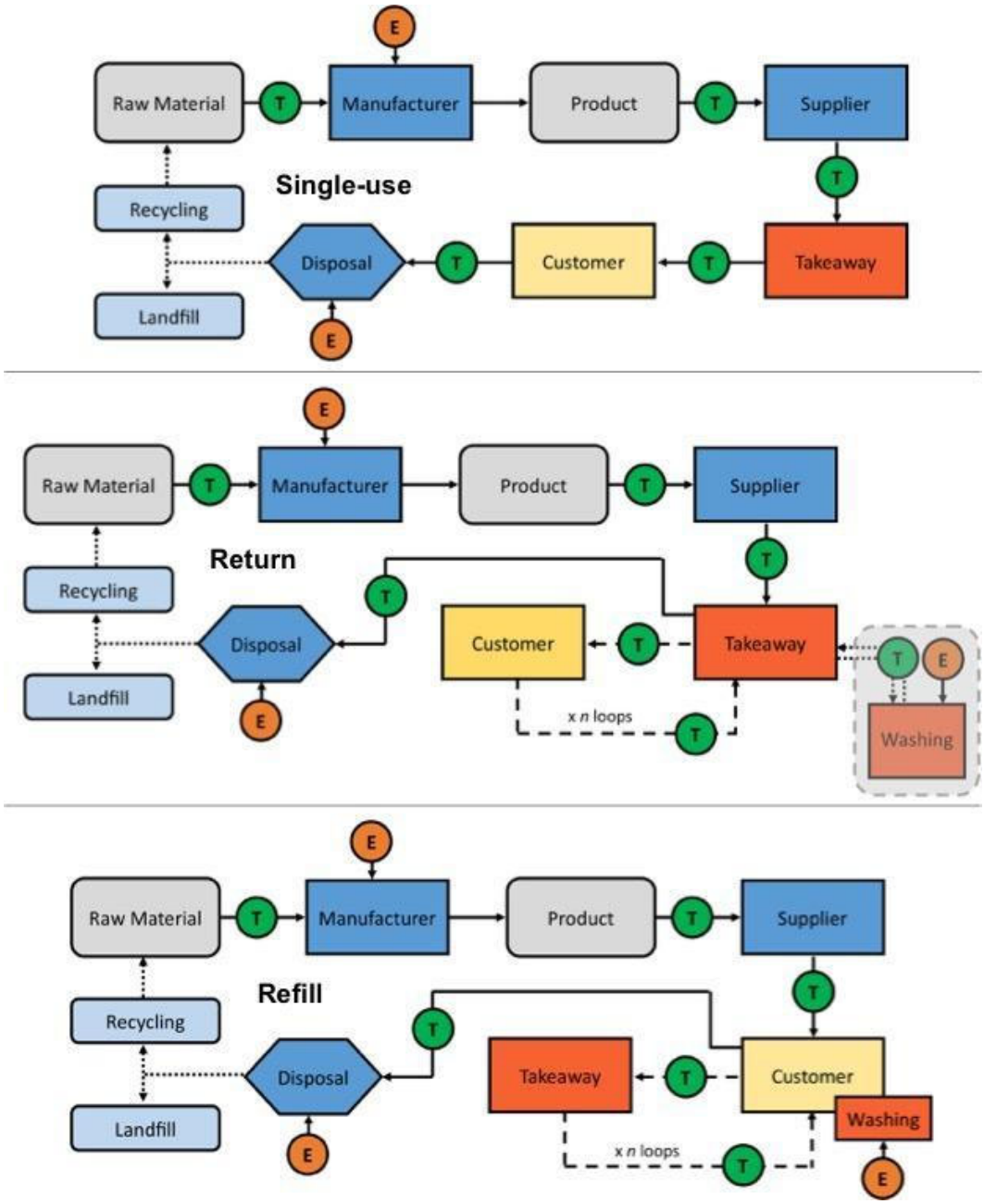


Figure 2.3 *Flowchart for the single-use (top), return (middle) and refill (bottom) cases. Products, processes and locations are shown, with major transport ("T") and energy ("E") inputs highlighted.*

In the return case, the container is purchased from a supplier by the takeaway food outlet, and first transported to, then stored at, the takeaway. It then enters a loop, where it is filled, transported to the customer's home, and then back to the

takeaway, where it is washed and stored ready for reuse. It is assumed that the returnable takeaway containers are reused by a single takeaway, rather than being used at multiple takeaways as part of a larger scheme. However, assuming that each takeaway was a similar distance from the customer's home and there were no significant differences in the washing process between takeaways, the results of this study would hold true for a larger scheme. If the collective return model (2.2.1.1) is employed, whereby the container is transported to a third party for washing and then returned to the takeaway, an additional transport process is required. If the container is washed on site, there is not a transport contribution at the washing stage.

In the refill case, the container is owned by the customer, so is purchased from the supplier and stored by the customer. The loop is similar to the return case, but with washing taking place at the customer's home before storage ready for reuse.

2.3.1.2 Inventory analysis

The life cycle inventory, including transport details, is given in Tables A1 and A2 in the Appendix. A high-level summary is shown in Table 2.1:

Container	# Uses	Weight / g	Country of origin	Disposal method
EPS clamshell	1	14	China	Landfill
PP + PP lid	1	34.4	China	Landfill
Al + card lid	1	6.2 + 5.7	China	Recycling (lid - landfill)
Bagasse clamshell	1	22	Brazil	Landfill
PBT + PE lid	50	25.6 + 15.7	Germany	Landfill
Tupperware (return and refill) + lid and seal	50	40 + 1.3 (seal)	China	Landfill
Steel mess tin	200	185.15	China	Recycling

Table 2.1 *selected summary information from the LCA inventory – format and material, weight, country of origin and disposal method.*

Inventory data was taken from a range of sources. Although some general manufacturing process information was available, no specific data was available directly from container manufacturers, so previous literature on the subject was consulted. Existing studies highlighted the most likely manufacturing locations and

methods for some containers (Fangmongkol and Gheewala, 2020; Gallego-Schmid et al., 2019; Ligthart and Ansems, 2007) but did not provide sufficient data to conduct LCA, so additional data was taken from the Ecoinvent 3.5 (Weidema and Wesnæs, 1996) database, with further supplementary material data from Plastics Europe via the Industry Data 2.0 database. For each container, the main manufacturing processes used (as identified in the literature or industry information) were applied using representative processes from the Ecoinvent 3.5 database in SimaPro. These processes were modified if necessary to represent the correct country of manufacture, as shown in Table A1. Raw material data was collected through direct measurement (by weighing containers with a digital weighing scale), and the most appropriate material was selected from the Ecoinvent 3.5 database or data supplied by Plastics Europe. In all cases, manufacturing methods are based on common actual production facilities, and the most common manufacturing location and method, supply route, and transport method have been applied. The EPS Clamshell, PP Microwave Tray and Aluminium Tray are assumed to be manufactured in China, then transported by lorry to Shanghai port, where they are shipped by sea to Felixstowe port, then transported to a large catering supplies company, assumed to be in Bristol. From here they are assumed to be transported to the takeaway in Sheffield. In the EPS and PP cases, the manufacture of polymer and moulding of boxes are assumed to take place at the same facility. In the aluminium case, aluminium ingots are assumed to be produced in Hebei province and then transported by lorry to Jiangsu province for foil manufacture. The bagasse raw material is a waste product from the sugarcane refining process. This process primarily produces sugar, with co-products including ethanol and bagasse produced simultaneously. Production data was taken from the Ecoinvent database and is based on a large sample of production volume and time period. The allocation methods suggested in this dataset were applied. For impacts other than CO_2 emissions, the allocation of impacts of the sugarcane refining process between these co-products was based on economic allocation, meaning that the impacts are divided between each co-product based on their economic value. For CO_2 emissions, the allocation was based on carbon balance, meaning that the CO_2 emissions attributable to the sugarcane refining process were divided between co-products based on their relative embodied CO_2. Information on the production of bagasse products was based on previous work (Fangmongkol and Gheewala, 2020).

The bagasse clamshell is assumed to be made in the USA using raw material from Brazil. PBT and PE used in the manufacture of the Luxembourg box are manufactured in Germany, as confirmed by the manufacturer.

Manufacturing process data was taken from Ecoinvent in all cases and was based on the most common method of manufacture for each product. Full manufacturing processes were modelled in each case (see Table A1). Details of the end-of-life treatment of each container are given in Table A2. The manufacturing location was selected based on the most common manufacturing location of products offered by the largest UK supplier (Nisbets, 2020). This supplier was also used for the calculation of transport distances. Transport distances were measured using online mapping (Google, 2020) for road transport and the SeaDistances website (Sea Distances, 2020) for marine transport. Road transport emission standards were based on the current standards (International Transport Policy Standards, 2020) in relevant countries (EURO5 equivalent in China, Brazil and USA, EURO6 in Europe).

A reusable container must be washed before being reused: for the refill case this washing takes place at the customer's home, whereas for the return case washing takes place at the restaurant. The default case assumes a domestic dishwasher and a commercial dishwasher are used for the refill and return cases respectively, but sensitivity analysis is also performed on the mode of washing for the reuse case as only around half of the households in the UK have a dishwasher, so hand washing of dishes is also likely. Handwashing has the potential to increase CO_2 emissions and water use, due to an increase in the volume of water used relative to using a dishwasher, but the handwashing process varies widely between consumers, for example in the amount of water used per wash, the water temperature, and (assuming water is used to wash other products as well as the takeaway container) the acceptable level of water contamination before water is replaced. The domestic dishwasher is the default case for the refill model due to the higher confidence in inventory parameters.

The water and energy required for the washing stage are included in the analysis. However, the treatment of wastewater produced during the washing is considered to be outside the system boundary. Organic load in the wastewater due to food residue will vary dramatically with both the type of food contained, the amount of food left, and the consumers' cleaning habits before washing. As this analysis looks

at the packaging and not the food, treatment of the wastewater is not considered, although it should be noted that this will increase the impacts of reuse models slightly and should be explored in future work.

	Return	Refill	
	Commercial Dishwasher	Domestic dishwasher	Handwashing
Water use per wash (litres)	4	20	9
Energy use per wash (kWh)	0.5	1	0.264
Takeaway tray allocation of total (%)	4%	1.6%	10%
Water use per takeaway container (litres)	0.16	0.32	0.9
Energy use per takeaway container (kWh)	0.02	0.016	0.0264

Table 2.2 *Inventory for washing sensitivity analysis showing water and energy usage for washing in a commercial dishwasher (return), and a domestic dishwasher and handwashing (refill).*

The inventory for the washing sensitivity analysis is given in Table 2.2. A takeaway container in a domestic dishwasher (in the refill case) takes up approximately 1.6% of the available space, therefore 1.6 % of the energy and water use of a standard dishwasher (20 l of cold tap water and 1 kWh electricity per cycle) are allocated to washing the container. For the return case, a commercial dishwasher (4 l cold water and 0.5 kWh electricity per cycle) is assumed to be used, with the container having a 4% allocation by volume. (Note: a small commercial dishwasher was chosen on the basis that a takeaway would not have a lot of space available. The volume that can be washed in time is larger because the wash cycle for the commercial dishwasher takes about 2 minutes vs approximately an hour for the domestic dishwasher). For handwashing, 9 litres of water are assumed to be used per wash, with a water temperature of 50ºC, and an allocation of 10% for the container being washed.

End-of-life treatment was as follows:

- Extruded polystyrene is not commonly collected for municipal recycling in the UK, and polypropylene is not collected by all councils, so it was

assumed that these containers were sent to landfill at the end of life. This applies to the single-use microwave trays and the refill and return Tupperware containers.

- Aluminium foil trays are assumed to be recycled by municipal collection, but their cardboard lids are assumed to be disposed of in landfill, since these are coated and are likely to be contaminated, meaning that they cannot be accepted for recycling.

- Bagasse is assumed to be disposed of in landfill at the end of life. Though other disposal routes are possible (such as industrial composting), there is no data available on the rates of use of these routes, and such routes are unlikely to be available in a UK domestic setting.

- PBT is not collected for recycling in the UK, so at the end-of-life is assumed to be sent to landfill.

- Steel is fully recyclable and is assumed to be collected by municipal collection and recycled.

In the reuse cases, it was assumed that plastic containers (Luxemburg and Tupperware cases) were used 50 times before disposal. Steel containers were studied with both 100 and 200 uses. An additional 2g mass was added to the single-use containers sent to landfill to represent contamination since it is assumed the customer would not wash this container before disposal.

Full details of the life cycle inventory applied at the end of life for each container type are given in Table A2.

As highlighted in 2.3.1.2, electricity consumption in Aluminium and steel recycling processes were modelled by setting the mass of offset virgin material to represent the difference between using recycled and virgin material. This was done using published data on the relative energy use of virgin and recycled materials. In the aluminium case, industry data (Corus, 2000) suggests that a unit of recycled aluminium requires 5% of the energy required to manufacture the same mass of virgin material. Consequently it can be said that the recycled material offsets 95% of the energy use of the manufacture of virgin aluminium. The same value was applied across all impact categories to determine the impact of recycling aluminium

at the end of life. Although energy use is a key contributor to many impact categories, the application of this value across all impact categories is a potential source of inaccuracy. The sensitivity of the results to these values was tested and it was found that varying the energy use per unit mass of recycled aluminium between 0% and 10% of that of virgin aluminium had no effect on the break-even points described in 2.3.1.4. Energy use in steel manufacture was considered in the same way. Here the reported burdens of recycled and virgin steel vary. A study on stainless steel (Johnson et al., 2008) suggests a recycled steel burden of 33% of that of virgin steel. This value was adopted and a sensitivity analysis was again conducted, which found that changing this value between 20% and 50% had no impact on the break-even points described in 2.3.1.4. Due to the long lifetime of the product, the impacts derived from the end-of-life treatment of steel are a very small part of the overall steel results (less than 1% of overall impact for most impact categories).

2.3.1.3 Impact assessment

The Impact Assessment Method was ReCiPe 2016 Midpoint (Hierarchical) (Huijbregts et al., 2017). The method contains 13 out of 14 impact categories recommended for the Product Environmental Footprint (Manfredi et al., 2012). The remaining category "Eutrophication - terrestrial" is assumed to be covered by Marine eutrophication, Terrestrial acidification, Freshwater eutrophication and Terrestrial ecotoxicity.

2.3.1.4 Calculation of break-even global warming potential

The point at which each reusable option achieves lower global warming potential than the number of single-use items required to do the same number of takeaways was termed the "break-even point" and was calculated for both refill and return cases. The global warming potential (gCO_2e) of a reusable product (i) after n uses ($GWP_{i,n}$) was calculated as shown in Equations 2.1 and 2.2. When n is greater than the lifetime of one product (e.g. for the Tupperware if n is greater than 50 uses), a second product is assumed to enter service and the emissions associated with the first product are added to its emissions (i.e. a = 2), similarly a third and fourth product as required. $GWP_{i,n}$ is then compared to n times the GWP of the single-use item (j). The break-even point is the lowest value for n for which $GWP_{i,n} \leq n\ GWP_j$.

$$GWP_{i,n} = a(M_i + T_i + E_i) + nW_i \quad \textit{(Equation 2.1)}$$

$$\lceil a \rceil = \frac{n}{l} \quad \textit{(Equation 2.2)}$$

where:

i = reusable packaging being considered

j = single-use packaging being considered

M_i = GWP associated with the manufacturing (raw materials and processing) of i

T_i = GWP associated with transport of i from manufacturing location to customer/business

E_i = GWP associated with end-of-life of i

W_i = GWP associated with the washing of i

n = number of times the reusable packaging is used

l = number of times the packaging can be used before end of life

a = number of reusable items required to achieve n uses

2.3.2 Willingness to engage methodology

2.3.2.1 Materials and procedure

This work was performed by HB, with input from SG and RB-P, and supervised by TW. An online survey was conducted, via the survey software, Qualtrics (www.qualtrics.com/). Participants were invited by email and online adverts to participate in a study exploring people's views about different packaging used for products commonly found in UK supermarkets. Those who were interested in taking part were asked to click on a link to the online survey. First, participants were presented with information about the study, and if they decided to participate, they were asked to complete a consent form. Participants were then asked to provide demographic information, including their age, gender, ethnicity, and country of origin.

To explore what people are willing to reuse, participants were presented with images of different products commonly found in UK supermarkets and asked to decide whether or not they would be willing to use the packaging again. A total of 90 product images were taken from online shopping websites; 54% of the products were food or drink (e.g. food condiments, raw meat, soft drinks), 24% were homecare products (e.g. cleaning products, washing detergents), and 21% were

personal care products (e.g. deodorants, facewash, toothpaste); for a full list of products see Tables A3 and A4 in the Appendix.

Participants were shown a random selection of 30 products and were asked to make a series of decisions with respect to what they would do with the packaging of that product *if they had the option* (see Figure 2.4 for an overview of the task). Images of the products appeared on the screen one at a time. First, participants were asked whether they would: (i) put the packaging in the bin, (ii) recycle the packaging, or (iii) reuse the packaging. Participants who indicated that they would be willing to reuse the packaging were then asked *how* they would be willing to reuse the packaging (i.e. would they prefer to refill, return, or repurpose the packaging?), and which model of reuse they would prefer (i.e. refill or return from home vs refill or return on-the-go). Participants were then asked to specify why they had selected that option for that product in order to understand people's decisions with respect to reuse. Participants were then shown an image of the next product and were asked the same questions in relation to the new product shown (Figure 2.5 presents images for each stage of the survey).

Figure 2.4 *Flow diagram representing the decisions that participants were asked to make for each of the products shown.*

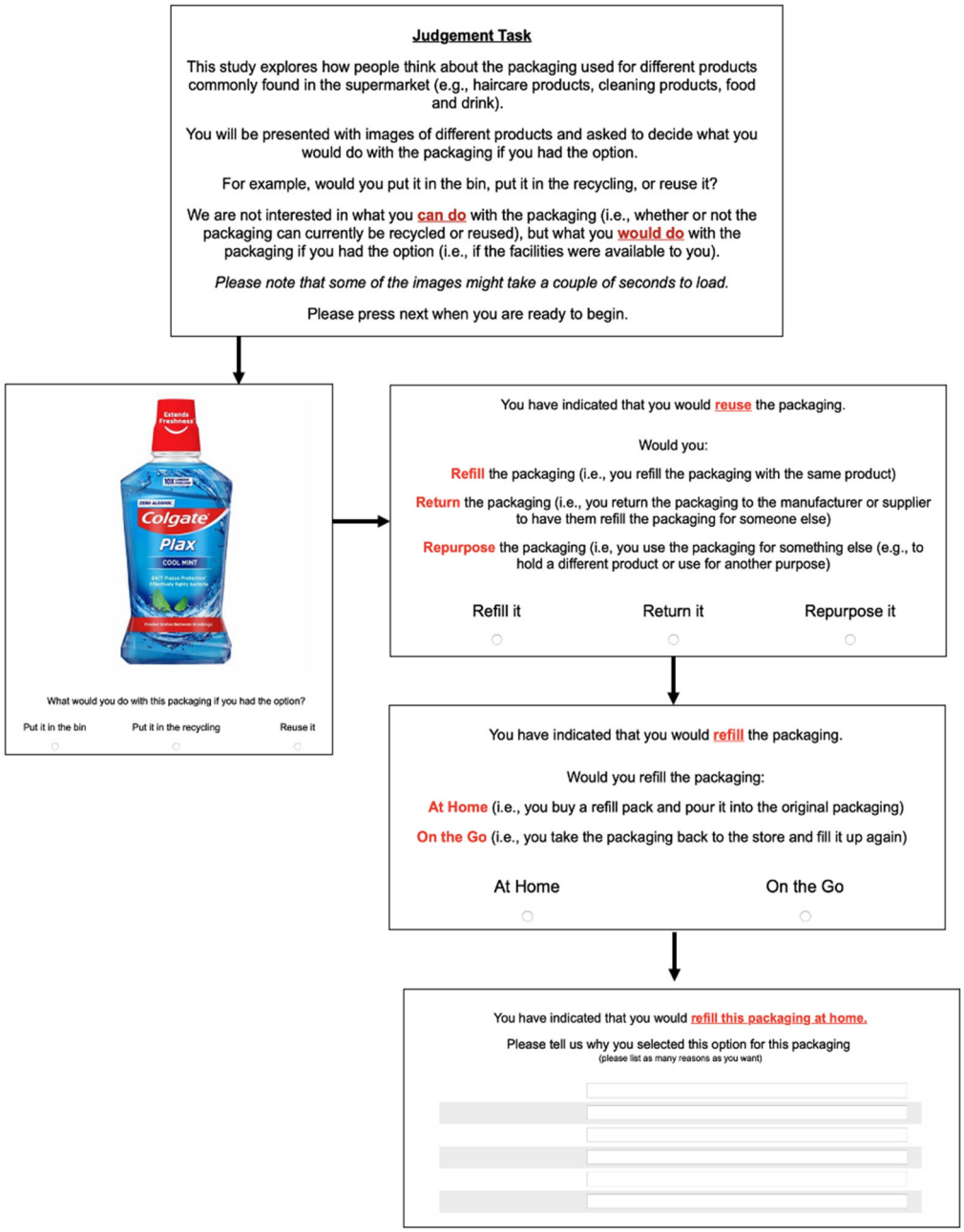


Figure 2.5 *Images showing each stage of the online survey as a flow chart as it would appear to a respondent.*

To explore what aspects of the product and/or packaging influenced whether or not people were willing to reuse the packaging, a number of different physical characteristics and attributes of the packaged products were coded (e.g. the material used for the packaging, the nature of the contents, shelf life, frequency of purchase) for the statistical analysis in MATLAB.

The coding framework was informed by previous research (e.g. (Lindh et al., 2016a)), product databases e.g. Mintel (2025), participants' responses, and

discussions during the project workshop held in July 2019. The coding was done by HB, RBP and SG. The full coding framework is shown in Table 2.3 - Instructions for coding were as follows:

> ***Instructions:*** *Below you will see 90 products commonly found in the supermarket. We would like you to code each of these products (and their packaging) according to a number of different physical characteristics/ attributes. In column A you will see a list of different characteristics, in column B you will see how we have defined the characteristic, and in column C you will see the various coding options. For each of the products shown, please indicate which code you would assign to the product/ packaging. If the characteristic is not relevant to the product (e.g., the category 'Raw food vs Cooked food' will only be relevant to food items), then please leave the box for that product blank. If you feel that another coding option would be more appropriate, and it has not been listed, then please write which category you would assign to the product in words.*

Properties/attribute of product	Definition of property/attribute	Coding options
Nature of the product	What is the purpose of the product?	1 = Food/Drink; 2 = Personal care; 3 = Home care
State of matter of the contents	What form of matter is the contents of the packaging	1 = Gas; 2 = Viscous liquid; 3 = Non-viscous liquid; 4 = Powdered solid; 5 = Soft-solid (e.g., can be spread); 6 = Hard solid; 7 = mixed
Type of packaging material	The main material that comprises the packaging	1 = Rigid Plastic; 2 = Film/ flexible Plastic; 3 = Glass; 4 = Paper/ card; 5 = Aluminium/tin; 6 = Foil
Is the packaging made from multiple materials?	Using the above criteria on different types of materials to code (not including labels)	1 = Yes; 2 = No
Can the components be separated for recycling?	Using the above criteria on different types of materials to code whether these main materials (i.e., rigid plastic, flexible plastic) can be separated	1 = Yes; 2 = No
Pack type	What type of container is used for the packaging?	1 = Aerosol; 2 = Pouch; 3 = Jar; 4 = Bottle; 5 = Can; 6 = Tray; 7 = Tube; 8 = Bag; 9 = Carton/ Box; 10 = tub; 11 = Wrap; 12 = Sachet
Dispensing method	How does the consumer empty the contents of the packaging?	1 = Squeeze; 2 = Spray; 3 = Pump; 4 = Pour; 5 = Unwrap; 6 = remove product with hands or utensil
Closure type	What is the closing mechanism for the packaging?	1 = Lid; 2 = Cap; 3 = Clip/ tape; 4 = Dispenser (e.g., spray or pump, roll top); 5 = Ring-pull; 6 = Sealed plastic/ foil; 7 = Metal/ plastic zip
Does the packaging have a window/can you see the product inside?	Are the contents of the product visible to the consumer prior to opening the packaging?	1 = Yes; 2 = No
Pack size	Whether or not the packaging contains more than one serving portion.	1 = Single-portion; 2 = Multiple portions
Shelf-life (if the product is unopened)	The length of time for which a product remains usable or fit for consumption	1 = weeks; 2= months; 3 = years
Can the (main) packaging currently be recycled?		1 = Yes (widely); 2 = Sometimes (i.e., check locally); 3 = No (Not currently recycled)
Raw food vs cooked food	Can the contents of the packaging be consumed without being cooked first?	1 = Raw food; 2 = Cooked food; 3 = typically needs heating/mixing to consumer, but not considered 'raw'
Resealable packaging	A packaging that, once opened can be resealed by the consumer multiple times	1 = Yes; 2 = No
Easy to open	It requires little effort to open the packaging.	1 = Yes; 2 = No
Durability of the packaging	Could the packaging be used time and time again, without wear or damage to the packaging.	1 = Durable; 2 = Not durable
Would the appearance of the packaging change over time?		1 = Yes; 2 = No
Would the structure of the packaging change over time?	Once empty, it is easy for the consumer to clean the inside of the packaging.	1 = Yes; 2 = No
Easy to clean	Once empty, it is easy for the consumer to clean the inside of the packaging.	1 = Yes; 2 = No
Place of use of the product	Where would the product be used/ consumed?	1 = Only used at home; 2 = Can be used at home or on-the-go.
Frequency of purchase	How often the consumer buys the product.	1 = Daily; 2 = Weekly; 3 = Monthly; 4 = Yearly

Table 2.3 *Key for full coding framework showing product qualities/attributes for each of the 90 products used in the study. (A more detailed version is included in the Appendix, A3 and A4).*

2.3.2.2 Sample size and characteristics

The survey was completed by 276 adults currently living in the UK. The majority of participants (90.58%) were recruited via the online recruitment platform, Prolific (https://www.prolific.com), with the remainder (9.42%) recruited via social media. Participants recruited via Prolific were paid £2.50 for completion of the survey, whereas participants recruited via social media had the option to enter a prize draw to win a £20 Amazon voucher. Prolific was chosen as the online recruitment platform as it has been shown to produce higher quality data (i.e. data that is more accurate and reliable) than other recruitment platforms (e.g. (Peer et al., 2017)). Only participants currently living in the UK were eligible to take part as the images depicted products from UK shopping websites. The age of participants ranged from 18 to 75 years old (M = 34.89; SD = 13.18) and the majority of the sample was female (71.70%) and White British (94.60%).

2.3.2.3 Analysis

To explore what factors influence what people are willing to reuse, the percentage of people willing to reuse packaging was examined as a function of a number of different physical characteristics and attributes of the products using Univariate Analyses of Variance (ANOVA). ANOVA is a statistical technique for comparing an outcome (in this case willingness to reuse) between two or more groups (e.g. packaging made from glass vs plastic vs cardboard) in order to determine whether there is a statistically significant difference between the categories (i.e. a difference that is larger than would be expected by chance alone).

2.4 Results

2.4.1 Life cycle assessment

All of the impact categories highlighted in the Product Environmental Footprint method are shown in Figure 2.6, and Figure 2.7 shows the global warming impact, land use and water use, respectively, for each type of container considered. The impacts in Figure 2.6 are for 200 uses, i.e. 200 containers for the single-use options, and 200 uses of the reusable containers (assuming container lifetimes shown in Table A1 in the Appendix). The global warming potential of the single-use containers show the same trend as found by Gallego-Schmid et al., (2019) with the EPS clamshell having the lowest carbon footprint and the PP microwave container the highest. It is clear from all three figures that the impacts of reuse and refill containers are significantly less than those for single-use containers. Variation between containers used for reuse (either return or refill) is significantly less than the difference between reuse and single-use. This highlights that, in this scenario, as long as a container is reused, it makes very little difference what the container is made of. The more times a container is reused, the lower the impact.

The return options show slightly lower impacts across all three categories presented than the refill options. This is due to the difference between domestic and commercial dishwashers. The small magnitude of the difference between the return and refill options means that both options are good. The choice of which is best will depend on the collection infrastructure for the return model and the extent to which refill is considered an acceptable option for the specific product. Transport accounts for only a small proportion of the impacts, despite the long distances involved, confirming that whilst locations are chosen for the model, the exact location has a low impact on the results.

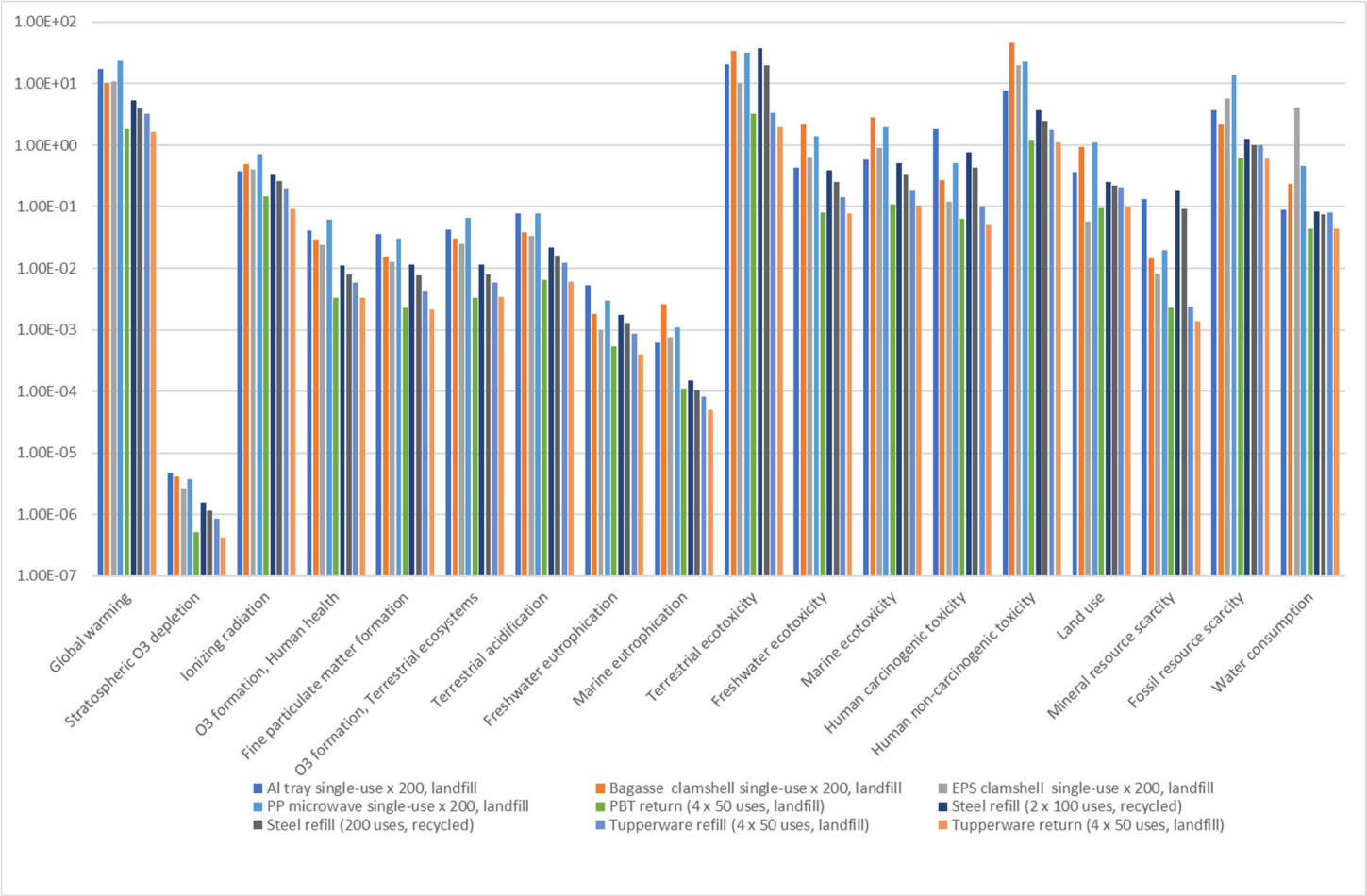


Figure 2.6 *Full LCA results showing environmental metric on the x-axis and magnitude on the y-axis. The ReCiPe 2016 Midpoint (H) model was used to calculate the impacts. Details of the goal and scope are given in section 2.3.1 and the inventory is given in Tables A1 and A2 in the Appendix).*

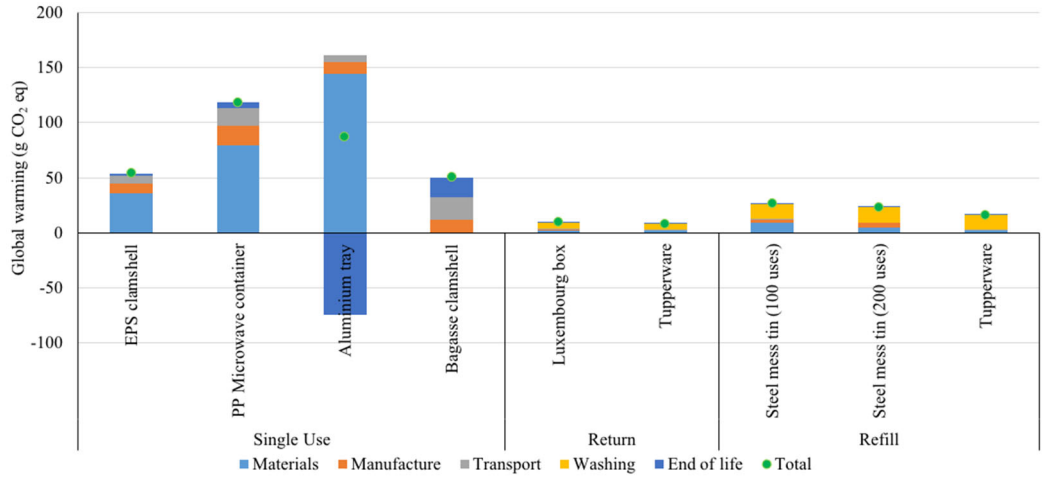


Figure 2.7 a) Global warming potential

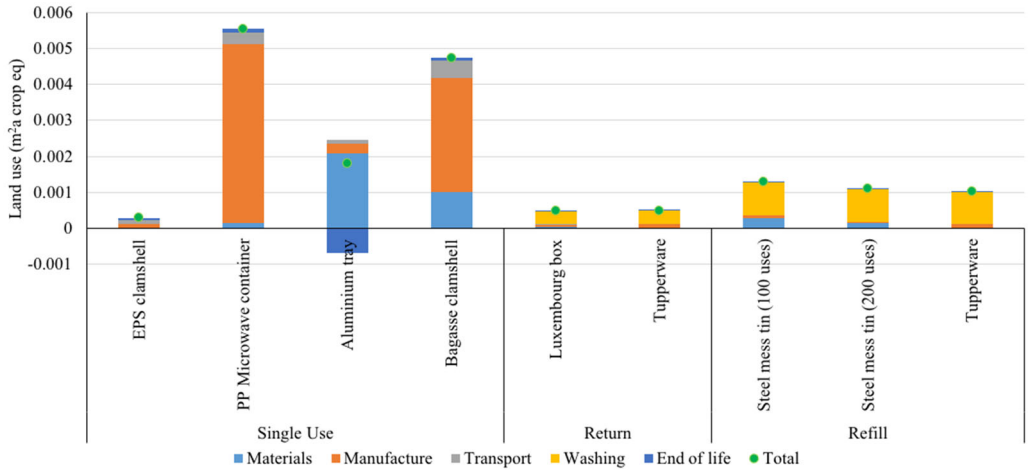


Figure 2.7 b) Land use

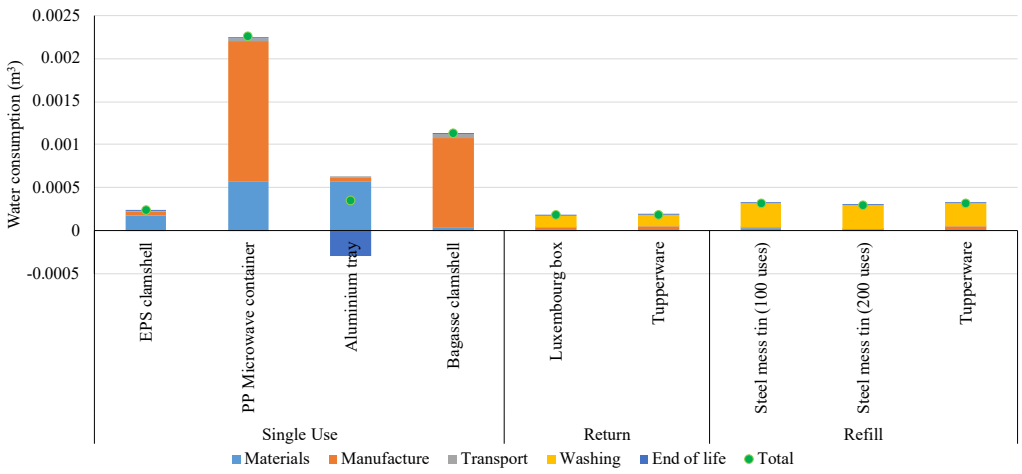


Figure 2.7 c) Water consumption

Figure 2.7 *Impact of one use of each takeaway container (assuming reusable containers are used for the lifetime given in Table A1 in the Appendix - i.e. 50 uses for the Luxembourg box, Tupperware, and 100 and 200 uses for the steel mess tin) on a) Global warming potential b) Land use and c) Water consumption.*

The high land use associated with the PP containers is due to the use of forest products (wood chips) for the incineration of hazardous waste by-products from the PP manufacturing process (Bourgaul, 2011). The high land use for bagasse is due both to the use of forest products for incineration and the land used to grow the sugar cane. The results presented assume PP goes to landfill and is not recycled; when sensitivity analysis is performed to take into account recycling of PP, there is negligible difference in the global warming impact, land use and water use compared to the landfill option.

A sensitivity analysis of the washing process was undertaken for the Tupperware container, as this is considered both for return and refill. Three cases were compared as described in Table 2.2, namely the domestic dishwasher used in the refill case, the commercial dishwasher used in the return case, and a domestic handwashing alternative. The domestic and commercial dishwasher results (see Figure 2.8), as in the Return and Refill cases, show that the commercial dishwasher has a lower energy and water use per wash. Handwashing is likely to increase greenhouse gas emissions and water consumption relative to using a dishwasher, though since there is wide variation in the energy and water use of this process this result should be treated as indicative.

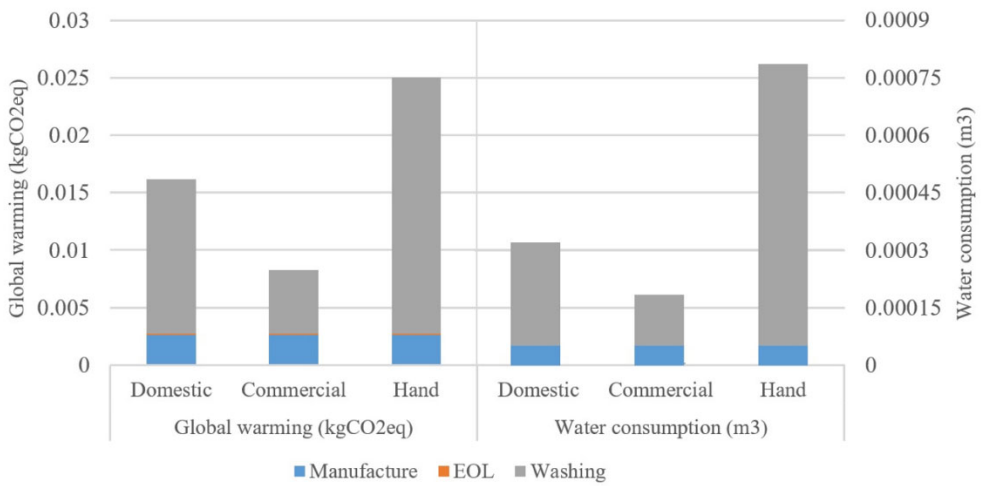


Figure 2.8 *Changes in global warming potential (left, with left axis) and water consumption (right, with right axis) for a single Tupperware container (average per use values for a box with 50 use lifetimes and landfill disposal) with three washing options: Domestic dishwasher (as in the refill case), Commercial dishwasher (as in the return case), and handwashing. Details as given in Table 2.2 .*

Table 2.4 shows the number of times that a reusable container needs to be used to break even with a single-use plastic container in terms of global warming potential. For all plastic reuse options considered, less than five uses are required for the carbon footprint of reuse to be lower than single-use. In the case of the steel mess tin, it must be used between 13 and 33 times to be better than the single-use containers. If a steel mess tin is replaced after 50 uses, then the carbon footprint becomes greater than that of an EPS clamshell from 50 - 64 uses before once again having a lower footprint. This is due to the high global warming impact of the heavier steel container. Gallego-Schmid et al. (2019) also compared single-use EPS and aluminium with a refill Tupperware container, finding that 11 and 18 uses were required to break even on global warming potential with aluminium and EPS, respectively. The Tupperware considered in that work was 3.5 times heavier than that used here and the end-of-life scenarios and washing also differ. There may also have been differences in the calculation method of break-even which was not published.

	Number of uses required			
	Luxembourg Box	Return Tupperware	Steel Mess Tin (Refill)	Refill Tupperware
EPS Clamshell	4	3	33	4
PP Microwave Tray	2	2	13	2
Aluminium Tray	3	2	18	2

Table 2.4 *Number of uses of reusable containers needed to break even with the global warming potential of single-use containers.*

2.4.2 Willingness to engage in reuse

When people were asked what they would be willing to do with the packaging of various products, recycling was the most commonly selected option (53%), followed by putting the packaging in the bin (34%) and then reusing the packaging (13%). These findings support the idea that recycling has become a deeply entrenched norm (Kunamaneni et al., 2019). When participants were willing to reuse packaging, then refilling and repurposing the packaging were the most commonly selected options (6% each for refilling and repurposing, compared to 1% for returning the packaging). To explore which types of packaging people were willing to reuse, the products were categorised according to what participants indicated they would be willing to do with the packaging of that product. This revealed 13 products that people were willing to reuse the packaging of, including biscuits in a metal tin, milk in a glass bottle, coffee in a glass jar, cleaning sprays and handwash in plastic bottles. People were most willing to repurpose a biscuit tin, glass jars used for coffee, mayonnaise, and pasta sauce and a metal tin used for petroleum jelly. People were most willing to refill handwash and a tub of dishwasher tablets, and people were willing to return glass bottles used for milk. Table A4 in the Appendix shows the percentage of people willing to reuse (refill, return, and repurpose) each of the products included in the study.

Note that incentives to reuse, i.e. the use of deposit return systems or strategic product pricing were not explored. A price-promotion was, however, deployed during the practical trial studied in Chapter 3.

2.4.2.1 What factors influence what people are willing to reuse?

Table 2.5 shows the percentage of participants willing to reuse packaging according to aspects of the packaging and product. The results are statistically significant where P is less than 0.05:

Aspect of the packaging/ product	N	Mean	SD	F	P
Nature of the product				0.03	.970
Food/Drink	49	13.00	17.06		
Personal care	19	13.94	11.51		
Home care	22	12.99	11.12		
State of matter of the contents				1.97	.124
Gas	5	3.10	2.29		
Liquid	30	16.95	13.70		
Solid	48	11.31	15.61		
Mixed	7	17.30	11.77		
Packaging material				6.06	<.001
Rigid plastic	37	14.46	10.91		
Film/ flexible plastic	25	4.76	4.21		
Glass	5	37.08	14.27		
Paper/ cardboard	11	15.27	13.39		
Aluminium/tin	11	16.41	25.75		
Foil	1	0	0		
Packaging format				7.02	<.001
Aerosol	6	3.70	2.52		
Pouch/ sachet	8	6.21	4.87		
Jar	4	36.48	4.00		
Bottle	20	19.87	13.19		
Can	2	3.35	3.18		
Tray	5	4.56	7.76		
Tube	5	8.00	7.20		
Bag	11	5.20	4.18		
Carton/ tub/ box	19	22.56	18.84		
Wrap	10	1.75	1.79		

Aspect of the packaging/ product	N	Mean	SD	F	P
Dispensing method				0.13	.880
Pour/ squeeze	29	14.34	12.17		
Spray/ pump/ roll	11	12.60	15.53		
Remove with hands/utensil	50	12.67	15.88		
Closure type				9.83	<.001
Lid/ cap	38	22.23	16.13		
Clip/ tape/ zip	6	7.20	3.36		
Dispenser (e.g., spray, pump)	11	12.60	15.53		
Ring pull	2	3.35	3.18		
Sealed plastic or foil	32	4.31	5.13		
Packaging has a window/ product can be seen inside				0.78	.381
Yes	38	14.79	14.82		
No	52	12.04	14.47		
Number of portions				6.30	.014
Single portion	15	4.81	6.87		
Multiple portions	75	14.88	15.18		
Shelf-life (if the product is unopened)				1.08	.343
Weeks	18	8.95	13.47		
Months	22	15.58	19.20		
Years	50	13.68	12.52		
Is the product a raw food?				0.37	.693
Yes	4	5.98	11.23		
Not raw, but requires heating	28	13.35	18.65		
No	17	14.08	15.79		
Can the packaging be resealed?				19.84	<.001
Yes	56	17.51	15.29		
No	27	4.02	5.08		

Aspect of the packaging/ product	N	Mean	SD	F	P
Is the packaging easy to open?				0.30	.558
Yes	81	13.48	14.63		
No	9	10.68	14.93		
Is the packaging durable?				34.96	<.001
Yes	37	21.16	17.12		
No	42	4.82	4.97		
Would the appearance of the packaging change over time?				19.01	<.001
Yes	40	5.95	6.22		
No	13	24.87	25.69		
Is the packaging easy to clean?				14.25	<.001
Yes	48	19.46	16.46		
No	17	4.19	3.71		
Where is the product typically used/ consumed?				1.46	.231
Only at home	66	15.00	15.89		
At home or on-the-go	13	9.45	10.02		
Frequency of Purchase				0.14	.939
Daily	12	13.72	23.70		
Weekly	23	12.14	14.72		
Monthly	34	14.61	12.00		
Yearly	12	12.88	11.36		

Notes: *N* = number of products in the category; *M* = Mean percentage; SD = Standard Deviation, *F* = F-statistic from univariate ANOVAs, indicating the magnitude of the difference between the categories, p = likelihood that the difference occurred by chance alone. In the present study a *p* value ≤ 0.05 (reflecting a 1 in 20 chance that the difference occurred by chance alone) is considered statistically significant. Note that some of the values of N for an aspect do not add up to 90 (the total number of images used) this is where a code has not been assigned, e.g. non-food items were not coded as to whether they were raw or cooked.

Table 2.5 *Percentage of participants willing to reuse packaging according to aspects of the packaging and product, the results are statistically significant where P is less than 0.05.*

As can be seen in Table 2.5, the material, type of packaging, and the closure mechanism all had a significant influence on whether people were willing to reuse the packaging. Specifically, it was found that people were more willing to reuse packaging made from glass (37% of those surveyed) compared to packaging made from film, flexible plastic, or foil (5% of those surveyed). In terms of the type of packaging and type of closure, people were more willing to reuse jars (20%), bottles (19%), and boxes or cartons (22%) compared to wraps (1%), cans (3%), and aerosols (4%). It was also found that people were most willing to reuse packaging with lids and dispensers, and that being able to reseal the packaging was associated with greater willingness to reuse. The dispensing method, whether the packaging was easy to open, and whether the packaging had a window through which the product inside can be seen were not associated with people's decisions with respect to reuse ($P < .05$).

People were more willing to reuse packaging that was resistant to change over time. For example, it was found that the durability of the packaging, whether the appearance of the packaging was likely to change with use, and whether the packaging was easy to clean (all determined collectively by the researchers who coded the products, see Section 2.3.2) were all associated with people's decisions with respect to reuse, such that people were more willing to reuse packaging that was durable, resistant to changes in appearance, and easy to clean. The implication of these findings is that materials technology is needed to develop containers that are resistant to frequent reuse and repeated industrial washing for use in a return model. However, where this is not possible or feasible, then consumers' beliefs about the implications of changes in appearance (e.g. that it is indicative of contamination) could be challenged by an appropriate intervention.

Table 2.5 shows that people's decisions with respect to what they would be willing to reuse were not associated with the nature of the product (e.g. food or drink vs personal or home care), state of matter of the contents (e.g. liquid or solid), shelf-life of the product, where the product is used or consumed, or the frequency with which it is typically purchased ($P > .05$).

2.5 Limitations

The Life Cycle Assessment conducted here has some limitations. These stem largely from the Life Cycle Inventory data, which includes assumptions around materials, manufacturing processes, and end-of-life treatment. Sensitivity analyses were conducted to understand the impact of these assumptions wherever possible, and on all aspects of the study that have the potential to influence the results significantly. Manufacturer data on specific material details and primary data on manufacturing processes would enhance the reliability of the results of this study, but the present assessment gives a useful comparison between container types and systems of reuse.

Landfill was used as the default option for end-of-life for materials that are not typically recycled, as this is historically how waste has been managed in the UK. In 2019-2020, 48% of England's municipal waste (all materials) was incinerated, 41% recycled, and 8% went to landfill (UK Government, 2025). The contribution of end-of-life treatment to the overall impact on GWP, land use and water usage shown in Figure 2.7 is, however, small. Incineration and recycling are considered as end-of-life options in the next chapter.

The sample that was asked to complete the willingness survey was obtained via opportunity sampling and, as such, may not be representative of the UK population. Although there is no reason to suggest that the findings might differ according to age, gender or ethnicity, future research might seek to recruit a more representative sample. However, recruiting the majority of the sample from Prolific was advantageous in some ways because these participants were paid for their participation. As such, they have not necessarily chosen to take part in this study because they are more environmentally conscious consumers (i.e. self-selection bias).

2.6 Discussion and recommendations for future work

The findings presented here provide a sound foundation for future research. For example, identifying packaging and packaging systems that have the lowest environmental impact allows future work to present consumers with computer-simulated and physical prototypes of reusable containers, along with hypothetical

scenarios (e.g. ordering a takeaway), in order to explore what packaging and systems consumers would be willing to use.

The life cycle assessment demonstrated that both kinds of packaging reuse systems, refill and return, can have a reduced overall environmental impact, provided that the containers are used a minimum number of times. Whilst the format of use was much more significant than the material used for the container in this scenario, it is anticipated that where the containers are transported any distance as part of the food delivery cycle, the weight of the containers will become more important and hence durable plastic will become more attractive as a material choice. Steel containers needed to be used many more times than reusable plastic containers to reach the break-even point when compared to single-use plastic due to both the raw materials and their heavier nature incurring greater transport emissions. Further work should consider a collective return model with a centralised washing facility and the incorporation of a delivery option to complement the takeaway collection considered here.

As the energy supply decarbonises in the future, the carbon impact of any washing and transport phases in reuse will come down. The energy mix is considered for the washing phase of takeaway bowls in the next chapter.

The findings from the willingness work suggest that recycling is still the norm when people consider what they would do with the packaging of different products given the option. However, people were willing to reuse the packaging of some products (e.g. biscuits in a metal tin, milk in a glass bottle, coffee in a glass jar, cleaning sprays and handwash in plastic bottles) and the results suggest that willingness is primarily driven by aspects of the packaging (e.g. packaging material and type of packaging) rather than aspects of the product inside (e.g. nature of the product and state of matter of the contents).

This work also sought to explore the factors that influence which method of reuse people prefer for different packaging (i.e. refill at home or on the go, return at home or on the go, or repurpose). However, reuse was rarely selected as an option, perhaps given that reuse is not commonplace in the UK, meaning that there was insufficient data to permit meaningful comparisons. As reuse models become more mainstream, it would be valuable to extend the approach used here to identify factors associated with willingness to engage with specific reuse systems. Comparably, international contexts where reuse still plays a large role (particularly

in the beverage sector) such as Germany, Denmark and Mexico (Beswick-Parsons et al., 2023; WRAP et al., 2008) may produce different results with more people accustomed to and therefore willing to engage in reuse. Alternatively, future research could present novel reuse models in order to explore which ones people will engage with and how.

The findings showed that consumers are more willing to repurpose and refill packaging than they are to return packaging. Where respondents were willing to return or refill packaging this was for products where reuse systems already exist (e.g. milk in glass bottles). One interpretation is that consumers' behaviour is relatively habitual, such that they are willing to engage in what they, or others like them, have done previously (e.g. carbonated drinks bottles for return-on-the-go), but are less willing to do something new (e.g. reuse microwavable trays). As respondents did not typically envision using return and refill systems which were not already in use (or had been in use previously), it follows that consumers may need to trial any new reuse system, or see it demonstrated, in order for them to become engaged. Another interpretation is that they will do what is most convenient; rinsing a glass milk bottle and placing it outside their front door involves very little effort.

The pricing of reusable vs non-reusable alternatives is also likely to have an effect on willingness - handwash was the most popular choice for refill-at-home (29% of respondents), and the UK's largest supermarket retailer sells bulk refill pouches with a price per ml that is less than 60 per cent of that of the standard pack (Tesco, 2025). Additionally, in the work for Chapter 3, a marked increase in people engaging in coffee cup rental from University of Sheffield cafes was observed during a promotion offering heavily discounted hot drinks when a reusable cup was used, demonstrating that, in this case, people are motivated by price, and that the reward of getting a hot drink for one pound is a good incentive to get people to download the app, when otherwise uptake was low.

For a reusable packaging system to be truly successful, it needs to be accessible to everyone from a price and ease-of-shop perspective. This is discussed in more detail in Chapter 4 (4.4.5). Deposits and late fees are methods of ensuring containers are returned (Zero Waste Europe, 2024), but may exclude those on a low income. Containers and the refill or return process must be designed with accessibility in mind, accommodating not only individuals with physical disabilities (Yoxall et al.,

2019), but also those who may struggle with working memory. For example, remembering to bring a refillable cup or return a container could be especially difficult for people with neurodivergent conditions (Alderson et al., 2013; Partridge, 2025).

Whichever material is chosen for a reusable packaging container, the willingness of consumers to use that container multiple times is crucial. If a container has to be used five times to break even with single-use alternatives, but the appearance is unacceptable to the consumer after three, any scheme will become environmentally unviable, and probably economically unviable too. The number of uses before which the consumer rejects a container on appearance must always be higher than the break-even number of uses for the system to be viable. Changes in the appearance of packaging over time (and related factors such as durability and ease of cleaning) were all found to be associated with people's willingness to reuse. Containers that are frequently refilled and reused are likely to become worn and discoloured over time as they are exposed to a range of physical and chemical conditions (Greenwood et al., 2020). Manufacturing durable containers that are designed for reuse requires significantly more energy and resources than packaging intended for single-use and, therefore, must be used multiple times in order to extract sufficient value from the raw resources, as shown by the results of the LCA. At the time of the study, there was scant literature available on the properties of different plastics after many washing cycles and this is an area that requires a much larger body of research evidence. This is now an active area of research (Buddie-Pack, 2025; RECOUP, 2024a). Understanding the number of uses before which the consumer rejects a container on appearance also requires more research, and this is addressed in the next chapter.

The development of a model, such as the EVR discussed by Wever and Vogtländer (2013) that is able to combine environmental impacts with willingness to engage into a combined factor would be very valuable. The 'value' used by Wever et al. is the product sale price, which inherently includes aspects such as a consumer's attitude to convenience and eco-consumerism, however it would be impossible to unpick willingness to engage with reuse from other behaviour. This is also addressed in the next chapter.

The need to describe different forms of packaging reuse before asking participants what they would be willing to do highlighted how official definitions (BSI, 2004) and how consumers describe reuse may diverge. Constructing a vision which prioritises the reuse of plastic packaging must therefore be underpinned by an understanding of public perceptions of plastic and associated actions such as recycling and reuse. Discourses that produce and reproduce worldviews around plastics and reuse are likely to shape people's responses, but are also likely dominated by the current norms of recycling. Linguistic research has shown that terms such as *recycling* and *reuse*, referring to complex processes, or *packaging* and *container*, referring to concrete objects, are first used in narrow, technical contexts, but then tend to undergo semantic change, in the form of semantic broadening and increasing vagueness, as they are used by the public in ever expanding contexts (Kortmann and Nerlich, 1993; Mehl, 2020; Pap and Ullmann, 1959; Sperber, 1938). Semantic broadening can be further complicated by affective associations of each word (Blank, 2013; Mehl, 2020). For example, *recycle* will have developed affective associations and increasingly vague meanings, among many or most English users, as it has moved from strict technical use into broad public use, and become a normative term for a wide range of processes and behaviours. In contrast, *reuse* is at an earlier stage in its semantic development, and may acquire broader meanings among more language users as the process of reuse, and the term *reuse*, become more mainstream. Madria and Tangsoc, (2019) have shown that visual information on packaging, including language around *recycling* or *reuse*, can influence consumer behaviour. Therefore, further research is required to examine the semantics of these terms across language users, and to connect semantics to behaviour. Ultimately, connecting linguistic and behavioural findings can help to inform communication by manufacturers, policymakers, and campaigners.

2.7 Conclusions

Reusable packaging systems can be a viable way to reduce waste and the broader impacts of single-use packaging. The research presented here shows that both refill and return systems that use plastic containers for takeaway food in the scenario investigated have a lower global warming potential than single-use plastic containers after just 2 to 4 uses. The lightweight nature of durable plastics makes them good potential materials for reusable packaging containers, providing that the materials are sufficiently durable and that people are willing to use a container after multiple use cycles.

Reusable steel containers must be used considerably more times to break-even with single-use packaging on global warming potential, they are however, likely to be more durable than their plastic counterparts. If the consumer is willing to engage with their reuse, steel containers could also represent a viable option for reusable packaging systems.

The survey shows that consumers are more willing to recycle than to reuse packaging and that people are more willing to engage with systems with which they are already familiar, indicating that future study should involve consumers trialling a system or have it demonstrated to them. Consideration of the factors that influence consumers' willingness to engage with reuse (e.g. durability and ease of cleaning) points to potential ways that reuse might be promoted. Furthermore, a clear understanding of what the term 'reuse' means is also important.

Together, the life cycle assessment and behavioural work presented here illustrate the need for a multi-disciplinary approach in order to determine where and how to implement reusable packaging systems with the aim of making their adoption mainstream.

Chapters 3 and 4 build upon this work; Chapter 3 integrates behavioural and environmental science with materials technology to better understand return systems using a practical example of a returnable takeaway bowls scheme. Chapter 4 investigates the enablers and barriers to the introduction of a returnable container scheme for yogurt through stakeholder workshops and interviews seen through the lens of a socio-technical systems approach.

3 Integrating behavioural, material and environmental science to inform the design and evaluation of a reuse system for takeaway food

3.1 Background

The work presented in this chapter is the output from the first of two cross-work package studies which were part of the project Many Happy Returns (MHR), for which Greenwood was co-principal investigator. This interdisciplinary study was a collaboration between the Materials Technology, Psychology and Environmental Assessment work packages, combining a Life Cycle Analysis on returnable takeaway bowls used in university cafes with people's acceptance of images of bowls created using a simulated wear and staining protocol. A shorter version has been published in Resources, Conservation and Recycling, 'Integrating behavioural, material and environmental science to inform the design and evaluation of a reuse system for takeaway food'.

SG led the study and chaired the project meetings. She researched and interviewed prospective system providers, and supported Unicus, the university's commercial operation in the implementation of the scheme. She contributed to the provision of data for the LCA, and following the initial results, initiated a sensitivity analysis on weight and the energy mix for washing. SG derived the formulae for the calculations in 3.4.6 and performed the analysis on the cost of the scheme. She wrote sections of the first draft and contributed to the responses to the reviewers' comments. More detailed analysis performed by SG has been added to this chapter; 3.5.1 on the performance of the trial in the university cafés, 3.5.2.3 and 3.5.5.4 comparing the heavy and light testing regimes, and 3.6.3 on the importance of return rate when designing a system.

Contributors: **Maryam Hoseini**, Chemical and Biological Engineering, first author of published paper and LCA analysis; **Sarah C. Greenwood**, Chemistry, study lead, project co-PI, investigation (see above for contribution); **Saima Eman**, Psychology, investigation; **Paul Mattinson**, Mechanical Engineering, materials testing; **Harriet M Baird**, Psychology, investigation and supervision; **Rorie Beswick-Parsons**, Human Geography, project team; **J. Patrick A. Fairclough**,

Mechanical Engineering, supervision of materials testing; **Thomas L Webb**, Psychology, PI and supervision; **Anthony J Ryan**, Chemistry, co-PI and supervision; **Rachael H Rothman**, CBE, supervision and corresponding author of published paper.
Many Happy Returns: Enabling reusable packaging systems, Grant code NE/V010638/1, part of the Smart Sustainable Plastics Packaging Challenge, delivered through NERC.

3.2 Summary

Reusable packaging systems (both return and refill) are a key part of achieving a circular economy, however adoption and uptake are low. A reuse system must be environmentally beneficial, economically viable and acceptable to users such that they are willing to use it. Here, the study of a returnable takeaway food system running at the University of Sheffield is used to develop a methodology that combines the simulation of wear associated with use, assessments of consumer willingness to reuse worn containers, and quantitative life cycle assessment (LCA). The findings are positive, suggesting that environmental break-even points may be lower than the number of times people are willing to use a worn container. The light-weighting of containers and improvements to the washing stage can improve the environmental benefits, and behavioural interventions can be delivered to increase people's willingness to use containers. Such interdisciplinary research enables careful system design to ensure that reuse systems confer the maximum environmental benefit.

3.3 Introduction

3.3.1 Brief Description of the scheme

Vytal is are packaging-as-a-service company based in Germany (Vytal, 2021). They provide reusable containers to food service companies to use as an alternative to single-use packaging. The containers are owned by Vytal who charge the business customers a small fee per use on top of a minimum monthly fee and an onboarding cost. Access to a digital platform for tracing the containers is also provided, and two versions of a mobile phone app, one for the café's customers to scan a container out, the other for the outlet to scan containers back in.

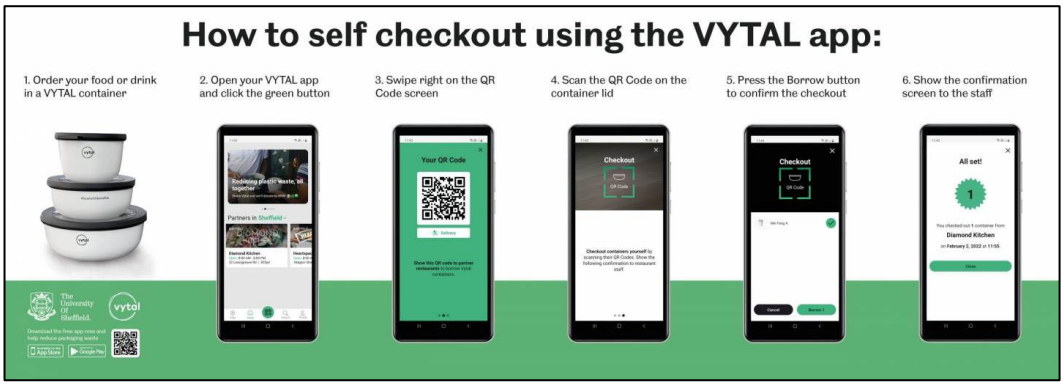


Figure 3.1 *Step-by-step instructions that are displayed in the cafes for customers to use the Vytal scheme as it appears in the phone app. Source: UNICUS*

Figure 3.1 shows step-by-step instructions for customers to use the Vytal scheme, which are displayed in the cafes. When customers order their food or hot drink, they have to ask for it to be served in one of the reusable containers. The server gives them the container lid, which is labelled with a QR code and the customer scans this with their phone app. The customer pays for their food as normal and then has up to two weeks to return the empty container. This is done either by handing it over to a server or depositing it in a collection point, after which it is scanned back into the café's system. There is no charge to the customer unless they return the container late, in which case they are automatically charged £10 (or £4 for a cup) via the phone app, and the container now belongs to them.

3.4 Method

3.4.1 Summary

A container borrowing scheme for takeaway meals and hot drinks was set up in selected University of Sheffield cafés in August 2021. The existing single-use and eat-in options were still available, with a 20 pence charge for single-use containers. Because of the length of time it would take to generate worn containers for a consumer acceptance study, bowls were artificially aged in the laboratory by PM and PF. The bowls were photographed after each ageing cycle, and the resulting images used by the Psychology team (SE, HB and TW) to assess the level of ageing beyond which people would not be willing to use a container. A Life Cycle

Assessment was also conducted (MH and RR, with strategic and practical input from SG), and the results were considered alongside those of the psychology work. Additional analysis was performed by examining the lifetime of a container within a system and the uptake of the scheme within the university (SG).

3.4.2 Trial metrics

University catering and academic staff have access to the platform dashboard, 'Grafana', which displays metrics on container rental. Sales and commercial data were also accessed via the university's commercial services team.

3.4.3 Durability testing

Containers supplied by Vytal of the same material specification used in the cafés, were subjected to up to 30 cycles of controlled abrasion, staining with foodstuffs and washing in a commercial dishwasher. A subset of samples was also microwaved with the food inside to maximise the degree of staining. An initial set of samples was washed only for 75 cycles without scratching or staining to assess the effects of multiple washes in the commercial dishwasher.

3.4.3.1 Scratching

Wooden and plastic cutlery did not create any observable damage to the bowls, only metal cutlery. To simulate the use of metal cutlery in a controllable manner, a test rig was designed (Figure 3.2).

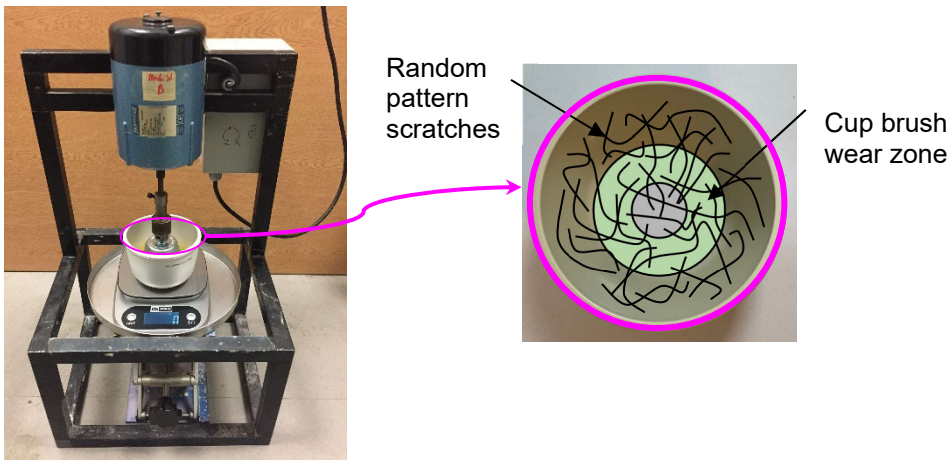


Figure 3.2 *a) The rig used for the mechanised scratching of containers and b) The top view of a bowl showing random pattern scratches from manual scratch testing and the cup brush wear zone from the mechanical testing.*

The bowl was held in place as a wire cup brush was rotated in contact with the inner surface. The brush rotation was at a speed of 80 rpm with a force of 1.9 N, measured using a balance beneath the bowl, for a period of 30 seconds. Additional scratching was performed manually. Both a metal serrated knife and a brass wire brush were used 20 times/cycle. This method created a more realistic wear pattern on the surface and on areas of the bowl untouched by the cup wire brush (Figure 3.2).

3.4.3.2 Staining

A selection of commonly used foods and combinations thought to provide a variation in pH and type of staining compounds, including lycopene (tomatoes), curcumin (turmeric) and tannin (tea and coffee) was selected for this part of the study (see Table 3.1): A number of food combinations were prepared and placed into the containers for 1 hour per cycle. A subset of the samples was also heated in a 900W microwave until boiling (3 minutes in the microwave on Medium power setting) to generate more intense staining and labelled 'heavy'.

3.4.3.3 Washing

Washing was carried out using a Classeq D500 commercial 2-tank under-counter dishwasher using Suma Nova L6 detergent (containing sodium hydroxide and 1-hydroxyethane-1,1-diphosphonic acid), and Suma Rinse A5 Rinse Aid (containing alkyl alcohol alkoxylate, sodium cumenesulphonate and glutaral). The bowls were washed on a medium (2 min) wash cycle at 55°C and rinsed at 82°C. The containers were washed upside down on a wash rack with the use of a retaining mesh to avoid movement during washing. After washing, the containers were removed from the washer in the rack and allowed to dry at room temperature before being photographed. The photography was done using a lightbox for consistency. The images were then collated to be used for the willingness study.

Foodstuff	Ingredients	Preparation/ dilution ratio
Tomato Soup	Heinz brand	n/a
Pasta Sauce	Tomatoes (60%), Tomato Purée, Garlic Purée, Parsley, Rapeseed Oil, Sugar, Red Chilli, Sea Salt, Concentrated Lemon Juice, Extra Virgin Olive Oil, Dried Red Chilli (Sainsburys.co.uk)	n/a
Baked Beans	Beans (50%), Tomatoes (36%), Water, Sugar, Spirit Vinegar, Modified Cornflour, Salt, Spice Extracts, Herb Extract (Sainsburys.co.uk)	Turmeric:Beans 1:100
Chopped Tomatoes	Tomato (65%), Tomato Juice, Acidity Regulator (Citric Acid) (Amazon.co.uk, 2023)	n/a, Turmeric:Chilli:Tomatoes 1:1:100
Tomato puree	Concentrated Tomato Purée, Acidity Regulator (Citric Acid) (Appy Shop, 2023)	1:1 puree to water
Tea	PG Tips tea bags (no milk)	Light /heavy use – 5/10 min brew in 250ml of freshly boiled water
Coffee	Co-op Standard ground coffee (no milk)	Light /heavy use – 15/30g in 250ml of freshly boiled water 5/10 min brew.
Sunflower Oil	Sunflower Oil	n/a, and 1:1:100 Turmeric:Chilli:Oil, and 1:1 tomato puree
Balsamic vinegar	Balsamic vinegar	n/a
Soy Sauce	Soy Sauce	n/a
Turmeric	100% Turmeric	See above
Chilli Powder	Chilli Pepper, Cayenne Pepper (20%), Cumin (8%), Sea Salt, Oregano (4%), Garlic Powder (2%) (Tesco.com)	See above

Table 3.1 *Ingredients and dilution rates of foodstuff used to stain the PP bowls. Where chilli powder and turmeric used, this were added at a ratio of 1:100 each to the main ingredient, where tomato puree used this was diluted at a ratio of 1:1 with oil or water.*

3.4.3.4 Comparison of heavy and light testing regimes

A qualitative visual comparison of the two data sets was performed to see if it is possible to extrapolate the light number of uses from the heavy data set and therefore apply this to the combination of break-even-point and willingness threshold analysis in section 3.5.5.3.

Images of the light and heavy-aged bowls were compared for the 3 most strongly staining foods and tea. The cycle number of the most strongly stained bowl from the light set of image data was recorded and then compared with the heavy set of image data. The number of cycles of the image that most closely matched the first image was then recorded. Where the corresponding heavy image was greater than 1, a match for a lower number of cycles was also sought and recorded. The ratio between the values was calculated and recorded.

3.4.4 Acceptability

To investigate whether and how changes in the appearance of containers over time influence participants' willingness to use the containers, a computer-based paradigm that was developed by Baird et al. (2022) was adapted. The work was done under ethics approval number 039349. Participants were asked to imagine that they were getting lunch 'to go' in their local town centre and that the restaurant that they had chosen had replaced their single-use container with a reusable container. They were told that they would be shown images of different reusable containers and asked to decide whether they would be willing to eat from the container displayed on the screen (indicating 'Y' for 'yes, they would be willing to eat from the container', and 'N' for 'no, they would not be willing to eat from the container').

Figure 3.3 *Example of images shown to respondents - bowl 9, which had been tested with baked beans on the heavy use regime after 1 cycle (left) and 28 cycles (right).*

Figure 3.3 shows examples of the images that were used, in this case, the bowl used for the heavy use simulation regime with baked beans after 1 and 28 cycles. The images were presented to the participants using the interleaved staircase approach. A single staircase starts with an image of a particularly clean (or worn) container, the containers in the images become increasingly more worn (or clean), and the container for which they were just as likely to answer 'yes' as 'no' is their 50% threshold. This is analogous to an optician determining a patient's eyeglass prescription. Baird et al. (2022) previously found in a similar experiment with images of water coolers that the result depended on whether participants were shown a dirty or a clean image first. They developed the interleaved approach, illustrated in Figure 3.4, which runs both the ascending and descending staircases simultaneously to reduce any anchoring effects of the initial starting point. The paradigm therefore identified two thresholds for each participant - one for the ascending staircase and one for the descending staircase.

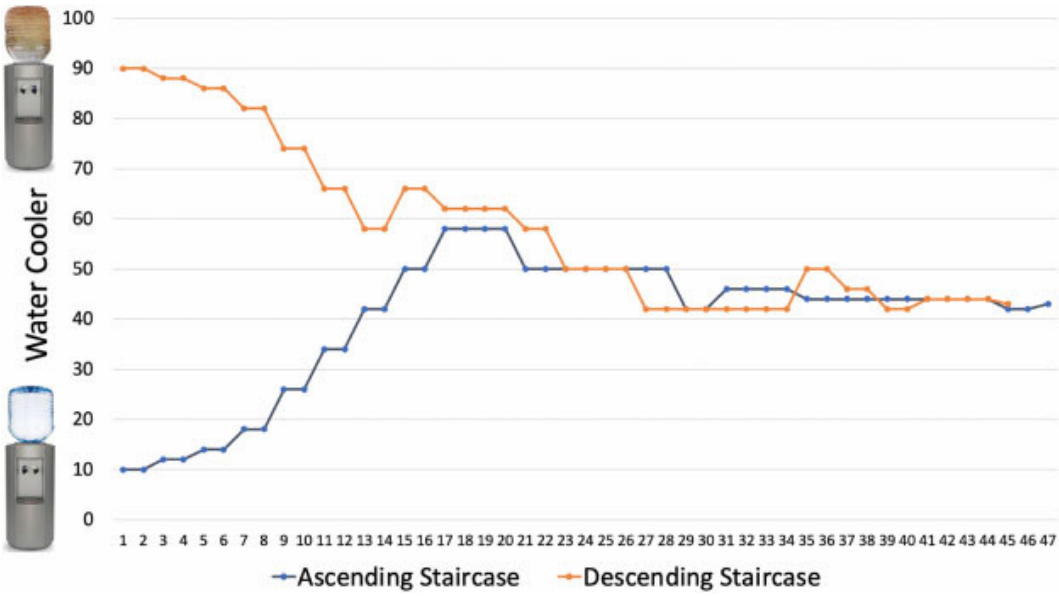


Figure 3.4 *Illustration of how the interleaved adapted staircase procedure is used to identify a participant's 50% threshold, reproduced from (Baird et al., 2022). A step down on the graph indicates a 'no' response, whereas a step up on the graph indicates a 'yes' response.*

3.4.4.1 Stimuli

Eight sets of 28 images showing the condition of reusable containers following different numbers of cycles from the durability testing component of the research (3.4.3) were used as inputs for the willingness threshold study. The 'heavy' subset of prepared samples was used, i.e. the samples that had experienced the most aggressive staining regime.

3.4.4.2 Design

The experiment was designed as an '8 between x 2 within' study. '8 between' refers to the participants being shown one of 8 sets of images of bowls treated with different foodstuffs (baked beans, chopped tomatoes, chopped tomatoes with turmeric and chilli, tomato pasta sauce, tomato puree with water, tomato soup, coffee, and tea). '2 within' refers to the ascending and descending staircases. The participants' threshold was the dependent variable.

3.4.4.3 Procedure

Participants were recruited through Prolific (an online participant recruitment platform) and directed to Qualtrics (an online survey platform) to read more information about the study and complete a consent form. Participants were then asked to complete a pre-questionnaire consisting of demographics (e.g. age, gender, ethnicity), questions relating to how hungry they were (on a scale from 1 to 10 where 1 indicated 'Not hungry at all' and 10 indicated 'Very hungry'), and how long it had been since they had last eaten (in hours). Participants were then directed to Pavlovia (a platform used to run behavioural experiments online) to complete the paradigm designed to measure their willingness to reuse. On completion of the task, participants were redirected back to Qualtrics, where they were provided with a written debrief. Participants were reimbursed £2 for their time. The intention was to recruit 100 participants for each of the 8 different food types.

3.4.5 Environmental impacts: Life cycle assessment (LCA) methodology

Life Cycle Assessment was carried out in accordance with ISO14040 and ISO14044 guidelines. This includes four phases: goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA), and results

interpretation (ISO, 2006a, 2006b). The analysis was conducted by software SimaPro 9.3 and using the Ecoinvent V.3.8 database.

3.4.5.1 Goal and scope definition

The aims of this life cycle assessment were to 1) to assess the cradle-to-grave environmental impact of reusable and single-use containers for takeaway meals from University of Sheffield cafés and 2) determine the minimum number of times a reusable container needs to be used before it performs better on selected environmental metrics than the equivalent single-use containers.

The reusable container is made from polypropylene with a lid made from thermoplastic elastomer (TPE) and polypropylene. The single-use container is a lightweight board box (corrugated) with a PET lining (Table 3.2).

	Container	Material	Weight (g)
	Reusable	**PP, TPE**	**177.5**
	Single-use	**Corrugated paper, PET liner**	**16.11**

Table 3.2 *Image, materials and average weight of the reusable and single-use containers analysed.*

The functional unit was chosen as the use of a container that can hold 650 ml of takeaway food purchased from a catering outlet at the University of Sheffield, UK and consumed close to the point of purchase e.g. in an office or outdoors. Transport between the takeaway and the consumption location was assumed to be on foot (as in Chapter 1) and to have no energy consumption or environmental impacts associated with it. This is a reasonable assumption if the takeaway and place of consumption are close to each other. Additional packaging for ordering takeaway food is not included in this study since it is assumed that such packaging would be required regardless of the takeaway container used. Figure 3.5 depicts a generic system boundary diagram for the reuse and single-use containers.

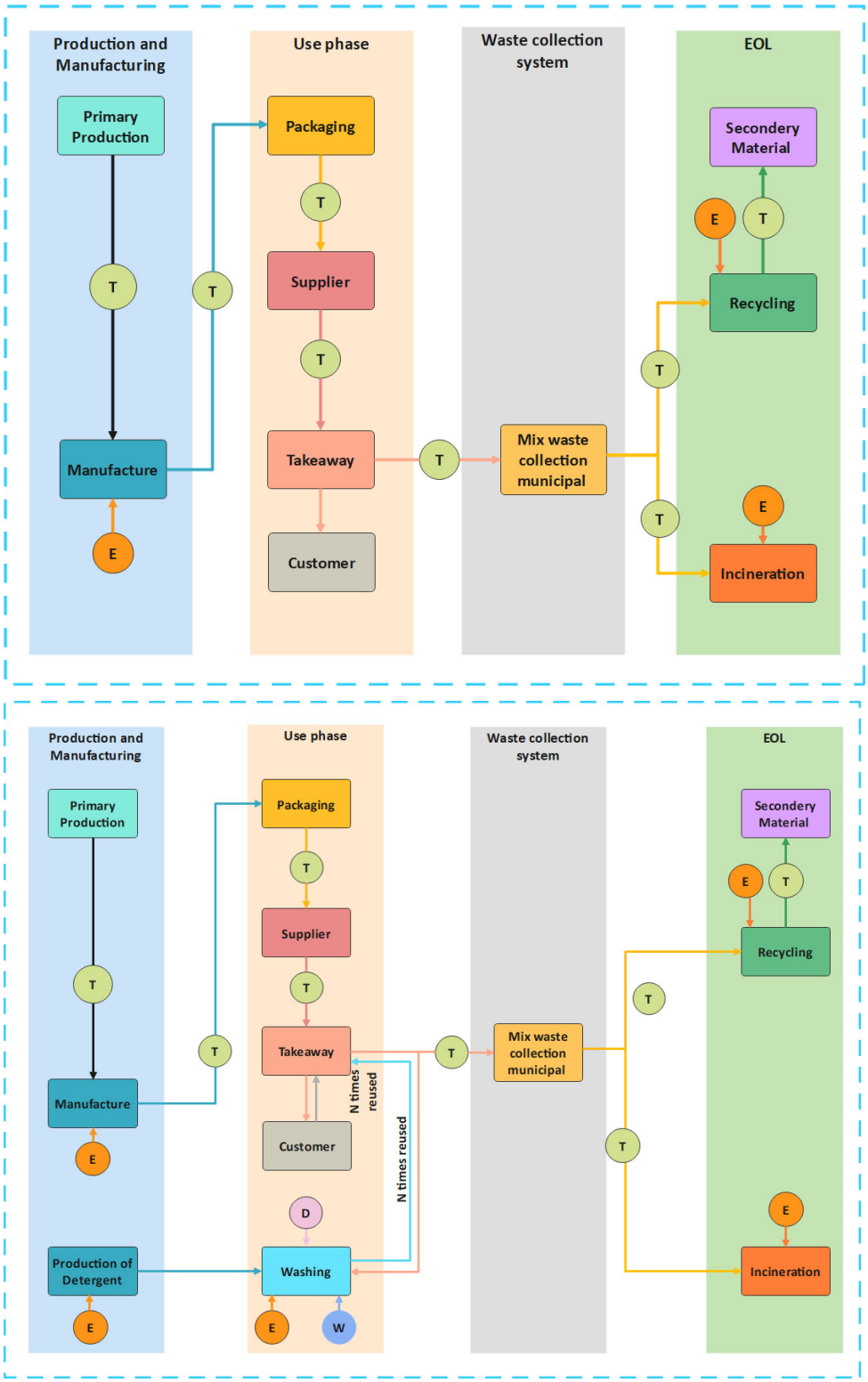


Figure 3.5. *System boundary for life cycle assessment of a) reusable container (top) and b) disposable container (bottom). The avoided burden approach is used to define the system boundary. Products, processes and locations are shown, with major transport (T), energy (E), water (W) and detergent (D) inputs highlighted.*

Global warming potential and water usage were chosen as the indicators to focus on; Global warming as CO_2 equivalent emissions, given the UK's net zero targets, and water as the critics of reuse schemes critics often (rightly) question the amount of water consumed in reuse.

The system consists of four stages: (i) production and manufacturing, (ii) consumption (use phase), (iii) waste collection and (iv) waste treatment (End of Life, EOL). For (i), the production stage, the raw materials are produced, transported and converted into containers. These are then transported to a supplier who then delivers them to the University of Sheffield to distribute to catering outlets around the campus. Note the bulk packaging for containers is not included, this information was not available, so it has been assumed that it is the same for both cases as any differences are likely to be small. In (ii) the use phase, the containers are stored at the outlets and enter a loop, where they are filled and given to the customers, who once finished bring the containers back (to any university catering outlet taking part) to be washed and stored ready for reuse. The washing takes place on site so there is not a transport contribution for the washing stage. (iii) Once a container is no longer useable, e.g. it is damaged or the amount of wear is no longer acceptable, it is placed in the municipal waste collection (either as general waste or for recycling depending on the scenario) before entering the waste treatment stage (iv). In this assessment, the end of life of the containers considers the different scenarios of recycling and incineration with energy recovery.

3.4.5.2 Life cycle inventory

The life cycle inventory is listed in Tables A5 and A6 in the Appendix. Inventory data was taken from a range of sources. Some general manufacturing process information was modelled based on the Ecoinvent 3.8. database. For each container, the main manufacturing processes were applied using representative processes from the Ecoinvent 3.8 database in SimaPro. These processes were modified if necessary to represent the correct country of manufacture, as shown in Table A5. For the washing stage, the required water and energy are included in the analysis, however the treatment of wastewater produced during the washing is not considered (see 2.1.3.2). For washing, a small commercial dishwasher was chosen which consumes 1.4 - 3.6 litres of cold water and 0.232 kWh electricity per cycle. It is assumed that the whole volume of each cycle is allocated to the 9 containers.

The avoided burden approach has been used, meaning that production and recycling of primary plastic is included in the analysis and that end-of-life is modelled so that the products of recycling (material) and/or incineration (heat and electricity) are credited to the system.

3.4.5.3 Life cycle impact assessment

The environmental impacts are expressed as midpoint results through ReCiPe 2016 Midpoint (Hierarchical) (Huijbregts et al., 2017). The method contains 13 out of 14 impact categories recommended for the Product Environmental Footprint.

3.4.5.4 Break-even point assessment

The break-even points for CO_2e and water usage were calculated for the reusable container vs the single-use container as per the method in the previous chapter, 2.3.1.4.

3.4.5.5 Data quality

The data quality of all processes has been assessed on the basis of 6 criteria and then averaged to obtain the general appropriateness of the data, in line with the recommendations of the PEF (Product Environmental Footprint). A score of 1 represents very good quality, and a score of 5 represents very poor quality.

3.4.5.6 Sensitivity analysis

After the completion of the main LCA, sensitivity analyses were performed on the reusable container weight, the energy source used for washing, and the end-of-life treatment, as it was anticipated that these might influence the environmental break-even points. This was done by varying the weight of the container between the actual weight and 40g (the weight of the PP reusable container considered in Chapter 2), using more renewable energy in line with the predicted future energy mix, and considering recycling as well as incineration.

3.4.6 Theoretical lifetime of a container in a system

The theoretical average number of uses per container in the system used in the LCA analysis was calculated from the return rate reported by the Vytal online dashboard as follows:

Consider a system that starts with N containers (say 1000). After each container has been through the first cycle, n=1, some containers are lost from the system. The ratio of those returned and going through to the next cycle being r (e.g. 50 of 1000 containers lost means r = 0.95, or a 95% return rate). The system is topped up with new containers each cycle to ensure a constant pool size. Assuming that r is constant, the theoretical lifetimes of the original N containers can be calculated thus;

Number of containers of the original N containers remaining for a given value of n:

$$N_n = N_0 r^n \qquad \textit{(Equation 3.1)}$$

The total number of uses, U_{total}, from N containers with a return rate of r is:

$$U_{total} = \sum_{n=0}^{n=\infty} N_0 r^n = \frac{N_0}{(1-r)} \qquad \textit{(Equation 3.2)}$$

So the theoretical mean number of uses *per container* is:

$$U_{mean} = \frac{N_0}{(1-r)} \div N_0 = \frac{1}{(1-r)} \qquad \textit{(Equation 3.3)}$$

Equation 3.1 can be used to determine the theoretical possible maximum (by setting N_n as 1):

$$n_{max} = \log(r)\ (1/N_0) \qquad \textit{(Equation 3.4)}$$

But only a tiny fraction of containers could ever reach this number. As the number of original containers experiences exponential decay, a half-life i.e. the number of cycles at which only half of the containers remain, is more useful:

$$n_{0.5} = \log(r)\ 0.5 \qquad \textit{(Equation 3.5)}$$

e.g. for a return rate of 99% the container half-life is 69 uses, for 95%, it is 14 uses and for 80% (i.e. 2 in 10 containers are not returned) it is just 3 uses (see Table 3.8)

3.5 Results

3.5.1 Vytal container renting scheme

3.5.1.1 Merchant dashboard figures

Figure 3.6 is a screengrab from the Grafana analytics platform showing the metrics from the Vytal scheme run at the University of Sheffield from August 2021 to 15th June 2023.

Over the almost three-year period, a total of 6958 rentals were made by 759 scheme users, with a return rate of 99%. The scheme ran across 7 catering outlets in total; initially the Heartspace Café and the Diamond Kitchen from August 2021 using bowls and cups, the Jessop Café, the IC Café and Café 1828 from early 2022 (cups only), and New Leaf, a takeaway-only salad bar in the student union and (bowls only), and the Social Sciences Café (cups only) in September 2023. 6221 of the rentals were for hot drink cups and 737 bowls, 89.4% and 10.6% respectively. Table 3.3 compares the net number of check-ins vs check-outs per venue, showing that containers are not necessarily returned to the point of purchase - a net 16% of the containers rented from the Jessop Café are returned to the Heartspace café, a 5-minute walk away (0.2 miles).

Venue	**# Check-outs**	**# Check-ins**	**Difference**	
			#	**%**
Diamond	3056	3075	19	0.62
Heartspace	1495	1501	6	0.04
Jessops	790	708	-82	-10.4
IC	1159	1202	43	36
Cafe 1828	159	155	-4	-2.5
Social Science Cafe	79	65	-14	-1.3
New Leaf	220	197	-23	-10.5
Total	6958	6903	55	-

Table 3.3 *Number of container check-outs and check-ins for each venue, showing a net flow of containers from the lower volume rentals venues to the larger and 55 containers either currently on loan or lost from the system as non-returns.*

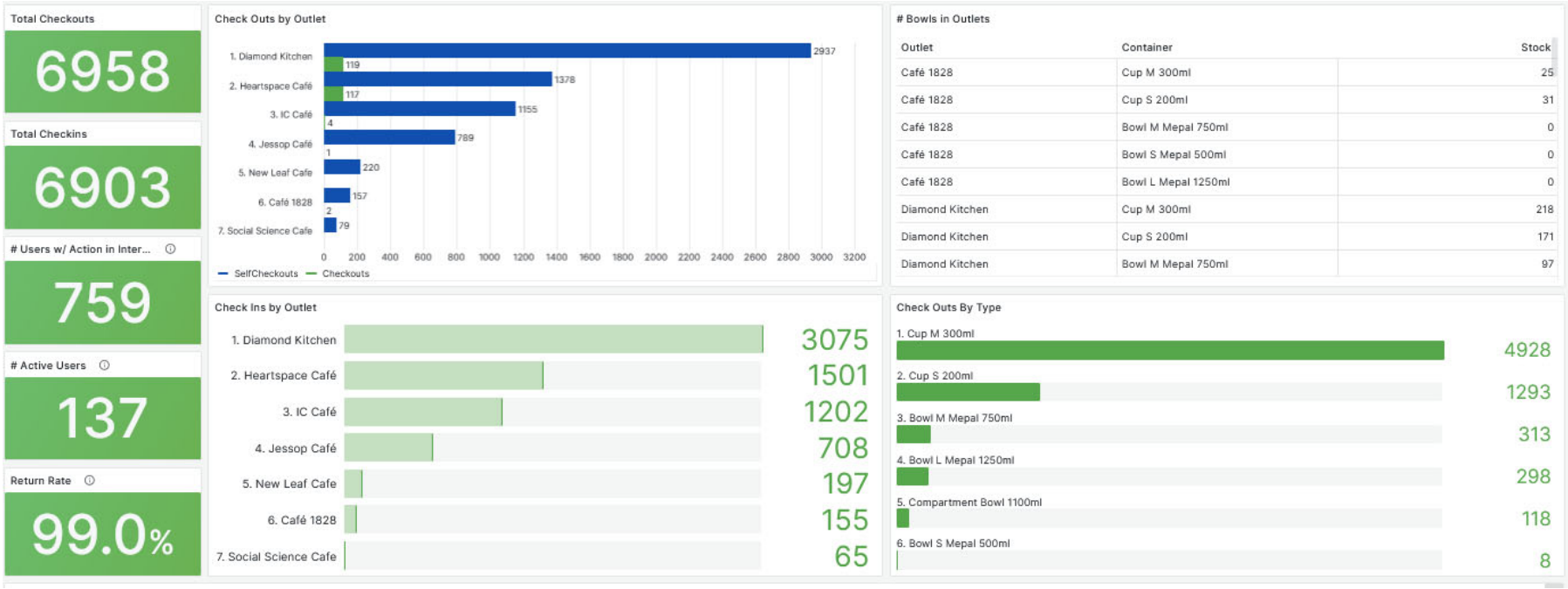


Figure 3.6 *a) Screengrab from the Grafana dashboard showing metrics for the Vytal scheme running at the University of Sheffield from August 2021 to 15th June 2024, including total number of checkouts and check-ins, total number of users, active users within the last month, return rate, number of checkouts by outlet, the number of containers currently held it each outlet, checkouts by container type.*

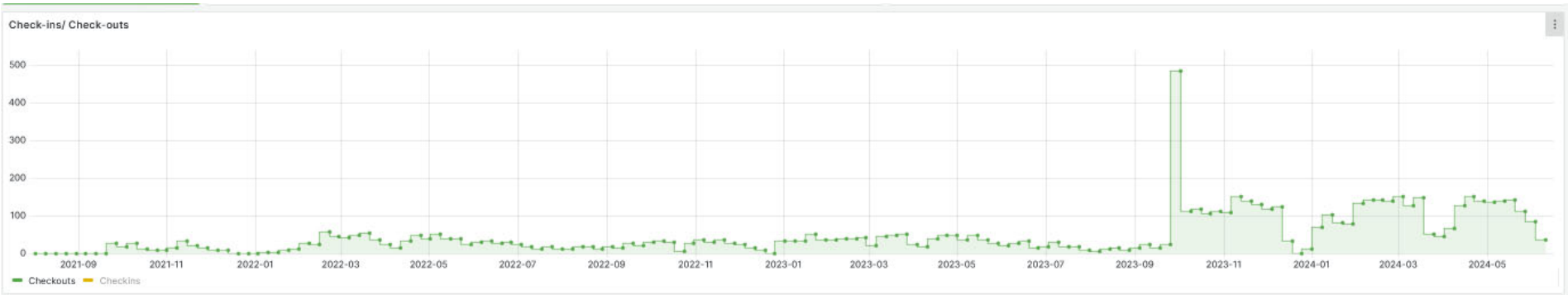


Figure 3.6 *b) Graph showing the number of containers, including cups and bowls, rented per week over the period August 2021 to 15th June 2024.*

The focus of this study was the 750ml bowls; 150 of these were provided by Vytal at the start of the scheme, and there were 313 rentals during the time period examined, working out as an average of just over two uses per bowl. Conversely for the 300ml cups, 350 of these were provided and there were 4928 rentals, which is just over 14 uses per cup.

3.5.1.2 Types of meal sold in the containers

Of the cafes taking part in the scheme, two, the Heartspace Café and the Diamond Kitchen provided takeaway meals in reusable containers throughout the trial period. The Heartspace serves Jacket potatoes, soup and sandwiches, and has a salad bar. At the start of the trial, the Diamond served jacket potatoes, curry and rice, burgers and chips, and wraps. This changed to wraps and burrito bowls in September 2023. New Leaf served salads for the academic year 2022-2023, and all other venues, although serving food, used the Vytal scheme for hot drinks only.

3.5.1.3 Figures for comparison

In order to put the figures above into perspective, there were 30,307 students and 8,606 staff at the University of Sheffield in the academic year 2022-2023 (University of Sheffield, 2023), meaning that the 759 participants in the scheme were 1.95% of the total population.

In the first two years of the scheme there were 313 bowl rentals from the Diamond and 97 from the Heartspace. For the same period, 24,720 single-use food containers were bought for the Diamond and 6,590 for the Heartspace (source: personal communication from Peter Anstess). This works out as rentals being 1.3% of takeaway food sales.

Table 3.4 shows total hot drink sales across the university for the period 1st October to 23rd March in the academic years 2022 to 2023 and 2023 to 2024.
Vytal rentals accounted for a tiny proportion of sales, even after the promotion (0.4% of hot drinks sales in 2022-23, going up to 1.7% in 2023-24). Over the same periods people using their own cup went up (from 9% to 11%), and single-use cup usage went down from 61% to 50%. The percentage of people drinking in went up by 3%. Note that other than for Vytal, the data below relies on the server pushing a

button at the right time, so human error needs to be taken into account, and is an explanation for the 'unaccounted' figures.

Year	Total hot drinks	Percentage of total / %				
(1/10 to 23/3)		Drink in	Own cup	Single-use	Vytal	Unaccounted
2022-2023 (20p charge)	236464	23	9	61	0.3	8
Takeaways only	163992	-	12	87	0.4	-
2023-2024 (30p charge)	261719	26	11	50	1.1	12
Takeaways only	162943	-	17	81	1.7	-
2023-2024 promotion week	12146	28.6	12.4	55.8	3.95	-0.8
(hot drinks £1 if in own / Vytal cup)	7549	-	17.2	77.3	5.5	-

Table 3.4. *Total hot drinks sales across university outlets for the time period 1st October to 23rd March for the academic years 2022 to 2023 and 2023 to 2024, broken down by drink-in, bring-your-own cup, single-use cups and Vytal cup rentals. Source: ACS UNICUS Commercial Services, University of Sheffield.*

Scheme uptake

Whilst the return rates from the active users are very high, the number of people participating in the scheme was disappointingly low. This is despite posters and 2m banners in the outlets (and table talkers for the initial launch), point-of-sale instructions, advertising on the till screens, a staff incentive scheme to get customers to sign up, and a free hot drink after 5 rentals via the university's Genius loyalty scheme. There is also a charge to customers to use a single-use container; which was 20 pence on its introduction in September 2021, increasing to 30 pence in September 2023. It is important to note that although the scheme was initially marketed for the food bowls only, rentals of hot drink cups quickly took over and account for the majority of rentals.

The single action with the most impact in improving uptake for cups was a promotion in the first week of October 2023. Hot drinks were heavily discounted to £1 if they were bought in a reusable cup (either a Vytal or the customers' own). Rentals that week sky-rocketed to 485. The previous record was 57 in February 2022 when the staff incentive was in operation (and an average of about 26 rentals per week). Post-promotion, the rental figures settled down to an average of 106 rentals per week. The promotion appears to have been particularly effective in the

IC café (in the main university library); for the whole period up to the promotion (Feb 21 to Sept 23), there were 156 rentals; in the period after (October 23 to June 24) there were 1002. Pre-promotion, 231 people had used the scheme at least once; by June 2024, this has increased to 759.

Large 1250 ml Bowls were introduced to the scheme via the New Leaf salad bar in the students' union in September 2023. Over the academic year 2023-2024 there were 197 rentals from the outlet, over a quarter of the total bowl rentals from the whole three years, so a success compared with the other venues. Despite this relative success, the scheme was not used for the next academic year, the outlet moving to fibre-based bowls with a plastic lid in place of the original PET clamshells.

3.5.2 Durability: How does the appearance of containers change with use?

3.5.2.1 Initial tests

The brand-new polypropylene bowls that were washed repeatedly in the dishwasher showed no visual signs of abrasion and remained as glossy as new after 75 cycles. The use of plastic or wooden cutlery with the bowls made no distinguishable marks. However, metal cutlery led to multiple scratches and the creation of small amounts of friable material (i.e. microplastics).

3.5.2.2 Wear, staining, microwaving and washing regime

The matrix in Figure 3.7 shows photographs of the treated and washed bowls ordered in increasing number of cycles from left to right and the type of foodstuff and cycle conditions from top to bottom. Microwave heating accelerated the staining process significantly. The stains caused by tomato (lycopene), turmeric (curcumin) and chilli (various carotenoids) containing foods were not particularly reduced by washing, unlike the stains induced by the tannin from the tea and coffee. This can be explained by the solubility of the compounds in the plastic, which is isotactic polypropylene (iPP). The solubility coefficients of substances in oil can be used as a proxy for this; iPP is semicrystalline in structure with crystalline and amorphous phases, it is the amorphous phase that the compounds from the foodstuff migrate into and chemically this is similar to oil.

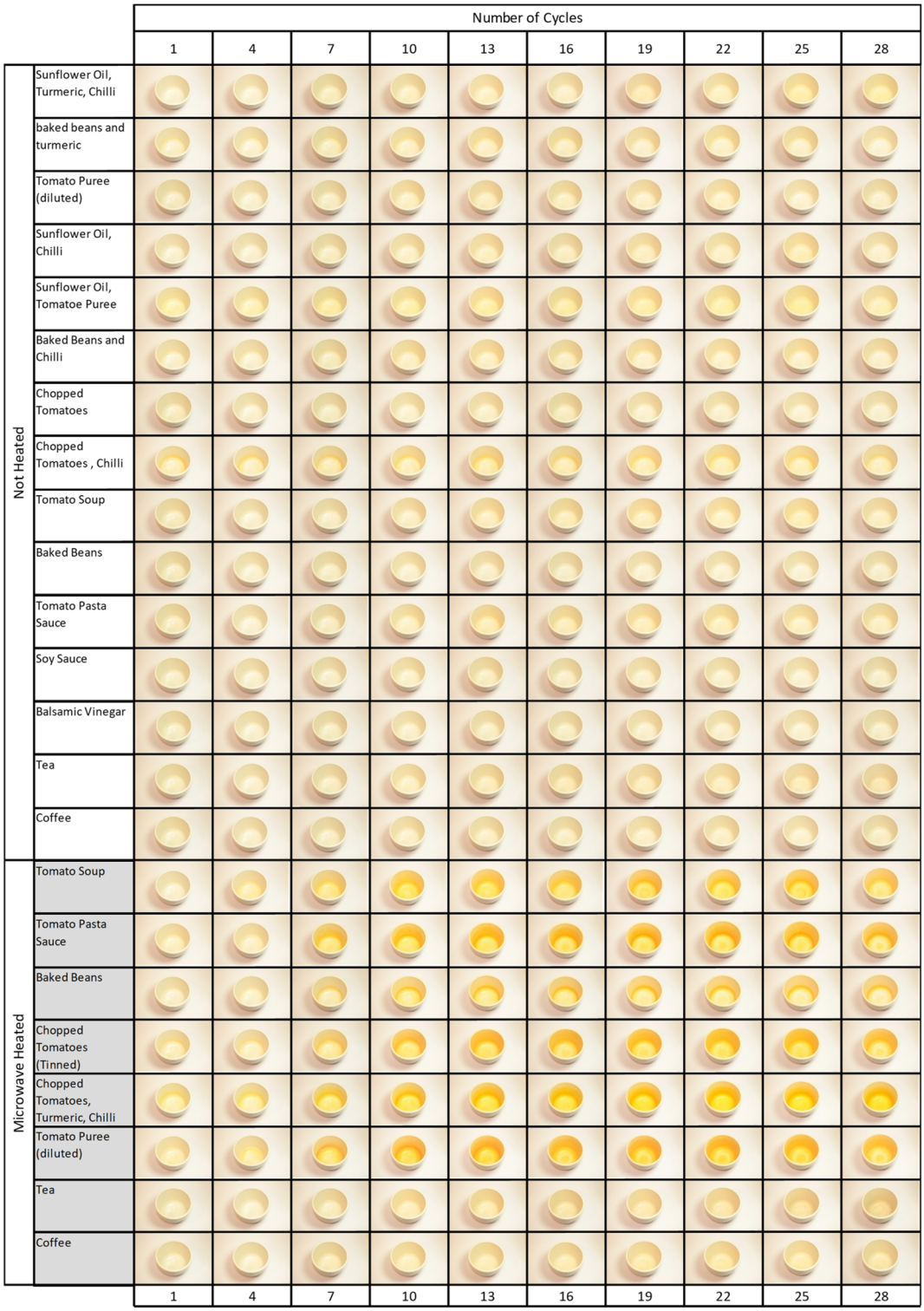
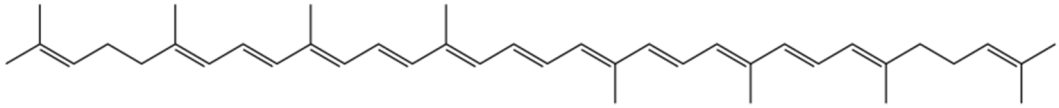
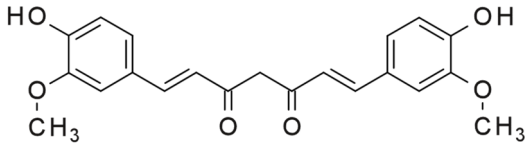


Figure 3.7 *Matrix showing photographs of artificially aged bowl samples. The rows show the different foods used for the staining process, and the columns show the number of cycles after which the photo has been taken. The top half of the table shows 'light' ageing (no microwaving stage), and the bottom half 'heavy' ageing (bowls microwaved for 3 minutes). Credit: Paul Mattinson*

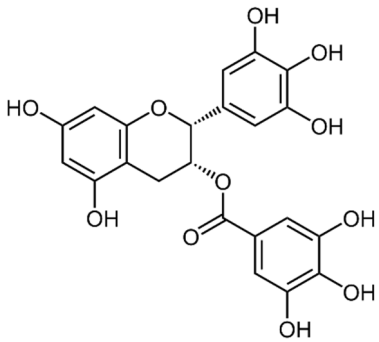
Lycopene and Curcumin (Figure 3.8 a and b) are hydrophobic, so insoluble in water (Aditya et al., 2015; Cámara et al., 2013), but are soluble in oil. Lycopene, a carotenoid, has a solubility of 1.15 +/- 0.25 mg/ml in olive oil (Guo et al., 2019), Curcumin 0.45 +/- 0.01 mg/g in olive oil (Takenaka et al., 2013). Tannins are not oil-soluble (Tanaka et al., 2018). The most prevalent tannin in tea is epigallocatechin-3-O-gallate (EGCG) (Figure 3.8 c) which has a solubility in water of 108.18 ± 7.53 mg/ml (Li et al., 2013; Tanaka et al., 2018). Any staining is more likely to be at the surface of the container (possibly with precipitated solids) and therefore more easily removed by the washing process.



a) Lycopene - $C_{40}H_{56}$



b) Curcumin (keto tautomer) - $C_{21}H_{20}O_6$



c) epigallocatechin-3-O-gallate (EGCG) - $C_{22}H_{18}O_{11}$

Figure 3.8 *The chemical structures of a) lycopene, the red pigment in tomatoes, b) curcumin, the active staining component in turmeric and c) EGCG, one of the main tannins in tea.*

The respective solubilities can be explained by the chemical structures shown in Figure 3.8. Lycopene (3.8 a) is made up entirely of carbon and hydrogen atoms, making it non-polar, explaining its high solubility in oil. Conversely, EGCG (3.8 c) has eight hydroxyl groups, making it polar and soluble in water. The structure of EGCG will also affect its permeability through a polymer matrix - it is branched, and the aromatic rings are rigid, making it less flexible than lycopene, so it is physically more difficult for it to migrate. The lower solubility of curcumin (3.8 b) compared to lycopene can be explained by the presence of the two hydroxyl groups. The permeation of the staining molecules into the plastic was more pronounced on the microwaved samples because their solubility (S) and diffusivity (D) increase with temperature:

$$P = D \times S \qquad \textit{(Equation 3.6)}$$

Where P is the permeability coefficient, D is the Diffusion coefficient and S is the solubility coefficient (e.g. (Yang et al., 2020)).

iPP is a semi-crystalline polymer and is above its glass transition point at room temperature. For the microwaved samples, the surface of the bowl in contact with the foodstuff will have reached 100°C. As the temperature increases, the polymer chains in the amorphous regions become increasingly mobile, allowing the staining molecules to permeate the matrix more freely. While the melting temperature of PP is approximately 170°C (depending on the grade), the Vicat softening temperature is significantly lower, at around 125°C. If reusable plastic containers are expected to be used in the microwave for heating, it would be worthwhile investigating the use of a plastic material with a higher softening temperature, but also considering the glass transition temperature if they are expected to be used in the freezer (see Chapter 6 for a more detailed discussion on materials selection).

3.5.2.3 Comparison of heavy and light testing regimes

Table 3.5 shows the results of the visual comparison of selected bowls from the light and heavy ageing protocols as described in 3.4.3.4.

Foodstuff and bowl numbers compared	#cycles - bowl from Light set	#cycles - bowl from Heavy set	Ratio
Tomato pasta sauce (bowl samples – Heavy 16 and Light 7)	27 6	4 1	6.75 6
Baked beans (bowl samples - Heavy 9 and Light 15)	28 22	2 1	14 22
Tomato soup (bowl samples Heavy 2 and Light 14)	27	2	13.5
Tea (bowls samples Heavy 21 and Light 20)	27 1	6 3	4.5 3

Table 3.5 *Results of a visual comparison test between images of bowls from the light and heavy image sets for Tomato Pasta Sauce, Baked Beans, Tomato Soup and Tea. The most stained image from the light set is recorded with the closest match for appearance from the heavy data set recorded in the next column. Where the corresponding heavy image was from greater than 1 treatment cycle, a match for a lower number of cycles was recorded. The ratio between the number of cycles of the corresponding light and heavy images is displayed in the column on the right.*

The results suggest that *very approximately* the heavy testing protocol produces staining 6 times faster for the Tomato Pasta Sauce and 4 times faster for tea. The ratios for the baked beans are too different to be able to make an inference and there is only one data point for the tomato soup, so not enough information to make even a rough approximation.

3.5.3 Acceptability: At what point are people unwilling to use a container?

Images from 3.5.2 were presented to participants following an interleaved, adaptive staircase procedure (see 3.4.4). The responses were used to determine their 50% thresholds (that is the number of uses of the container that a respondent is willing to eat from 50% of the time). The thresholds could range from 1 (i.e. only willing to use the new container) to 28 (i.e. willing to use containers that had been through 28 cycles). Average thresholds ranged from 7 to 16 uses for the different food and drink substances (M = 9.89, 95% CI = [9.11, 10.26] (see Table 3.6 and Figure 3.9). Participants were more willing to reuse containers that had been exposed to tea and coffee (M = 15.98, 95% CI = [14.21, 17.74]) (i.e. lighter staining) than containers exposed to highly staining foods (M = 6.61, 95% CI = [5.72, 7.51].

		Threshold								
		Ascending Staircase			Descending Staircase			Average		
Condition	**N**	**M**	**95%**	**CI**	**M**	**95%**	**CI**	**M**	**95%**	**CI**
Baked Beans	94	6.88	5.41	8.35	6.34	5.26	7.43	6.61	5.46	7.76
Tomato pasta sauce	92	7.34	5.85	8.82	6.36	5.26	7.46	6.85	5.68	8.01
Tomato puree with water	68	9.99	8.26	11.72	5.34	4.06	6.61	7.66	6.31	9.02
Tomato soup	76	7.72	6.09	9.36	6.71	5.50	7.92	7.22	5.94	8.50
Chopped tomatoes with turmeric and chilli	67	9.81	8.06	11.55	7.10	5.82	8.39	8.46	7.09	9.82
Chopped tomatoes	65	11.03	9.26	12.80	7.92	6.62	9.23	9.48	8.09	10.86
Coffee	69	18.01	16.30	19.73	13.09	11.82	14.35	15.55	14.21	16.90
Tea	90	16.64	15.14	18.15	15.31	14.20	16.42	15.98	14.80	17.16

Table 3.6 *The mean willingness thresholds for each foodstuff, using the ascending staircase, descending staircase and the average of the two, along with the confidence index*

Figure 3.9 shows the mean willingness threshold and confidence levels for each of the 8 foodstuffs tested.

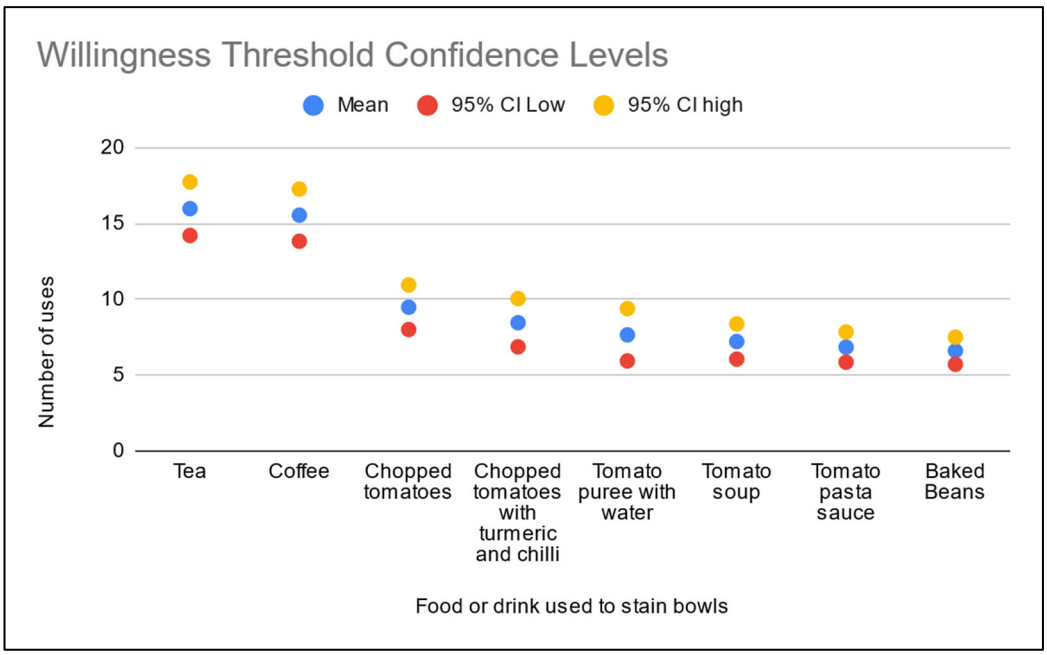


Figure 3.9 *Graph showing the mean willingness thresholds for each food or drink item used to stain bowls with the confidence interval.*

3.5.4 Environmental impacts: What are the environmental impacts of reusable and single-use containers?

3.5.4.1 LCA results

Figure 3.10 shows the global warming (GW) impact and water consumption for single-use and reusable containers for 70 uses and different scenarios for the end-of-life treatment (EOL) of the reusable container. This value was chosen as it corresponds to the container return rate of the Vytal scheme, 98.3% at the time of the analysis, calculated using Equation 3.4. The results of the other impact categories assessed are shown in Figure 3.11.

The reusable container showed a 13% lower global warming impact than the single-use containers with incineration as the end-of-life treatment, 36% lower global warming impact when the reusable container is recycled. The negative component of the end-of-life global warming impact associated with the single-use container is due to the embedded biogenic carbon (from the paper) and the energy recovery from incineration as this avoids the burning of fossil fuel.

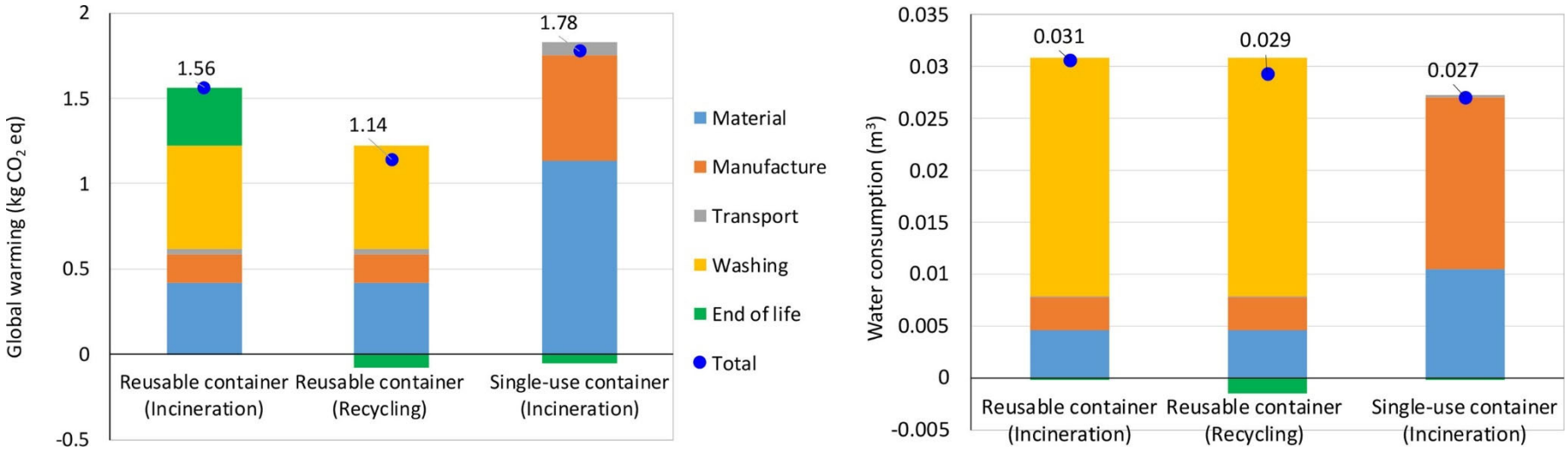


Figure 3.10 *Global warming (left) and water consumption (right) of use of 70 single-use containers (assuming reusable containers are used for 70 cycles, calculated from the scheme return rate) with different EOL treatment scenarios.*

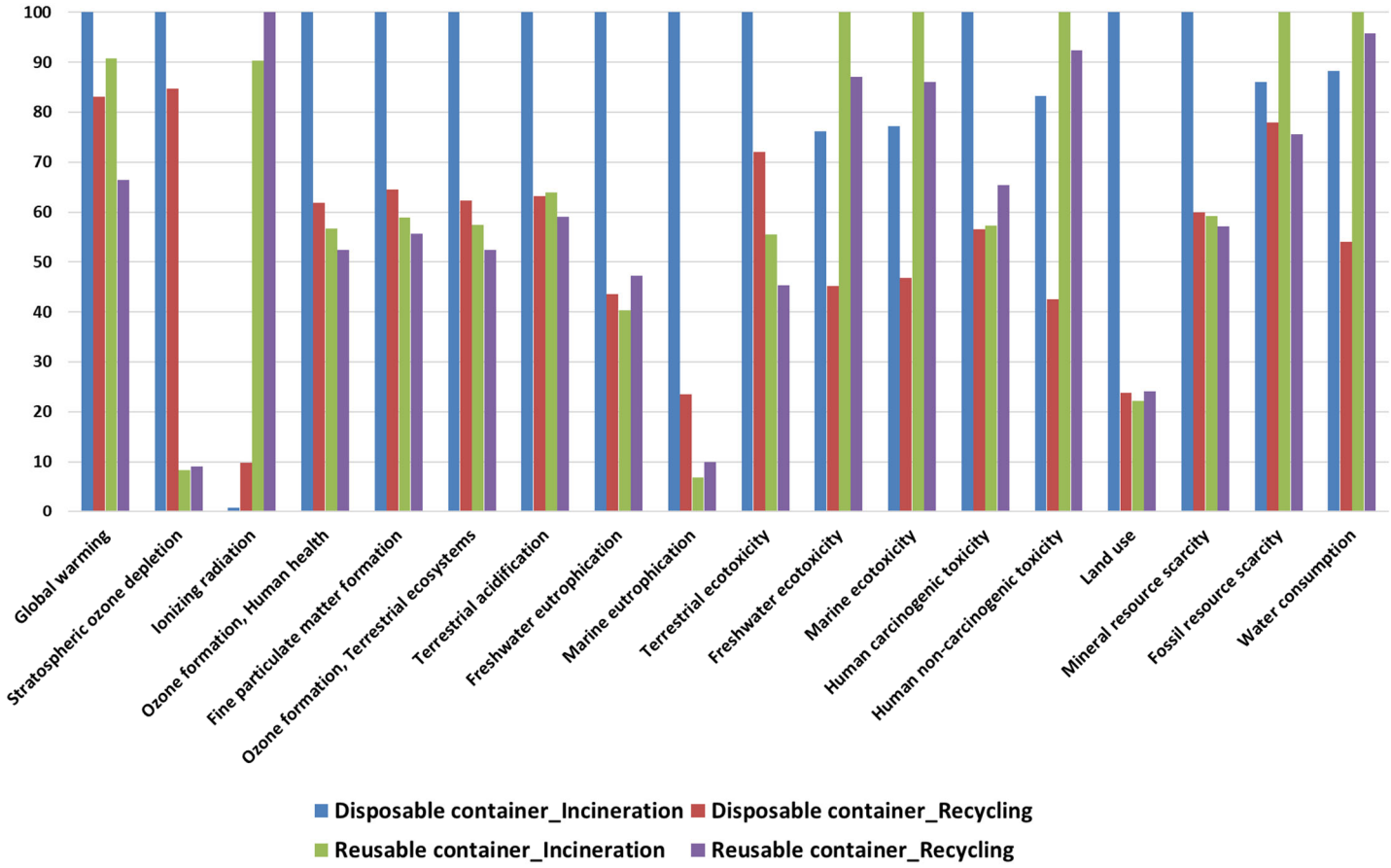


Figure 3.11 *Full life cycle assessment results. The ReCiPe 2016 Midpoint (H) model has been used to calculate the impacts for 70 uses of each container for 18 different environmental indicators. The Y-axis is normalised for the highest-scoring packaging type for each indicator.*

Recycling of the reusable container over incineration makes such a big difference to the global warming potential because this avoids the (effective) burning of fossil fuel as PP is made from petrochemicals.

The reusable container consumed approximately 13% more water than the single-use containers assuming incineration as the end-of-life treatment. Recycling the reusable container reduced water consumption marginally, by 4%, but this was still 9% higher than for the single-use containers.

The biggest contributions to the global warming potential for the reusable container came from the washing and manufacturing phases, 39% and 27% respectively.

Use format and end-of-life option	**Number of indicators as the worst performer**	**Number of indicators as the best performer**
Single-use with incineration	12	1
Single-use with recycling	0	5
Reuse with incineration	5	4
Reuse with recycling	1	8

Table 3.7 *Summary of results in Figure 3.11, showing the number of LCA indicators that each use and end-of-life scenario performs best and worst at. Cell colour-coding - red indicates worst, green best, and the intensity of colour indicates the number of indicators that are the best or worst per scenario.theme.*

Table 3.7 summarises the results of the full analysis (Figure 3.11). The single-use container with incineration as the end-of-life treatment was the worst performer in 12 of the 18 indicators evaluated in the assessment (Global Warming, Stratospheric Ozone Depletion, Ozone Formation Human Health, Fine Particulate Matter Formation, Ozone Formation Terrestrial Ecosystems, Terrestrial Acidification, Marine Eutrophication, Freshwater Eutrophication, Terrestrial Ecotoxicity, Human Carcinogenic Toxicity, Land Use and Mineral Resource Scarcity). The reusable container with incineration at end-of-life performed the worst for 5 indicators (Freshwater Ecotoxicity, Marine Ecotoxicity, Human Non-carcinogenic Ecotoxicity, Fossil Resource Scarcity and Water Consumption), and the reusable container with recycling at end-of-life scenario performed worst for

Ionising Radiation. These results illustrate that there is rarely one scenario in an LCA that is better than the others for all environmental metrics and emphasise the importance of choosing which metrics to focus on, for example, in countries prone to drought, water usage will become more important, and single-use may end up being the better option.

3.5.4.2 Data quality

The results of the data quality analysis are shown in Table A7 in the Appendix. Due to a lack of data, almost all processes have been scored as having 'Very poor' completeness. All processes fall into the 'Good quality' rating as described by the PEF (Product Environmental Footprint, (Manfredi et al., 2012)). The PEF recommends that at least 70% of the contributions to each environmental footprint have a score lower than 3.0, which has been fulfilled in this study.

3.5.4.3 Sensitivity analysis:

Container weight

If the weight of the container is reduced from 177g to 40g (the weight of the PP container used in Chapter 1), there is a 47% reduction in global warming potential (using the worst-case scenario of incineration with energy recovery as the end-of-life treatment) (Figure 3.12).

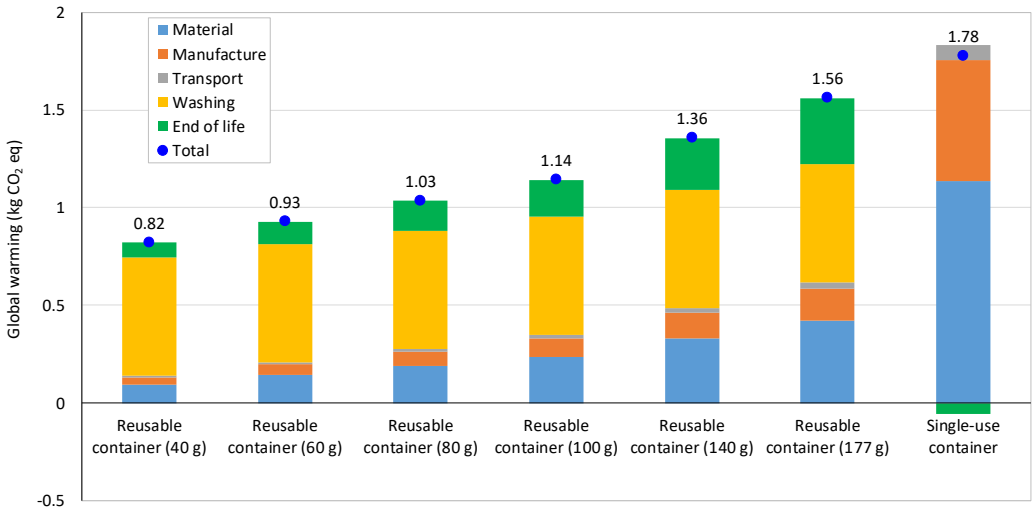


Figure 3.12 *Sensitivity analysis on the weight of the reusable container which is assumed to be used 70 times (calculated from the scheme return rate).*

Energy source

For this study it was assumed that UK grid electricity is used for washing, where 83% of the energy comes from non-renewable energy sources. The global warming impact of the washing phase can be reduced by between 68% and 90% by moving to a higher proportion of renewable energy, i.e. hydro run-of-river, wind and solar (Figure 3.13). This equates to an overall global warming reduction of up to 34%.

The results of the sensitivity analysis show that both the weight of the container and the energy source used in the washing phase are important factors in the success of a reusable container scheme.

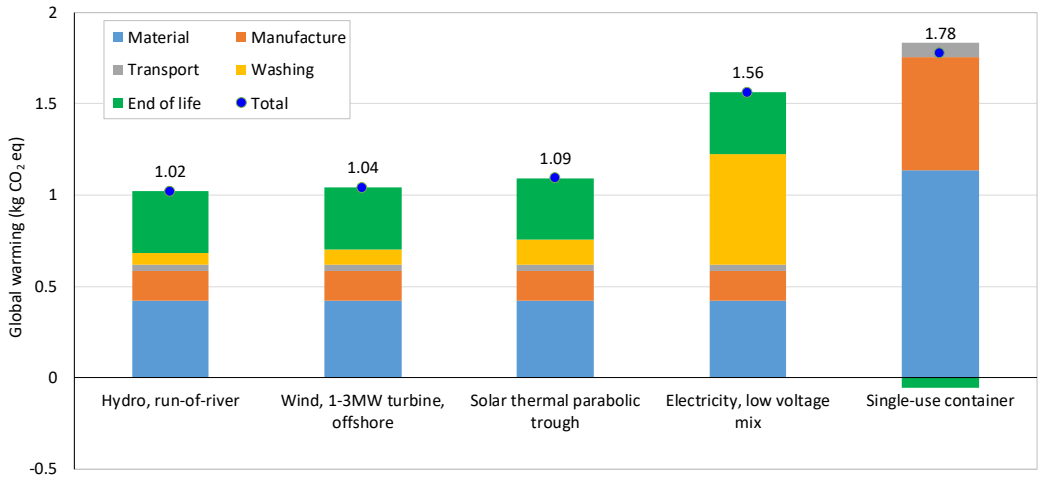


Figure 3.13 *Sensitivity analysis on the energy source used in the washing phase. Reusable containers are assumed to be used 70 times (calculated from the scheme return rate).*

3.5.4.4 Break even points

The break-even points were calculated for global warming potential and water usage as 60 and 136 respectively (both containers incinerated at end-of-life and grid electricity used for washing the reusable containers). For this study the number of uses used for comparison with single-use was 70, the theoretical number of uses calculated from the actual return rate at the time the LCA was performed (see 3.4.6). The global warming impact break-even-point therefore falls within the theoretical number of uses of a container within the system; the water consumption break-even point way beyond it, further illustrating the findings above that while the scheme will benefit the environment in terms of

global warming potential compared with single-use, there is (currently) increased water usage.

3.5.4.5 Financial impact

Vytal charges a fee of a few pence per rental in addition to an onboarding fee and a minimum monthly charge per outlet. Their intention is for the total cost to be cheaper than using a single-use container. The university buys single-use packaging using a bulk discount, so the cost per unit is less than the fee paid to Vytal. This is even when the cost of disposal of both the single-use (via general waste) and reusable containers (via recycling) to the university is considered (about 0.5 pence and 4.5 pence respectively). This means that **in this specific case, there will never be a financial break-even point for reuse versus single-use**, unless the rental fee to the university comes down, or the cost of the single-use packaging goes up, e.g. via EPR, by around 6 pence per unit. However, the 30p single-use charge made to customers is used to subsidise the scheme, meaning that once the cost of washing and associated staff time is considered (approximately 0.1 pence), one single-use container subsidises the rental of 5.4 bowls, as there is no additional cost to the customers. In this case, the scheme therefore relies on the ratio of reusable to single-use sales to be 5.4:1. If no single-use containers were used (which is unlikely, given the rental figures in 3.5.1), then it would cost the university money to run the scheme.

3.5.4.6 Theoretical lifetime of a container in a system

Table 3.8 shows the total, mean and maximum number of uses of a container when part of a system for 1000 containers, alongside the number of cycles after which 50 per cent of the containers are lost for a selection of return rates. These figures were calculated from the equations in 3.4.6.

The graph in Figure 3.14 shows the mean number of uses per container plotted against the return rate, showing an exponential relationship, which is discussed more in 3.6.3.

Return Rate %	r	Total number of uses (for 1000 containers)	**Mean number of uses per container**	Maximum number of uses (1000 containers)	Number of cycles after 50% of containers lost (half-life)
10	0.1	1111	**1**	3	**0**
50	0.5	2000	**2**	10	**1**
80	0.8	5000	**5**	31	**3**
90	0.9	10000	**10**	66	**7**
95	0.95	20000	**20**	135	**14**
97	0.97	33333	**33**	227	**23**
99	0.99	100000	**100**	687	**69**
99.5	0.995	200000	**200**	1378	**138**

Table 3.8 *Total number of uses per 1000 containers, mean number of uses per container, theoretical maximum possible number of uses for a container and number of cycles after 50% of an initial set of containers are lost from the system (container half-life) shown for increasing return rates, where the return rate is the percentage of containers that are returned after each cycle. Calculated as per 3.4.6 in the method section.*

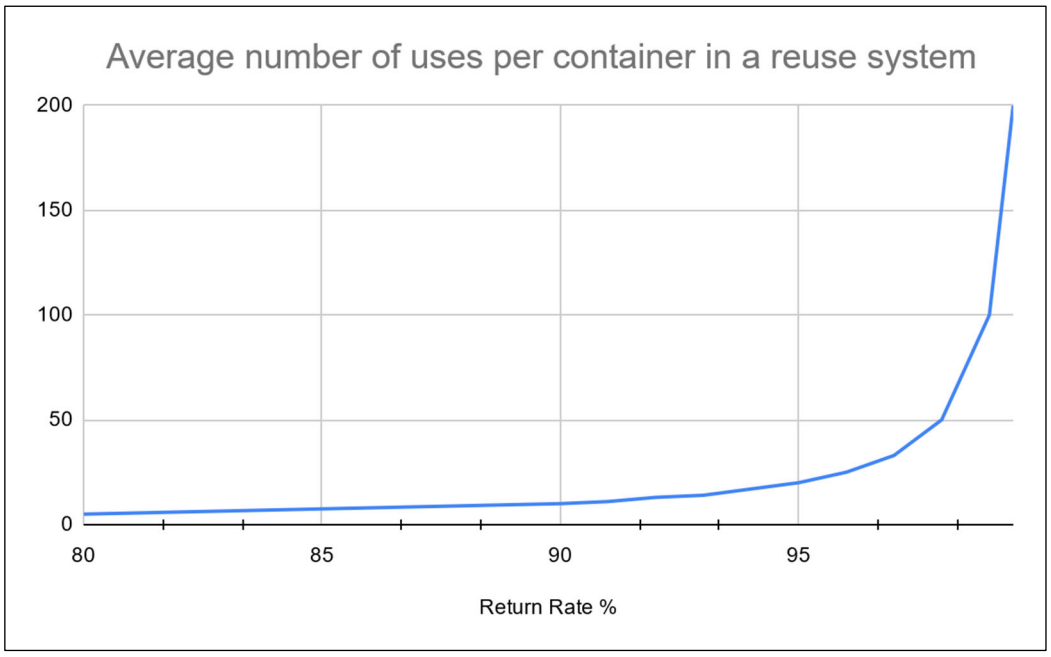


Figure 3.14 *The average lifetime of a container in a return system (y-axis) vs the return rate calculated as per 3.4.6 in the method.*

3.5.5 Integrating insights across disciplines: Strategies for aligning the BEP with consumer willingness

For a reuse scheme to be better than the single-use equivalent for any given environmental metric, the number of use cycles corresponding to the level of wear or staining of a container that people will accept must exceed the environmental break-even point and ideally be as close as possible to the lifetime of a container in the system based on the customer return rate. Integrating the insights across the different components of this research suggests that (in a worst-case scenario) people may become unwilling to reuse containers before they have been used a sufficient number of times to provide and advantage over the single-use alternative. That is, willingness thresholds ranged from 7 to 16 uses, while the break-even point for global warming potential was 60 uses. To be a favourable system in terms of global warming potential, either the break-even point must decrease or the number of times that people are willing to use a container must increase.

The findings of the LCA showed that the container weight, energy source used and end-of-life treatment method all had an impact on the global warming potential. Table 3.9 shows the effects of a number of factors on the break-even points for global warming potential and for water usage;

	Scenarios	BEP (GW) no. of uses	BEP (water consumption)
Weight (g)	Mass_177	60	136
	Mass_140	46	106
	Mass_100	33	76
	Mass_80	26	61
	Mass_60	20	46
	Mass_40	13	30
Renewable energy	UK grid	60	136
	Wind	40	82
	Hydro run of river	40	80
	Solar	42	84
EoL	Incineration (energy recovery)	60	136
	Recycling both samples	46	-8
	Reusable container_Recycling Disposable container_Incineration	33	113
Best case scenario	Weight: 40g Electricity source (washing phase): Wind EoL: Recycling	5	15

Table 3.9 *Break-even point (BEP) for different scenarios depending on the weight of the container, the amount of renewable energy used and the end-of-life scenario. The default scenario is incineration for end-of-life treatment with grid electricity.*

The default scenario for the calculation of the break-even points is the 177g reusable container, incineration as the end-of-life treatment for the reusable and single-use containers, and the use of grid electricity.

3.5.5.1 Break-even point (BEP) for global warming potential

The graphs in Figure 3.15 show the effects of a) weight b) end of life and c) energy source on the global warming break-even point for reusable containers in the scheme studied. Container weight had a significant impact on the BEP. There was a substantial reduction from 60 to 13 uses when the weight of the reusable container decreased from 177 to 40 g, taking it well within the willingness threshold. Moving to renewable electricity for washing reduces the BEP from 60 to 40 uses, but this is still significantly higher than the (heavy usage) willingness threshold. The BEP changes dramatically depending on the end-of-life scenario; by using recycling rather than incineration for the reusable container, the BEP shifted from 60 to 33 uses.

3.5.5.2 Break-even point (BEP) for water usage

The graphs in Figure 3.16 show the effects of a) weight b) end of life and c) energy source on the water usage break-even point for reusable containers in the scheme studied. Reducing the weight of the reusable container to 40g reduces the break-even point for water consumption when compared to the single-use container by 78% - from 136 to 30 uses. Note, a 177 g container washed using grid electricity as the energy source will never have lower water consumption than a single-use container which is *recycled* after use.

3.5.5.3 Comparing the BEPs with the Willingness Threshold

The best-case scenario for environmental impacts (i.e. a 40 g container, electricity from wind and recycling at end-of-life) is shown in Figure 3.17 by a blue line, indicating a break-even point for global warming potential of 5 uses. This is less than the lowest willingness threshold (7 uses for baked beans), indicating that people will be willing to use the containers enough times in order for the system to show an environmental benefit. For water consumption, however, the break-even point for the best-case scenario is 15, which is still more uses than the corresponding number of uses to the level of wear that most people are willing accept. It is however

well within the expected lifetime in the system of the container (70 uses). A summary of the break-even point values for all scenarios for global warming potential and water consumption is presented in Table 3.9.

In addition to investigating ways to reduce the break-even point for reusable containers, strategies could also be employed to increase people's willingness to reuse containers. This might be achieved either through advances in materials (e.g. developing containers that are less likely to show signs of wear) or behavioural interventions that identify and placate people's concerns over using containers that show signs of previous use. In order to achieve this, the team advocates the use of established frameworks for developing interventions, e.g. the Behaviour Change Wheel (Michie et al., 2011) that link behaviour change techniques (Michie et al., 2013) to presumed determinants of behaviour (for a review, see Allison et al.,(2022)). For example, if research identified that people are concerned about potential contamination, then an intervention might try to alter how users think about signs of wear (e.g. view them as 'battle scars' earned from fighting the battle against plastic waste (Collis et al., 2023)). Alternatively, interventions might penalise single-use (as has been done for carrier bags (Poortinga et al., 2013)) and/or incentive reuse, either financially or via a reward scheme or positive feedback (e.g. on the accumulated environmental benefit of the person or group's behaviour) in an effort to motivate people to be more tolerant of signs of previous use.

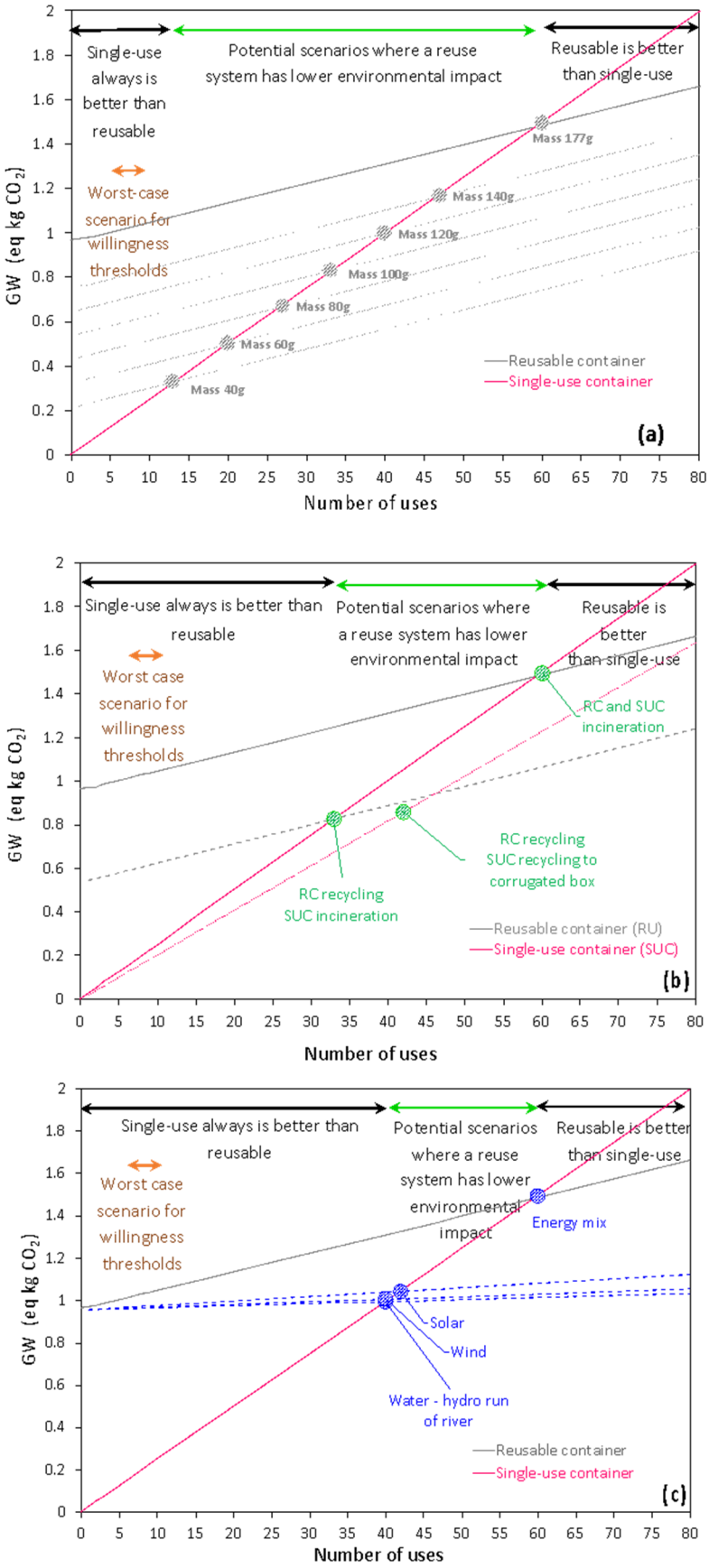


Figure 3.15 *Effect of a) weight b) end of life and c) energy source on the global warming break-even point for reusable containers in the scheme studied.*

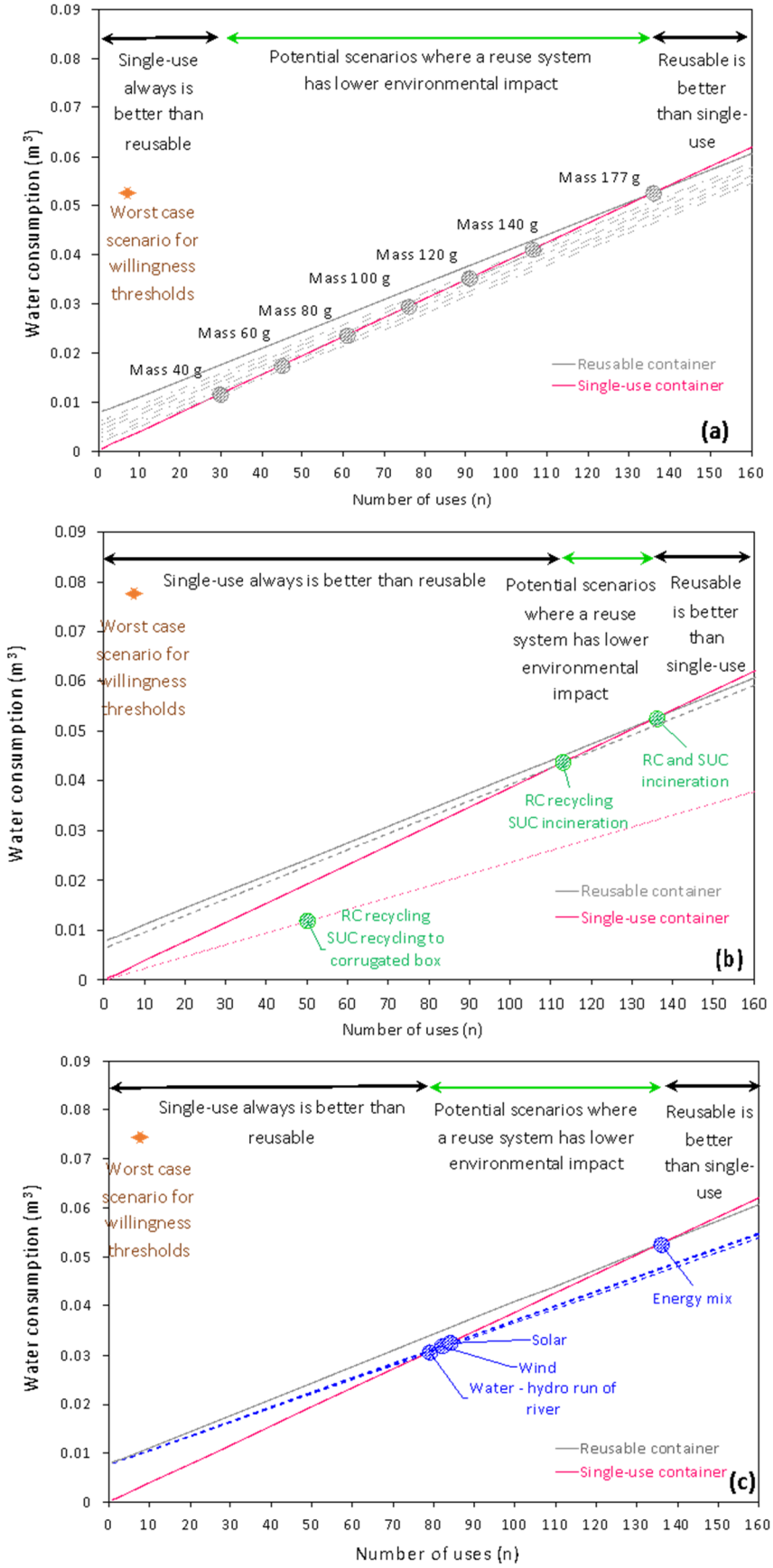


Figure 3.16 *Effect of a) weight of reusable container (RC), b) EoL and, c) energy type on water consumption break-even point for reusable containers in the scheme studied.*

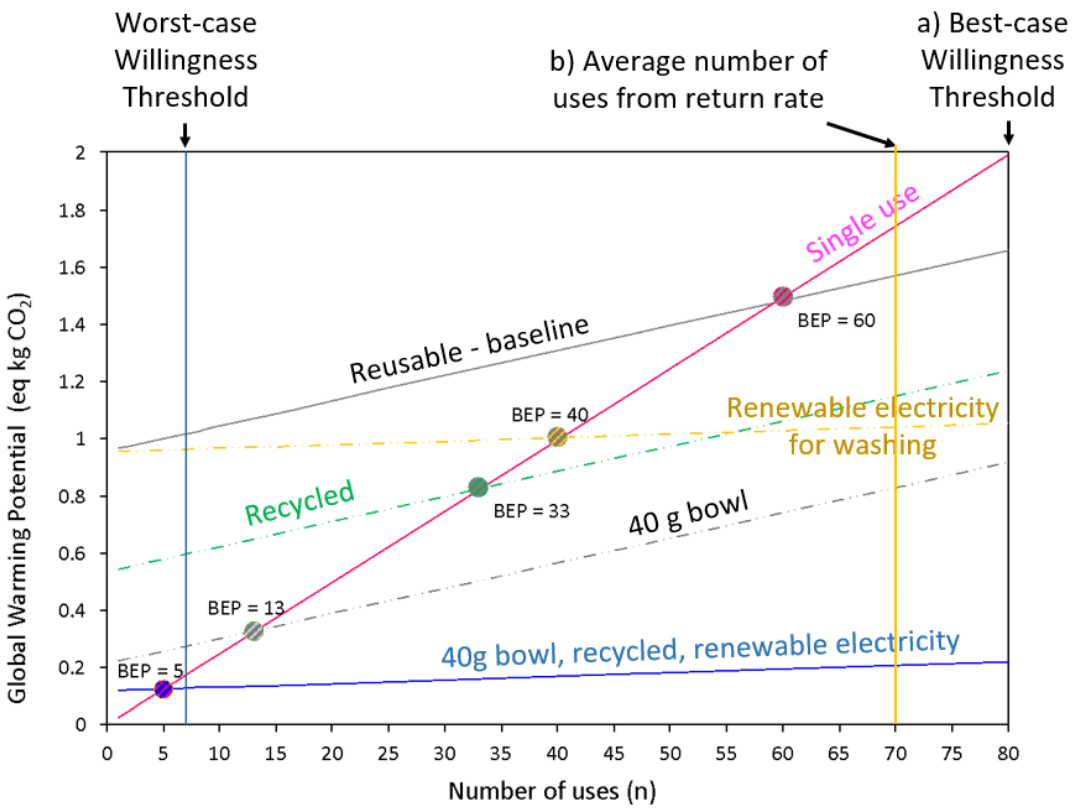


Figure 3.17 *"Best-case scenario" for recycling and energy, with a container weight of 40g, showing the break-even point (BEP) for each scenario, worst- and best-case willingness thresholds and the average number of uses per container given the return rate. The practical viability of these scenarios would need to be ascertained.*

3.5.5.4 Further analysis

For the success of the scheme at the university, it is encouraging that the original simulated ageing protocol (light use) did not produce bowls with severe enough staining to use for the willingness investigation. There is no point-of-sale data that says which type of meals have been sold in the bowls. However, inspection of the menus from the two cafes taking part (3.5.1.2) produces a conservative estimate that the number of highly staining meals served is no more than one in two. Therefore, using the tomato pasta sauce as an example, the standard-case rather than worst-case scenario is:

$$ST = WT \times r \times m \qquad \textit{(Equation 3.7)}$$

Where WT is the willingness threshold, r is the calculated ratio from Table 3.8, and m is the proportion of highly stained foods sold in the bowls in the university scheme.

So, Standard threshold = 6.85 x 6 x 2

~ 80 cycles (shown as point (a) in Figure 3.17)

which exceeds the average number of cycles a container will go through in the university system (point (b) in Figure 3.17).

However, this can only be an approximate figure - the elevated temperatures experienced when microwaving the bowls means that the oleophilic staining compounds (Lycopene and Curcumin) will penetrate further into the plastic, than they would do over extended repeated cycles (Yang et al., 2020) so this can only be used as a very rough indicator (so the actual figure may be higher than 80). It also assumes that the customers eat the food immediately and do not reheat the food before consumption.

The above, however, does not negate the work presented in section 3.5.5, this could be used by the operator of any potential reusable container system in order to understand container lifetime, e.g. pasta sauce in a returnable container; the current single-use container is used to heat the sauce in a microwave, so consumers would expect to be able to do this with a reusable equivalent.

3.6 Discussion

3.6.1 The lifetime of a reusable container in a system

The lifetime of a reusable container can be thought of as being a result of a combination of factors:

1) The return rate of the containers by the customers back into the scheme (as measured by the Grafana dashboard).
2) The durability of the container – i.e. how many cycles the container can withstand before being retired. A container could be retired by the scheme operator as a result of cumulative physical damage – e.g. chips, heavy scratching, distortion by the heat of the washing process, staining on the inside of the container, scuffing on the outside of the container, or contamination by non-food products. In a food service setting, this is most likely to be done by a visual inspection or rejection from a customer; in a scheme where

containers are sent back to a factory - e.g. milk or carbonated drinks bottles, these will be subject to a rigorous quality control procedure.

3) There is also the possibility of catastrophic damage to a container before its expected number of cycles - e.g. through misuse (used to store non-food ingredients, deliberate damage, etc).

The work presented above considers this using the visual appearance of the inside of artificially worn containers as a useful proxy for the durability of the container. The return rate from the Grafana dashboard considered only the customer return rate - there is no way of confirming the number of containers rejected at café level.

3.6.2 The optimisation of system and packaging design

The comparison of the lifetime of the containers, predicted by consumer willingness, and the BEPs calculated from the system LCA, and their life in the system based on customer return rate, can be a useful tool in terms of improvements to container and system design in order to achieve the best outcome for environmental indicators.

The results from the initial LCA resulted in a break-even point for GWP of 60 and 136 for water consumption. The average lifetime of a container in the system was calculated as being 70 uses (by June 2024 this was 100), so, for GWP at least, the scheme is an improvement on the single-use equivalent but much less so than estimated in Chapter 2 where the theoretical BEP was calculated as being 2-4 uses. The work here has shown how important the weight of the containers is, the containers need to be as light as possible. However, by reducing the weight of the containers to 40g, there is the risk that these may not be durable enough to withstand the BEP associated with the weight and this would need further work to establish.

The washing phase is particularly important in determining the BEPs. In the cafes the bowls are simply laid flat in a universal dishwasher loading tray. By employing a bespoke washing rack, reducing water usage, and optimising the shape of the containers for dishwashing, the BEPs could be improved even further. i.e. doubling the packing density halves the water and detergent usage and contributes significantly to GHG reduction.

End-of-life treatment scenarios and the energy mix used are also effective in reducing the BEPs. They are less controllable than container and system design, but indicative of the success of a project in the future where recycling rates and the proportion of sustainable energy in grid electricity are expected to increase. This illustrates the importance of recycling and energy sources in achieving a circular economy.

3.6.3 The importance of return rate in system design

The relationship between return rate and average number of uses is exponential, as can be seen in Figure 3.14 and Table 3.8. A 90% return rate results in an average number of uses of just 10, a 99% return rate, 100 uses. This is important because if a container has been designed to be as robust as possible (such as the 177g containers used in this study), but there is a return rate of less than 90%, the scheme is extremely unlikely to break even on environmental indicators. It is also important that any scheme does not rely upon a high break-even point, above, say 20 uses, as the average number of uses is very sensitive to the return rate above 95%.

The logic follows that if a scheme designer knows that they will never get over a particular return rate, then the container lifetime should be tailored to the expected number of uses in the same way that consumer goods are designed for a target lifetime through planned obsolescence (Bisschop et al., 2022).

Return rates in established systems have been as high as over 99% for business-to-business produce crates (Rasines et al., 2024) and as low as 50%, the figure AG Barr quoted when they announced that they were moving away from returnable carbonated drinks bottles in 2015 (Eardley, 2015; Fraser, 2015).

The return rate for the Sheffield scheme at the time the LCA was performed was very high at 98.6%, relating to an average container life of 71 uses. This can be attributed to the fact that a fine is charged for non-returns (and possibly the relative ease of return as the containers will most likely be rented, used and returned within a relatively limited geographical area). The scheme provider, Vytal, quotes an overall return rate of 99%, which the university scheme has also now achieved, relating to an average container life of 100 uses. Schemes that rely on less severe methods to encourage returns will almost inevitably have lower return rates. This is a potential risk to the success of a scheme - if an operator used the same bowls but executed rentals in a different way, say by asking for a cash deposit, there would

be a risk that they would not get enough containers back to break even on global warming potential (or other important environmental indicators).

Note that for the ease of calculation in the work above, it has been assumed that the containers have infinite durability, i.e. they are lost from the system before showing any signs of wear and do not need to be taken out of service by the operator.

A point of interest is that in this simplified model, after all the original containers have been lost through attrition and replaced with new ones, the average age of the containers being used (in terms of number of uses) is equal to the average lifetime of the containers in the system; If the system contains 1000 containers and the return rate is 95 per cent, the average age of a container in the system will be 20 uses, with a range of 1 to 135 uses. In reality, as schemes with high return rates develop, it is likely that containers will have to be retired due to damage or wear, which will affect the overall return rate (and it is more appropriate to use the term 'loss rate').

3.6.3.1 Was the practical scheme at the university a success?

Although the global warming potential break-even point (GWP BEP) of the bowls was very high at 60 when compared with the existing single-use packaging, the theoretical average number of uses of a bowl in the system by the end of the period examined was 100 uses. Estimating the amount of staining and wear given the type of products sold, and assuming the bowls were not microwaved at any point produced a best-case willingness threshold of approximately 80. Whilst not ideal, the break-even point is less than both the willingness threshold for light usage and the average number of uses of a container in the system, so the use of reusable containers potentially provides an environmental benefit. However, customer uptake was very low and taking into account the number of bowls in stock, it is estimated that it will take over 25 years to reach that point.

The 300ml cups are quite different: preliminary work on the cups (unpublished) resulted in a GWP BEP of 7, and given the success of the scheme for cups, this was met relatively quickly, breaking even on GWP sometime in autumn 2023. These two examples demonstrate the importance of stock management of reusable containers, referred to in the industry as the container pool size.

3.7 Findings, conclusions and recommendations for future work

1) A takeaway bowl and container scheme was implemented in selected cafes at the University of Sheffield and as of March 2025 has been in operation for three and a half academic years. Whilst uptake was disappointing at less than 2% of the student and staff population, when it was used, container return rates by June 2004 were very high at 99%. The scheme was originally marketed for the food containers only, but rentals for hot drinks cups quickly dominated and were almost 90% of total rentals over the period examined.

2) A simulated wear, staining and washing protocol has been developed in order to create images of bowls of varying degrees of ageing for the psychology team to present to study participants. 8 different foodstuffs were used. A microwaving stage was introduced to a subset of samples to accelerate the staining of the bowls ('heavy' use case), as the non-microwaved bowls ('light' use case) took a large number of uses to show signs of staining.

3) These images were used to quantify the degree of wear and staining participants would accept using an interleaved staircase model. Willingness thresholds were determined for each. These varied between 7 and 10 for the tomato-based foodstuffs and were 15 for tea and coffee (heavy use case).

4) An LCA was performed on the 750ml bowls, comparing them to the existing single-use container, a corrugated paper box with a PET liner and window. Break-even points were calculated for global warming potential (60 uses) and water usage (136 uses) for the reusable containers vs single-use, and sensitivity analyses performed on the weight of the reusable container, the energy mix used for washing and the end-of-life treatment scenario.

5) The Willingness thresholds, which can be used as a proxy for container durability, and environmental break-even points were combined to show the viability of the scheme and illustrate that changes

to system parameters such as container weight and water usage, along with behaviour interventions can be used to minimise the impact of a reusable packaging system. The WT must be, as an absolute minimum greater than the BEP and for the maximum benefit, be marginally greater than the average number of uses a container in a system will go through given the customer return rate. This was 70 at the time the LCA was performed, and 100 at the end of the period studied.

6) Visual correlation of images of the heavy and light use cases, combined with assumptions on the proportions of staining foods served in the university cafés indicate a WT of approximately 80, above the original BEP but less than the potential average number of uses when a 99% customer return rate is achieved.

7) It has been demonstrated in 3.6.3 that it is essential that the likely customer return rate is considered in the system design alongside the environmental BEPs, as a small fluctuation in return rate around the 90% mark has an exponential effect on the potential average number of uses in a system. It makes sense to design systems to operate with as low a BEP as possible in order to mitigate this.

8) The low number of rentals, and the high break-even point for GHG emissions mean that for the practical trial during the time period examined here, no net environmental benefit was achieved by using the 750ml bowls in place of the single-use containers

4 Establishing the barriers and enablers to the introduction of returnable packaging using a hypothetical model of yogurt supplied via UK retailers in returnable pots

4.1 Introduction

The potential of reusable packaging systems has been widely reported (Chapter 2), and reuse features in the national plastics pacts, voluntary agreements set up to reduce the impact of plastic packaging (see Chapters 1 and 5). However, uptake has been very limited to date (George, 2020). In this chapter, a hypothetical system of yogurt packaged in returnable 500g pots has been used as a case study. The Dairy category was chosen by the Many Happy Returns project team for investigation because there was already a precedent of reuse in the category with doorstep milk delivery, and the total amount of plastic packaging for dairy accounts for approximately 12% of the total for groceries (Thomson et al., 2018). Yogurt, custard and cream, supplied using returnable pots with pooled container ownership was chosen as the model to develop in an online workshop with industry stakeholders in February 2021. Semi-structured interviews were then held with stakeholders from across the proposed supply chain, and the transcripts were analysed for common storylines. The Multi-Level Perspective, a framework used to examine socio-technical transitions, has been applied to the findings from the interviews to examine the reasons for the slow adoption of reuse and what is needed for the scale-up of reusable packaging systems being operated at scale. This work was part of the second of the two cross-work package studies in the Many Happy Returns project.

SG led the study and ran the co-creation workshops. She conducted the stakeholder interviews, and the analysis presented here has been done with the supervision of Dr Rorie Beswick Parsons.

4.1.1 The yogurt market

The dairy sector is responsible for 112 kt per annum of consumer plastic packaging placed on the market, 12% of all grocery. It includes Milk, Yogurt, Cheese, Butter and Cream. Milk is the biggest contributor to this figure at 83kt (74%), and Yogurt the second at approximately 16 kt pa (14%) (Thomson et al., 2018). The sales value

of fermented milk products in the UK was just under £350M in 2022, with an additional £37M exported and £450M imported (International Trade Centre, 2024; Office for National Statistics, 2023). Currently in the UK, 5.52 million people eat yogurt two to three times a week (Statista, 2025).

4.1.2 Returnable packaging for Dairy products

There is a strong historical precedent for returnable packaging in the dairy sector: The glass milk bottle was first patented in the United States in the late 19th Century and became the norm in the UK in the 1920s and 30s (University of Reading, 2025). In 1975, 94 per cent of milk was delivered to people's doorsteps in returnable glass bottles. However, this had declined to 3 per cent by 2018 (Parsons in Greenwood et al., 2020). Glass bottles were used for cream and portions of yogurt in the 1950s and 1960s by Express Dairies in the UK (Express Dairy Tales, 2025), although these were soon replaced with waxed paper cartons and plastic pots. There are recent instances of suppliers using returnable glass jars for yogurt at a very small scale, e.g. in Germany and the UK (Naranjan, 2024; River Cottage, 2023).

4.1.3 Modern yogurt packaging

In 2018, 63% of yogurt pots were made from polystyrene (PS), not recyclable in the UK recycling system; 18% polypropylene (PP), technically recyclable but rarely collected, and polyethylene terephthalate (PET), which is readily recyclable in bottle form, but less so as a pot (see 5.5.4.5). The container closure is lidding film (usually pre-printed), which provides a hermetic seal, and at the time of the interviews, it was commonplace to include a thermoformed clip lid on packs containing multiple servings. Single-serving pots are usually form-fill-seal (FFS), where the pots are thermoformed from a roll of plastic sheeting, which is softened by infra-red heat, shaped in moulds with the aid of a vacuum, filled immediately with the product and sealed. The containers for multi-serving packs are premade, again thermoformed from PS, PP or PET, and are often a composite structure - a lightweight plastic pot inside a printed paperboard sleeve (e.g. 'Desto ®' cups or Greiner K3 r100).

4.1.4 Socio-Technical Systems theory and the Multi-Level Perspective

Socio-technical systems theory (STS) is a way of looking at organisational structures from a multi-disciplinary perspective. Technological change is examined as a result of multiple interactions between different actors and processes in the system, e.g. technologies, regulations, practices, markets, cultural meanings, and networks of distribution and support at different scales (Spijkerboer et al., 2022).

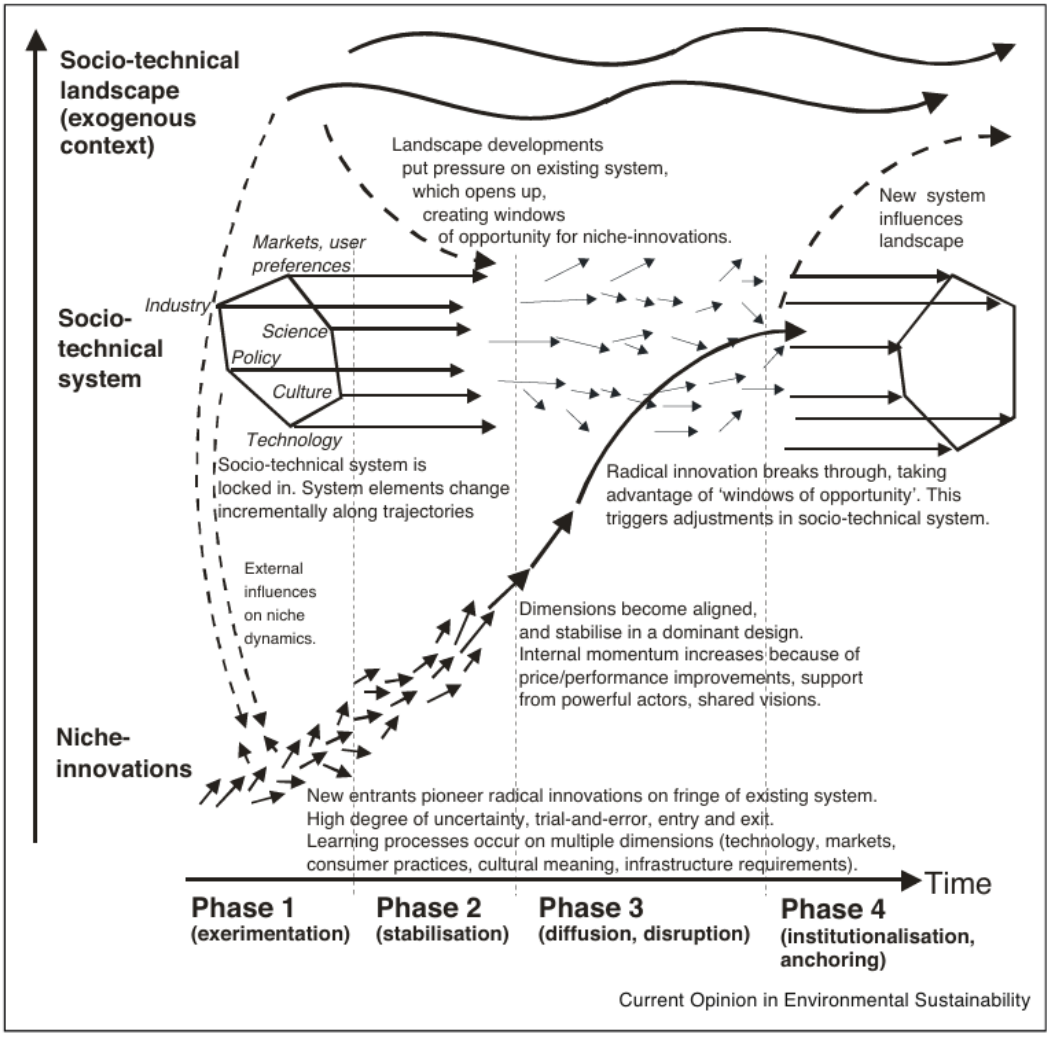


Figure 4.1 *Multi-Level Perspective on socio-technical transitions, showing the 3 levels, niche, regime and landscape along the y-axis and time along the x-axis, reproduced from Geels (2019).*

The Multi-level Perspective (MLP) is a heuristic (problem-solving) framework that has commonly been used in analysing transitions to more sustainable socio-technical systems (Geels, 2019). The MLP considers three levels: the landscape, the regime and niche innovation, with processes of change (or not) a result of the

interactions that happen between the different socio-technical elements and processes across these levels (see Figure 4.1)

At the top level is the socio-technical *landscape*, e.g. the economy, infrastructure, and climate change, which are slow to change and cannot be influenced easily. The middle level is the socio-technical *regime*, the established system, e.g. the supply of grid electricity generated from fossil-fuel powered stations. The lower level is *niche-innovations*, technological advancements which operate at a small scale, often for decades before becoming part of the regime (if at all) or becoming a new regime (i.e. by becoming the dominant technology), e.g. solar and wind power are now a significant percentage of energy supplied. The diagram in Figure 4.1, reproduced from Geels (2019) illustrates these 3 levels and how they might interact with each other over time, in this case showing the technological substitution pathway (see 4.1.5).

4.1.5 MLP transition paths

Transitions are said to occur as a result of 'interplay between the processes at niche, regime and landscape levels'. There are various terms for the different paths of change within MLP (Geels, 2019, 2011). *Reproduction* is incremental change along existing trajectories, what would happen if there were no innovation in the niche and no exogenous pressure from the landscape. A *transformation path* is where there is some pressure from landscape factors, which leads to the regime adapting by making changes; niche innovators are unable to take advantage of the situation because the innovation is not advanced enough. The *de-alignment and re-alignment path* is when the landscape factors exert enough pressure on the regime, but no one niche innovation takes over immediately; there is a period of uncertainty while niche innovations compete with one another until a new stable regime is formed. *Technological substitution* occurs when there is sufficient landscape pressure, and the niche innovations are adequately developed to become the new regime. The *reconfiguration pathway* is when niche innovations become absorbed into the regime, rather than take over

Figure 4.1 shows the *technological substitution path,* which the proponents of reuse are aiming for. In this path, Geels describes the transition from a technology being niche to part of the regime in 4 phases: In phase 1) the regime continues as normal, with the niche activity working independently (e.g. the test and learn period of

alternative power technologies), in phase 2) the niche innovation is more developed, but not yet a threat to the regime (e.g. a factory installs a wind turbine to power their own operation). Phase 3) is when the new innovation starts to become competition for the regime (e.g. ´green´ energy tariffs are available), and phase 4) is when it has become part of it (a significant proportion of grid energy is now from a renewable source).

4.1.6 Summary

The work presented in this chapter uses collaborative workshops and semi-structured interviews of dairy and supply chain stakeholders to understand the nature of barriers and enablers to the introduction of a possible returnable system for yogurt via bricks and mortar retail in the UK. MLP is then employed to examine a possible transition from an exclusively single-use regime for the sale of groceries to a regime where reuse plays a significant part (e.g. 20% plus (EMF, 2019)), with the outcome being reduced plastic packaging waste and resource use for packaging containers.

4.2 Method

4.2.1 Co-creation workshops

This work was co-created with the Many Happy Returns project stakeholders, which included several actors specific to the dairy supply chain, including retailers and manufacturers, as well as actors involved in promoting reuse systems, including NGOs, a design company, and reuse and refill packaging start-ups. An online workshop was held in February 2021 using the collaborative tool Miro. Different dairy products and reuse models were considered (see Chapter 2). Yogurt, custard and cream, supplied using returnable pots with pooled container ownership was chosen, with the recognition that this was a complex challenge. Additional stakeholders specific to the yogurt supply chain were brought on board, including yogurt manufacturers and a logistics company. The original intention was to set up a small-scale reusable yogurt packaging trial. After several meetings, it became clear that this was not feasible, and the team agreed to study a hypothetical system developed collaboratively in a shared online document (4.3.1).

4.2.2 Semi-structured interviews and discourse analysis

Using the hypothetical scheme as a guide, stakeholders were identified to be interviewed from every stage of the process. After ethics approval was gained (University of Sheffield ethics application number 045027), semi-structured interviews were conducted by SG using the following:

1. Tell me about your company and your role within it.
2. Have you engaged in packaging reuse at home?
3. Please describe your operational processes and materials (e.g., manufacturing process, delivery logistics, selling of goods, transport and/or washing of empty packaging containers etc).
    a. Does your company see single-use plastics as a problem, if so what have you done to address this?
4. Has your company engaged in reusable packaging systems either on a commercial or trial basis, historically or recently? Have you been directly involved?
5. Are there benefits to your company in the introduction of such schemes?
6. What are the barriers to the introduction of such schemes?
7. What would alter your company's position on this?
    a. (Prompt on EPR and DRS after first answer).
8. Is there anything else you would like to add?
9. Is there anyone else you think we would benefit from talking to?

The interviews took between 30 and 60 minutes. They were then transcribed by a 3rd party and checked for accuracy by SG. Anonymised versions are stored online at the UK Data Service (Greenwood, 2025).

The transcribed interviews were studied for common storylines and supporting narratives. A storyline is 'a condensed statement that summarizes and encompasses more specific narratives used by people as shorthand in discussions'. A narrative is a more complex element which gives a storylines meaning, a common understanding of an issue (Hajer, 2006; Rosenbloom et al., 2016). These were recorded in an Excel spreadsheet and were assessed to determine whether they supported ('legitimising') or undermined ('delegitimising') the goal of achieving a

viable returnable packaging system for consumer packs of yogurt at scale (Rosenbloom et al., 2016).

4.3 Results

4.3.1 System schematic

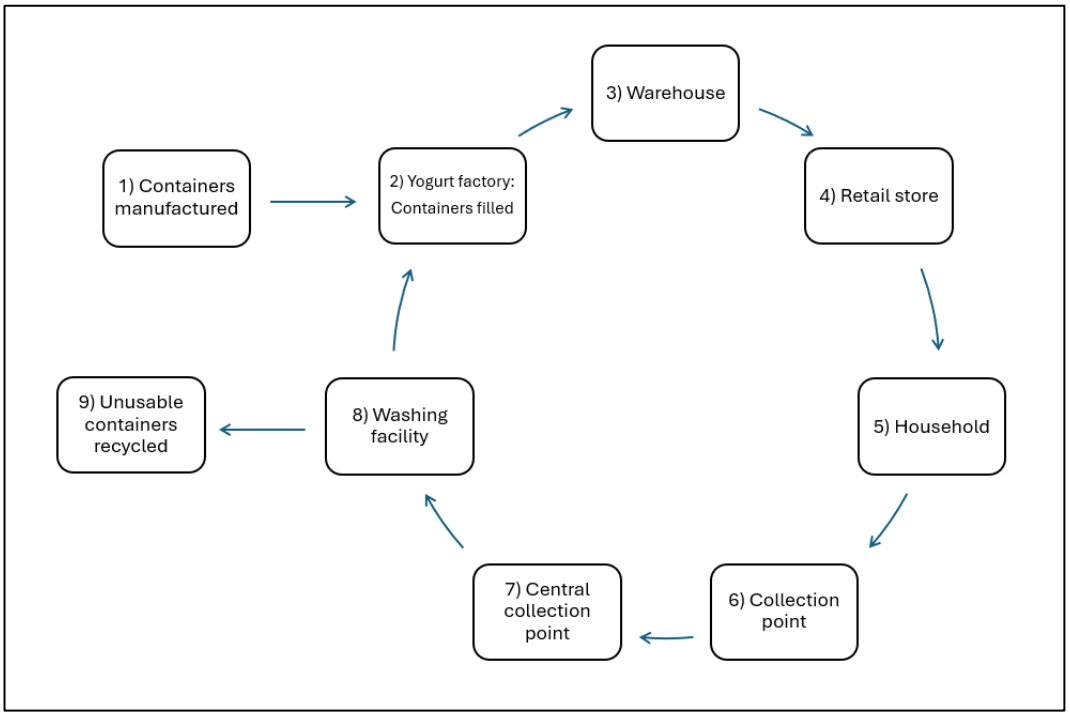


Figure 4.2 *A schematic diagram of the co-created model for a returnable packaging system for the supply of yogurt in multiple servings.*

The hypothetical system for the supply of yogurt in reusable multi-serving pots in Figure 4.2 is as follows:

1) *Pots and lids are manufactured from PP and supplied to the yogurt manufacturer.*
2) *The manufacturer fills and seals the pots (either with a screw-on or snap-on lid or a single-use lidding film). A tamper-evident label and time and date stamp are added. The filled pots are packed into cases (secondary packaging) and stacked onto pallets for distribution.*
3) *The pallets of filled pots are transported to a warehouse (this could be the manufacturer's own warehouse and/or a retailers' distribution centre).*

4) *Individual cases of filled pots are sent to retailers' stores, where they are put on display and individual pots are purchased by customers.*
5) *The customer takes the pot home, keeping it in their fridge until the product is used up.*
6) *The customer returns the (rinsed) pot to a return point - this could be at the original store or a stand-alone collection point.*
7) *The pots are taken to a central collection point (e.g. at a retailer's distribution centre).*
8) *The pots are taken from the central collection point to a reconditioning plant (which could be stand-alone or collocated at the filler), where they are checked for damage and washed, with any labels being removed before being sent to a manufacturer to be used again. Unusable pots are set aside for recycling (9).*

4.3.2 Interviewees

Table 4.1 shows the people interviewed (names changed) with a description of their company, job role and the company's attitude towards reusable packaging.

Running through the system described in 4.3.1, there is: a plastic packaging manufacturer, two yogurt producers (one national, one international), two retailers (one large supermarket and smaller convenience stores, the other mainly convenience stores), a reusable packaging scheme innovator, a campaign group, an established logistics company that rent out business-to-business reusable packaging, a start-up company that washes containers and a waste management company.

No	Name*	Company type	Actor (Regime/Niche)	Role(s)	Business Description	Attitude to Reuse
1	Mark	Large waste management company	Regime	Director level	Proactive in investigating new solutions in general.	Positive
2	Vicky	Refill systems start-up	Niche	Director level	Reuse innovator	Activist, proactive
3	Sally	Not for profit whose campaigns include reuse and run reuse trials	Niche	Senior management	Campaigner, activist, innovator	Activist, proactive
4	Derek	Leading logistics company, supplying business to business reusables.	Regime	Business development	Rental of B2B packaging	Proactive
5	John	Large UK retailer	Regime	Compliance and Environmental Sustainability	Retailer	Fairly proactive
6	Peter, Sophie	Large dairy products producer, international	Regime	Packaging development manager, packaging technologist	Dairy producer - supplies as a brand and retailer own label	Neutral and interested
7	Helen, Rachel, Steve	Medium UK dairy producer	Regime	Customer service manager (to retail customers), product technologist, packaging technologist	Dairy producer, supplies as a brand and own label to retailers	Neutral on reuse, but passionate about sustainability
8	Mark	Plastics packaging manufacturer	Regime	Design manager	Packaging manufacturer	Neutral, proactive
9	Andrew	Large UK retailer (convenience)	Regime	Packaging development manager	Retail	Fairly proactive
10	Jason	Startup offering packaging cleaning as a service	Niche	Business development	Washing packaging as a service	Positive, Proactive

Table 4.1 *People interviewed (names changed) with a description of their company, job role and the company's attitude towards reusable packaging, and coded with a number which is used in the analysis.*

4.4 Analysis – storylines and narratives

The analysis of the interview transcripts revealed eight main storylines. The first of which i) '**There is a place for reuse in the future of supply chains**', is positive and clearly legitimising for reuse. However, the majority of the storylines highlight barriers to the creation of a viable returnable packaging system for consumer packs of yogurt. These were ii) '**We don't have the numbers**' to demonstrate that schemes will be beneficial, and not enough information is being shared iii) '**There is no room for altruism in the boardroom**', iv) '**Brand is packaging**' i.e. brand owners are reluctant to lose the product differentiation that bespoke single-use packaging provides, v) '**Consumers aren't ready**' for reusable packaging, vi) **Collaboration** and vii) **Considerable effort** are required before progress can be made, which is only likely to happen once viii) **Legislation and standardisation** is introduced.

Table 4.2 shows these 8 main storylines, whether they are legitimising or delegitimising, the more detailed narratives that they are built from, and their counter-narratives. These are then discussed in turn.

Storyline	Legitimises or delegitimises reuse at scale	Narratives
1) Reuse is the future	L	it [reuse] is the direction of travel (6) this has a big part to play in a 2030 onwards kind of vision (1) 'It is vital for the plastics packaging industry - if we don't do it someone else will' (8) (2) and (3) implicit, (10) obviously see a business opportunity, (4) business development (7) and (5) more neutral and pragmatic. we know that we need to introduce reuse (9). (3) we wanna take everyone with us and grow the movement. *Counter-storyline: (delegitimises reuse): '**how do we collectively get there**[?]' (6)*
2) The is no room for altruism in the boardroom	D	We live in a capitalist economy where if you don't make money you don't exist (9) The challenge is to make sure that doing good and making profit are aligned (6, 4) is it worth scaling up new innovation when we can make a bigger impact on our core business? (4) it will cost more money so if our retail customers and their shoppers are willing to pay for it then we could introduce (7). The return on investment and improved sustainability can be achieved in other ways. I guess the onus is back on, let's say us as an industry to demonstrate reuse can generate growth. (6). (5) talks of commercial and operational success. *Potential solution: "**I guess the onus is back on, let's say us as an industry to demonstrate reuse can generate growth.**" (6)*
3) We don't have the numbers	D	Businesses don't have enough confidence to invest in infrastructure and reverse logistics. There is doubt over the environmental benefits of reuse over single-use (e.g. water and energy) and how to measure it. There is a need for good business propositions so people invest to allow further scale-up (4,6) and consumer uptake on trials so far has been low. There is internal reluctance to change (6) (i.e beyond those with an interest in sustainability). Secrecy is impeding progress. *Counter-storyline: The legitimising counter-storyline is that **actors in the niche and on the fringes of the regime are beginning to collaborate and generate open data.***

Storyline	Legitimises or delegitimises reuse at scale	Narratives
4) Brand is Packaging'	D	Standardisation of packaging formats is required to make reuse systems efficient, but this is at odds with brand identity. "Some of them [big brands] still see the packaging that they're goods come in as being the number one way in which they communicate their brand, their brand value and other things to the consumer" (4). *Counter storyline:* ***Brands can work WITH reusable packaging****. There is some optimism that this can be overcome. (3) brands willing to invest in 'Sexy' packaging before the cost of living crisis. The collaborative project that (4) is looking at is working on addressing communication without packaging.*
5) Consumers aren't ready for reuse	D	The increase in the anti-plastics sentiment post-2017 is not translating into the uptake of reuse schemes. Businesses say 'consumers aren't ready for it' (3) Consumer uptake on trials so far has been low (5). *Counter-storyline****: Reuse isn't ready for consumers*** *If schemes are more widely available then customers will use them. 'you have to bring the customer on a journey with you' low (5). Reuse needs to be made easy and cheap for consumers .*
6) A collaborative approach is needed	D / L	A national, independently run infrastructure is needed and similar containers between companies. Competition law is being cited by companies as a reason for not collaboration. Being 'the first to' won't work in this situation. *Counter-storyline: see 3****) actors in the niche and on the fringes of the regime are beginning to collaborate and generate open data.*** *New pilot schemes involving actors from every part of the supply cycle have been set up, including some of the interviewees. Innovation and risk costs are shared.*
7) Considerable effort is required	D / L	Supply chains are optimised by and for single-use (9,2). A test-and-learn approach is needed, which is a slow process (6). Businesses have other, more pressing challenges. Reverse logistics, washing, product manufacturing efficiencies, space utilisation, branding, and communications all need to be considered. There will be considerable technical challenges with yogurt in particular. Dedicated teams and investment required *Counter-storyline: as for 6)*

Storyline	Legitimises or delegitimises reuse at scale	Narratives
8) Legislation and standardisation are essential	D / L	The introduction of some sort of legislative driver, e.g. incorporation into EPR regulations will mean that everyone will be obliged to move, and at once, rather than innovate in order to gain a competitive advantage, creating different, and hence less efficient systems. Voluntary agreements are ineffective. Standardised packaging formats will enable efficiency at scale. Washing standards need to be developed and agreed upon. There is some feeling that regulation should not be overly complicated or restrictive. A trade body to represent companies working in this field would help. *(minor) Counter-storyline: There is some feeling that regulation should not be overly complicated or restrictive. Competition law is cited by companies for non-collaboration*

Table 4.2 *Storylines and supporting narratives from the interviews of supply chain stakeholders for the supply of multi-serving pots of yogurt.*

4.4.1 Reuse is the future

As expected, the niche innovators (2,3,10) are positive about reuse and proactive in working towards its success. The reuse systems start-up director (2) and the campaign group director (3) used phrases such as *'rattling cages'* and *'banging drums'*, indicating an activist approach; the business development manager at the container-washing start-up (10) was very much more commercially oriented. Moving on to the regime actors, the plastics packaging manufacturer (8) is pragmatic:

> "*It is vital for the plastics packaging industry - if we don't do it someone else will*"

which they are demonstrating by performing speculative development and working within a collaborative development project. The logistics company development manager (4) '*mentors and coaches*' niche actors as part of his business development activities (who he describes as 'activist start-ups'), and the waste management company sustainability manager (1) is

> "*…convinced this has a big part to play in a 2030 onwards kind of vision of how sustainable resource management operates and how society lives its way*".

The two retailers (5,9) and the larger of the two yogurt manufacturers (6) expressed a generally positive attitude to reuse, all having engaged in business-to-business reuse and having operated or trialled business-to-consumer reuse. It is important to note, however, that none of these operate(d) at significant scale. The convenience retailer was more interested in refill rather than return. Only the medium-sized yogurt producer took a very neutral approach:

> "*[we will do it]If our customers ask for it and are willing to pay for it".*

The counter-narrative to the above is that there is uncertainty, however, about how reuse at scale will progress. As the international yogurt producer (6) puts it,

> *"Because actually, longer term, it is the direction of travel, it's* ***how do we collectively get there*** *[?]"*

This uncertainty is seen in all of the remaining storylines.

4.4.2 There is no room for altruism in the boardroom

Companies have to make a profit for their shareholders. For a scheme to succeed financially, the large yogurt manufacturer (6) says:

> *"it has to make sense, otherwise no business will do it. That's the absolute crux of it. Things like being altruistic are really nice words but they will not stand up in a boardroom."*

Even so, making a profit may not be enough if there are other ways for a business to provide growth for the shareholders and demonstrate improved sustainability; the logistics company development manager (4) reasons:

> "*is it worth scaling up new innovation when we can make a bigger impact on our core business [by doing something else]?*"

More a solution to the delegitimising storyline than a counter storyline, the large yogurt manufacturer (6) posits:

> *"I guess the onus is back on, let's say us as an industry to demonstrate reuse can generate growth."* (6)

4.4.3 'We don't have the numbers'

Businesses don't have enough confidence to invest in infrastructure and reverse logistics.

> "*looking at multi million pound investment to lead the way in an area that's unproven, not gonna happen'* and *'What does an investment programme for scalability look like?"* (6)

Reuse proponents come up against doubt over the environmental benefits of reuse over single-use (e.g. water and energy involved in the reverse logistics and washing procedure). The campaign group director (3) comments:

> "*Whenever I end up in one of those groups with the packaging industry... I always get challenged about carbon within the reusable process".*

There is also doubt over what environmental metrics to measure and how. (3) continues:

> *"but LCAs don't ever really show the externalities of the process....it only goes so far....we don't have a number for the impact of biodiversity loss"*

and logistics company development manager (4) asks:

> *"what is a good answer? what metric should the focus be on? what is the best solution?*"

It is seen that there is a need for good business propositions, so people invest to allow further scale-up (4,6).
The director of the reuse systems startup (2) observes that secrecy is impeding progress:

> *"There's a lack of information sharing because I don't believe people accurately share what really happens in their trials, so you've got lots of people making decisions based on ... very patchy, patchy data".*

The legitimising counter-storyline is that actors in the niche and on the fringes of the regime are collaborating and generating open data.

4.4.4 'Brand is packaging'

The standardisation and interoperability of packaging formats is seen as being required to make reuse systems efficient, but this is at odds with brand identity and therefore brand equity. Single-use packaging is seen by brands as a primary way to communicate with their customers and is almost infinitely customisable, offering differentiation from competitors' products and brand tiering (good, better, best) which creates value when customers trade up. The reuse systems start-up (2) states:

> *"There are lots of, er engagement barriers for brands because of the importance of single-use packaging to their brands. I mean they really are 'brand is packaging'."*

The legitimising counter-storyline is that there is optimism by the campaigning group director (3) and the logistics development manager (4) that there will be ways around this, with (3) being confident that if it wasn't for the cost-of-living crisis, large brands would be prepared to invest in attractive prefill packaging. However, this is at odds with (6) who remarks that reusable packaging containers need to be boring so that people will return them.

4.4.5 Consumers aren't ready for reuse

The increase in the anti-plastics sentiment post-2017 is not translating into the uptake of reuse schemes. The campaigning charity (3) says that businesses say:

> *"oh nobody's ready for it and people don't want it and actually there's a cost of living crisis, so let's do something else."*

This is supported by the comments from the larger of the two retailers (5) reporting low uptake on their own return and refill trials. The two retailers, have tried reuse or refill but are much more focussed on plastic reduction for which they have targets, and these appear to be as a result of customer demand: The larger retailer (5) states that reduction in plastic is *"important to our customers"* and the convenience retailer (9) says:

> *"what customers have told us was that, erm, they don't like plastic they want us to reduce plastic, they want us to reduce packaging but plastic's really what they're bothered about."*

(3) reports that perhaps taking advantage of the situation, packaging suppliers of different materials are engaging in a "*Top Trumps of LCA"*, i.e. the packaging materials suppliers are pushing for the substitution of plastics by other materials.
(9) also comments that:

"they [customers] don't want niche bits of packaging innovation that are just there for the sake of innovation and some of the refill systems that are out there might, might be seen as that."

Further apathy to reuse is illustrated by the container manufacturer (8) reporting that containers from a pilot return scheme with a large monetary deposit are being found in the recycling system. People are therefore unwilling to return or don't know how to. There is also an acknowledgement that reuse only appeals to a small group of people -

"how do you make sure that it doesn't stop at early adopters, like it did with in-store refill?" (6)

(3) and (9) agree that there needs to be increased awareness of reuse systems for it to progress. (9) thinks that a *"Blue Planet moment for reuse"* with a *"shocking reveal"* could create demand from customers. (3) would like to see a reuse "*milk marketing board"*

Half of the interviewees, those closest to the consumers, state that any scheme should be convenient to use. Cost to the consumer is also important. The larger retailer (5) states:

"[reuse] has to be accessible - accessible from a price perspective, accessible from an ease of customer shopping perspective"

There is, again, optimism that the situation will improve; the reuse system startup says:

"I firmly believe if it was available in every store, people would use it more. part of my work currently is to myth bust this opinion that ... a lack of evidence for consumer demand means consumers don't want it"

and the larger retailer (5) is hopeful that things will improve as more and more reuse options become available over time:

"you have to bring the customer on a journey with you."

So the counter-storyline to ***'consumers aren't ready for reuse'*** is arguably ***'Reuse isn't ready for the consumers'***.

The remaining 3 storylines focus on some of the actions that are needed for progress to happen. These can be considered to be both delegitimising and legitimising for reuse, as the storylines identify the perceived need for progress in these areas, which hasn't happened to a suitable level, but also that progress in these areas will be a way forward.

4.4.6 A collaborative approach is needed

It is agreed that a national infrastructure for collection and washing, with similar containers is required in order for a container return system to work efficiently, which means collaboration between competitors. (2) says that businesses quote competition law to her as a reason for inaction yet argues:

> *"I'm yet to be given one example of case law to show anyone that was ever penalised for trying to collaborate across the industry on a reuse project."*

Collaboration *across* the value chain is also required, (8) comments:

> *"probably the biggest problem we face is that you need a consortium to run one [a reuse system] it's never able to be run by just one company."*

Many of the interviewees are already part of collaborative groups. The logistics company (4) in particular is interested in mentoring start-ups, even though they may become competitors one day.

The reuse systems start-up director (2) is positive about their consortium:

> *"it is a cost effective way of them [the other members] doing innovation because they are sharing, they're pooling their resources by collaborating to develop one system, which shares the innovation risk and costs."*

There is also the question of how ownership and cost of a collaborative scheme is managed. As a waste management company (1) is already used to this: 'we want to maximise the value and the value is shared pretty much across all of our contracts

so it's in both parties' interests to get good quality in, good quality out.' (waste management).

4.4.7 Considerable effort is required

The existing supply chains are optimised by, and for single-use. The convenience retailer (9) states:

> *"over the last probably 30 years the convenience retail sector has created a relationship of mutual interdependence with single-use plastics… all of our supply chains now have been optimised to enable single-use. So, that's why introducing reuse systems in convenience is so challenging because it will mean completely breaking down our business model, which is totally linear and … reimagining it into a circular solution." (9)*

This is echoed by the reuse systems startup (2), who states that supply chains are over-reliant on single-use. In order to make progress, a test and learn approach is needed to gain experience and knowledge, which is a slow process. The international yogurt manufacturer (6) oberves:

> *"Even brands like Coke who have come out and said they will do 20%. They've done lots of test and learns, they'll be doing test and learning, and doing, for years and years and years. They've got loads of knowledge and experience, and yet they're still only getting to the stage where they are with about 20% etc. And, if we test it and learn from it, what are we testing and what are we gonna learn from it? What's the pathway?"* (6)

There will be significant technical challenges Yogurt is a fermented milk product containing harmless strains of bacteria, and is eaten raw, making it a high-risk product for food safety. Microbial contamination from other sources can have very serious consequences (Aryana and Olson, 2017), so a manufacturer would have to add to their safety protocols to prevent this from happening. The smaller of the two yogurt producers (7) describes this challenge:

"from a technical perspective obviously you have to ensure that [reconditioned containers are] food-safe which obviously does incur costs as well… because obviously we wouldn't want to bring anything in that could potentially contaminate ongoing products,…it wouldn't just affect follow-on product, it would affect the factory's hygiene as a whole …we'd have to have very, you know, strict rules in place." (7)

They go on to explain the impact new containers could have on site operations, i.e.:

"so at the moment our packaging is all denestable[1]*...and every single machine is set up for that,… if you had packaging that wasn't denestable that would erm drastically change our business."*

There is also a potential issue with the space that reusable containers would take up, especially during transport, which could increase the number of loads required. Labelling was also highlighted as an issue by (7), and (6) says branding and communication need to be considered as well.

The convenience retailer (9) echoes the reservations about extra space and reverse logistics and (6) says they would need a dedicated cross-functional team too - they have other, more urgent priorities with a *'burning platform'* of not being in the right materials (e.g. Polystyrene, which is due for elimination in the UKPP).

4.4.8 Legislation and standardisation are essential

With the industry left to self-regulate (including voluntary agreements) development will be restricted, (2), especially, believes that voluntary agreements don't work. The introduction of legislation (e.g. the incorporation of reuse into the upcoming EPR regulations) will oblige everyone to move at the same time:

"Legislation will drive businesses, has to drive change. If you leave it to industry, you'll have those who do it because they see a competitive advantage by doing it. First move advantages don't last long, unless you have a barrier to entry, other people can't follow and you have a reuse system all of your own. What's the point of that? The whole point

[1] Pre-made pots are stacked inside one another, 'nested', for space and manufacturing efficiency. De-nesting is the separation of the containers immediately before they are filled.

of reuse is that it becomes more national, more, more available to everybody. So who's gonna be the first mover when there's no competitive advantage." (6)

Legislation could also be used to introduce a commercial advantage to moving to reuse, the convenience store packaging development manager (9) states:

"if it became much cheaper through the EPR system to use reuse systems than to use single-use, er, that would encourage our commercials teams to look again at reuse I think"

The larger retailer (5) suggested looking to countries like France, which has implemented legislation on reuse as part of its waste and circular economy regulations (French Government, 2020), and learning from their progress.

There is some feeling that although necessary, regulation should not, and need not be overly complicated or restrictive; the reuse systems start-up director (2) questioned that the need for washing standards is a legitimate barrier to the implementation of reuse systems:

"I believe that our food safety and food hygiene regs are perfectly adequate ... we know how to clean plates in a restaurant so we're not poisoning one customer to the next. Like, we know how to do all of this stuff, it's just a tweak and making them appropriate for reusable packaging."

Standardised, interoperable container design will enable efficiency at scale, but there is currently no route to achieving this. The NGO (3) would like to see the formation of a reuse trade association for the industry to influence the development of legislation as one body.

4.5 MLP analysis and discussion

4.5.1 The Multi-Level Perspective on a transition to reuse

The storylines and comprising narratives above show clearly that the sale of groceries to UK customers, including yogurt, is firmly locked into a regime that relies on single-use packaging. The current regime is in a very slow 'transformation

path' state of change (See 4.1.5): Regulation from within the regime, packaging regulations guided by the waste hierarchy, and the UK Plastics Pact are attempts to minimise the problem of plastic packaging waste by improving the incumbent process of waste management, namely recycling. Pressure from the landscape - consumer and NGO demands attributed to the Blue Planet II effect - is evident from the interviews, but reuse was not (and still is not) at a stage of development that could have potentially taken advantage of the window of opportunity that was created in 2018 to break into the regime. Instead, virgin plastics reduction initiatives and the substitution of plastics with other materials have continued to dominate. Even so, the proportion of plastic packaging collected for recycling has only reached 52.5 per cent, and the amount of plastic packaging waste created per year was at the same level in 2023 as in 2013 (Defra, 2024), so current efforts appear to be preventing growth in the amount of waste plastic packaging, but not reducing it. The return form of reuse is evidently still at the niche level of the MLP. A number of criteria to progress reuse have been identified, including making systems as convenient and cheap as possible in order to extend reach beyond early adopters, and developing sound business propositions for investment, as considerable effort and capital expenditure are required to move from the single-use regime to an alternative that includes reuse at a significant level. Collaboration between niche and regime actors, and regime actors and their direct competitors is seen as being required, alongside legislation, and standardisation that will encourage this to happen. This is already happening at a small scale; niche and regime actors are collaborating in a test-and-learn period. A transition to reuse as being mainstream can therefore be considered to be at, maybe the end of, Phase 1 or at the very start of Phase 2 in Figure 4.1 in section 4.1.4, the test and learn experimentation stage as described in Geels (2019).

Whilst many of the interviewees agree that reuse has a part to play in a future grocery sales regime, they say that there is no obvious path to achieving this. WRAP announced a successor to the UKPP in October 2025 with Reuse and Refill roadmap, so this could be a solution, although as a voluntary agreement, there is little accountability if signatories do not comply with any target for collaboration. Businesses are not confident that consumers are willing to engage, (2) believes strongly that this is because of a lack of availability, (9) says customers are not impressed by niche developments, whilst (3) suggests a coordinated awareness

campaign to overcome this. A significant barrier to the progression of reuse systems is the requirement for more information: to give regime companies the confidence to commit to the investment and effort required to get return systems working, whether reuse is the right thing to do environmentally, that they can maintain their brand image (and hence equity), and for actors already working in this area to share their learnings rather than keep them to themselves.

Upcoming changes to legislation may stimulate increased activity in this area from the regime, and as a result of campaigning, including from the activist startups. With the amount of work that needs doing, it would appear that it will be some time before return systems are in a position where they can break through to the regime. Looking at Europe (as (5) suggests), the most obvious accelerator will be to set binding targets for reuse (Policy Connect, 2023) and to establish a mechanism to oblige actors to collaborate. France has set reuse targets, with a financial incentive through its EPR scheme, and some success is now being reported (CIWM, 2025). (3) suggested the formation of a trade association for reuse actors who could represent their interests in the development of legislation.

Examining the socio-technical landscape factors, the anti-plastics sentiment has to some extent put pressure on the regime to act, but not in the direction of reuse. The cost-of-living crisis and COVID-19 appear to have reduced activity in this area (5, 3). It is not possible to predict what future landscape factors could contribute to a faster shift: Climate change was not mentioned explicitly as a driver by the interviewees, but could become an important influencing factor over the next few years. Alternatively, a scare in the tabloid press or social media such as has happened previously with Bisphenol A (BPA), a monomer used to make polycarbonate and epoxy resins (Blair, 2016), or phthalates, used as plasticisers for PVC (Park, 2009), could increase mistrust in plastic reusable containers which could have an adverse effect on progress. The influence landscape factors can have is highlighted by the convenience retailer (9), when suggesting that a Blue Planet II moment for reuse could shift citizen opinion and place the necessary pressure on regime practices to change, indicating the strength of the anti-plastics sentiment at the time of the interviews. However, it is difficult to see how people will want to push for something they are unaware of.

It is suggested here that development in the niche is currently happening too slowly and there is insufficient pressure from the socio-technical landscape for any

meaningful transition to occur without a dramatic change in the landscape, or an intervention in the regime, such as legally binding reuse target figures.

4.5.2 Limitations

Whilst the interviews were limited to UK stakeholders, it would have been valuable to speak to industry actors in other international contexts. For example, in France, there is already legislation with targets for reuse, and therefore storylines may be somewhat different. Furthermore, the professionals we spoke with were typically sustainability professionals within their organisations. Whilst these individuals may have a level influence, it would have added depth to speak with decision-makers, such as the buyers at the retailers (5) and (9), who have ultimate responsibility for the products they purchase from their suppliers, and may be less open to the implementation of reuse. The activist organisations are optimistic ('I firmly believe'). However, the professionals interviewed from within the regime will be very experienced in the barriers to the introduction of new technology, especially within their own organisations.

The Multi-Level Perspective produces only a qualitative understanding of a sociotechnical system. A simple frequency analysis of the narratives reveals that confidence of businesses to invest (storyline 2) and the acceptability to the consumers (storyline 5) occur the most often. A more detailed examination could therefore be performed to support the MLP analysis, weighting the storylines. There is also the potential for subjectivity, for example some overlap exists between the different transition paths.

The analysis of the interviews presented here was performed by one researcher only (SG), meaning there is the potential for bias. The next stage is to combine this with the analysis of another researcher to mitigate this.

4.6 Conclusions and recommendations

A hypothetical model of the supply of yogurt in returnable 500g/500ml containers was co-produced with the help of industry stakeholders from the Many Happy Returns project. This was then used to identify stakeholders along the proposed supply chain to be interviewed. The transcribed interviews were analysed for storylines made up from a series of narratives, and the Multi-Level Perspective heuristic applied to assess a potential future transition from the existing regime of

household food groceries being supplied in single-use (plastic) packaging, to a new regime with return, where the containers are washed and refilled by the yogurt manufacturer, accounting for a significant proportion of the amount of the product sold.

The interviews revealed 3 types of storyline: a) that the majority of those interviewed see that there is a future for reuse, b) that identify barriers to the mainstream adoption of reuse and c) that identify actions that need to be done in order to make progress. The Multi-Level Perspective analysis concludes that there is insufficient pressure from the landscape, and that reuse systems are not well enough developed for there to be a significant shift to reuse within the socio-technical regime at the current time. Instead, the existing regime is realigning to reduce the amount of virgin single-use packaging being used without having to utilise reuse systems.

Brands lack the confidence to move forward with reuse from a business perspective. They say that consumers are not ready, as evidenced by reports of low uptake in trials and the failure of uptake to expand beyond early adopters. The reuse advocates say that people will engage in reuse if they are given the opportunity to, but they do not have the data to convince brands to act in any meaningful way. Therefore:

The transition to reuse becoming mainstream is in a deadlock.

The way forward is recognised as involving a large amount of work in a test-and-learn stage, as well as collaboration between stakeholders along the supply chain and among competitors to create efficient, standardised systems. Legislation is seen as essential to drive this. Incentivising the development of reuse systems within the upcoming EPR regulations is seen as a way, but not the only way, of legislating for reuse.

4.6.1 Recommendations

It is recommended that if reuse is to progress, legally binding reuse targets are brought in for the introduction of reuse systems, including an agreed process for environmental and financial assessment, and a mechanism introduced to ensure actors collaborate to avoid duplication of effort and the creation of competing systems, resulting in financial and environmental inefficiencies.

5 Fresh produce on the loose: examining the coherence between plastic packaging and food waste policy using the case study of fruit and vegetables in the UK

5.1 Background and Summary

5.1.1 Background

This chapter is an extended version of the paper 'Fresh produce on the loose: Examining the coherence between plastic packaging and food waste policy using the case study of fruit and vegetables in the UK'. It was co-authored with Dr Christian Reynolds and published in Environmental Research: Food Systems (IOP) (Greenwood and Reynolds, 2024). This work was supported by the Natural Environment Research Council (NERC), grant number NERC NE/V010654/1 'Reducing plastic packaging and food waste through product innovation simulation', part of the Smart Sustainable Plastics Packaging Challenge, and University of Sheffield HEIF Policy and Knowledge Exchange Impact funding.
Greenwood was the lead and corresponding author with supervision by Reynolds, principal investigator of the project.

CRediT author statement

Greenwood: Conceptualisation, Methodology, Investigation, Visualisation, Writing - Original Draft and Revisions

Reynolds: Conceptualisation, Methodology, Visualisation, Supervision, Funding Acquisition, Writing - Original Draft

Supplementary Information

This work involved internet searches and the downloading of supermarket policies on packaging, plastic and food waste - these are saved online with the Open Science Framework (Greenwood, 2022).

5.1.2 Summary (paper abstract)

The UK fresh produce sector (fruit and vegetables) uses 38 kt of plastic consumer packaging per year and is the fifth largest product category for the creation of plastic waste in the UK. One way of addressing this is to sell fresh produce loose, without packaging. This study takes a mixed methods approach of a literature search of historical loose produce trials and a policy coherence analysis of plastic packaging and food waste policy, addressing the research gaps in those areas. The results are used to check progress against UK Plastics Pact (UKPP) targets and alignment with Courtauld 2030 (C2030) and the United Nations Sustainable Development Goal (SDG) 12.3 on food waste. Both methods highlight a tension between food waste and plastics reduction policies at all levels and the literature survey shows there is now a will amongst retailers to overcome this. This incoherence is mitigated using caveats in the plastics policies, such as 'where shelf-life is unaffected'. There is additional scope to harmonise further by addressing compostables and reduction targets. Supermarkets' plastics policies are shown to be generally coherent with each other and the pact, but implementation of individual policies between retailers varies considerably. For the removal of consumer packaging from fresh produce to continue, food waste in the supply chain, the amount of transit packaging used, and wider social engagement on packaging and food waste must be considered. The need for better data on packaging usage is highlighted.

5.2 Introduction

Plastic food packaging is predominantly single-use and made from virgin materials which use fossil resources. Food packaging has evolved to prevent food waste by protecting and preserving food, in addition to functions such as information transfer about the product it contains (Evans et al., 2020; Parsons, 2022; Rundh, 2016). In the UK, one million tonnes of plastic packaging waste is generated annually from the grocery sector, with only 52% of this being collected from households for recycling (McBeth, 2023; Thomson et al., 2018).

Food waste is a critical issue with both economic and environmental implications on a global scale (Food Wastage Footprint, 2013; World Bank, 2020; WWF-WRAP, 2020). In 2022 1.05 billion tonnes of food was wasted globally in the retail, food service and household sectors combined (UNEP, 2024). In the UK, 9.5 Mt of food waste is generated post-farm-gate per year; 73% of this is from households, 12% from hospitality and food service, 11% from manufacture and 4% from retail (WRAP, 2023).

Although there is a growing body of literature showing that food waste and plastic packaging waste are linked at a systems level (Chan, 2022; Heller et al., 2019; Verghese et al., 2015), they have become independent issues of public concern. This has resulted in a tension of separate actions to reduce plastics and food waste which can be seen at the global level within the Sustainable Development Goals, non-statuary targets for countries in the United Nations (UN, 2022b). Sustainable Development Goal 12.2 focuses on all materials (including food and plastics): "By 2030, achieve the sustainable management and efficient use of natural resources", while 12.3 explicitly states "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses.".

In this chapter, the concept of Policy Coherence Analysis (OECD, 2021) is applied to plastic packaging policy and food waste policy in the UK (gov.uk, 2018b), using the Fresh Produce sector as a case study.

The Fresh Produce category (fresh fruit and vegetables) is an important category for plastic packaging and food waste reduction. In the UK, c.2.5 million tonnes of Fresh Produce food waste is generated every year by households, with 500,000 tonnes of fresh produce wasted in hospitality and food service, and 170,000 tonnes in the supply chain (Parfitt et al., 2016; WRAP, 2014). Consumer packaging for

Fresh Produce uses 38,000 tonnes of plastic. It is the fifth biggest category for food-related plastic packaging waste (Thomson et al., 2018).

The plastic packaging used for fresh fruit and vegetables consists of 'pots, tubs and trays' (PTT), which includes punnets, typically made from PET or PP, and film used as lidding or to make bags, typically PE, PP or PET depending on the application (SUEZ, 2021). Only one third of pots, tubs and trays, and 7% of plastic film were collected from households for recycling in 2018. This compares to 59% for plastic bottles, used for Milk and Soft Drinks (Morgan et al., 2020). The Fresh Produce category is therefore one of the biggest challenges in terms of packaging waste management, and this is compounded by consumer pressure - press articles often question the need for plastic packaging on fruit and vegetables (Dewdney, 2018; Poulter, 2006) and pressure groups campaign for its removal e.g. Surfers Against Sewage (2018).

A dominant policy-led solution to reduce the amount of consumer single-use plastic packaging waste for fresh produce is to eliminate consumer packaging by selling fresh produce loose: the French government introduced a law banning plastic packaging on most fresh produce in January 2022 (French Government, 2021) and the Spanish Government have announced draft legislation for implementation in 2023 (BBC News, 2021; Spanish Government, 2021). Other solutions include setting targets for composability, recyclability, and reuse (Ellen MacArthur Foundation, 2017). Legislation for the removal of packaging from fresh produce in packs less than 1.5kg in weight by 2030 was introduced for all of Europe in February 2025 (European Union, 2024).

The UK charity, and one-time quango, WRAP (the Waste and Resources Action Programme), announced in December 2021 that packaging for fruit and vegetables was to be investigated for elimination as 'unnecessary packaging' as part of the voluntary agreement the UK Plastics Pact (UKPP) (Quinn, 2021) and expanded on this in guidelines issued in February 2022, following laboratory trials on the home life of 5 produce items sold loose versus packaged (Parry and White, 2022).

Several in-store trials have been performed by UK retailers in recent years with the aim of selling more fresh produce loose, with only basic information on (some) of these having been reported in trade publications, e.g. (M&S, 2019; Wells, 2019). Indeed, it has not been possible to find any published academic research on the

loose produce trials in the UK. A review by White and Lockyer (2020) comes the closest and Mattsson et al. (2018) have completed a study in the Swedish context.

The majority of industry and government policy on plastic packaging and food waste reduction in the UK is focused through the use of voluntary agreements (VAs). Voluntary agreements have become a popular governance mechanism for managing environmental concerns since the 1990s (Mol et al., 2000; WWF-WRAP, 2020). In VAs public and private sector organisations make joint commitments to improve their environmental performance, without the need for direct government legislation or sanctions.

Since 2005, WRAP has also administrated the Courtauld Commitment (WRAP, 2024a) (CC). The CC is a series of voluntary agreements with a focus on food waste reduction that have reduced the carbon and wider environmental impact of the UK food and drink sector. The Courtauld Commitment is estimated to cover more than 95% of the food retail sector by sales (EMF, 2023; Parry et al., 2020).

In food policy, policy coherence is defined as 'the alignment of policies that affect the food system with the aim of achieving health, environmental, social and economic goals, to ensure that policies designed to improve one food system outcome do not undermine others.' (Nilsson et al., 2012; Parsons and Hawkes, 2019).

Policy coherence has been used as a method in food policy analysis to examine food security and nutrition issues (Thow et al., 2018), or to examine the coherence of wider food system policy (OECD, 2021, 2016). Parsons and Hawkes (2019) highlighted that policy incoherence across organisations in the food system often undermines the multiple objectives set in individual policies. However, there is a lack of plastic packaging and food waste policy coherence analysis in the literature. Instead, contemporary food waste and/or plastic packaging policy analysis has focused on the analysis of multilevel actors (international, national and subnational) engaged in governance and policy development of plastics (Abril Ortiz et al., 2020) or food waste (Brooks, 2014; Reynolds, 2022). In particular, there has been analysis of multi-level development and coordination of plastic packaging and food policies through mechanisms such as extended producer responsibility schemes (Diggle and Walker, 2020) or voluntary agreements (Nunan, 1999). This establishment of multi-level voluntary agreements as governance and agenda-setting tools may have led individual brands and company-level targets/policies around plastic packaging to

be similar to national or global policies. This process can be referred to as policy 'harmonisation'; the shifting of regulatory requirements or governmental (or institutional) policies of different jurisdictions to be similar or identical (Drezner, 2005; Majone, 2014). However, due to systems complexities, policy harmonisation does not occur evenly. This lack of harmonisation may lead to a lack of coherence between different policies - again, this has not been explored adequately in the plastic packaging or food waste literature. There are also gaps in the academic literature reviewing the evidence on UK single-use plastic packaging waste and packaging reduction trials related to fresh produce and food waste.

This chapter fills the research gaps by reviewing grey literature (non-academic publications, such as project reports and news articles) to document the results of these trials and providing results of informal store audits to assess packaging formats and materials conducted in July 2021. The findings are then compared to supermarket packaging and food waste policies to highlight the harmonisation and coherence of the current situation regarding the circularity of plastics in the fresh produce sector and how individual retailer policies fit in with UKPP and CC2030 targets. Combined, the findings also attempt to answer the question '**is going packaging-free the answer to the UK's plastics waste problem?**' and suggestions for future research and policy improvements to make this happen are made, which will also be of interest to countries and regions that are part of the Plastics Pact Network (EMF, 2023).

5.3 Method

A mixed methods approach has been taken to assess the current landscape of actions and policy focused on primary packaging used for fresh produce in UK supermarkets to establish if there are tensions between packaging and food waste prevention:

5.3.1 Literature review

A literature search was performed between June 2021 and January 2022 covering both academic and grey literature. The platform Scopus was used to search for academic literature using the terms 'plastic shelf life fresh produce', 'packaging shelf life fresh produce, 'loose produce' and 'loose produce and shelf life' over all available articles. An internet search was performed using Google with the search

terms ‘produce and shelf-life’ and ‘loose produce’ and ‘historic loose produce sales UK’. The UK trade magazine Packaging News website archive (Packaging News, 2023) was searched using the term ‘loose produce’ between 2007-2022. The search terms were chosen specifically to find trials with multiple products rather than single product lines. This search yielded just 15 references, including one academic paper (White and Lockyer, 2020), all listed in Table A8 in the Appendix. Documents from the coherence analysis below were also searched for references to loose produce. Relevant UK legislation, voluntary agreements and high-profile environmental campaigns have been reviewed and added to the timeline in Figure 5.1 along with the dates of loose produce trials reported by retailers.

5.3.2 Store audit

To get a sense-check on the amount of loose produce on sale, packaging formats, and progress towards the goals of the UK Plastics Pact, a small store audit was held in three stores in July 2021. These were a discounter, a mid-range and a premium supermarket, using a simplified version of the methodology in Devine et al. (2022). A checklist was drawn up prior to the first visit and a copy was filled in at each store to evaluate; the general look and feel of the sales area, the amount and condition of the loose produce on sale, the type of secondary packaging (crates or cardboard boxes), and features of the primary packaging used e.g. materials, formats and colours. The amount of produce sold loose was estimated by counting the proportion of product lines rather than the volume on display. Results of the Audit are reported in 5.4.3. Table A9 in the Appendix shows the checklist used and observations made in the stores. A reusable produce bag, a giveaway bag and the packaging from a 6-pack of apples were also weighed for comparison.

5.3.3 Policy harmonisation and coherence analysis

The level of harmonisation and coherence has been analysed by examining UK level documents and guidance, and specific supermarket policies and website pages on packaging and plastics. The supermarket specific documents were reviewed to gauge progress in reducing the impact of their plastic packaging and the harmonisation of their policies to UKPP targets. These policies were then compared with the same UK level documents and guidance, and supermarkets’ polices on food waste. Between the 15th and 17th Feb 2022, a Google search from a private

window was performed for packaging and food waste policies (the use of a private window eliminated any influence of cookies from previous searches). The search terms were '[name of retailer] and packaging policy' and '[name of retailer] and food waste policy'. A total of 98 web pages and downloadable documents of interest were saved and stored alongside the search results at the Open Science Framework (Greenwood, 2024). Key information was extracted manually and added to 2 spreadsheets, Tables A10 and A11 in the Appendix, a summary of which is shown in Table 5.1. The information from each retailer was compared with the targets of the UK Plastics Pact and Courtauld 2030. To investigate the framing of specific terms related to packaging and provide further rational for instances of incoherence between different supermarkets, documents were searched for the terms 'hygiene' 'safe*', 'protect*', 'convenien*' and 'food waste'. The supermarket plastics and food waste policies were then attributed a score (-3 to +3) using the framework from Nilsson et al. (2018, 2012). This was performed by SG and verified by CR.

5.4 Results

5.4.1 Literature review - the current landscape and trials to date

5.4.1.1 The current landscape

Prior to 2018 it was difficult to find data on the spilt of loose vs packaged fresh produce. In 2018 the British Growers Association found that that 49% of fresh produce items were sold in 'plastic wrap' and 15.5% loose (Refrigerated and Frozen Foods, 2018). In 2019, major UK retailers self-reported loose sales as between approximately 17 and 19 percent (Environmental Investigation Agency; Greenpeace, 2021; Statista and Kantar Worldpanel, 2022). The figures for 2019 are shown in Table 5.1 alongside market share.

5.4.1.2 Trials to date

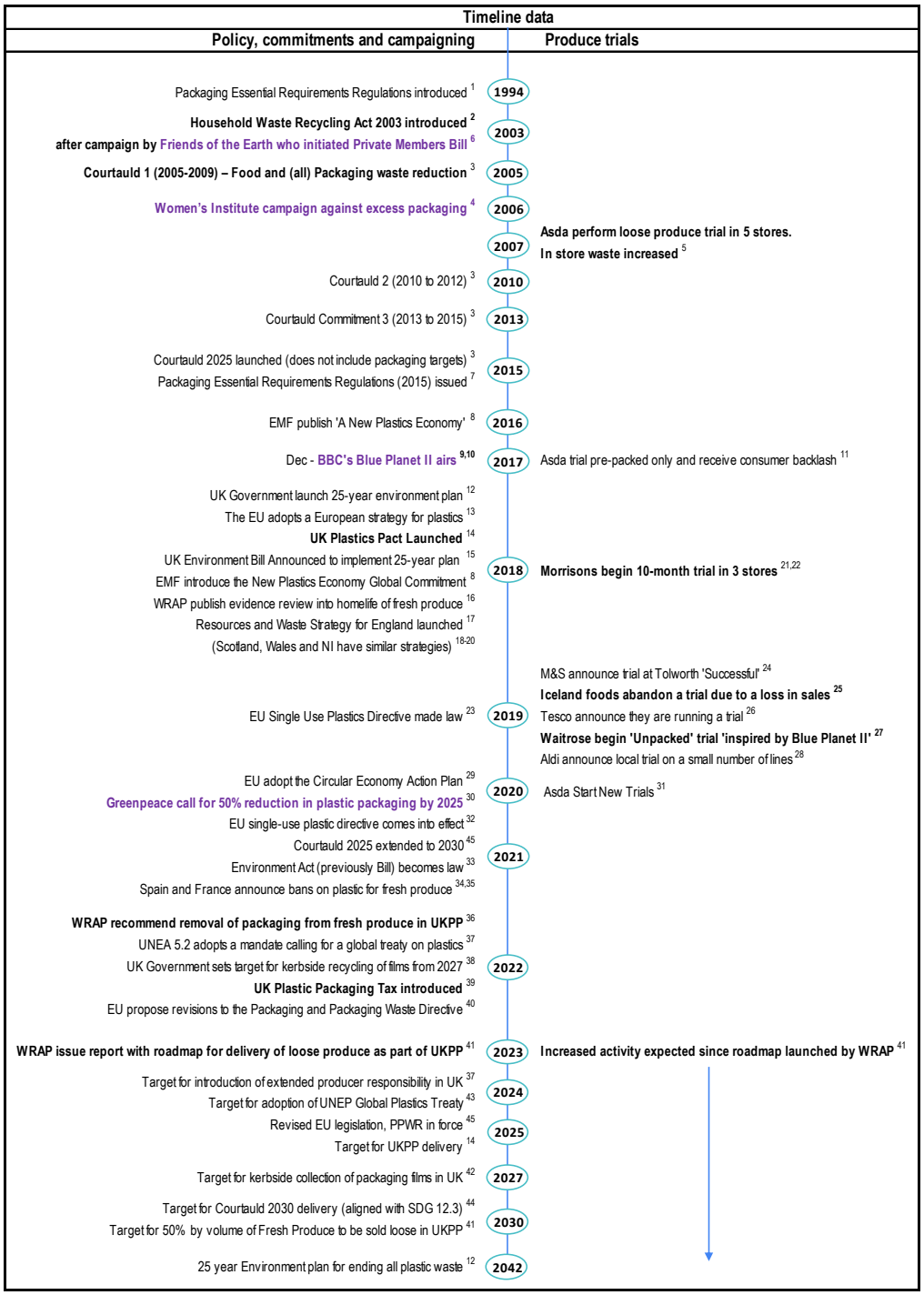
Several trials have been run at store level by UK retailers, however published academic literature on these could not be found. Trials where (at least some of) the results have been made public by other means include from Asda (Packaging News, 2007), Morrison's (Perkins, 2021; WRAP, 2021), Iceland (Barrie, 2019) and Waitrose (John Lewis Partnership, 2021).

Retailer	Market share % ‡	% sold loose†	Trials of loose F+V	Results reported?
Tesco	27.3	17.0	2019	No
Asda	14.9	-	2007 2017 - pre-packaged only 2020	Y - increased waste Y - abandoned N
Sainsbury's	15.3	22.0	No trials announced	
Morrisons	10.4	24.4	2018	Y - detailed report
Aldi	7.9	19.0	2019	N
Co-op	6.2	15.0	2018 - cucumbers only	Y
Lidl	5.7	17.0	N	N
Waitrose	5	20.0	2021	Y - detailed report
Iceland	2.1	3.0	2019	Y - loss of sales
Ocado	1.4	0.01	N	N
M&S	Part of 'other multiples' 1.9	5.0§	2019	Y

†EIA / Greenpeace figures self-reported by retailers, Asda did not report. ‡June 2019 (Statista and Kantar Worldpanel, 2022). §M&S figure

Table 5.1 *Loose Fresh Produce sales percentages and historic trials listed by retailer, year and whether results were reported or not.*

Others have stated that they have or intended to perform trials but have not published the results e.g. Aldi (Searle, 2020; Wells, 2019). Table 5.1 contains a summary of these trials, with a detailed version in Table A8 in the Appendix, and Figure 5.1 shows a timeline of trials alongside notable legislation, commitments and campaigning.



[1](European Union, 1994), [2](UK Government, 2003), [3](WRAP, 2024a) [4](Poulter, 2006), [5](Packaging News, 2007), [6](Friends of the Earth, 2016), [7](legislation.gov.uk, 2015), [8] (EMF, 2018a), [9,10](BBC, 2017; Gell, 2019), [11](Paterson, 2017), [12](gov.uk, 2018a), [13](European Commission, 2022a), [14](WRAP, 2018), [15](Harvey, 2021), [16](White and Stanmore, 2018), [17-20](gov.uk, 2018b; Scottish Government, 2016; UK Governments, 2020; Welsh Government, 2021), [21,22](Perkins, 2021; WRAP, 2021), [23](European Commission, 2019), [24](M&S, 2019), [25](Barrie, 2019), [26](Edie.net, 2019), [27](John Lewis Partnership, 2021), [28](Wells, 2019), [29](European Commission, 2020), [30](Greenpeace, 2020), [31](Asda, 2020), [32](European Commission, 2019), [33](gov.uk, 2021), [34,35](French Government, 2021; Spanish Government, 2021), [36](Parry and White, 2022), [37](UNEP, 2022), [38](DEFRA, 2022), [39](HM Revenue and Customs, 2022), [40](European Commission, 2022b), [41](Conroy, 2023), [42](DEFRA, 2022), [43](UNEP, 2022), [44](WRAP, 2022a), [45](European Union, 2024)

Figure 5.1 *Timeline of historic loose produce trials alongside notable legislation, voluntary agreements and campaigning.*

Asda was one of the first retailers to trial selling loose produce at scale in 2007, across five stores. This was during a period of public concern with plastic packaging, including high-profile campaigning from the UK Women's Institute (Poulter, 2006). For context, this was also the time of the first Courtauld Commitment (WRAP, 2024a). In a news item Asda reported that the trial was unsuccessful - in-store spoilage rates doubled to approximately 6% caused by "*acceleration of the ripening process, produce becoming damaged and not subsequently purchased and the practical difficulties of keeping track of stock rotation"*, and that many customers *"preferred to buy packaged produce"* for reasons of convenience and hygiene (Wells, 2008).

In 2017, around the time of a subsequent wave of plastic dissatisfaction, often termed the "Blue Planet Effect" (BBC, 2017; Gell, 2019), and just before the introduction of the UK Plastics Pact, UK retailer Morrison's began a comprehensive 10-month trial in three stores. The project evaluation report states initial waste levels were 2.7 times higher than normal, but this was brought back to average levels through improvements to store processes and management (WRAP, 2021). Their intention was to roll out to a total of sixty stores with the potential to save 156 tonnes of plastic waste. The Grocer reported in 2021 that Morrison's had dedicated loose produce areas in 63 stores in 2019 and that in 2020, 332 of their 497 stores included loose produce (Perkins, 2021). It was reported that in a customer survey as part of the trial 75% of customers preferred to buy fresh produce loose (WRAP, 2021).

Iceland Foods Ltd, who famously declared they would rid their supermarkets of all plastic packaging by 2023 (BBC News, 2018), abandoned a 2019 trial quoting a loss in sales of 30% stating *"What people want is pre-packaged convenience. Lots of people pop in and spend small amounts of money. We need to keep prices low and the trial cost us more in the end."* ending with a resolution to use this as a learning experience and try again in the future (Barrie, 2019). Loose produce formed part of the wide-ranging Unpacked trial in Waitrose in the Botley Road, Oxford store starting in 2019 (John Lewis Partnership, 2021). Waitrose reported that in-store food wastage increased at the start of the trial (due partly to *"ordering too much pre-packed soft fruit"*) but they do not detail the value that this levelled off to. They considered the trial a success in the reduction of the amount of plastic waste generated and they seem confident that there is scope for overall greenhouse

gas reduction. Customer feedback included that there was a loss of quality of some of the naked products. Waitrose reported that it was likely that customers would return to the packaged version if this was the case.

Other retailers that stated an intention to run trials but did not report detailed results included M&S, Tesco and Aldi (Edie.net, 2019; M&S, 2019; Searle, 2020).

Investigating a move in the opposite direction, Asda provoked internet outrage by experimenting with selling only pre-packed produce in 2017 (Paterson, 2017). Perhaps learning from this, they started to investigate loose produce again in a store dedicated to trialling sustainable initiatives (Asda, 2020).

5.4.2 Review of retailer packaging and food waste policies

5.4.2.1 Summary of retailer plastic and packaging policy

All the retailers searched for were found to be members of the UK Plastics Pact apart from Iceland, and all are members of Courtauld 2030.

Retailer policies are broadly in line with the UK Plastics Pact targets, with their own dates for implementation varying. Each retailer has their own take on the Rs of sustainability - e.g. Tesco have their 4Rs of sustainability - 'Remove, Reduce, Reuse and Recycle', and M&S have 'Refuse, Redesign, Reduce, Reuse, Recycle' (See Table 5.2).

In addition to the four UKPP targets, all retailers have their own targets for the reduction of plastic packaging (some for all packaging materials - Aldi, Lidl, M&S and Waitrose).

Target 2 of the UK Plastics Pact is for plastic packaging to be reusable, recyclable or compostable by the end of 2025. For all retailers the focus is very much on recyclability with varying, much smaller commitments to reuse. Compostable materials do not feature prominently in targets for any of the retailers. The Co-op sell compostable carrier bags and Waitrose have compostable giveaway bags for loose produce; both encourage customers to use these as food waste caddy liners. However, it is in neither company's policies to use compostables for consumer packaging. Tesco have compostables on their 'red list' of materials to be avoided (See Figure 5.2), and Morrison's quote that they are not investigating the materials because of a lack of waste infrastructure. Only Iceland, who are not plastic pact

signatories, say they are lobbying for composting collection to become widely available.

In their documents most retailers acknowledge the role of packaging in protecting the product (mentioning either protection, safety or hygiene) and four of the eleven explicitly mention food safety. Ten of the eleven quote the importance of packaging in the reduction of food waste (or keeping food fresh). Consumer acceptance (legislation.gov.uk, 2015), and convenience, a service which is provided by to the consumer through plastic packaging (Evans et al., 2020), and can be considered a subset of acceptance, however, are mentioned considerably less - only 3 of the 11 mention or even allude to this (e.g. Morrisons state that it must be 'in a form suitable to meet the customer's needs').

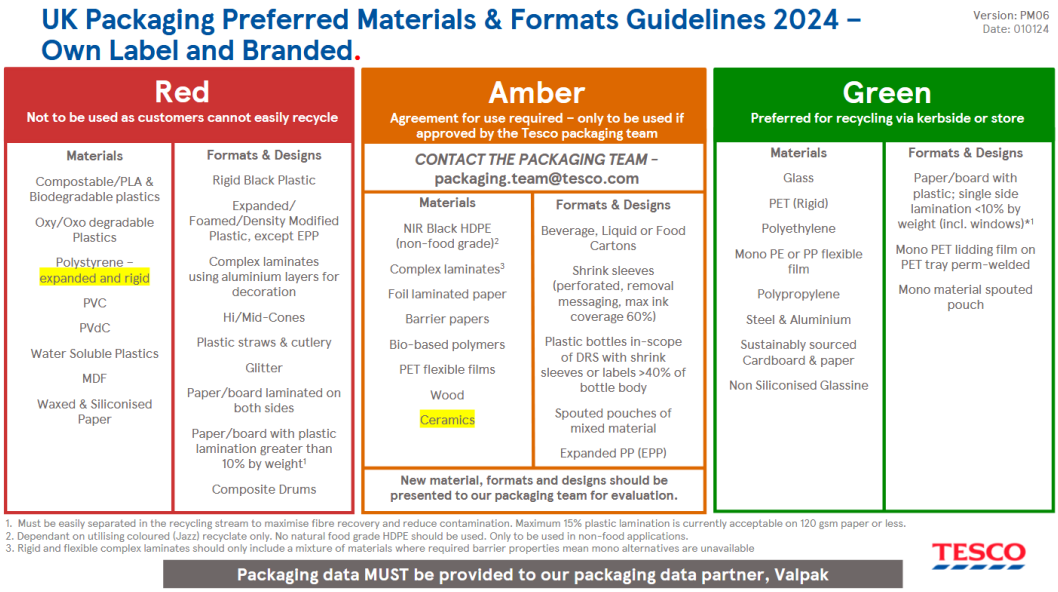


Figure 5.2 *Tesco preferred materials and formats guidelines for suppliers to use when specifying packaging (Source: Tesco.com).*

5.4.2.2 Summary of retailer food waste policy

Food waste policies are simpler and vary less between retailers. All the retailers examined are signed up to Courtauld 2030 (see Table 5.2), in line with the United Nations sustainable development goal 12.3. Here food waste is targeted from farm to fork - i.e. in manufacture, retail, hospitality and food service, and household. There is a focus on operational food waste with nine of the eleven retailers stating this explicitly, four retailers expand on this and discuss supplier and/or customers' waste, and two of the retailers discuss food waste in a mere general sense.

As with plastics, individual retailers may publicly set themselves interim targets, and these differ from retailer to retailer.

Ten of the eleven retailers acknowledge the role of plastic packaging in reducing food waste when used appropriately (e.g. Dhall, 2012), although they tend to generalise by stating 'the supply chain' and do not specifically state whether this is in-store or in-home. Plastic packaging and food waste policies are generally aligned for all of the retailers. Although greenhouse gas emissions from food waste are an important issue, policies are much less complicated than for plastics; this is discussed in 5.5.2.

Retailer	**Tesco**	**Sainsbury's**	**Asda**	**Morrisons**	**Aldi**	**M&S**	**Co-op**	**Lidl**	**Iceland**	**Waitrose**	**Ocado**
UKPP member?	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Policy aligned with T1? (elimination of 'unnecessary' items)	Y + all materials	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Policy aligned with T2?											
RECYCLABLE?	Y	Y	Y	Y	Y	Y	Y	Y	n/a	Y	Limited info
REUSABLE?	Y	Y	Y	Y	Y	Y	Y	Y	n/a	Y	Limited info
COMPOSTABLE?	N	N	N	N	?	N	Carriers	N	Y - lobbying for waste stream	Produce giveaway bags only	Limited info
Policy aligned with T3? (70% effectively recycled or composted)	Y	Y	Y	Y	Y	Y	Y	?	n/a	?	Limited info
Policy aligned with T4? (30% recycled)	'contains recycled content where possible"	Say they are working towards (8)	Y	Y	Ambiguous.	Target to exceed	Achieved and target to exceed	Ambiguous	n/a	Not much on recycled content - (ready meal trays)	Limited info
Retailer strategy name / description?	4 Rs (**Remove Reduce Reuse Recycle**)	Reduce by 50% by 2025 - **Removed Reduce Replace Recycle**	3 Rs of waste management (**Reduce Reuse Recycle**)	Plastic and Packaging Policy	7 Plastic and Packaging Pledges	Plastics Plan- 5 Plastic Principles - **Refuse, Redesign, Reduce, Reuse and Recycle**	Action on Plastics. Across supply /disposal chain.	Circular motion' strategy - **Reduce, Recycle, Reuse, Engage, Collaborate** (21)	**#TooCoolForPlastic** Complete removal by 2023	Taking Action on Plastics	Limited info
Reduction targets?											
Plastic	-	50%	3 bn pieces	50%	-	30% (2027)	15% (2022)	40%	100% (2023)	50%	-

Retailer	Tesco	Sainsbury's	Asda	Morrisons	Aldi	M&S	Co-op	Lidl	Iceland	Waitrose	Ocado
All packaging	50% by 2023	-	-	-	50%	-	-	25%	-	One third	-
Paper and Board	100% sustainable by 2025	-	-	-	Y	-	-	Y	-	-	-
Acknowledgement re:											
Food waste prevention	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	-
Protection, (protection, safety, hygiene)	Y	Y	Y	Y	Y	Y	Y	Y		Y	
Consumer acceptance/ convenience	-	-	Y	Y	-	-	-	-	-	-	Y
Courtauld 2030 Signatory? (WRAP, 2022d)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Reference document in supplementary information	1,3,4,6,10,11,12,46,47, 51, 94,102	7-9, 12a, 13, 48, 49, 76	14, 15, 60, 61, 86, 89	16-19, 83, 95, 101	20, 20a, 65, 72, 74	27-34, 50, 69, 77, 82, 85, 87, 88	35-39a, 70, 73, 75, 79, 80, 91, 92	21-23, 53-55, 62, 97-99	24-26, 56-59	40-45, 78, 90, 93, 103	52, 63-64, 71, 96, 104

Table 5.2 *Summary of UK supermarket plastics, packaging and food waste policies, showing whether signed up to the UKPP and C2030, alignment with UKPP Targets, plastics and packaging reduction targets, if policy stated on sustainability of paper and board, and whether they acknowledge food waste prevention, product protection and the need for consumer acceptance (see Tables A10 and A11 in the Appendix for more detail. The numbers in the final row refer to the downloaded documents saved at the Open Science Framework (Greenwood, 2022).*

5.4.3 Store audit

The in-store observations are recorded in Table A9 in the Appendix. In terms of the amount of loose fresh produce on sale, there was around 10% of the number of products on offer (estimated visually) in both the discounter and mid-range store. The premium store had a wider offering at approximately 15%. The quality of the loose product appeared as fresh as the pre-packed in all stores for most products.

Where loose produce is sold, giveaway bags are often provided for shoppers to put their selections into. While bags were available at the discounter, they weren't offered at the mid-range store. The premium store provided compostable giveaway bags, and both the mid-range and premium stores sold reusable bags. All three stores had scales for customers to check the weight of their items before purchase.

The UK Plastics Pact recommends that certain difficult-to-recycle plastics are not used for consumer packaging - namely (non-infra-red-detectable) black plastic, PVC, Polystyrene and laminates combining different materials (Wrap, 2019). In all three stores where rigid plastic (pots, tubs and trays) was used, this was almost all clear and most likely PET or PP (Thomson et al., 2018). Mushroom trays were coloured, not black. There was no evidence of expanded polystyrene (EPS) in use (moulded pulp trays were seen in use in the premium store to protect the more delicate 'ripe and ready to eat' lines). There seemed to be a heavier usage of rigid plastics in the premium store compared with the discounter and mid-range stores. A card tray was used for a couple of products instead of a plastic one - for tomatoes in the discounter and grapes in the premium store.

The flexible packaging appeared to be mainly either LDPE or PP films. Two lines in the premium store were made from a compostable material. Throughout the three stores, cling film was used on some products (e.g. mushrooms), but it was not possible to tell if it was PVC or the more easily recycled LDPE film from this visual inspection.

Non-recyclable nets were in use in all stores for citrus and also, unusually, for tomatoes and peppers in the discounter store.

The type of secondary packaging varied considerably from store to store. The discounter used almost all single-use card crates, the mid-range store about 70% returnable black plastic crates, and the premium store about 95% returnable green plastic crates. This variation is likely to be a result of differences in the supply chain

and whether the retailers' suppliers are equipped to use returnable crates. The amount of refrigeration also varied; the discounter only refrigerated the high respiration or delicate products - bagged salad, mushrooms and soft fruit, whereas the midrange store was at 60% refrigeration and the premium store around 90%.

5.4.3.1 Giveaway vs reusable produce bags vs packaging

The weights of a reusable bag (woven recycled PET), packaging (FFS printed OPP film) and lightweight giveaway bags (HDPE) were weighed for comparison, these were 9g, 3g, and <1g respectively, meaning that in this context the reusable bag has to be used 3 times in order to break even on plastic packaging weight when compared to the pre-packed produce and 9 times when compared with the giveaway bags, of course there is nothing to prevent someone reusing the giveaway bags. Note that since the audit was completed, many retailers no longer use giveaway bags at all.

5.4.4 Policy analysis

Table 5.4 shows the results of the coherence analysis of the four targets of the UKPP and the food waste component of Courtauld 2030. Table 5.5 shows the results of the coherence analysis of their plastics and food waste policies detailed in Tables 5.2 and A10 in the Appendix in relation to the UK Plastics Pact and Courtauld 2030. The scheme for allocating scores is shown in Table 5.3, and the results are discussed in 5.5.2.

5.4.4.1 Policy coherence analysis - UKPP aims, individual targets and food component of C2030

Table 5.3 shows a Policy coherence analysis of the UKPP individual targets compared to each other, the headline aims of the pact and the food component of C2030, using the coding scale in Table 5.4. Here the score is the impact of the target in the rows on the target in the column.

	UKPP				Headline aims of the pact			C2030 (food waste only)
Targets	T1	T2	T3	T4	Increase circularity of plastics	Reduce plastics in the natural environment - Litter	Reduce plastics in the natural environment - Landfill	
T1	-	3	1	1	3	3	3	-1 (0 *)
T2	1	-	2	2	3	0	3	-1 (0 **)
T3	0	1	-	1	3	0	3	0
T4	0	1	1	-	3	0	2	0
C2030 (food waste only)	-1	-1	-1	0	-1	0	-1	-

* With the caveat that packaging for uncut loose produce should only be removed if food waste is unaffected and tacitly implied for others. ** with IMPLIED caveat that shelf life is unaffected. Target 1, T1 is the elimination of 13 unnecessary items, PVC and EPS, T2 is for 100% of plastic packaging to be reusable, recyclable or compostable, T3 is for 70% of plastics to be effectively recycled or composted, T4 is for plastic packaging to contain 30% average recycled content.

Table 5.3 *Policy coherence analysis of the UKPP individual targets compared to each other and the food component of C2030, using the coding scale in Table 5.3. Here the score is the impact of the target in the rows on the target in the column.*

Interaction label	Description	Meaning
+3	Indivisible	Progress on one target automatically delivers progress on another
+2	Reinforcing	Progress on one target makes it easier to make progress on another
+1	Enabling	Progress on one target creates conditions that enable progress on another
+/- 0	Consistent	There is no significant link between the two target's progress
-1	Constraining	Progress on one target constrains the options for how to deliver on another
-2	Counteracting	Progress on one target makes more difficult to make progress on another
-3	Cancelling	Progress on one target automatically leads to a negative target on another

Table 5.4 *coding framework for coherence analyses in tables 5.4 and 5.5 ref* (Nilsson et al., 2018, 2012) *showing the meaning of each interaction label.*

Progress on Target 1 automatically means progress in Target 2 and enables Targets 3 and 4. Target 1 increases the circularity of plastic when non-recyclable plastics are replaced with recyclable plastics, and items that are replaced by materials substitution mean that there is less plastic packaging waste in the environment e.g. in landfill or through being littered (although not necessarily less packaging waste of other materials).

Once Target 2 is met, this provides the conditions for Targets 3 and 4 to progress; Target 3 is then largely dependent on collection and reprocessing infrastructure, which is outside of the direct influence of most pact members. Target 4 depends on the availability of the right quality of recycled material, which will be enabled by progress on Target 3.

Targets 3 and 4 follow on from Targets 1 and 2 and progress on 3 and 4 have less impact on the progress of 1 and 2, hence the lower scores.

To summarise, the four targets of the UKPP are all aligned with each other to varying degrees and with the umbrella aims of increasing the circularity of plastics and reducing the amount of plastics in the environment (here taken to be in landfill / as litter).

Some difficult-to-recycle plastic packaging has excellent food preservation properties - e.g. multi-material multilayer flexibles (Soares et al., 2022) so moving to more recyclable alternatives could mean a loss in barrier, and hence in food preservation properties. Progress on targets 1 and 2 could constrain progress on the food waste target (-1 values in table column 8). However, the WRAP guidance on selling uncut fruit and veg states explicitly that packaging should not be removed if it increases food waste. This caveat that food waste should not be affected is implied in other areas - e.g. p14 of (WRAP, 2022b), the UK Plastics Pact Roadmap to 2025, which states that a difficulty of moving from multilayer structures is finding nanomaterials with equivalent barrier properties.

Examining the food waste target for C2030, there are no such caveats for the impact on plastic waste, hence the values of -1 in row 5, resulting in a dominance of the issue of food waste over plastic packaging waste. Progress on food waste targets may require food suppliers to keep using non-recyclable packaging, hence slowing progress in the increased circularity of plastic food packaging.

5.4.4.2 Policy coherence analysis - retailers' plastic and food waste policies compared with the UKPP targets and the C2030 food waste goal

Table 5.5 shows a coherence analysis of the retailers' policies as related to the ambitions of the UK Plastics Pact and Courtauld Commitment.

Retailers' Plastics Policies

All retailers apart from one score 3 against UKPP Target 1 for the elimination of unnecessary items. The outlier, Ocado does not provide explicit information on this so is marked as a 1 and has been scored the same against Targets 2-3 for the same reason). Target 2 of the UKPP is for 100% of plastic to be recyclable, reusable, or compostable. Consequently, only one of these three has to be met for the goal to be achieved. E.g. Tesco have an anti-compostables stance, but the remaining packaging could be recyclable or reusable, so Tesco plastic scores 3 vs UKPP Target 2. Retailers' plastic policies mainly score a 2 against Target 3 as they enable recycling, but they don't actively engage in recycling at scale (other than Morrisons who have pledged to recycle as much plastic as they put on the market in their own facilities (17)). Retailers' plastic policies score 3 against Target 4 if they explicitly state they are targeting 30% or more recycled content and 2 if they are 'working towards' (as with Tesco).

10 of the 11 retailers acknowledge the benefits of plastic in preventing food waste, hence the score of 0 for retailer plastic policy against the food waste component of C2030.

Retailers' food waste policies

For all retailers, the food waste policy scores 3 against the food component of C2030, -1 against Target 1-Target 3 of the UKPP and 0 against Target 4. The food waste policies are all in line with the food component of C2030. The role of plastic packaging in the reduction of food waste is acknowledged by all retailers. Therefore, a score of -1 has been allocated to Target 1 - Target 3 as it may be necessary to keep hold of difficult-to-recycle packaging specifications in order to maintain/reduce food waste levels. 0 has been allocated to Target 4 as there is no correlation between the recycled content of plastic packaging and food waste.

Retailer	Policy	Reduction Target in policy / % (see Table 5.2)	UKPP				C2030 (food waste only)
			T1	T2	T3	T4	
Tesco	Plastic	50% (All Packaging)	3	3	2	2	0
	Food Waste	n/a	-1	-1	-1	0	3
Sainsbury's	Plastic	50% (Plastic)	3	3	2	2	0
	Food Waste	50%	-1	-1	-1	0	3
ASDA	Plastic	3 billion pieces	3	3	2	3	0
	Food Waste	n/a	-1	-1	-1	0	3
Morrisons	Plastic	50% (Plastic)	3	3	3	3	0
	Food Waste	50%	-1	-1	-1	0	3
Aldi	Plastic	50% (All Packaging)	3	3	2	2	0
	Food Waste	50%	-1	-1	-1	0	3
M&S	Plastic	30% (Plastic)	3	3	2	3	0
	Food Waste	50%	-1	-1	-1	0	3
Co-op	Plastic	15% (Plastic)	3	3	2	3	0
	Food Waste	50%	-1	-1	-1	0	3
Lidl	Plastic	40% (All Packaging 25%)	3	3	2	2	0
	Food Waste	50% (in-store)	-1	-1	-1	0	3
Iceland	Plastic	100% (Plastic)	3	3	2	0	0
	Food Waste	50%	-1	-1	-1	0	3
Waitrose	Plastic	50% (Plastic)	3	3	2	1	0
	Food Waste	50% (operational)	-1	-1	-1	0	3
Ocado	Plastic	n/a	1	1	1	1	0
	Food Waste	100% (operational)	-1	-1	-1	0	3

Table 5.5 *(in)Coherence analysis of the retailers' policies as related to ambitions of the UK Plastics Pact, and Courtauld Commitment. using the framework from (Nilsson et al., 2018, 2012), shown in Table 5.3. Target 1, T1 is the elimination of 13 unnecessary items, including PVC and EPS, T2 is for 100% of plastic packaging to be reusable, recyclable or compostable, T3 is for 70% of plastics to be effectively recycled or composted, T4 is for plastic packaging to contain 30% average recycled content.*

5.5 Discussion

5.5.1 Trials

Asda's 2007 trial (Packaging News, 2007) highlighted the complexities involved in selling produce loose. The doubling of in-store waste was, at the time, considered evidence enough not to continue, illustrating the function of packaging in preventing food waste at the store level. However, a key finding of this review shows that in the period from 2018 onwards, following Blue Planet II and the launch of the UKPP, there is now an apparent drive to overcome this. Similar levels of wastage to the Asda trial were initially experienced by Morrisons and Waitrose in 2018 and 2019 (John Lewis Partnership, 2021; White and Stanmore, 2018) yet on these occasions, there was a will to find solutions to bring the waste figures down. M&S did not make waste figures public, though they stated that their Tolworth trial was successful and rolled out more loose lines across their stores (M&S, 2019). Iceland expressed a wish to try again following their abandoned trial of 2019, and Asda themselves announced another attempt in 2020 (Asda, 2020).

There is no information available however, on additional costs to the businesses. It is possible that the process improvements Morrisons implemented require ongoing additional staff time and resources. Likewise, additional costs to employ the trained greengrocers that M&S deployed for the Tolworth trial. There is no mention if there was any additional secondary packaging required to protect the produce through the supply chain, even though this is an important function of packaging in this context (Verghese et al., 2015).

Consumer acceptance is an essential factor in moving to loose fresh produce. Asking time-poor consumers to have to start selecting their own fruit and vegetables may prove to be a challenge. The loss of the convenience of packaged goods was reported as a factor in the failure of the 2007 Asda and 2018 Iceland trials, although a survey performed as part of the Morrisons trial is more positive, stating that just 25% of customers preferred packaged produce (WRAP, 2021)). This difference could be attributed to a difference in demographics between the stores' customers or possibly an example of the Intention-Behaviour Gap (Sheeran and Webb, 2016) The loss of packaging also means the loss of a communication channel with the consumer (Lindh et al., 2016b) and a perceived reduction in the hygiene of the product (Wells, 2008; WRAP, 2021). This highlights that cultural and social factors

could have a strong role in plastic packaging reduction. It is interesting that less than half (3 of the 11) of the retailers in this study acknowledge consumer acceptance as an issue and this warrants further investigation.

5.5.2 Policy (in)coherence and implications

5.5.2.1 Plastics

The results in Tables 5.2 and 5.5 show that 10 of the 11 retailers examined in this study are signatories of the UK Plastics Pact, and most of their individual targets are aligned with the pact, ensuring that at a top-line level their plastics policies are harmonised. The outlier, Iceland, is aiming to eliminate all plastic by substitution with other materials. Despite Iceland's non-participation in the UKPP, their plastics policy scores in Table 5.5 are in line with other retailers - this is because although their plastics reduction target is bigger, they still acknowledge that some plastic will be required in the interim and their policy for the remaining targets is in line with the UKPP targets. Note that for the retailers the targets are for their own-brand packaging only, although some put in aspirations for their suppliers' packaging. Whilst it is difficult to view guidelines for suppliers to the retailers on public websites, a high proportion of those suppliers will also have signed up to the pact.

Elimination is not unique to Iceland, all bar one of the other retailers examined also have a target for plastics elimination in addition to the UK Plastics Pact targets. These additional targets are for between 15% and 50% reductions; 6 are plastics only, 4 are for all packaging materials, and one has no specific targets (see Tables 5.2 and 5.5). Alone, these additional reduction/elimination policies would also have the potential to undermine the food waste goal of the C2030. This is because these reduction targets are very ambitious (Greenpeace, 2020) so retailers risk either not achieving their own packaging reduction goals or by substituting other materials, that are not as good at protecting and preserving the packaging's contents, increasing the amount of food waste. This is addressed by 10 of the 11 retailers acknowledging the role plastic packaging plays in preserving food (Table 5.2) and in UKPP guidance (WRAP, 2022c)). Additionally, materials substitution may result in unintended consequences, such as an increase in the carbon footprint of the packaging component itself, although this is outside the scope of this study.

One aspect of the UKPP where the retailers are almost all aligned with each other, but not the UKPP agreement itself is the introduction of compostables - only two

of the eleven, Iceland and the Co-op, have a strong positive stance towards these materials. The others have no targets for the introduction of compostables. Conversely, Tesco has added compostables to their red list of the materials that suppliers should not use (see Table 5.2 and Figure 5.2). Potential reasons for this are discussed in 5.5.4.4. Although this general negative stance does not affect whether Target 2 of the pact is met, for policy alignment and (in)coherence, this presents either an opportunity to modify the rules of the pact to align with the retailers, or for the targets in the commitment to be strengthened, e.g. by separating out compostability and reuse targets. In either case, this shows an interesting issue of policy harmonisation.

Wider aspects of the retailers' individual policies are fragmented. For example, Tesco targets all materials, not just plastic for recycling, and Morrisons made a commitment to recycle the amount of plastic they put onto the market in their own facility. The reason for these fragmented objectives may be as a response to the gap between legislation and previous commitments, and also the much higher expectations of consumers (e.g. because of campaigning from the UK's Women's' Institute in the mid-2000s (Poulter, 2006). The fragmented policy goals could also be a result of setting the goals most achievable for each retailer's operations or even to gain a competitive advantage to be 'the first to…' as is seen in some of their policies e.g. (47) and (8) in the supplementary information (Greenwood, 2022). This demonstrates innovation being chosen over what works in other contexts and these different objectives and policies at the supermarket level may hinder the collective ambition. This is not reflected in the scores in Table 5.5 as these differences could slow down progress, but not inhibit it. It might be argued that moving projects that address plastic waste to a pre-competitive collaboration may yield more effective results in the long term.

5.5.2.2 Food waste

All of the retailers investigated are signed up to Courtauld 2030 targets: (1) the reduction of food waste by 50%, (2) GHG emissions associated with food and drink by 50% and (3) 50% of fresh food sourced from areas with sustainable water management (WRAP, 2022a). The food waste part of the commitment is for all stages where food waste can occur from 'farm to fork'. The retailers' policies on food waste are simpler than for plastics and more aligned with each other. The

reason for this could be because of a longer presence of VAs in the food waste policy space, the rapid rise of concern of citizens around plastic waste from 2017, resulting in the knee-jerk creation of policies, and that the implementation of solutions is more complex for plastics than for food waste.

5.5.2.3 Packaging and food waste

At the top level, the food waste (Courtauld 2030) and plastic (UKPP) voluntary agreements are incoherent - plastic packaging can extend shelf-life and hence reduce food waste in the supply chain. However, WRAP use the caveat 'where shelf-life is unaffected' when recommending the removal of consumer packaging from fresh produce in the UKPP (WRAP, 2022d) and it is implied in other areas (WRAP, 2022c) which can be seen as an attempt to harmonise the UKPP and Courtauld 2030. In line with this most retailers state the importance of packaging to prevent food waste or keep food fresh. Less than half of the retailers, however, acknowledge that packaging provides convenience to, and must be acceptable to the consumer in the form it takes, including its removal (see Table 5.2). **It is proposed that this is to avoid appearing to direct the blame of the plastics problem onto the consumers themselves and instead focus on systems level solutions.**

To summarise, the voluntary agreements the UKPP and the food waste part of C2030 support the UK national ambitions set out in the 25-year environment plan. At the top-level the UKPP and the food waste component of C2030 are incoherent, but caveats, explicit and implied, in the UKPP help mitigate this and help to harmonise the policies. Supermarket level policies on plastic packaging and food waste are generally aligned with each other and with the national level ambition. The fact that there are caveats in the UKPP, but not C2030, indicate the dominance of food waste policy over plastics, and this is entirely appropriate given their relative impacts on greenhouse gas emissions.

Although most retailers are not actively working on compostables, and the implementation of reusables is limited, this does not affect coherence with the UKPP, as there are not specific targets for these solutions, only collectively with the dominant solution, recyclability. However, despite the general alignment, there is also a lack of coherence and harmonisation between supermarket policies at a more granular level. Fragmented supermarket objectives and policies may arise

from the need for "competitive edge": enacting policies that are easy to implement structurally, and appeal to the specific retailer's clientele. UK retailers are sensitive about publicly sharing information on their food waste reduction measures (Feedback, 2018) and single-use plastic packaging waste reduction initiatives and trials - as evidenced by the results in Tables 5.1 and A8. This hints at the lack of a transparent and coherent (consistent) approach to sharing evidence on solutions to single-use plastic packaging waste, and the need for understanding of single-use plastic packaging waste in a wider food systems context (as identified by Zhang et al. (2022)).

5.5.3 Store audit

The simple store audit gave an indication of the amount of loose produce on sale, about 10% of SKUs, and that the packaging specifications and formats were generally in compliance with the UKPP (e.g. no black plastic, no EPS trays).

5.5.3.1 Giveaway bags for loose produce

Examination of retailers' policies (see detailed spreadsheet Table A8 in the Appendix) and a recent informal observation (conducted in May 2024) indicates that retailers are eliminating the lightweight HDPE bags given away to customers for the collation of loose produce. Instead, they are offering reusable bags for sale or using alternative materials to plastic. Whilst eliminating the giveaway bags reduces a retailer's plastics footprint, there is a risk that if they are substituted by other materials, there will be an increase in GHG for packaging materials, or if only reusable bags are available then this will nudge customers to buying pre-packed over loose. This warrants further investigation, i.e. does the elimination of giveaway bags disincentivise customers from buying loose produce, and what are the overall impacts on GHG emissions if they are buying only the quantity of food they need?

5.5.4 Alternatives to selling fresh produce loose

Selling loose is not appropriate for all produce items, especially those with high respiration rates such as spinach or salad leaves. In these cases, 1) lightweighting of packaging components, and 2) for packaging to be 100% reusable, recyclable or compostable (UKPP Target 2) are more appropriate than the elimination of plastic

packaging. Additionally, the optimisation of pack sizes and the introduction of added packaging features have the potential to minimise both food waste and packaging waste. Each of these is now discussed in turn.

5.5.4.1 Lightweighting (reduction)

Reduction, including removal of unnecessary components, and light-weighting has been a focus since the first of the Courtauld commitments (WRAP, 2024a). In addition to the plastics pact targets, most retailers have also set out their intention to reduce the total amount of plastic and/or packaging they use. Five of the ten retailers investigated in this study have a target to reduce their plastic packaging (or all packaging) by 50% by 2025 (see Table 5.2, and Table A10 in the Appendix). This target does not feature in the UKPP or the 25-year environment plan. However, it does appear in a Greenpeace report (Greenpeace, 2020) which called for this to be a target in the Environment Bill, and in 2022 there was an attempt to get this target introduced into legislation through a private members' bill (UK Parliament, 2022). It is possible that the frequent occurrence of the same target in supermarket documents is because of this wider lobbying context.

5.5.4.2 Reuse

Reuse is explored in detail in Chapters 1, 2 and 3. In the fresh produce sector reusable business-to-business packaging is already widely used, evidenced in the store audit with two of the three retailers using returnable crates. The sale of loose produce, encouraging customers to use their own reusable bags, can be considered as a form of refill. Providing the more complex return systems, where a reusable pack is returned by the consumer, washed and used again is an ambitious task, and there is still much research to be done in this area (Accorsi et al., 2022). A good example is strawberries. Although container design is relatively simple in this context (RECOUP, 2024b) early season fruit is grown in the south of England, late season in Scotland. Outside of the UK season they are supplied from Spain. These could all be from different growers, so the logistics involved in making sure reusable containers are where they are needed, and who owns them is complicated. Given the complexity of the produce supply chain, it is more practical for retailers to investigate other product categories first.

5.5.4.3 Recyclable

Recyclability is a key area in all of the retailers' policies. There has been a distinct effort to eliminate the less recyclable plastics, rigid PVC and Polystyrene, as per UKPP target 1, and also black plastic (covered by Target 2). The results of the store audit support this - virtually no black plastic or EPS trays were observed.

This reduced selection of materials for rigids (mainly PET and PP) means that in theory, most rigid plastics used in the produce sector are now recyclable, although only about a third of pots tubs and trays are currently collected for recycling (see 1.5.1). Flexible plastic packaging poses an even bigger challenge with collection rates of just 7% (1.4.1). A concerted attempt is being made to make progress in this area, in 2021 in-store collection points for 'soft' plastics in store became widespread (The Co-operative, 2021; White, 2021) and kerbside collection is due to be introduced in 2027 (DEFRA, 2022). However, collection is only part of the solution, and improvements in sorting and processing need to be made alongside the development of end markets for the recycled material. This is being addressed through initiatives such as CEFLEX (2022). If these succeed, then there is no reason why produce packaging cannot eventually be 100% recyclable. However, achieving this within the timeframe of the UK Plastics Pact seems unlikely

5.5.4.4 Compostable

Compostable plastics are a subset of biodegradable plastics which break down safely into water, biomass and gases under specific conditions (Purkiss et al., 2022). To qualify as 'compostable' materials have to be certified as either industrially or home compostable (BSI, 2000b; TUV Austria, 2019). Industrially compostable plastics will not necessarily home-compost as the processing temperatures are higher. As with reuse, compostable plastics are currently niche; just 8,000 tonnes were used for packaging in the UK in 2018 (Ricardo Energy & Environment, 2019) and in 5.5.2.1 it has been shown that retailers have no targets of their own for the introduction of compostable materials. There are a number of potential reasons for this, including the lack of national targets and the lack of collection sorting and processing infrastructure for industrial processing (UCL Plastic Waste Innovation Hub, 2020) and the fact that only a minority of UK citizens home-compost (UCL Plastic Waste Innovation Hub, 2022). There is also the added complication that compostable films could contaminate the nascent flexible plastics recycling stream,

e.g. the Co-operative do not accept compostables in their 'soft plastics' recycling scheme (The Co-operative, 2023). There is an obvious advantage to the introduction of compostable labels for loose produce with a peel that will end up in food composting, but without an established waste stream to deal with the waste packaging, retailers appear reluctant to investigate other packaging components. Once food waste collection has been made available to all households in the UK, originally due in 2023 (Defra Press Office, 2020), this may be reviewed. The inconsistency in food waste collection highlights that the collection and recycling of plastics is not the only sector of the UK with less than perfect harmonisation between local government authorities.

5.5.4.5 Recycled content

To be as circular as possible, plastic packaging should also have some recycled content (an average of 30% target for the UKPP). PET and HDPE are available in food contact grades, but food-grade PP is only available in trial quantities (Packaging Europe, 2024), and LDPE only from chemical recycling, which is more energy-intensive than mechanical recycling (Hyslop, 2021). There is also progress to be made before pots, tubs and trays can be closed-loop recycled. PET is the most widely recycled plastic in the UK, thanks to the relatively mature bottle recycling process, but PET trays are not suitable for the bottle recycling process (RECOUP, 2021).

The Plastics Packaging Tax introduced on 1st April 2022 may help to drive this: Plastic packaging that does not contain a minimum of 30% recycled content is now subject to a tax with an initial charge of £200 per tonne (HM Revenue and Customs, 2022). It should be noted, however, that the demand for recycled plastic is already outpacing supply (O'Connell and Kumar, 2021). This means that an increase in recycling infrastructure in the UK will be required for UKPP signatories to fulfil their commitments (Moore, 2020).

5.5.4.6 Optimisation of pack sizes and added packaging functionality

Where packaging has been shown to be necessary, for shelf life or consumer acceptability, there is an opportunity to optimise pack sizes, or consider other packaging features, e.g. barrier coatings, resealability or improved product use instructions in order to prevent food waste in the home. For example Williams et al

(2020) identified packaging size and detailed information of food safety and storage as important factors in reducing food wastage. Making pack sizes smaller or, for example, adding a reseal-strip have the potential to reduce this food waste but may increase the amount of packaging material used. However, with some exceptions, the embedded carbon in food packaging is typically a fraction of that of the product is protecting (Heller et al., 2019; INCPEN, 2009). This presents the opportunity to study the trade-off between food and packaging waste at a household level. The WRAP report, which provided evidence for the recommendation to sell uncut fresh produce loose, used Discrete Event Simulation (DES) to model household consumption through the Household Simulation Model (HHSM) (Kandemir et al., 2020). The HHSM has now been adapted to incorporate packaging variables in order to assess food waste vs packaging waste for different scenarios.

5.5.5 The future

Following the trials on Apples, Bananas, Broccoli, Cucumbers and Potatoes by WRAP (Parry and White, 2022), the current recommendations are that uncut fresh produce is sold loose "as long as shelf-life is unaffected" (as well as the removal of best-before dates and for most items to be stored at under 5 °C). This means that plastic packaging on uncut fresh produce will now be considered for elimination in Target 1 of the Plastics Pact, and signatories will be asked to consider its removal. The relevant members have now been set targets to investigate a minimum number of uncut produce lines within a set timeframe before the end of 2025 (Conroy, 2023), the delivery date for the targets of the UKPP.

The studies included in Parry and White (2022) only measure the shelf-life of loose vs packed produce in simulated home conditions. The supply chain up to the point of sale has not been considered, nor has the shelf-life, and hence the amount of food waste of the produce while on display, or conversely if extra secondary packaging may be required to maintain existing food waste levels (Verghese et al., 2013). A key recommendation from this chapter is for **future research to expand to cover the entire fresh produce supply chain considering both food and packaging waste levels, examining key environmental impacts including greenhouse gas emissions, water usage and land usage.**

This future work would support retailers and their suppliers in investigating alternative systems and technologies to reduce single-use packaging whilst

avoiding increasing other environmental impacts associated with food waste throughout the entire supply chain.

In addition to considering the total environmental impact, the introduction of these alternative technologies must also carefully consider the multiple trade-offs between cost, culture, consumer acceptance and convenience.

5.5.6 Limitations - availability and accuracy of information

The figures from the British Growers Association and Greenpeace/EIA suggest the amount of fresh produce sold loose in the UK is somewhere between 15% and 18%. It is most likely that this figure is by the number of lines (stock keeping units) on offer rather than sales volumes, so gives a limited picture. It would be useful for there to be publicly available information on the relative sales volumes.

Similarly, the amount of plastic packaging used in the fresh produce (or any) category is difficult to estimate accurately: WRAP report that of the 141 kT of pots, tubs and trays placed on the market in 2017 28% was used in fresh produce (Thomson et al., 2018) . This works out as 39.5 kT, not including flexibles, yet the total amount of packaging used in fresh produce is estimated to be just 38 kT. Consumer film placed on the market in 2017 in total was 375 kT. Making the very broad assumption that the same proportion of films is used in the produce category as in pots, tubs and trays, this would make the amount used 105 kT, which is clearly incorrect. This illustrates the need for more accurate data on the weight of packaging used.

As there is little academic literature on the subject, information on trials has been extracted from news and trade publications and retailer websites. This information is limited in nature, it is also likely that additional trials have been performed but not reported on, especially if unsuccessful.

The store audit was intended only as a quick sense-check so the results are limited. The three stores covered just 25% of the market in July 2021. Seasonal availability and origin impact the supply of fresh produce. A future study should include more stores in an audit and span a year for better representation.

5.6 Conclusions and recommendations

Selling fruit and vegetables loose will not solve the problem of plastic packaging waste from fresh produce alone, but it will be part of an integrated solution alongside other strategies including the increased recyclability of the packaging components. Retailers have harmonised their policies largely with Plastics Pact and Courtauld 2030 best practice, but there are still differences in adoption between retailers. Likewise, there remains incoherence and tension between plastic packaging and food waste policies for both the sector, and individual retailers. There is still progress to be made in recycling - collection rates still need to improve for pots, tubs and trays and the material is cascade-recycled rather than closed-loop recycled. Flexible packaging (i.e. bags and films) poses the biggest challenge in terms of recycling although improvements are being made to the collection, sorting and processing of packaging films. As kerbside collection for flexibles is not due for introduction in the UK until 2027, it will not be before then until the problem of plastic waste from the fresh produce category, at least from the perspective of the consumer, will be solved.

Key findings and future considerations are:

1) Grey literature has shown there is a renewed interest in attempts to remove the consumer packaging from fresh produce and now a will to mitigate the potential creation of food waste, rather than abandon trials because of it. Given that plastic for uncut produce has now been added to the UK Plastics Pact Target 1 for the reduction of unnecessary items, we may expect to see the revived interest in selling produce loose continuing with further trials.

2) This review shows that future trials must carefully monitor any impact on food waste through the supply chain, not just households, any additional secondary packaging required and consumer acceptance. Any future policy changes must also be carefully monitored for wider impacts on food waste. Wider social engagement on both food and packaging waste could be key to achieving consumer acceptance of loose produce over the convenience and perceived hygiene benefits of packaged produce.

3) There needs to be more accurate data available on both the amount of plastic used within the fresh produce sector and the sales volumes of fresh produce sold loose versus packed. There is minimal transparent reporting of this in publicly available data sources from retailers. Better data will help with determining the progress of this part of the pact (Target 1). The evidence in section 5.4.1 shows retailers are sensitive about sharing detailed data from trials on packaging and food waste, greater transparency will allow faster progress in reaching collective goals

4) The global tension between food waste policy and materials resource translates to UK retailers' operational policies on food waste and plastic waste. There is an attempt to mitigate this via the UKPP e.g. by using the phrase 'where shelf-life is unaffected' in guidelines for the removal of packaging from fresh produce. Conversely there are no such caveats in food waste policy, indicating its dominance over plastic waste policy.

5) Retailers' plastics policies are largely aligned with the goals of the UKPP. However there are notable exceptions (1) Compostable plastics do not feature significantly in retailers' policies and (2) ambitious additional targets at retailer level for the reduction of plastic packaging have the potential to undermine the food waste goal of C2030 by encouraging substitution by other materials which may not be as good at preserving the contents. For (1) This provides the opportunity for policymakers to make changes to increase alignment - e.g. either strengthen the targets for compostables or remove them. Progress on the ambitious targets in (2) is already restricted by materials substitution guidelines.

6 Summary and Conclusions

This chapter summarises the findings from each of the research chapters, brings them together in the discussion section and makes recommendations for future work. The research questions listed in the introduction are discussed in turn.

6.1 Summary of findings from chapters

6.1.1 Chapter 2 - Initial behaviour and environmental assessments

6.1.1.1 What factors influence what people are willing to reuse?

The survey in Chapter 2 asked people what they would be willing to do, given the opportunity, with the packaging of a selection from 90 different grocery items in a broad range of packaging formats covering food, personal care and household care. Recycling and disposal dominated, with reuse accounting for 13% of responses. This was split into 6% each for repurpose and refill, and 1% for return.

Property	**Variable**	**% (to 0 dp)**
Material	Glass	37
	Metal	16
	Paper	15
	Rigid Plastic	14
	Flexibles	5
Changes in appearance over time?	Yes	6
	No	25
Durable	Yes	21
	No	5
Easy to clean	Yes	20
	No	4
Format	Jar	36
	Bottle	20
	Carton / tub / box	23
	Other options all < 10%	
Closure type	Lid/cap	22
	Dispenser (e.g. spray, pump)	13
	Other options all < 10%	
Number of portions	Single portion	5
	Multi-portion	15
Can the packaging be resealed?	Yes	18
	No	4

Table 6.1 *Selected consumer preferences for packaging and product properties for reusable packaging from section 2.4.3 in Chapter 2.*

When refill or return options were selected, it was typically for products that were already available in that format, indicating that people need to see a scheme in action before they are willing to use it.

Selected consumer preferences for packaging and product properties are shown in Table 6.1. People were most willing to use reusable containers made from glass, and containers that are durable and easy to clean. In terms of container formats, the results also showed that people prefer jars, bottles and cartons/tubs/boxes for reuse, with a lid/cap or dispenser, that is resealable, and for products that contain multiple portions. People's decisions were not associated with the type of product or the nature of the contents.

6.1.1.2 Is reuse better than single-use, is return better than refill, and does the material used to make the container make a difference in a reuse system for takeaway food?

The second study in Chapter 2 was an LCA on a simple hypothetical food takeaway scenario, where containers of different materials and use systems were compared. Figure 2.7 in Chapter 2 shows that in the modelled scenario, global warming potential and water usage are lower for reuse than for single-use, and are slightly lower for the return version of reuse than refill.

Table 6.2 shows the Global warming potential, water consumption and land use (Chapter 2 only) for one use of the containers studied in Chapters 2 and 3, showing whether the container is single-use, return or refill, the number of assumed total uses and end of life scenario used in the analyses, alongside the weight of the containers and an approximate cost for the container (see 6.2.1 for the discussion around have these influence materials selection for reusable packaging).

Container	Single-use, refill or return	#uses	Global warming gCO_2e	Water consumption H_2O / m^3 x 10^{-3}	Land use m^2a crop eq x 10^{-3}	Weight /g	End of life	Study	£approx
EPS	SU	1	54	20.2	0.3	14	Landfill	1	0.10
PP	SU	1	118	2.3	5.6	34	Landfill	1	0.20
Al / Card lid	SU	1	88	0.4	1.8	12	Recycling (Al) landfill (card)	1	0.10
Bagasse	SU	1	50	1.2	4.7	22	Landfill	1	0.10
PBT refill	refill	50	17	0.4	1.0	41	Landfill	1	6.00
PBT return	return	50	9	0.2	0.5	41	Landfill	1	6.00
Tupperware refill	refill	50	16	0.4	1.0	41	Landfill	1	2.00
Tupperware return	return	50	8	0.2	0.5	41	Landfill	1	2.00
Steel 50 refill	refill	50	80	1.5	4.4	185	Recycling	1	15.00
Steel 50 return	return	50	32	0.3	1.1	185	Recycling	1	15.00
Steel 100 refill	refill	100	27	0.4	1.3	185	Recycling	1	15.00
Steel 100 return	return	100	19	0.2	0.8	185	Recycling	1	15.00
Steel 200 refill	refill	200	20	0.4	1.1	185	Recycling	1	15.00
Steel 200 return	return	200	13	0.2	0.6	185	Recycling	1	15.00
Paper carton, PET liner and window	SU	1	25	0.4	-	16	Incineration	2	0.20
PP incineration	return	70	22	0.4	-	178	Incineration	2	10.00
PP recycling	return	70	16	0.4	-	178	Recycling	2	10.00

Table 6.2 *Global warming potential, water consumption and land use (Chapter 2 only) per use of the containers studied in Chapters 2 and 3, alongside the number of uses used for the study, container weight, end-of-life process and an estimated cost for a single container.*

Table 2.5, reproduced below, presents the global warming potential break-even points for selected comparisons of reusable and single-use containers examined in Chapter 2.

	Number of uses required			
	Luxembourg Box	Return Tupperware	Steel Mess Tin (Refill)	Refill Tupperware
EPS Clamshell	4	3	33	4
PP Microwave Tray	2	2	13	2
Aluminium Tray	3	2	18	2

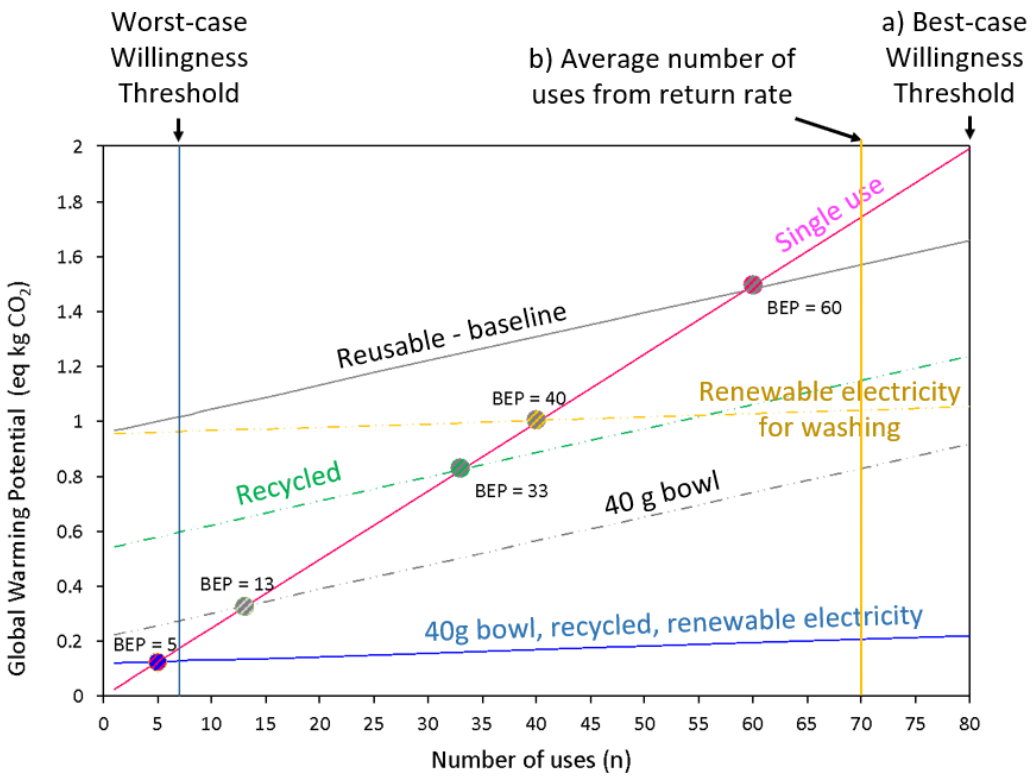
Reproduction of Table 2.5 *Number of uses of reusable containers needed to break even with the global warming potential of single-use containers.*

As can be observed, in this scenario, the BEPs for steel are approximately an order of magnitude greater than those for plastic alternatives.

6.1.2 Chapter 3 - Integrating behavioural, material and environmental science to inform the design and evaluation of a reuse system for takeaway food

A real-world returnable bowl scheme running in university cafés was used as the basis for the studies in this chapter. Environmental break-even points of the returnable containers compared with the single-use cartons. Sensitivity analyses on weight, energy mix for washing and end of life options were combined with willingness thresholds, determined using images of artificially worn samples, and the predicted average number of uses of a container from the return rate in Figure 3.17, reproduced below.

Even though the GWP break-even point for the bowls vs single-use was high at 60, this was less than the predicted lifetime of a bowl in the system and the best-case willingness threshold, so a net reduction in global warming is predicted over time (although careful stock management of containers is necessary). Reducing the container weight, recycling the containers at end of life, using renewable energy for washing optimises the BEP further.



Reproduction of Figure 3.17 *"Best-case scenario" for recycling and energy, with a container weight of 40g, showing the break-even point (BEP) for each scenario, worst- and best-case willingness thresholds and the average number of uses of a container given the return rate. The practical viability of these scenarios would need to be ascertained.*

6.1.3 Chapter 4 - What are the barriers and enablers to the introduction of returnable packaging, using a hypothetical model of yogurt supplied via UK retailers in returnable pots?

A hypothetical system for the provision of yogurt in returnable pots was developed through stakeholder workshops. Anonymous stakeholder interviews were analysed, which revealed that the existing system is responding to the plastics waste problem by steady incremental changes to recycling and recyclability. Brands lack the confidence to move forward from a business perspective, i.e. they don't want to fund schemes without knowing that they will generate a return on investment, and conversely reuse advocates argue that people will engage if given the opportunity to do so. Therefore:

The transition to reuse becoming mainstream is in a deadlock

The introduction of legislation to incentivise businesses to act is seen as a way to break this deadlock, as development is not happening fast enough, and the anti-

plastics sentiment amongst the public is strong, but not enough to force change to reuse.

6.1.4 Chapter 5 - Fresh produce on the loose: examining the coherence between plastic packaging and food waste policy using the case study of fruit and vegetables in the UK

Progress in the removal of plastic packaging from fresh produce was examined as a case study to assess the coherence between plastic packaging and food waste policies.

6.1.4.1 "ls going packaging-free the answer to the UK's plastic waste problem for fresh fruit and vegetables?"

There is renewed momentum toward eliminating consumer packaging for fresh produce, accompanied by an increased focus on mitigating potential food waste rather than abandoning trials due to it. Retailers are often reluctant to share detailed data from packaging and food waste trials. Packaging-free initiatives represent only one component of a broader strategy to address plastic waste from fresh produce, which also includes lightweighting, improving recyclability and recycled content, and optimising pack sizes.

6.1.4.2 "How well aligned are supermarket packaging policies on food waste and packaging waste with the UKPP and the Courtauld 2030 voluntary agreements?"

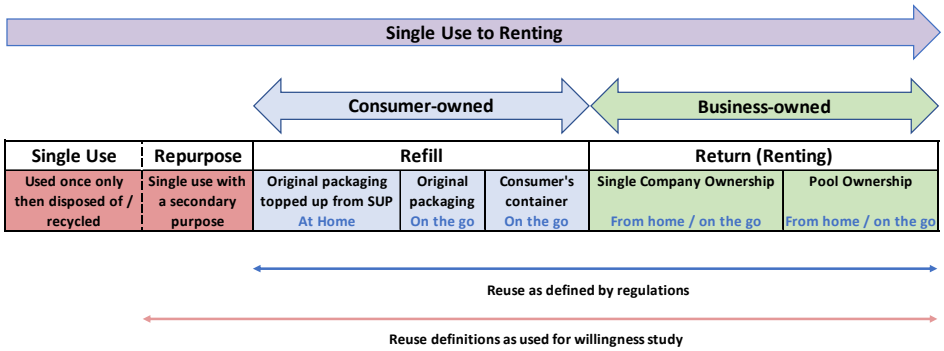
The global tension between food waste prevention and materials resource efficiency is reflected in UK retailers' policies. This is partially mitigated by the UK Plastics Pact caveat *"where shelf life is unaffected",* which aims to balance packaging removal with food preservation. Retailers' plastics policies are largely aligned with the Pact; however, few are investigating compostable alternatives, and many have adopted reduction targets that may be overly ambitious and challenging to achieve.

6.2 Discussion

This section draws from each of the 4 research chapters in order to discuss the design of reusable packaging systems and consumer acceptance of technologies intended to reduce the use of single-use plastic packaging.

6.2.1 Materials Selection for reusable packaging containers

Single-use packaging has been refined over the last few decades with light-weighting, disposability, and only recently, recycling in mind. It therefore does not automatically follow that the same materials are the most suitable for packaging containers that are intended to be used for multiple cycles.



Reproduction of Figure 2.1*: Scale showing Single-use to Reuse ordered in decreasing levels of anticipated packaging waste from left to right showing definitions (including the EMF's taxonomy shown in blue) based on (Greenwood et al., 2020).*

Moving across the scale in Figure 2.1, reproduced above, the main materials used for *single-use* packaging are plastics, paper, metal (steel and aluminium), glass, and composite structures, with plastics being split over LDPE, HDPE, PP, PET (and some PS and PVC) (see Chapter 1).

For *refill*, containers for this subset of reuse are often the original single-use container, which is either topped up from light-weight refill packs for refill-at-home or taken into a store for refill-on-the-go. Alternatively this can be a dedicated refill container, for example, The Body Shop sells bottles for refill in aluminium rather than the standard single-use PET equivalent (The Body Shop, 2025). The customers' own containers may also be used in refill-on-the-go situations, e.g. for dried foods in a zero-waste store, which in theory could be any format or material, as long as the retailer accepts their use. The environmental benefit of refill

containers is therefore not simple to measure. Unless a branded refill container is issued and a means of tracking its number of uses is implemented, it is difficult for a scheme operator to understand the full environmental benefit. Whilst the scheme operator may have made a saving in the amount of single-use packaging used, the customers may not use the containers enough times before growing tired of a scheme, and more waste created. This provides scope for further research. The remainder of this section discusses containers for use within a return system.

In the few *return* consumer packaging systems that exist, have existed or have been trialled, glass, plastic and steel have all been used (Interpack, 2025; Knott, 2024), with glass being the material of choice historically. PP is the dominant material in return schemes for takeaway food and hot drinks. Table 6.3 shows a simple comparison of plastic, stainless steel and glass for return applications, which is discussed below.

The analysis of the questionnaire results in Chapter 2 shows glass as a clear favourite with consumers, with a general acceptance of the other main packaging materials. This particular study covered a broad range of fast-moving consumer goods, and the responses mainly covered the refill and repurpose subsets of reuse, so they do not necessarily apply to return systems. However, the greater acceptance of glass may be due to people's familiarity with its historical use in the 20th century, particularly through doorstep delivery, which was the primary route for selling milk.

At first glance, the BEPs from the LCA study in Chapter 2 comparing containers of different materials favour reusable plastic containers over steel (Table 2.4). However, calculations using the values in Table 6.2 show that the CO_2e for the returnable steel container, at 32 g CO2e per use, is four times that of the return Tupperware, at 8 g CO2e. The steel container has a mass of 184.5g compared with 41g for the Tupperware, 4.5 times greater. This illustrates the significance of the mass of a reusable container in determining break-even points. Material specification also has an effect on the break-even points – the PBT bowl with a PE lid had marginally higher break-even points for the single-use items compared to the Tupperware (PP) container, even though they were the same weight.

In other words, if it is possible to design steel containers that are strong enough to last 100 uses with minimal material usage, steel could be a viable materials choice for reusable containers.

Material	Advantages	Disadvantages
Plastic	Cheap Lightweight, so good for customer convenience and carbon emissions Easy to process	Prone to wear and staining Risk of contamination of product by previous contents/degradation products from plastic as it ages Risk of the generation of microplastics Anti-plastics sentiment of consumers The thermal processing required for recycling causes polymers to degrade Relatively low recycling rates for commodity polymers and limited recycling routes for engineering polymers (e.g. PBT)
Stainless Steel	Durable Good chemical resistance Easily sorted for recycling and high recycling rates Optimised design could create containers comparable to plastic on break even points	Expensive Heavy, proving inconvenient for return and refill on the go and high transport emissions
Glass	A clear favourite with consumers It has high clarity and excellent chemical resistance Recyclable and high recycling rates	Heavy and fragile, making it impractical for on-the-go return and refill, and increased carbon emissions for transport, although this will improve as energy decarbonises

Table 6.3 *Advantages and disadvantages for plastic, stainless steel, and glass as the material for reusable containers.*

The weight sensitivity analysis in Chapter 3 supports the above, with there being a linear relationship between mass and the environmental indicators.

Another significant factor in reducing the BEP between the reusable bowl and the single-use carton in Chapter 3 was recycling as the end-of-life treatment of the bowl

over incineration (correspondingly, if the carton is also recycled, this pushes the BEP back up a little as its impact is also reduced). This shows that **in order to get the maximum benefit from reusable packaging, the containers should be recycled once no longer serviceable,** in line with (WRAP, 2010a). This currently presents an issue for some plastics: a polymer with good scratch, staining, and impact resistance, or a high strength-to-weight ratio compared with other polymers, may not have a viable recycling route, which could have a negative impact on the overall environmental impact. This certainly rules out thermosetting plastics, such as melamine, used since the mid-20th century for picnic wear (and for a brief period homeware), and possibly composite materials, such as the glass fibre-reinforced PBT currently being used for takeaway bowls by ReCircle (2025). This warrants further investigation.

Finally for materials selection, cost is an important factor. Indicative prices per container are shown in Table 6.2 above. PP scratches and stains relatively easily but is light, and as a commodity polymer is cheap. PBT may provide better performance, but as an engineering plastic is more expensive. The steel containers studied in Chapter 2 retail at £15. Even with lightweighting and a bulk discount, it will struggle to match the cost of PP. Rather than looking at optimising steel, which could be prohibitively expensive, an alternative option is to look at developing surface coatings or treatments for PP that will protect it from scratching and staining without affecting its recyclability, and to lightweight it further by using foam-core technology e.g. from Bockatech (2025). Alternatively, different thermoplastics could be investigated, as the nature of PP makes it susceptible to staining if used to heat foods. There are potential issues which are unique to using plastic, and these are discussed below in 6.2.1.1.

Glass was not considered in Chapters 2 and 3. Its weight and brittleness make it impractical for food-on-the-go reuse applications. Glass is used in European countries for reuse at scale for soft drinks and beer, and has been used for this purpose in the UK historically. It has excellent chemical resistance, and the work in Chapter 2 shows that consumers like it. Unpublished work from Grantham Centre colleagues in Plastics: Redefining single-use (the project that funded the work in Chapter 2) compared 1pt (568ml) glass milk bottles with single-use HDPE bottles for doorstep delivery. A 1pt (568ml) standard milk bottle weighs approximately 250g, the 2-litre single-use plastic alternative, 46g. On a delivery

route of 18 miles, the BEP for the bottles on water and energy usage was approximately 15 uses, but there was an increased cost to the customer. A longer delivery route would increase the BEP and is perhaps part of the explanation for the shift to single-use plastic, which allows longer supply chains with economies of scale. In addition to making it inconvenient for consumers to carry around, weight is therefore an issue with glass as a material for any modern return system and poses a materials science challenge to find a lightweight, recyclable solution if glass is to be part of the future of reuse. There appears to be some interest in this route with PepsiCo actively seeking solutions to this (Yet 2, 2025). As more sustainable energy sources are used for transportation in the future (e.g. at the small scale, electric milk delivery vans), this could reduce the environmental impact of using glass for reuse.

In essence, as for single-use packaging, there is no one material that is best for reusable containers; rather, it will depend on the individual application. This is confirmed by LCA reviews by UNEP (2021) and Dolci et al. (2025). The work in Chapters 2 and 3 shows the importance of keeping the container as lightweight as possible, recycling containers once they no longer become serviceable, and the energy and water consumption in the reconditioning phase. The physical durability of the material is important in ensuring containers are used enough times to reach the environmental break-even points vs single-use, and the cost of the containers is an important factor. Consumer acceptance is vital, and this is discussed in 6.2.3.

6.2.1.1 Specific challenges with using plastics for reusable containers

Microplastics

Microplastics are defined as being under 5mm in diameter, and nanoplastics between 1 and 1000 nm (a thousandth of a mm). 2024 marked 20 years of research into microplastic pollution (Thompson et al., 2024). The presence of micro- and nanoplastics in the environment is becoming of increasing concern to the general public. E.g. a recent study detected microplastics being shed from baby bottles made from PP (Hussain et al., 2023). It is therefore likely that at some point (possibly because of an item in the popular media) all plastic packaging, including reusables will be a target for increased NGO campaigning, including from trade bodies who represent or are influenced by single-use packaging manufacturers. In

the study in Chapter 3, microplastics were detected when metal cutlery was used on the bowls. This can be mitigated by recommending the use of reusable plastic cutlery (single-use plastic cutlery was banned in the UK from 1st Oct 2023) or single-use wood or paper cutlery. Smaller micro- and nanoplastic particles like the ones studied in Hussain et al were not found in our study as the minimum sieve mesh was too large. Additionally, they only studied the containers on the first use and it would be interesting to know if the generation of microplastics decreases (or increases) after multiple cycles.

Substance migration to and from plastics

In addition to microplastics, there are a number of other sources of substances that could contaminate food from a pre-used container. 1) chemicals that are additives in the plastic itself, 2) substances absorbed from the previous contents, and 3) substances absorbed from the misuse of the container (e.g. to drain the oil from a motorbike or store brush cleaner). All packaging placed on the market has to comply with limits for the migration of certain substances from the packaging into the product (legislation.gov.uk, 2015). It would be prudent to perform a review of these and if the repeated use of plastics likely to be used for reusable containers could create degradation products that are considered harmful, or if continued washing could cause compounds to migrate from the body of the material to the surface (e.g. mould release agents). Limonene, used as a flavouring in soft drinks and as an ingredient in cleaning products, is an example of a compound in products that can be absorbed by plastic. Even when a container has been washed, a strong odour can remain; it is a requirement for recycled PET to have a minimal limonene content (as well as other substances) (Lambré et al., 2024). The willingness method described in this thesis could be adapted to use physical samples of varying degrees of odour contamination to evaluate what level would be acceptable. Allergens are another area of concern; even a tiny amount of an allergen, e.g. peanut protein, can cause anaphylactic shock in the severely affected. Reusable packaging scheme operators need to be sure that allergens are not transferred to users via an improperly cleaned container. As containers become more scratched with age, there is an increased possibility that they could harbour microbiological pathogens. Again, this needs to be evaluated. An important part of the commercialisation of returnable packaging schemes will be ensuring due diligence is performed to ensure the

containers are safe for consumers. In the first instance, assay testing can be utilised in further lab-based research to check for the presence of allergens and microbes.

6.2.2 Container and system design for reuse

6.2.2.1 Container design

In comparison to single-use packaging, there are a number of additional functions that reusable packaging containers have to perform. As already discussed, they have to be physically robust enough to withstand multiple trips around the system, including transport and washing, and be resistant to expected levels of wear and staining. The work in Chapter 3 highlighted that the washing phase is very important, and it makes sense to optimise the fit of the containers in the washing facilities, as well as for bulk transport, as is already done for single-use. The smaller of the two yogurt manufacturers highlighted requirements for the containers in order for them to run through the factory – their single-use multi-serving pots arrive 'nested' to save space, and the ability of any reusable container to do this, and to 'denest' i.e. be separated from the other containers easily is important for operating efficiencies.

Being easy to clean was highlighted as a desirable property in Chapter 2 and was echoed by the same interviewee, explaining that there would have to be very strict rules on hygiene in order to ensure the re-used containers are *'food grade clean'*.

Finally, the packaging container design must be acceptable to consumers. This is discussed in more detail in 6.2.3

6.2.2.2 System design

The calculated environmental metrics for one use of a container changes dramatically depending on how many total uses are completed. For example, for the refill (customer-owned) steel containers, the global warming potential is 80, 27 and 20 g/CO2e for 50, 100 and 200 total uses respectively. This illustrates not only the importance of making sure that reusable containers are used enough times to perform better than single-use, but also the usefulness of employing environmental break-even points (see 2.3.1.4), as these are **independent of the total number of uses** so comparisons are easier to make.

Figure 3.17 in Chapter 3 is useful in visualising how different parameters affect the BEP (building on similar diagrams described by Cottafava et al. (2021)). The

environmental indicator vs the number of uses fits a linear equation. Where the (extrapolated) line intercepts the y-axis shows the contribution of the burden of manufacture (and disposal) of the container, and the gradient shows the impact of preparing for reuse: the steeper the line, the higher the impact per cycle, and the lower the BEP with the single-use reference. The best- and worst-case willingness thresholds and the average number of uses calculated from the return rate are added as vertical lines and indicate boundaries that the BEP cannot exceed for a system to stay in credit in terms of the environmental indicator.

The scheme in the university cafes was for in-person collection only, so there was no contribution to the collection and washing phase from transport. It can therefore be expected that the gradient will increase and the BEP will go up once delivery is introduced or larger schemes (such as yogurt in returnable pots) are investigated.

Although it is only touched on in this work, the number of available containers in a system, the pool, is also important as hinted by the number of bowls in stock in the cafés scheme vs the number of rentals (3.6.3.1, Golding, 1999; WRAP, 2010a).

6.2.2.3 End of life - landfill versus incineration

The end of life of the containers must also be considered when considering the whole system. Landfill was used as the end-of-life process for all of the plastic containers in Chapter 2. Incineration was used as the default process for the takeaway bowls studied in Chapter 3, as this is how residual waste is managed in Sheffield, and plastic pots, tubs and trays are not currently collected for recycling in the city. Globally in 2019 49% of plastic waste was sent to landfill, 19% was incinerated, 22% was mismanaged and 9% recycled (OECD, 2023).

The sensitivity analysis in Chapter 3 illustrated the importance of the end-of-use process once the container is no longer usable. Closed-loop recycling, when possible, offers the best advantage. Incineration, however, results in the release of carbon dioxide and thus has an impact on the break-even points, e.g. for the 177g bowl, the break-even point was reduced to 33 from 60 as a result of the content being closed-loop recycled, using the avoided burden approach. This is almost possible currently – food-grade recycled PP will be available in larger quantities shortly (Berry, 2023). One thing that was not considered in this work was the direct comparison of landfill and incineration. Because the landfilling of plastic means the carbon is stored and not released back into the atmosphere as CO_2, this is almost

certainly the most beneficial of the two in terms of GWP, aligning with the thinking that incineration should be at the bottom of the waste hierarchy for plastics (see 1.5.1).

6.2.3 Consumers' engagement with new (old) retail methods

Less than 2% of fast-moving consumer goods are sold in reusable packaging (George, 2020). The takeaway trial run in the university's cafés, detailed in Chapter 3, had less than 2% of the university population use the scheme at least once. In the period examined, there were 6221 cup rentals and just 737 bowl rentals, even though the (initial) marketing was for the bowls only. This could be explained by the café customers already being familiar with the concept of customer-owned refillable cups; it is a relatively small step for a customer from using their own cup to borrowing one, but it is a much bigger step to borrow a container for food. Two interventions had an effect on the number of rentals: 1) early in the scheme there was a staff incentive to get customers to sign-up, rentals plateaued once all of the regular customers had been asked; and 2) The heavily discounted hot drinks promotion during the students' intro week in 2023 resulted in a peak in rentals for cups for those 5 days. Notably there was also a 4-fold increase in cup rentals after the promotion which stayed stable for the rest of the academic year. This demonstrated that once people had downloaded the app and used the scheme, they were more likely to continue using it. The Many Happy Returns project team wanted to ban the use of single-use cups in university cafés, which the head of retail declined to implement for fear of loss of sales (citing that when the sale of still mineral water in single-use bottles was banned in the student union, sales in the university-run cafés went up by 20%).

The residual increase in cup rentals after the promotion aligns with the suggestion in the conclusion of Chapter 2 that people need to be shown exactly how a new scheme works, and ideally have experience using it before they will be willing to engage with it.

This is also reflected in the findings of the dairy supply chain interviews in Chapter 4. The storyline **'Customers are not ready for reuse'** emerged: brands believe that consumers are not ready for reuse, and this is evidenced by reports of low uptake in trials and uptake not expanding beyond the early adopters. The reuse activists believe that if schemes are made more widely available and promoted,

consumers will engage. The uplift in cup rentals after the promotion had ended gives (a small degree of) legitimacy to this belief. There are broader issues to consider, in that **reuse needs to be made easy and cheap for customers**, these adding to the counter-storyline that instead of consumers not being ready for reuse, in fact **'reuse is not ready for the consumers'**.

Reluctance to accept change is also reflected in the 'Brand is Packaging' storyline in the dairy study. Brands see their packaging as *'the number one way in which they communicate their brand, their brand value … to the consumer'*. The reticence of brands to change even the smallest details of packaging design (both constructional and graphic) can be seen in the displays at the Museum of Brands (2025) where the packaging of selected brands is displayed in chronological order over a decadal timeframe (see also Opie, 2013). Packaging changes are incremental to maintain visual identity, an extreme example of this phenomenon is the Lyle's Golden Syrup tin, which has barely changed in appearance for 150 years. It may be that the place to start with returnable packaging is in a supermarket own-label context where branding is executed differently - typically products belong to a low, standard or premium tier ('good, better, best'), with the associated graphic design used on generic packaging. Products are almost always manufactured by a third party, which is likely to supply more than one retailer, providing an inroad to the standardised reusable packaging route.

Compared to reuse, the sale of loose produce is doing very well, the study in Chapter 5 identified loose produce sales as being 15-18 %. It is not clear from this data how many people buy fresh produce loose and what proportion this is in comparison to what they purchase pre-packed.

The limited information on the response of customers to retailers' trials to increase this was mixed: The loss of the convenience of packaged goods was reported as a factor in the failure of the 2007 Asda and 2018 Iceland trials. Conversely, a survey performed as part of the Morrisons trial was more positive, stating that just 25% of customers preferred packaged produce (WRAP, 2021). Perceived hygiene and a loss of packaging as a communication channel have also been identified as issues.

Whilst there are very vocal opponents to pre-packed produce, and there have been for some time (e.g. the Women's Institute in 2007, and backlash to Asda's 2017 pre-packed only trial (Paterson, 2017; Poulter, 2006)), it is possible that the majority of people are not bothered either way e.g. sales figures from the Co-op's

single product trial on cucumbers in 2018 indicated that customers had no preference as to whether the fruits were wrapped (Table 5.1). Care therefore needs to be taken in the event of the called-for ban on the sale of uncut loose produce as this could affect sales to, and the diets of, the less motivated shoppers (and also the profits of the retailers). This is a good example of 'consumer acceptance' and another situation where *'you have to bring the customer on a journey with you' is* applicable.

As introduced in Chapter 1, consumer acceptance appears in the Packaging Essential Requirements regs (2015) in the following statement:

> *"Packaging must be so manufactured that the packaging volume and weight is limited to the minimum adequate amount to maintain the necessary level of safety, hygiene and acceptance for the packed product and for the consumer." (legislation.gov.uk, 2015)*

When looking at a packaging container purely from a resource point of view, this part of the legislation is the 'get out of jail free card' for the brand owner on rare occasions when anyone would want to take them to court for over-packaging under the regulations. Take, for example, artisanal gin - a 500ml glass bottle can weigh 700g compared with 465g for a standard 750 ml bottle. There is an association between quality and weight (Demorest, 2023) so there will be an expectation from the consumer that the bottle will be heavier, and the company may risk sales by using a lightweight generic bottle. Similar 'over-packaging' can be seen with premium potato crisps, with laminate film much thicker than it really needs to be for protection and preservation purposes.

It is interesting that consumer acceptance is not acknowledged in most of the retailers' plastics and packaging policies (Chapter 5). This could be interpreted as a deliberate action to avoid transferring the blame of the plastics problem onto the consumer, which could be viewed as antagonistic, or even to avoid reminding the customers that the retailers are there to make a profit.

6.2.4 Legislation and policy

The 30p charge in the university cafés (Chapter 3) had little effect on deterring customers from using single-use cups; for the period examined in 2023-2024, 81% of takeaway hot drinks were in single-use cups. The University's head of retail did

not want to implement a ban on single-use cups, fearing loss of trade. Although a national 'Latte Levy' proposed in 2017 wasn't implemented, voluntary town and city-wide schemes to seem to be gaining some traction, e.g. The Killarney Coffee Cup Project (The Irish Times, 2024). In these schemes, if all retailers take part, then none of them are at a commercial disadvantage.

The stakeholders interviewed in Chapter 4, from both the existing regime and niche innovators, agreed that binding reuse targets would drive development in return systems (4.4.8), and there are calls to ban plastic packaging on specific fresh produce items (Conroy et al., 2024). This is supported by past experience; although plastic recycling rates have now stagnated, it was legislation arising from the European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging (European Union, 1994) that has driven recycling rates from almost zero to their current level (Chapters 1 and 5). Three decades later, the new regulation, 2025/40 on packaging and packaging waste (European Union, 2024) has set both targets for reuse and the removal of packaging from loose produce under 1.5 kg by 2030. No longer a member state of the European Union, there is currently no provision for these in the suite of legislation relating to packaging waste being implemented in the UK (described in Chapter 1).

Some individual member states of the European Union already have their own legislation in place. For example, France has reuse targets and has banned packaging on fresh produce with a pack size under 1.5Kg (Chapter 5). A small percentage of the money raised through EPR is used to promote reusable packaging through the AGEC (Anti-waste and Circular Economy) Law (French Government, 2020; Zero Waste Europe, 2021), and some progress in the adoption of reuse is happening there (CIWM, 2025). However, the adoption of increased amounts of loose produce in France has hit a stumbling block. The French high court was successful in overturning the ban on packaging for fresh produce, citing a 'significant procedural flaw' and that it is 'a barrier within the single market since it demands stricter conditions for the sale of fruit and vegetables than those required by EU law and implemented in other EU countries.' (Horsman, 2024). Germany requires companies selling takeaway food to offer a reusable packaging option, but progress is slow (Theobald et al., 2024). These examples can serve as test-and-learn cases for the whole of Europe, enabling policy harmonisation for 2030.

6.3 Recommendations

6.3.1 Materials and container development

Further development could include the design of a lightweight steel container for reuse applications (although this is unlikely to compete with plastic on price), or investigating a materials engineering solution to making glass more lightweight. Aluminium was not considered for reusable containers in this study. It is energy-intensive to make virgin material, but it has a lower density than steel, so it could prove advantageous in the right application, especially when recycled content is included.

Despite the fact that plastic is not as chemically inert as glass or as physically durable as steel, it is therefore still a viable material for reuse containers due to it being lightweight and inexpensive to produce. The following further steps are suggested:

1) Plastic Material – investigation into different plastic grades, e.g. polycarbonate or PBT. Wear over time, performance v. cost, recyclability, and behaviour at temperatures associated with microwave heating and freezer storage.
2) Investigate coatings/treatments for PP that will make it less prone to wear and staining, that do not affect its recyclability (or develop an additive, similar to oleamide slip additives which is added to the bulk plastic when made, and then migrates to the surface after each wash, providing a new nano-scale surface each time).
3) Microplastics – quantification of generation of microplastics during use and washing.
4) Allergen and pathogen testing on worn containers and containers heated with allergen-containing food.
5) Understand the risk of migration of undesirable and potentially harmful substances to and from the containers (including odour-causing substances).
6) Perform willingness threshold work on odour (e.g. limonene).
7) Perform willingness threshold work on external scuffing of containers. How important is this compared to the effects of wear and staining on the inside?

8) Container colour – will making containers darker increase the willingness threshold or put people off?
9) Durability and willingness threshold on lightweight containers, e.g. foamed-core PP cups. Will consumers simply throw away a container if it is lightweight, thinking it is disposable? Investigate interventions that decouple the weight of the packaging from the quality perception of the contents/value of the packaging component.
10) Ethnographic work to understand why consumers are not engaging in the cafés scheme (work in progress by the Sheffield Buddie-Pack team), and then investigate interventions to improve uptake of the scheme - e.g. provide information on cleanliness of the containers (done in, Buddie-Pack, (2025))
11) Ethnographic work to understand how customers use the takeaway cups and bowls. How likely are they to use metal cutlery or reheat food in the bowls in the microwave? Use this information to inform LCA work.
12) Does people's aversion to single-use plastic extend to reusable plastic containers too? Could this negate plastic as a viable material for reusable containers? If so, is there a simple intervention to improve this whilst avoiding greenwashing?

Progress has already been made on 1,2,3,9 and 10 by Sheffield researchers in either the TRACE or Buddie-Pack projects (Buddie-Pack, 2025; UKRI, 2025).

6.3.2 Returnable container and system design

The combined studies in Chapter 3, which provided the data for Figure 3.17, took many hours to complete. For this to become a more accessible tool to assist with designing a reuse system, it could be useful to develop a library of images and/or samples of different materials (steel, glass, different plastics) showing varying degrees of wear which can then be used for the determination of the willingness threshold for various scenarios. With materials science input, images could be manipulated to represent a variety of packaging formats (bottles, tubs, trays etc), and data could be collected from different types of schemes to estimate a likely return rate. Rather than performing a full LCA, these results could be combined with a simpler carbon and water foot-printing tool, e.g. the Excel-based carbon

footprint calculator developed by Utrecht University for the Netherlands (KIDV, 2024) to guide decision making.

6.3.3 Plastic packaging and food waste

The relationship between plastic packaging and food waste is under-investigated, and there are opportunities for further research, especially on consumer acceptance and engagement with reuse and loose produce.

6.3.4 Loose produce

There is an opportunity to look at systems within the supply chain to enable customers to buy fresh produce loose and thus save food waste in the home by buying exactly the amount they need whilst saving packaging waste. These new systems must be designed so that there is no additional food waste created. It is also vital that if it is made a legal requirement to sell certain items loose, as is being called for by WRAP (Conroy et al., 2024), the majority of consumers accept the change, and that diets, and the profits of the growers do not suffer. Greater transparency on trial data would accelerate collective progress toward sustainability targets. Whereas there is little data available from the trials examined in Chapter 5 on consumer behaviour, WRAP has started to collect basic consumer data in this context (WRAP, 2024b). It is also worth examining sales methods e.g. a 'click and collect' fruit and vegetables returnable box could save customers the extra time that will be required to select loose produce. With loose sales, there is also the issue of imperfect items being left behind by choosy customers and going to waste (e.g. single bananas and misshapen fruits). Interventions could be explored to prevent such occurrences.

6.3.5 The takeaway cup and bowl scheme

Despite the low uptake and a higher proportion of customers using their own refillable cups (which is good), the Vytal scheme is now operating in seven university cafes and remains available for further research opportunities, e.g. nudge interventions and ethnographic work. Manchester University has recently introduced the same scheme and is experiencing much higher usage rates; the reason for this should be investigated. Vytal's French operation is also being used as a use case study in the Horizon project Buddie-Pack (Business-driven sustainable

solutions for sustainable plastic packaging reuse schemes in mass market applications), which some members of the MHR team (including SG) are working on.

6.3.6 A return system for yogurt

In addition to the work described in Chapter 4, a start was made to model the system using Discovery-Driven Planning (McGrath and MacMillan, 2014). This is an iterative technique which allows for uncertainties in a potential system. A 'reverse income statement' is compiled listing all stages of the process in development (in this case, the straw model developed in Chapter 4) and associated costs of each stage entered as a range and then used as an input into a Monte Carlo simulation, the outputs of which highlight the areas that either need the most attention in obtaining more accurate input data, or that need examining in more detail to reduce the cost, and a learning plan developed from this. A first pass was completed, highlighting that the **return rate**, **reusable container cost**, the **transport** profile (distance between consumption and production), the **cost of the single-use container** used in the comparison, and the cost of **washing** were the most important values. A follow-on project could complete this work, look at developing prototypes for a container, test consumers' response to using a proposed scheme, and include carbon footprinting.

6.3.7 Legislation and policy

In terms of voluntary agreements, it is recommended that targets for reuse are strengthened, and targets for compostable packaging are either strengthened or eliminated altogether in the follow up to the UK Plastics Pact.

Retailers' plastic packaging reduction policies are fragmented and over-ambitious, probably as a survival reaction to strong public sentiment. Greater public awareness of the pact and its successor, e.g. through marketing campaigns, could be used to demonstrate a united front on the reduction, and increased recyclability, of plastic packaging.

Legally binding targets for reuse and the sale of loose produce, with financial incentivisation, e.g. through EPR, and careful monitoring of the environmental impact should be considered. The UK can learn from the progress of similar targets in Europe, already incorporated in European legislation.

6.4 Conclusion

Packaging is an essential element of the systems that deliver fast-moving consumer goods from the producer to the end users. It protects the products from damage, facilitates handling through the supply chain, and provides a means of communication to the end user through product information and branding. However, the majority of packaging is single-use, destined to be discarded at the end of its short useful life ending up as waste. Whilst recycling rates are fairly high for glass, metal and paper, a considerable percentage of used plastic packaging is poorly managed, and this is a critical issue.

Moving away from this linear economy to a circular economy, where materials are kept in circulation for as long as possible, involves the disruption of highly efficient linear operations, and this is a complex challenge. The work presented in this thesis investigated multiple aspects of this challenge. For reuse, in Chapter 2 an online survey was used to investigate products for which people would be most willing to reuse the packaging, and an LCA on different food takeaway options was conducted. The work in Chapter 3 built on this: behavioural analysis, environmental assessment, materials technology, and, crucially, the integration of these were used to assess the viability of an actual returnable takeaway bowl system. Findings from Chapters 2 and 3 were integrated in a discussion on materials selection and system design. Reuse was examined further in Chapter 4: semi-structured interviews were analysed using a socio-technical framework to identify enablers and barriers to the introduction of a hypothetical returnable packaging scheme for yogurt. The study revealed a number of key themes, the most significant being that the development of reuse systems is currently in a deadlock situation. Finally, in Chapter 5, progress in the removal of single-use packaging from fruit and vegetables was investigated alongside an analysis of the relationship between plastic packaging and food waste policies. The analysis concluded that food waste policies take priority over packaging waste policies, highlighting that future developments to remove single-use consumer packaging must consider environmental impacts along the entire supply chain, and vitally, gain consumer acceptance.

As discussed in Chapter 1, waste legislation for packaging is currently in a period of transition in both the UK and Europe, where once-in-a-generation changes are being implemented. In the UK, retailers, brands and the packaging industry are

beginning to understand the implications of the imminent Extended Producer Responsibility scheme (1.6 and 4.4.8). This is a pivotal moment: EPR could be used to disincentivise single-use and promote alternative technologies, breaking the deadlock in progress, or the extra financial burden could mean that businesses will be compelled to concentrate on core activities to remain operational. It is encouraging that the EU legislation already includes targets for both reuse and the sale of loose fresh produce. Advocates of reuse are hopeful that similar targets will also be accommodated in the UN Plastics treaty, currently under discussion (UNEP, 2022).

A fundamental understanding during the work presented here was the need to ensure that initiatives aimed at addressing the plastics problem do not have an adverse effect on other environmental issues, such as the reduction in greenhouse gas emissions. With changes in policy currently being made and implemented, this is a critical period. Targets for reducing single-use plastic packaging must be met through an evidence-based approach that does not hinder progress on other sustainability goals. A multi-disciplinary approach, as demonstrated in this thesis, will help achieve this balance.

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8 Appendix

Product	Raw materials	Processing	Production Location and Transport to port	Port to Supplier	Supplier to Takeaway	Lifetime uses
EPS Clamshell 14 g	14 g product requires 14.799 g raw material: Expandable polystyrene (EPS), white and grey - Plastics Europe; manufactured by suspension polymerisation process.	Thermoforming of plastic sheets {RoW} | processing | APOS,U	Raw materials and Production - Shanghai, China 48km to Shanghai international shipping container port (7.5-16 tonne EURO5 lorry)	19360 km Shanghai port to Felixstowe (transoceanic container vessel (10 knots)) 400km Felixstowe to Bristol (7.5-16 tonne EURO6 lorry)	280 km to Sheffield (3.5-7.5 tonne EURO6 lorry)	1
PP Microwave container 34.4 g	34.4 g product requires 36.36 g raw material: (Container and lid) Polypropylene, granulate – Ecoinvent	Thermoforming, with calendering {RoW}| production | APOS, U, container and lid	Raw materials and Production - Shanghai, China 48km to Shanghai international shipping container port (7.5-16 tonne EURO5 lorry)	19360 km Shanghai port to Felixstowe (transoceanic container vessel (10 knots)) 400km Felixstowe to Bristol (7.5-16 tonne EURO6 lorry)	280 km to Sheffield (3.5-7.5 tonne EURO6 lorry)	1
Aluminium tray 6.2 g	6.2 g product requires 6.5 g raw material: Aluminium, primary, ingot - Ecoinvent	Sheet rolling, aluminium {GLO} market for | APOS, U. Impact extrusion of aluminium, 1 stroke {GLO}| market for | APOS, U.	Raw material produced in Hebei province, China. Ingots transported 915km to Jiangsu province (7.5-16 tonne EURO5 lorry) for tray manufacture, then 139km to Shanghai international shipping container port (7.5-16 tonne EURO5 lorry.	19360 km Shanghai port to Felixstowe (transoceanic container vessel (10 knots)) 400km Felixstowe to Bristol (7.5-16 tonne EURO6 lorry)	280 km to Sheffield (3.5-7.5 tonne EURO6 lorry)	1

Product	Raw materials	Processing	Production Location and Transport to port	Port to Supplier	Supplier to Takeaway	Lifetime uses
Board lid for Aluminium tray 5.7 g	5.7 g product requires 5.985 g raw material: Liquid packing board container - Ecoinvent	Carton board box production {GLO}| market for | APOS, U	Raw materials and Production - Shanghai, China 48km to Shanghai international shipping container port (7.5-16 tonne EURO5 lorry)	19360 km Shanghai port to Felixstowe (transoceanic container vessel (10 knots)) 400km Felixstowe to Bristol (7.5-16 tonne EURO6 lorry)	280 km to Sheffield (3.5-7.5 tonne EURO6 lorry)	1
Bagasse Clamshell 22 g	22 g product requires 23.1 g raw material: Bagasse, from sugarcane (Brazil) ethanol by-product – Ecoinvent and Fangmongkol (2020)	Thermoforming, with calendering {RER}| production | APOS, U (electricity modified to Electricity, medium voltage {US}| market group for | APOS, U)	Raw material produced in Brazil. Transported 400km to Santos (7.5-16 tonne, EURO5 lorry), shipped 13674km (transoceanic container vessel) to Long Beach, then 604km (7.5-16 tonne, EURO5 lorry) to Fremont, CA, USA for clamshell manufacture, then 604km back to Long Beach (7.5-16 tonne, EURO5 lorry)	14228km Long Beach to Felixstowe, (transoceanic container vessel (10 knots)) 400km Felixstowe to Bristol (7.5-16 tonne EURO6	280 km to Sheffield (3.5-7.5 tonne EURO6 lorry)	1
Luxembourg Box 25.6 g	25.6 g requires 25.75 g raw material: Polybutylene terephthalate (PBT), granulate, bottle grade, Ecoinvent	Injection moulding {RER}| processing | APOS, U	Raw materials and Production - Minden, Germany. 587km to Calais ferry port (7.5-16 EURO6 lorry)	40.7km to Dover (transoceanic container vessel (10 knots)) 324km Dover to Bristol (7.5-16 tonne EURO6	280 km to Sheffield (3.5-7.5 tonne EURO6 lorry)	50

Product	Raw materials	Processing	Production Location and Transport to port	Port to Supplier	Supplier to Takeaway	Lifetime uses
Luxembourg Box Lid 15.7 g	15.7 g requires 16.06 g raw material: Polyethylene terephthalate (PET), granulate, bottle grade, Ecoinvent	Thermoforming, with calendering {RER}| production | APOS, U	Raw materials and Production - Minden, Germany. 587km to Calais ferry port (7.5-16 EURO6 lorry)	40.7km to Dover (transoceanic container vessel (10 knots)) 324km Dover to Bristol (7.5-16 tonne EURO6	280 km to Sheffield (3.5-7.5 tonne EURO6 lorry)	50
Steel Mess Tin 183.15 g	183.15 g Steel, chromium steel 18/8	Impact extrusion of steel, hot, 3 strokes inc. tempering {GLO}| market for | APOS, U	Raw materials and Production - Shanghai, China 48km to Shanghai international shipping container port (7.5-16 tonne EURO5 lorry)	19360 km Shanghai port to Felixstowe (transoceanic container vessel (10 knots)) 400km Felixstowe to Bristol (7.5-16 tonne EURO6 lorry)	280 km to Sheffield (3.5-7.5 tonne EURO6 lorry)	100 or 200 (see results)
Tupperware Box and Lid 40 g	40 g requires 41.3 g raw material: Polypropylene granulate, Ecoinvent	Thermoforming, with calendering {RoW}| production | APOS, U	Raw materials and Production - Shanghai, China 48km to Shanghai international shipping container port (7.5-16 tonne EURO5 lorry)	19360 km Shanghai port to Felixstowe (transoceanic container vessel (10 knots)) 400km Felixstowe to Bristol (7.5-16 tonne EURO6 lorry)	280 km to Sheffield (3.5-7.5 tonne EURO6 lorry)	50

Product	Raw materials	Processing	Production Location and Transport to port	Port to Supplier	Supplier to Takeaway	Lifetime uses
Tupperware Seal 1.3 g	1.3 g Synthetic Rubber, Ecoinvent	Extrusion, co-extrusion {GLO}| market for | APOS, U	Raw materials and Production - Shanghai, China 48km to Shanghai international shipping container port (7.5-16 tonne EURO5 lorry)	19360 km Shanghai port to Felixstowe (transoceanic container vessel (10 knots)) 400km Felixstowe to Bristol (7.5-16 tonne EURO6 lorry)	280 km to Sheffield (3.5-7.5 tonne EURO6 lorry)	50

Table A1 *Life cycle inventory for the packaging options considered in the LCA, including an EPS clamshell, PP container with lid, Al tray with carboard lid and bagasse clamshell for single-use, and PBT bowl with PE lid, PP bowl with lid and steel tin with lid for reuse*

Product	Transport	End-of-life process
EPS Clamshell 16 g (14 g container +2 g contamination)	6km transport distance by municipal waste lorry (0.000096tkm per container). Ecoinvent process: Municipal waste collection service by 21 metric ton lorry {RoW}| market for municipal waste collection service by 21 metric ton lorry | APOS, U	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill | APOS, U
PP Microwave container 36.4 g (34.4 g container + 2 g contamination)	6km transport distance by municipal waste lorry (0.0002184tkm per container). Process as above	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill | APOS, U
Aluminium tray 6.2 g	6km transport distance by municipal waste lorry (0.00192 tkm per container). Process as above.	Aluminium (waste treatment) {GLO}| recycling of aluminium | APOS, U Process modified to yield 0.95 kg avoided product per 1 kg recycled product.
Board lid for Aluminium tray 7.7 g (5.7 g container + 2 g contamination)	6km transport distance by municipal waste lorry (0.00231 tkm per container). Process as above.	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill | APOS, U
Bagasse Clamshell	6km transport distance by municipal waste lorry (0.000144tkm per container). Process as above.	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill | APOS, U

Product	Transport	End-of-life process
24 g (22 g container + 2 g contamination)		
Luxembourg Box and Lid 43.3 g (container 25.6 g + lid 15.7 g + 2 g contamination)	6km transport distance by municipal waste lorry (0.0002598 tkm per container). Process as above.	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill | APOS, U
Steel Mess Tin 183.15 g	6km transport distance by municipal waste lorry (0.0010989 tkm per container). Process as above.	Steel and iron (waste treatment) {GLO}| recycling of steel and iron | APOS, U Process modified to yield 0.67 kg of avoided product per 1 kg recycled product.
Tupperware Box, seal and lid 43.4 g (40 g box and lid + 1.3 g seal + 2 g contamination)	6km transport distance by municipal waste lorry (0.0002598 tkm per container). Process as above.	Municipal solid waste (waste scenario) {RoW}| Treatment of municipal solid waste, landfill | APOS, U

Table A2 *Life cycle inventory, showing component weights, transport conditions and end-of-life treatment*

Properties/ Attribute of Product	Definition of property/ attribute	Coding options	Definitions of coding options	Coder notes
Nature of the Product	What is the purpose of the product?	1 = Food/Drink; 2 = Personal care; 3 = Home care		
State of Matter' of the Contents	What form of matter is the contents of the packaging	1 = Gas; 2 = Viscous liquid; 3 = Non-Viscous liquid; 4 = Powdered solid; 5 = Soft-solid (e.g., can be spread); 6 = Hard solid; 7 = mixed	Viscous liquid = a thick consistency between a solid and liquid; non-viscous = thin, easy flowing liquid.	Combined to 1 = gas (including liquified gas); 2 = liquid; 3 = soild; 4 = mixed
Type of Packaging Material	The **main material** that comprises the packaging	1 = Rigid Plastic; 2 = Film/ flexible Plastic; 3 = Glass; 4 = Paper/ card; 5 = Aluminium/tin; 6 = Foil		
Is the packaging made from multiple materials?	Using the above criteria on different types of materials to code (not including labels)	1 = Yes; 2 = No		
Can the components be seperated for recycling?	Using the above criteria on different types of materials to code whether these main materials (i.e., rigid plastic, flexible plastic) can be seperated	1 = Yes; 2 = No	Only code for those products thaty indciated above were made multiple materials.	
Pack Type	What type of container is used for the packaging?	1 = Aerosol; 2 = Pouch; 3 = Jar; 4 = Bottle; 5 = Can; 6 = Tray; 7 = Tube; 8 = Bag; 9 = Carton/ **Box**; 10 = tub; 11 = Wrap; **12 = Sachet**	added 12 = sachet; Combine carton and box, cobine pouch and sachet	
Dispensing Method	How does the consumer empty the contents of the packaging?	1 = Squeeze; 2 = Spray; 3 = Pump; 4 = Pour; **5** = Unwrap; 6 = remove product with hands **or utensil**	Spreading isnt a dispensing mechanism - remove. Combine remove with hand/ utensil; Isn't unwrapping the same as removing with hands?	1 = pour/ squeeze, 2 = spray/ pump/ roll, 3 = remove with hands or utensil
Closure Type	What is the closing mechanism for the packaging?	1 = Lid; 2 = Cap; 3 = Clip/ tape; 4 = Dispenser (e.g., spray or pump, roll top); 5 = Ring-pull; 6 = Sealed plastic/ foil; 7 = Metal/ plastic zip	1 = Lid/ Cap; 2 = Clip/ Tape/ Zip; 3 = Dispenser (e.g., spray/ pump/ roll), 4 = Ring pull; 5 = Sealed plastic/foil/ card	
Does the packaging have a window/ can you see the product inside?	Are the contents of the product visible to the consumer prior to opening the packaging?	1 = Yes; 2 = No		
Pack size	Whether or not the packaging contains more than one serving portion.	1 = Single-portion; 2 = Multiple-portions	A single portion is a quantity for one individual and/ or one use.	
Shelf-life (if the product is unopened)	The length of time for which a product remains usable or fit for consumption	1 = weeks; 2= months; 3 = years		
Can the (main) packaging currently be recycled?		1 = Yes (widely); 2 = Sometimes (i.e., check locally); 3 = No (Not currently recycled)		
Raw food vs. cooked food	Can the contents of the packaging be consumed without being cooked first?	1 = Raw food; 2 = Cooked food; 3 = typically needs heating/ mixting to consumer, but not considered 'raw'		
Resealable Packaging	A packaging that, once opened can be resealed by the consumer multiple times	1 = Yes; 2 = No		
Easy to open	It requires little effort to open the packaging.	1 = Yes; 2 = No		
Durability of the Packaging	Could the packaging be used time and time again, without wear or damage to the packaging.	1 = Durable; 2 = Not durable		
Would the appearance of the packaging change over time?		1 = Yes; 2 = No		
Would the structure of the packaging change over time?		1 = Yes; 2 = No		
Easy to clean	Once empty, it is easy for the consumer to clean the inside of the packaging.	1 = Yes; 2 = No		
Place of use for the product	Where would the product be used/ consumed?	1 = Only used at home; 2 = Can be used at home or on-the-go.	On-the-go refers to anywhere outside of the home.	
Frequency of purchase	How often the consumer buys the product.	1 = Daily; 2 = Weekly; 3 = Monthly; 4 = Yearly		

Table A3 a) *key for full coding framework showing product qualities/attributes for each of the 90 products used in the study*

Properties/ Attribute of Product	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Nature of the Product	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
State of Matter* of the Contents	2	2	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3
Type of Packaging Material	3	1	3	5	1	2	1	2	1	3	4	2	4	2	4	2	1	1
Is the packaging made from multiple materials?	1	1	1	2	1	2	1	2	1	1	1	2	1	2	2	2	1	1
Separable for recycling?	1	2	1		1		1		1	1	2		1				1	1
Pack Type	3	4	4	5	4	10	9	2	6	3	9	2	9	8	2	8	6	6
Dispensing Method	3	1	1	1	1	3	3	3	3	3	3	1	3	3	3	3	3	3
Closure Type	1	1	1	4	1	5	1	2	5	1	1	5	1	5	5	5	5	5
Window/ product visible?	1	1	1	2	1	2	2	1	1	1	2	2	2	2	2	1	1	1
Pack size	2	2	1	1	1	2	2	2	2	2	2	1	2	2	1	2	2	2
Shelf-life (unopened)	2	2	2	2	2	2	2	1	1	3	3	3	3	3	3	1	1	1
Recyclable?	1	1	1	1	1	3	2	3	2	1	3	3	1	3	3	3	2	3
Raw food vs. cooked food	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	1	1	1
Resealable Packaging	1	1	2	2	1	1	1	1		1	1	2	1	2	2	2	2	2
Easy to open	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
Packaging Durability	1	1	1	2	1	2	1	2	2	1		2	2	2	2	2	2	2
Appearance of packaging changes over time?	2	1	2			1	1	1	1	2		1	1	1	1	1	1	1
Would the structure of the packaging change over time?	2	2	2		2	1	2	1	1	2		1		1	1	1	1	1
Easy to clean	1		1	2	1		1		1	1	1	2	1	1	2		1	1
Place of use	1	1	2	2	2	1	1	1		1	1		1	1		1	1	1
Frequency of purchase	3	3	1	1	1	3	3	2	2	3	3	1	3		1	2	2	2

Properties/ Attribute of Product	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Nature of the Product	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
State of Matter' of the Contents	4	3	3	4	4	3	3	2	2	3	3	3	3	3	3	2	2	3
Type of Packaging Material	4	4	4	5	1	1	1	2	1	6	4	2	2	2	1	1	3	2
Is the packaging made from multiple materials?	2	1	1	2	1	1	1	2	1	2	1	2	1	2	1	2	2	2
Separable for recycling?		2	2		1	1	1		1		1		1		1			
Pack Type	9	9	8	5	3	9	9	2	4	10	9	8	8	10	9	4	4	8
Dispensing Method	3	3	3	1	1	3	3	1	1	3	1	1	3	3	3	1	1	3
Closure Type	1	5	2	4	1	5	1	5	1	5	5	5	2	5	1	1	1	5
Window/ product visible?	2	1	1	2	1	2	1	1	2	2	1	2	1	2	2	1	1	1
Pack size	2	1	1	2	2	1	2	1	2	1	2	2	2	1	2	2	2	2
Shelf-life (unopened)	1	1	1	3	2	2	1	2	2	3	2	2	1	2	2	1	1	1
Recyclable?	2	3	3	1	2	2	2	3	1	3	1	3	4	3	2	1	1	2
Raw food vs. cooked food	1	2	2	3	3	3	2	3	3	3	2	2	2	2	2	2	2	3
Resealable Packaging	1	2	2	2	1	2		2	1	2	1		1	2	1	1		2
Easy to open	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Packaging Durability		2	2	2	1	2	2	2	1	2	2	2	2	2		1	1	2
Appearance of packaging changes over time?	1	1	1			1	1	1		1			1	1			2	1
Would the structure of the packaging change over time?		1	1	2	2	1	1	1	2	1			1	1	2	2	2	1
Easy to clean	1		1	1	1	1	1		1	2	1	1	1		1	1	1	1
Place of use	1	2	2	1	1	2	2	1	1	1	1	1	1	2	1	1	1	1
Frequency of purchase	2	1	1	2	2	1	1	3	3	3	2	2	2	1	2	2	2	2

Properties/ Attribute of Product	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
Nature of the Product	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3
State of Matter* of the Contents	3	3	3	3	3	3	3	3	3	3	3	2	2	2	3	4	2	2
Type of Packaging Material	2	2	1	2	2	1	4	2	2	5	2	3	2	1	4	2	1	1
Is the packaging made from multiple materials?	2	1	1	2	2	1	1	2	2	1	1	1	2	1	2	2	1	1
Separable for recycling?		2	1			1	2			1	1	1		1			1	2
Pack Type	8	8	6	8	8	6	7	8	10	9	10	3	2	4	9	2	4	4
Dispensing Method	3	3	3	3	3	3	3	3	3	3	3	1	1	1	3	3	1	1
Closure Type	5	2	5	5	5	5	1	5	5	1	5	1	5	1	5	2	1	1
Window/ product visible?	1	1	1	1	1	1	2	2	2	2	2	1	1	2	2	2	1	2
Pack size	2	2	2	2	2	1	2	1	1	2	2	2	1	2	2	2	2	2
Shelf-life (unopened)	3	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3
Recyclable?	3	3	2	3	3	2	3	3	3	1	3	1	3	1	1	3	1	1
Raw food vs. cooked food	3	2	2	2	2	3	2	2	2	2	2	3	3					
Resealable Packaging		2	2	2	2	2	1	2	2	1	2	1	2	1	1		1	1
Easy to open	1	1	1	1	1	2	1	1	1	1	1	2	2	1	1	1	1	1
Packaging Durability	2	2	2	2	2	2		2	2	1	2	1	2	1		2	1	1
Appearance of packaging changes over time?	1	1	1	1	1	1		1	1	2	1	2	1			1		
Would the structure of the packaging change over time?	1	1	1	1	1	1		1	1	2	1	2	1	2			2	2
Easy to clean	1	1	1			1				1		1		1	1		1	1
Place of use	1	1	1	1	1		2	2	2	1	1	1	1	1	1	1	1	1
Frequency of purchase	3	2	2	2	2	2	2	1	1			2	2	3	4	3	3	4

Properties/ Attribute of Product	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
Nature of the Product	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
State of Matter' of the Contents	2	4	2	2	4	4	2	3	1	3	3	1	3	3	2	3	1
Type of Packaging Material	1	5	1	1	2	1	1	2	5	1	4	5	2	2	1	4	5
Is the packaging made from multiple materials?	1	1	1	1	2	1	1	2	1	2	2	1	2	2	1	2	1
Separable for recycling?	1	2	2	1		2	1		2			2			2		2
Pack Type	4	1	4	4	2	9	4	10	1	10	9	1	10	10	4	9	1
Dispensing Method	2	2	1	1	3	3	2	3	2	3	3	2	3	3	1	3	2
Closure Type	3	3	1	1	2	1	3	5	3	5		3	5	5	1	5	3
Window/ product visible?	2	2	2	1	2	2	1	2	2	1	2	2	2	1	2	2	2
Pack size	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Shelf-life (unopened)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Recyclable?	1	2	1	1	3	3	1	3	2	3	1	2	3	4	1	1	2
Raw food vs. cooked food																	
Resealable Packaging	1	1	1	1		1	1	1	1	2	1	1	1	2	1	1	1
Easy to open	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1	1
Packaging Durability	1	1	1	1	2	1	1	2	1	2		1	2	2	1		1
Appearance of packaging changes over time?		2			1			1	2	1		2		1			2
Would the structure of the packaging change over time?	2	2	2	2	1	2	2	1	2	1		2	1	1	2		2
Easy to clean	1	2		1		1			2		1	2		1	2	1	2
Place of use	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Frequency of purchase	4	4	4	3	3	3	4	3		4		4	4	3	4		4

Properties/ Attribute of Product	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Nature of the Product	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
State of Matter* of the Contents	2	1	2	3	3	3	2	2	2	2	2	3	1	2	2	3	2	2	3
Type of Packaging Material	1	5	1	2	1	5	1	1	2	1	1	1	5	1	1	1	1	1	5
Is the packaging made from multiple materials?	1	1	2	2	1	2	1	1	1	1	1	1	1	1	1	1	1	1	1
Separable for recycling?	2	2			1		1	1	2	2	1	1	2	2	1	1	1	1	1
Pack Type	4	1	4	10	9	9	4	7	2	7	7	9	1	4	4	9	7	4	9
Dispensing Method	2	2	1	3	3	3	1	1	1	2	1	3	2	1	1	3	1	2	3
Closure Type	3	3	1	5	1	1	1	1	1	3	1	1	3	1	1	1	1	3	1
Window/ product visible?	2	2	2	2	1	2	2	2	1	2	2	2	2	2	1	2	2	1	1
Pack size	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Shelf-life (unopened)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
Recyclable?	2	2	1	3	2	2	1	3	3	3	3	2	2	1	1	2	3	1	1
Raw food vs. cooked food																			
Resealable Packaging	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Easy to open	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Packaging Durability		1	1	2	1	1	1		2	1	2	1	1	1	1	1		1	
Appearance of packaging changes over time?		2		1		2			1				2				1		
Would the structure of the packaging change over time?	2	2	2	1	2	2	2		1	2		2	2	2	2	2		2	
Easy to clean	2	2				1	1	2	2	2	2	1	2		1	1	2	1	1
Place of use	2		1			2	1	1	1	1	1			1	1			1	1
Frequency of purchase	3	3	3	3	4	3	3	3	3	3	3			3	3	3	3	3	3

Table A3 b) *Full coding framework showing product qualities/attributes for each of the 90 products used in the study. See Table 2.8 a) for key*

Product	N	Bin	Recycle	Reuse	Refill	Return	Repurpose	Refill at Home	Refill on the go	Return from home	Return on the go
Mayo in glass jar	89	6.70	58.40	34.80	4.49	0.00	30.31	3.37	1.12	0.00	0.00
Mayo in plastic bottle	91	14.30	75.80	9.90	6.60	0.00	3.30	3.30	3.30	0.00	0.00
Coke in glass bottle	91	2.20	81.30	16.50	3.30	6.60	6.60	2.20	1.10	0.00	6.60
Coke in can	91	3.30	95.60	1.10	0.00	1.10	0.00	0.00	0.00	0.00	1.10
Coke in plastic bottle	92	4.30	71.70	23.90	10.87	2.17	10.87	6.52	4.35	0.00	2.17
Lurpak in foil	91	74.70	25.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lurpak in plastic tub	89	14.60	65.20	20.20	2.24	2.24	15.72	1.12	1.12	0.00	2.24
Cheese in zip bag	90	61.10	32.20	6.70	3.35	0.00	3.35	2.23	1.12	0.00	0.00
Cheese in plastic tray	90	35.60	63.30	1.10	0.00	1.10	0.00	0.00	0.00	1.10	0.00
Nescafe in glass jar	90	4.40	53.30	42.20	16.67	0.00	25.53	14.45	2.22	0.00	0.00
Nescafe in cardboard tub	93	9.70	41.90	48.40	22.6	1.06	24.73	20.46	2.15	0.00	1.06
Nescafe in single sachet	93	68.80	30.10	1.10	0.00	0.00	1.10	0.00	0.00	0.00	0.00
PG tea box	93	3.20	78.50	18.30	12.92	0.00	5.38	9.69	3.23	0.00	0.00
PG tea bag	91	42.90	45.10	12.10	6.59	0.00	5.51	3.30	3.30	0.00	0.00
PG tea Sachet	90	50.00	47.80	2.20	2.20	0.00	0.00	1.10	1.10	0.00	0.00
Chicken in freezer bag	91	74.70	25.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chicken in tray	93	46.20	52.70	1.10	0.00	0.00	1.10	0.00	0.00	0.00	0.00
Bacon in tray	92	44.60	55.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eggs	92	5.40	71.70	22.80	10.85	2.17	9.78	4.34	6.51	0.00	2.17
Sandwich packet	89	36.00	62.90	1.10	0.00	0.00	1.10	0.00	0.00	0.00	0.00
Sandwich bag	91	49.50	47.30	3.30	0.00	0.00	3.30	0.00	0.00	0.00	0.00
Tin of beans	90	8.90	85.60	5.60	1.12	1.12	3.36	1.12	0.00	0.00	1.12
Beans in plastic tub	91	8.80	58.20	33.00	8.81	0.00	24.19	7.71	1.10	0.00	0.00
Pot noodle	93	24.70	65.60	9.70	0.00	0.00	9.70	0.00	0.00	0.00	0.00
Pasta box lunch	92	27.20	64.10	8.70	0.00	0.00	8.70	0.00	0.00	0.00	0.00

Product	N	Bin	Recycle	Reuse	Refill	Return	Repurpose	Refill at Home	Refill on the go	Return from home	Return on the go
Oxo sachet (pouch)	90	55.60	38.90	5.60	3.36	0.00	2.24	0.00	3.36	0.00	0.00
Knorr squeeze	92	25.00	66.30	8.70	4.35	2.18	2.18	1.09	3.26	0.00	2.18
Oxo cube	91	68.10	31.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Muesli box	91	2.20	87.90	9.90	3.30	1.10	5.50	1.10	2.20	0.00	1.10
Muesli in bag	91	51.60	39.60	8.80	3.30	0.00	5.50	1.10	2.20	0.00	0.00
Bread	91	57.10	34.10	8.80	1.10	0.00	7.70	1.10	0.00	0.00	0.00
Magnum ice-cream single	93	75.30	22.60	2.20	0.00	1.10	1.10	0.00	0.00	1.10	0.00
Magnum ice-cream tub	91	20.90	65.90	13.20	1.10	0.00	12.10	0.00	1.10	0.00	0.00
Milk in plastic bottle	90	4.40	82.20	13.30	6.65	2.22	4.43	4.44	2.21	1.11	1.11
Milk in glass bottle	91	2.20	41.80	56.00	10.98	31.86	13.16	6.59	4.39	29.67	2.20
Bag potatoes	91	50.50	38.50	11.00	8.80	1.10	1.10	3.30	5.50	0.00	1.10
Dry pasta	89	46.10	50.60	3.40	3.40	0.00	0.00	2.27	1.13	0.00	0.00
Onions in netting	91	61.50	35.20	3.30	0.00	0.00	3.30	0.00	0.00	0.00	0.00
Mushrooms in tray	87	27.60	54.00	18.40	4.60	1.16	12.66	2.30	2.30	0.00	1.16
Peppers in plastic	92	58.70	39.10	2.20	2.20	0.00	0.00	1.10	1.10	0.00	0.00
Salad in plastic bag	91	56.00	42.90	1.10	0.00	0.00	1.10	0.00	0.00	0.00	0.00
Ready meal	91	30.80	67.00	2.20	0.00	0.00	2.20	0.00	0.00	0.00	0.00
Pringles	89	23.60	57.30	19.10	5.62	0.00	13.48	3.37	2.25	0.00	0.00
Crisp packet	93	62.40	34.40	3.20	1.07	2.13	0.00	0.00	1.07	1.07	1.07
Mars bar	90	76.70	23.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biscuits in tin	93	1.10	14.00	84.90	9.68	0.00	75.22	9.68	0.00	0.00	0.00
Biscuits in plastic	93	53.80	44.10	2.20	0.00	0.00	2.20	0.00	0.00	0.00	0.00
Pasta sauce in jar	92	3.30	60.90	35.90	4.34	1.08	30.44	4.34	0.00	0.00	1.08
Pasta sauce in pouch	92	58.70	41.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Surf bottle	92	9.80	71.70	18.50	16.32	2.18	0.00	5.43	10.88	1.09	1.09

Product	N	Bin	Recycle	Reuse	Refill	Return	Repurpose	Refill at Home	Refill on the go	Return from home	Return on the go
Surf box	92	6.50	75.00	18.50	9.79	0.00	8.71	2.17	7.61	0.00	0.00
Surf pouch	89	49.40	39.30	11.20	7.84	1.12	2.24	4.48	3.36	1.12	0.00
Washing up liquid	91	9.90	67.00	23.10	18.71	0.00	4.39	15.42	3.29	0.00	0.00
Domestos bleach	90	23.30	71.10	5.60	5.60	0.00	0.00	2.24	3.36	0.00	0.00
Cif plastic spray	91	13.20	51.60	35.20	15.42	1.09	18.69	11.01	4.41	0.00	1.09
Cif bathroom aerosol	90	46.70	46.70	6.70	4.47	2.23	0.00	1.12	3.35	1.12	1.12
Cif cream cleaner	90	23.30	64.40	12.20	9.98	2.22	0.00	7.76	2.22	0.00	2.22
Fabric softener	91	11.00	65.90	23.10	16.49	2.19	4.39	9.90	6.60	0.00	2.19
Dishwasher tablets in	91	50.50	39.60	9.90	7.70	0.00	2.20	3.30	4.40	0.00	0.00
Dishwasher tablets in tub	94	26.60	41.50	31.90	21.28	0.00	10.62	20.21	1.06	0.00	0.00
Dettol spray	92	15.20	47.80	37.00	15.24	0.00	21.76	10.88	4.36	0.00	0.00
Dettol wipes	91	57.10	40.70	2.20	1.10	1.10	0.00	0.00	1.10	1.10	0.00
Dettol disinfectant aerosol	90	43.30	50.00	6.70	2.23	4.47	0.00	2.23	0.00	1.12	3.35
All purpose cloths	91	58.20	41.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Match box	90	10.00	73.30	16.70	4.46	1.12	11.14	2.23	2.23	1.12	0.00
Wood polish aerosol	92	47.80	48.90	3.30	3.30	0.00	0.00	2.20	1.10	0.00	0.00
Wood polish wipes	92	70.70	27.20	2.20	1.10	1.10	0.00	1.10	0.00	0.00	1.10
Toilet roll	92	53.30	43.50	3.30	1.10	0.00	2.20	0.00	1.10	0.00	0.00
Toilet duck plastic bottle	93	17.20	75.30	7.50	5.36	2.15	0.00	2.14	3.21	0.00	2.15
Cling film	91	11.00	81.30	7.70	0.00	1.10	6.60	0.00	0.00	0.00	1.10
Oven cleaner aerosol	92	52.20	44.60	3.30	0.00	2.20	1.10	0.00	0.00	1.10	1.10
Sure roll on deodorant	92	46.70	50.00	3.30	3.30	0.00	0.00	0.00	3.30	0.00	0.00
Sure deodorant aerosol	90	43.30	55.60	1.10	1.10	0.00	0.00	0.00	1.10	0.00	0.00
Tresemme shampoo	90	21.10	61.10	17.80	15.58	1.12	1.12	10.01	5.56	0.00	1.12
Simple face wipes	93	50.50	44.10	5.40	3.24	2.16	0.00	1.08	2.16	1.08	1.08

Product	N	Bin	Recycle	Reuse	Refill	Return	Repurpose	Refill at Home	Refill on the go	Return from home	Return on the go
Vaseline tub	90	21.10	57.80	21.10	10.00	3.33	7.76	6.67	3.33	0.00	3.33
Vaseline tin	91	30.80	38.50	30.80	7.70	2.19	20.91	3.30	4.40	0.00	2.19
Simple moisturizer	92	17.40	58.70	23.90	15.20	3.25	5.43	10.85	4.35	0.00	3.25
Simple facewash	89	32.60	61.80	5.60	2.24	2.24	1.12	1.12	1.12	0.00	2.24
Simple facewash pouch	92	41.30	45.70	13.00	8.67	2.17	2.17	4.34	4.34	0.00	2.17
Colgate standing tube	90	46.70	50.00	3.30	1.10	2.20	0.00	1.10	0.00	0.00	2.20
Colgate tube	88	58.00	40.90	1.10	1.10	0.00	0.00	0.00	1.10	0.00	0.00
Multivitamins	90	13.30	71.10	15.60	4.46	1.11	10.03	2.23	2.23	0.00	1.11
Hairspray	91	47.30	51.60	1.10	1.10	0.00	0.00	0.00	1.10	0.00	0.00
Dove body wash	92	16.30	73.90	9.80	8.71	1.09	0.00	4.36	4.36	0.00	1.09
Mouthwash	90	13.30	72.20	14.40	8.86	2.22	3.33	5.54	3.32	0.00	2.22
Hair gel Tub	91	35.20	51.60	13.20	4.40	1.10	7.70	2.20	2.20	0.00	1.10
Hair gel in tube	92	41.30	47.80	10.90	5.45	3.27	2.18	2.18	3.27	0.00	3.27
Carex handwash	93	11.80	50.50	37.60	33.31	1.09	3.23	29.02	4.30	0.00	1.09
Cotton wool buds	92	15.20	48.90	35.90	17.41	0.00	18.49	14.16	3.27	0.00	0.00

Table A4 *Percentage of people who selected each option for each product*

Activity		Process			Amount	Comments
Production of corrugated board box		Making corrugated cardboard box	Corrugated board box {RER}| production | APOS, U		12.85 g/ container	
		Making plastic sheet	Polyethylene terephthalate, granulate, amorphous {GLO}| market for | APOS, U		3.33 g/ container	Plastic Window and liner
			Extrusion, plastic film {RER}| extrusion, plastic film | APOS, U		3.33 g/ container	2.4% lost during extrusion based on Ecoinvent database
Transportation		Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | APOS, U			0	Transport from primary production to manufacture (Blackburn plant) (assumption primary production is same with manufacture)
		Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | APOS, U			0.00319 tkm /container	Transport from manufacture (Blackburn plant) to Catering 24 in Derby 198km
		Transport, freight, lorry 16-32 metric ton, euro6 {RER}| market for transport, freight, lorry 16-32 metric ton, EURO6 | APOS, U			0.00116 tkm/ container	Distributors to takeaway, from Catering 24 in Derby to Heart space cafe, University of Sheffield, 72 km,
EoL	**Incineration (energy recovery)**	Cardboard	Waste paperboard {CH}| treatment of, municipal incineration with fly ash extraction | APOS, U		1 kg/ 1 kg of total waste paper	The process has been modified to include the energy recovery credits
			Electricity, market medium voltage {GB}| market for | APOS, U Heat, central or small-scale, natural gas {RER}|		0.55498 kWh 3.989 MJ	Energy credits for paper container, Based on Ecoinvent
		Plastic window and liner	waste polyethylene terephthalate {CH}| treatment of waste polyethylene terephthalate, municipal incineration with fly ash extraction | APOS, U		3.26g/ Container	The process has been modified to include the energy recovery credits
	Recycling		Electricity, market medium voltage {GB}| market for | APOS, U Heat, central or small-scale, natural gas {RER}|		0.55498 kWh 3.989 MJ	Energy credits for PET (plastic window and liner of cardboard box), Based on Ecoinvent
		Production corrugated box of waste paper	Avoided burden of production of recycled paper	Corrugated board box {RER}| production | APOS, U	0.81 kg/ 1kg unsorted waste paper	Material losses provided by Ecoinvent processes
			Corrugated board box production	Waste paperboard, sorted {RER}| corrugated board box production | APOS, U	1 kg/ 0.986 kg corrugated board box	Uses 0.986kg of paper as input - the rest is material lost from sorting process as per Ecoinvent
			Sorting waste paper	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | APOS, U		

Table A5 *Life cycle inventory for the single-use container showing materials and energy consumption for production, transportation and end-of-life*

Activity	Process	Amount	Comments
Production of Vytal bowl	Polypropylene, granulate {GLO}| market for | APOS, U	12.5g /bowl	PP in lid
	Polypropylene, granulate {GLO}| market for | APOS, U	108 g/bowl	PP in bowl
	Synthetic rubber {RER}| production | APOS, U	24 g/bowl	Rubber in lid
	Injection moulding {RER}| processing | APOS, U	163.5 g/bowl	0.6 % loss was considered based on Ecoinvent
Transportation	Transport, freight, lorry 16-32 metric ton, EURO6 {GLO}| market for | APOS, U	0	Raw material transport from primary production to the manufacturing, If primary production and the manufacture are same
	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {GLO}| market for | APOS, U	0.009 tkm/ bowl	Transport from manufacturing to the distributors in the Netherlands from Losser to Lochem (50 km), Production site and distributors are in the Netherlands.
	Transport, freight, lorry 16-32 metric ton, EURO6 {GLO}| market for | APOS, U	0.0235. tkm/ bowl	Transport from the Netherlands to the main distributor in Germany i.e. Vytal central warehouse: Cologne/GER (163.2 km)
	Transport, freight, lorry 16-32 metric ton, EURO6 {GLO}| market for | APOS, U	0.0605 tkm/ bowl	Transport from Cologne to Calais by road, 419 km
	Transport, freight, sea, ferry {GLO}| market for transport, freight, sea, ferry | APOS, U	0.00737tkm/ bowl	Transport from Calais to Dover by ferry (car transfer), 51 km
	Transport, freight, lorry 16-32 metric ton, EURO6 {GLO}| market for | APOS, U	0.0581 tkm/ bowl	Transport from Dover to distributer in Sheffield (dpd), 402 km
	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {GLO}| market for | APOS, U	0.00144 tkm/ bowl	Transport from dpd to University of Sheffield, 10km
Washing phase	Tap water {RER}| market for | APOS, U	0.277 kg/ bowl	Dishwashing water: 1.4-3.5 litre per basket, 9 bowl in each basket, then, 2.5/9=0.277 litre/bowl
	Polycarboxylates, 40% active substance {RER}| production | APOS, U	0.000693 kg/ bowl	Detergent: 2.5 g/litre , then , 2.5*0.277/1000=0.0007kg/bowl
	Electricity, low voltage {GB}| market for | APOS, U	0.025 kWh	dishwashing energy: total cycle uses 0.13 kWh, for 1.4-liter cycle, for average 2.5 litre/cycle is 0.232 KWh apportionment is 11% so 0.232*.11= 0.025kWh.

Activity	Process				Amount	Comments
EoL		**Incineration (energy recovery)**	Reusable container	Waste polypropylene {CH}| treatment of, municipal incineration with fly ash extraction | APOS, U	1 kg/ 1 kg of plastic waste	The process has been modified to include the energy recovery credits
				Electricity, high voltage {GB}| market for Heat, district or industrial, natural gas {RER}| market group for	1.17 kWh 8.15 MJ	Based on Ecoinvent
		Recycling	Sorting of polypropylene waste	Waste polyethylene, for recycling, unsorted {Europe without Switzerland}| market for waste polyethylene, for recycling, unsorted | APOS, U	1.17 kg of waste plastic/1 kg of recycled granulate	The input amount recalculated as per losses reported in the database. Also, it is assumed that PP sorting is similar to PE
			Recycling of PP	Based on literature	1 kg / 1kg of waste bowl	Cottafavaa, 2021
			Avoided burden of production of recycled reusable container	Polypropylene, granulate {RER}| production | APOS, U	0.85 kg/ 1 kg of bowl	Cottafavaa, 2021
			Rubber in the lid	Waste rubber, unspecified {CH}| treatment of, municipal incineration with fly ash extraction | APOS, U	1 kg/ 1 kg waste	
				Electricity, high voltage {GB}| market for Heat, district or industrial, natural gas {RER}| market group for	0.8987 kWh 6.33 MJ	The process has been modified to include the energy recovery credits

Table A6 *Life cycle inventory for the reusable container showing materials and energy consumption for production, transportation, use and end of life for the system boundary in Figure 3.3*

Process	Comp	Method	Time	Tech	Geo	Para	DQR
Production of disposable container	4	1	1	3	2	3	2.3
Production of PET granule	4	1	1	3	5	3	2.8
Production of PET film lining	5	1	1	3	2	3	2.5
Incineration of disposable container waste	4	1	1	3	2	3	2.3
Avoided burden of production of corrugated board box from recycled disposable container	5	1	1	3	2	4	2.6
Sorting disposable container waste	5	1	1	3	2	3	2.5
Recycling of disposable container waste to corrugated box	5	1	1	3	2	3	2.5
Virgin PP granule production	4	1	1	3	5	3	2.8
Synthetic rubber production	5	1	1	2	5	3	2.8
Production reusable container from virgin PP	4	1	1	3	5	3	2.8
Incineration of reusable container waste	5	1	1	3	2	3	2.5
Sorting of plastic container (reusable) waste	5	1	1	3	2	3	2.5
Recycling of plastic container waste	5	1	1	4	2	4	2.8
Avoided burden of plastic recycling	5	1	1	3	5	3	3
Washing of reusable container	5	1	1	2	1	3	2.2

Table A7 *Data quality scores for the processes used in the study with scores for Completeness (Comp), Methodological appropriateness and consistency (Method), Time-representativeness (Time), Technological representativeness (Tech), Geographical representativeness (Geo), Parameter Uncertainty (Para) and Data Quality Rating (DQR)*

Table A8 detailed information on loose fresh produce trials in the UK

Retailer	Date	Method used	Products included (High and Low sales volumes)	Number of stores	Length of Trial	Amount of waste created in shops	Comment	Ref
Asda	2007-8	x	Vague '… trialling selling fruit and vegetable loose rather than pre-packaged.' (Packaging News, 2007)	1, extending to 4	1 month	'doubled waste to approx. 6%'	'acceleration of the ripening process; produce becoming damaged and not subsequently purchased; and the practical difficulties of keeping track of stock rotation.'	(Wells, 2008) (Packaging News, 2007)
Morrisons	2018	Increasing the number of fresh produce lines sold loose by - Changing the way fresh produce was merchandised; Displaying loose vegetables in wooden crates and creating chalkboard signage to enhance the 'market feel' of the aisle; Replacing plastic bags with recyclable brown paper bags for customers to use for loose fresh produce; Removing plastic wrapping from cucumbers during the summer season; Changing the price of some fresh produce lines from £ per kilo to per unit. Approach/Method: Qualitative research consisted of several elements… [Observation in trail store and comparison store; In depth interviews with customers and accompanied shops; In depth staff interviews and survey; Telephone interviews with suppliers] The approach included comparison store, Congleton, to provide a point of reference when exploring findings arising from the trial store, Skipton. Morrisons	'increased'	3	10 months	Initially normal levels x 2.7, then 'brought down using store management systems'	'Following the success of the … trial in Skipton, (and in stores in Guiseley and St Ives), Morrisons will be rolling out the initiative to 60 stores by the end of 2019. Morrisons estimates this initiative alone will save over three tonnes of plastic per week, equating to 156 tonnes a year'	(WRAP, 2021)

Retailer	Date	Method used	Products included (High and Low sales volumes)	Number of stores	Length of Trial	Amount of waste created in shops	Comment	Ref
		supplemented this with quantitative research of Skipton store customers using an online questionnaire.''						
M&S	2003	The study looked at the life cycle impact of loose product; non-biodegradable 'four packs' (with foam tray and film); and 'biodegradable' four-packs (biodegradable foam and film), considering the energy consumption, biodegradable and total waste caused by each method.	1 only (apples)	x	x	132 kg of loose apples were wasted per tonne compared to 106 kg per tonne of packaged apples	The study concluded that four-packs resulted in less food waste, but that if loose apples were transported in re-usable plastic crates instead of cardboard, loose apple packaging waste would be less than packaged. Overall waste would, at that point, become comparable between the two systems	(White and Stanmore, 2018)
M&S	2019	Trial in Tolworth store with trained greengrocers to offer customers advice (M&S, 2019)	90 (Edie.net, 2019)	1	x	x	'.. we've rolled out over 70 loose produce lines following a successful trial at our Tolworth store, and we're continuing to trial an additional 25 loose product lines at our test-and-learn renewal stores.' ((27) in (Greenwood 2024))	((27) in (Greenwood 2024)) (M&S, 2019) (Edie.net, 2019)
Co-op	Pre 2018	'A live trial was carried out comparing wastage rates on wrapped and unwrapped cucumbers with 40% of production being wrapped. This was a large-scale trial making the results statistically valid. The waste on wrapped over the 4 weeks	Cucumbers only	One depot	4 weeks	('supply chain') Wrapped 1.33%		(White and Stanmore, 2018)

Retailer	Date	Method used	Products included (High and Low sales volumes)	Number of stores	Length of Trial	Amount of waste created in shops	Comment	Ref
		averaged 1.33% and unwrapped 4.77%. Sales data from Newhouse (wrapped) and Lea Green Depots (unwrapped) was used to assess the relative impact on sales comparing the 4 weeks before the change to the 4-week trial period. Both showed an uplift in sales with Newhouse showing +21.28% and Lea Green +20.56%. This supports the view that customers had no strong preference between wrapped and unwrapped.'				Unwrapped 1.77%		
Tesco	2019	Not given	45 lines including 'varieties of apples, mushrooms, peppers, onions, bananas and avocados as loose produce.'	2				(Edie.net, 2019)
Waitrose	2019	'More than 200 products were removed from their packaging across a number of categories. Customer insight was collected through in-store interviews (90), exit surveys (400), comment boards in-store, a dedicated online form (740 responses), our social media channels and a focus group of 30 customers. Environmental consultancy Resource Futures was commissioned to do the environmental	''the largest range of loose fruit and veg of any national supermarket.''	2 (3)	11 weeks	The reported 'Some in-store food wastage' at the start of the trial, but confident scope for overall reduction of		(John Lewis Partnership, 2021)

Retailer	Date	Method used	Products included (High and Low sales volumes)	Number of stores	Length of Trial	Amount of waste created in shops	Comment	Ref
		modelling of the 11-week test to calculate the indicative amount of plastic and packaging saved through Unpacked and an estimate of its impact on greenhouse gas emissions.'				greenhouse gas emissions.		
Iceland	2019	'Trial will see 35 produce lines sold loose, and 27 lines packed in plastic-free packaging • Loose fruit and vegetables to be offered at cheaper price than pre-packed equivalent to encourage uptake • Plastic-free packaging solutions will include plant-based films, compostable nets, and paper bags' (Iceland Foods Ltd, 2019)	35	1	x		Abandoned, quoting a 30% drop in sales	(Barrie, 2019; Edie.net, 2019; Iceland Foods Ltd, 2019)
Aldi	2019		5 - savoy cabbage, red cabbage, white cabbage, pointed cabbage and cauliflower	All Scottish stores, then extended to other areas of the UK (Wells, 2019)	6-weeks+	x	In September 2020 start selling loose produce lines in 77 stores by the kg. (Searle, 2020)	(Wells, 2019) (Edie.net, 2019)
Asda (2020)	x	x	x	x	x	x	x	x

Table A8 *Detailed information on loose produce trials in the UK, showing retailer, date, methods used, trial length and number of stores, comments and references*

Note that the downloaded documents referred to as numbers in brackets can be located at: Greenwood, Sarah. 2024. "Downloaded Webpages and Documents." OSF. October 5. doi:10.17605/OSF.IO/47YCW.

	Discounter store 15/7/21	Mid-range store 15/7/21	Premium store 16/7/21
General look and feel			
Layout- easy to navigate?	Yes	Yes	Yes
Gondola ends / features,	No	Special offers	Organics, lovely herb display
Amount of refrigeration	High respiration rate salad only and mushrooms, soft fruit.	~60%	Almost all apart from potatoes
Anything unusual	card for some tomatoes	No	biggest range of exotic
Organics - separate/ aside?	None	Aside	Separate
Loose product			
Amount on sale	approx. 10% - mangoes, sweet potatoes, no loose onions (in nets)	~10%	~15%
Scales on site?	Yes	Yes	Yes
Availability of bags - material - messaging	Yes, HDPE	Reusable bags on sale	sell reusables for £6 a pack, compostable single use available
Does the loose product look fresh compared to packaged?	Yes	Yes	Mostly, a dodgy looking parsnip
Are grapes sold loose?	No	No	No - some in card punnets though
Secondary (transit) packaging			
Amount of reusable crates vs single use (corrugate and plastic)?	All card	70/30 Crates are black	95% crates Crates are green
Use of crate liners - materials (plastic, paper etc.) are any of these MAP?	None	Pulp trays for top-fruit, some plastic liners	Loose apples - pulp, bags have bubble wrap. Lots of plastic liners. Carrots/parsnips look like they may be MAP liners
In fixtures or on dollies?	All fixtures	Fixtures except potatoes - stand alone	All fixtures

	Discounter store 15/7/21	Mid-range store 15/7/21	Premium store 16/7/21
Primary (consumer) packaging			
Amount of flexible packaging formats vs rigid – i.e. pots tubs and trays	Rigids only used where absolutely necessary	Rigids only used where absolutely necessary	rigid plastics used a little more than for Lidl and Sainsbury's on semi-prep, but all clear
What are the flexibles - PP / PET / laminates / compostables? / Paper	PP and PE bags. 'Bag on reel' prepacked format used for pears	conventional plastics only (no paper or compostables)	Mainly conventional, a small amount of compostable present - e.g. organic bananas. Avocados in cloudy looking bag, but this is 'recyclable at store'.
What are the rigids? Materials, sealing, colour	Almost all clear PET. PP used for mushrooms	Mushrooms in coloured PP, other rigids clear, some card	PET and PP, clear PET mainly, coloured PP for mushrooms
Any unusual / innovative packs?	Netting used for some toms and peppers Chillies in a resealable bag, card packs for some tomatoes	Nothing unusual	Nothing unusual
Evidence of MAP	Bagged salads / herbs only. herbs sold at ambient	Bagged salad, some cut produce	Bagged salad, some cut produce
Resealable options - e.g. Parkside's integral resealable label, strips, zips	Not much (see chillies above)	Nothing unusual	Nothing unusual
Categories			
Prepared fruit and vegetables	Nothing remarkable	Nothing remarkable	Nothing remarkable
Fruit	Soft fruit chilled in punnets with film lids - large vent holes	Apples nearly all in 6 pack flowraps, very few loose. Bananas loose. Grapes uniform PET punnets with lidding film	Nothing remarkable
Exotic Fruit	Nothing remarkable	Nothing remarkable	Nothing remarkable
Vegetables inc. potatoes	Nothing remarkable	Swede still shrink-wrapped	Nothing remarkable
Salad	Nothing remarkable	British Cucumbers shrink-wrapped and signposting to plastics recycling bin	Nothing remarkable

	Discounter store 15/7/21	Mid-range store 15/7/21	Premium store 16/7/21
Herbs etc.	Growing looked good, but bagged tired (sold at ambient)	Nothing remarkable	Nothing remarkable
Notes			
	Quality not great in some cases (warm weather and high proportion sold at ambient temp) Some nuts sold loose - serve yourself	Very few loose or dirty potatoes. Fresh new pots in fridge	Old fashioned wire bin for markdowns, attractive wooden display to showcase fresh beets, fennel No expanded polystyrene trays - all moulded fibre now
General notes	Weather was warm and sunny for all visits		

Table A9 *Audit of packaging and related factors of the fresh produce section of a value, mid-range and premium UK supermarkets, including general look and feel of the Fresh Produce areas, the amount and appearance of loose produce on sale, secondary packaging formats, primary packaging formats and materials and notes on the individual categories within Fresh Produce.*

Table A10 Detailed Retailer Spreadsheet 1/6

	Tesco	Sainsbury's	Asda	Morrisons	Aldi	M&S	Co-op
Plastics / Packaging							
Own targets	Ensure we never use more packaging than is needed, and what we do use is from sustainable sources and goes on to be reused or recycled. 1. Our packaging will be fully recyclable by 2025 2. Remove hard to recycle materials from our UK packaging by the end of 2019 3. All paper and board used will be 100% sustainable by 2025 4. Halve packaging weight by 2025 (1)	We've pledged to cut plastic by 50% by 2025 (9). As members of WRAP's UK Plastic Pact, we are collaborating to eliminate unnecessary single-use packaging by 2025 and working towards all plastic packaging being 100 percent reusable, recyclable or compostable by 2023, as well as containing at least 30 per cent [recycled content] (48). Removing and replacing difficult to recycle plastics including black plastic, PVC, and polystyrene by 2021. • Averaging 30 per cent recycled content by 2022 • 100 per cent to be reusable, recyclable or compostable by 2023 (8)	The basis of our approach is to apply the "3 Rs" of waste management, focusing on reducing or avoiding plastic altogether. To remove three billion individual pieces of plastic by 2025 15% reduction on a like-for-like product list by 2021, and expect to have established Refill revenue streams across at least 40 products before 2025. Target to reach at least 30% recycled content in Asda Brand packaging, 25 viable projects utilising recycled material (e.g. saucepans) by 2025 (14).	2022 - Replace all coloured PET packaging with clear; removal of polystyrene; removal of PVC film. 2025 - 50% reduction in own brand primary plastic packaging vs 2017 baseline; 100% of plastic packaging recyclable, reusable or compostable; 30% average recycled content in our plastic packaging; 70% of plastic packaging to be recycled. Now - EPS, non-detectable black plastic and Rigid PVC already banned (16). Morrisons has also committed that by 2025, it will recycle and reuse the equivalent amount of plastic it puts on to the market within its own recycling facilities, to develop greater recycling in the UK (17).	1) Eliminate problematic plastic packaging (black plastic, pVC and EPS_ from core range food by 2020 (done). 2) 100% of own label packaging to be rr or c by 2022 (and branded products by 2025). 3) Reduce **plastic packaging** by 50% by 2025 (against a 2019 baseline). 4) Reduce **all packaging** by 50% by 2025 (against a 2015 baseline). 5) 50% of plastic packaging to be made of recycled content by 2025. 6) 100% pulp-based packaging across core range must be FSC or PEFC certified or made of minimum 70% recycled content by 2020 (achieved). 7) "we are pleased to announce that throughout 2021 we have been working to increase our reuse and refill transaction stations) (20).	We're targeting net zero carbon emissions by 2040, and further reducing and reusing our packaging is a vital step on that journey.We have set ourselves clear targets of: • 100% of our food packaging to be recyclable by 2022 • 30% reduction in the volume of plastic food packaging by 2027 (27). • 25% of our store esate to offer our packaging-free 'fill your own concept by 2023' (30 but not 27). **Plastics Plan** - M&S's Five Plastic Principles ...- Refuse, Redesign, Reduce, Reuse and Recycle (28).	We're committed to using a minimum of 50% recycled content in PET bottles, pots, tubs, trays and punnets and HDPE bottles by the end of 2021.(39) All Co-op own-brand packaging will be easy to recycle by Q2 2021 (home collection or collection of film in stores) (39). 15% plastic reduction by the end of 2022 (2018) (39).
UK Plastics Pact							
Signatory?	Y	Y	Y	Y	Y	Y	Y
OPRL Member?	Y	Y	Y	Y	Y	Y	Y
1. **Eliminate problematic or unnecessary single-use packaging** through redesign, innovation or alternative (reuse) delivery model.	Y + all materials (1) "In December 2020, we announced the permanent removal of **1 billion pieces of plastic** from the UK business. Working with our suppliers, we successfully removed plastic from a range of products, including 67 million pieces on tinned multipacks* and 24 million pieces on our sausage rolls and slices packaging" (46).	Y - remove and replace (9) in some instances swapping for paper or wood.	Y - got rid of some single use items (forks in salads, non-plastic party options) (14).	2022 and 2025 targets.	1) above.	Removed PS from pizzas and all black plastic (27). PVC not allowed from 2014 (32). in 2018 "commit to removing the most problematic plastics for recycling, such as polystyrene, by 2019" (28). We have already replaced the 75 million pieces of plastic cutlery with FSC certified wooden alternatives, removed the two million plastic straws we use in M&S Cafés by swapping with paper ones and taken the plastic out of all 450 million tea bags we sell per year (28).	Yes - examples in (35) card pizza bases replacing EPS, lighter pigment in milk bottle tops, mono materials for cooked meat etc mushroom packs no longer black.
2. **100%** of plastics packaging to be **reusable, recyclable or compostable**	Recyclable only (1). Trialling scalable reusable with Loop but no KPI (6).	Recycle (9) Trialled an Ecover refill station (48). Water refills in cafes, BYO for deli counters (9).	Refill with target (40 products), max recyclability (14) nothing on compostability.	2022 and 2025 targets. Encouraging Refill (e.g. at deli counters) (17) (Discounts 25p discount for refillable cup, pods for detergent bottles).	2) above 7) above.	1st bullet point above (27) no mention of compostable in this most recent document (unlike in (31) from 2008). Trialling Fill Your Own and loose produce.	78% easy to recycle from 46% (35). All Co-op packaging is now recyclable thanks to our soft plastic recycling units in store (37). No mention of compostable other than carriers, no mention of reusable other than carriers.

Table A10 Detailed Retailer Spreadsheet 2/6

	Lidl	Iceland	Waitrose	Ocado
Plastics / Packaging				
Own targets	By 2025, 100% of own label packaging will be recyclable, reusable, refillable or renewable. By 2025, reduce own label plastic packaging by 40% relatively against a 2017 baseline.By 2025, reduce own label packaging by 25% relatively against a 2019 baseline. By 2021, 30% of own label plastic packaging to contain recycled content (Complete). By 2023, 90% of own label & branded packaging to be recyclable, reusable, refillable or renewable. By 2025, 100% of own label & branded packaging to be recyclable, reusable, refillable or renewable. By 2021, we are committed to doubling the number of refillable/ reusable packaging available in our stores. By 2020, eliminate problematic plastic packaging (black plastic, PVC and EPS) from own label core food range (Complete). By the end of 2020, 100% of pulp and fibre-based own label packaging in core food range to be either responsibly sourced from FSC, PEFC, or equivalent, or made using recycled content (Complete). We reserve the right to delist branded suppliers with excessive or unrecyclable packaging (21).	To be plastic free by 2023 #TooCoolForPlastic. A 10 point manifesto - 1) Remove plastic packaging from Iceland own label products by the end of 2023 – because it is essential to turn down the tap on global plastic production. 2) Collaborate with and support our suppliers, and work with competitors and the packaging industry to find solutions. 3) Focus on materials that our customers can recycle easily at home and provide clear on-pack recycling information. 4) Minimise or remove packaging without creating more food waste or compromising food safety. 5) Go back to basics and use traditional materials like paper, board, glass, metal and wood. 6) Work quickly to remove PVC (polyvinyl chloride), polystyrene and black plastic, which are all very difficult to recycle. 7) Use widely recyclable plastic such as HDPE, PE, PP and PET*, but in smaller and smaller quantities as our journey progresses. 8) Use composite materials that are mainly made of paper and board but include small amounts of plastic – while we look for ways to replace it. 9) Lobby the Government to put in place national food waste collections for industrial composting alongside the consistent collection of a core group of packaging materials for recovery and recycling (25)	REDUCE - By 2021 we will reduce the use of single-use plastic in our own-brand packaging by 20% (44) increasing to 50% by 2025 (45). REUSE - We're removing single-use plastic items such as disposable cups and testing dedicated refillable zones to encourage customers to switch to reusable alternatives. RECYCLE - By 2021' plastic packaging on all own-brand and branded products will be widely recyclable and made from 30% recycled content. Eliminate Black plastic (by end 2019), polystyrene and laminated card (by end 2023) from own brand packaging. As part of our overall commitment to make our own-brand packaging reusable, widely recyclable or home compostable by 2023, we pledge to: - reduce the amount of own-brand packaging,including plastics, by a third by 2023. - remove 20% of plastic from our own-brand ranges by the end of 2021. - ensure branded and own-brand packaging contain at least 30% recycled content by 2021. - ban non-recyclable plastic from all branded and own-brand packaging by 2021. (44)	We frequently review our own-label range and make continual improvements to its recyclability and recyclable content.
UK Plastics Pact				
Signatory?	Y	N	Y	Y
OPRL Member?	Y	Y	Y	Y
1. **Eliminate problematic or unnecessary single-use packaging** through redesign, innovation or alternative (reuse) delivery model.	problematic plastics above (21)	Y	EPS, PVC, PLA. 'we want to eliminate plastic laminated board or paper which is used for products like sandwiches by 2021 and complex laminates like crisp packets by 2023. Black plastic from own-brand by end of 2019. Amount of plastic, including from PRODUCE (41)	We've eliminated all polyvinyl chloride (PVC), polystyrene and black plastics from our own-label range, but we have more to do
2. **100%** of plastics packaging to be **reusable, recyclable or compostable**	recyclable reusable **refillable or renewable** (again nothing on compostable) (21)	Focus is on recycling and move to paper/board	by **2023**. High profile Unpacked trial (41) in a small number of stores. Bring own containers to deli counters (40) Nothing on compostable (note elimination of PLA above). Focus on recycling. However a previous targets included hme compostable	We frequently review our own-label range and make continual improvements to its recyclability and recyclable content.

Table A10 Detailed Retailer Spreadsheet 3/6

	Tesco	Sainsbury's	Asda	Morrisons	Aldi	M&S	Co-op
3. **70%** of plastics packaging effectively **recycled or composted**		Target - increase recycling and make it easier for customers to recycle (13).	Our aspiration is to find sustainable ways to take back more difficult-to-recycle customer waste and give it a valuable second life.	2025 targets	Not so much on this - they use their own label designs to indicate what is recyclable or not.	Take back scheme for plastics (29).	see 2
4. **30% average recycled content** across all plastic packaging.	'contains recycled content where possible" (6).	They say they are working towards (8).	Target to have 30% content	2025 targets	5) above - ambiguous description.	Over the next 5 years we will increase our recycled content in any remaining plastic to 50% and reduce our overall packaging tonnage by 25% (27).	Achieved - 37% across own brand packaging (35).
Differences to UKPP	Not compostables, ALL packaging. Paper and board from sustainable sources.	No mention of compostables.	No mention of compostables,	Currently we do not support the use of biodegradable or compostable plastics due to the lack of end of life options (16).	Reduce plastic packaging by 50%, reduce ALL packaging by 50%. (they do not have a statement on not using compostables, but only teabags changed over)	30% reduction in the volume of plastic food packaging by 2027 (27).	Minimum 50% recycled content in specific plastic items. Reduction target.
Strategy	4Rs Strategy, preferred material list, **Remove** (1 bn pieces of plastic), **Reduce** (whilst keeping recyclable), **Reuse** (Loop, bags), **Recycle**. (soft plastic recycling brought into 117 stores, removed black plastic, PVC or polystyrene. Have a list of requirements for any new packaging (3) and a prefered materials list which excludes compostables (4). WWF basket.	**'We've pledged to cut plastic by 50% by 2025."** (9) **Remove, Reduce, Replace, Recycle**, no lightweight plastic bags (9) - byo or recycled reusable available to buy for 30p, paper for bakery products (7). **The pledge to reduce by 50% dominates.** Note plan for better scheme / report (13).	**Reduce, Reuse, Recycle**. Operational plastic film recycled into bags for life, "'96% of our fresh meat and produce being transited in reusable crates" But increasingly, consumers want to see fewer single-use plastics, especially when it comes to fresh produce. ", Also reporting on figures , backing up the data and reporting sources - that will please Greenpeace! Good to see they are talking about operational and food waste. (14)	50% reduction in own brand primary plastic packaging vs 2017 baseline (16). Morrisons has also committed that by 2025, it will recycle and reuse the equivalent amount of plastic it puts on to the market within its own recycling facilities, to develop greater recycling in the UK (17).	7 Plastic and packaging pledges (20)	part of 'Plan A' sustainability strategy (27) Plastics Plan- 5 Plastic Principles - **Refuse, Redesign, Reduce, Reuse** and **Recycle**	We're aware that plastics and packaging are important areas of concern to our members, and that's why we launched our ambitious plan to make all Co-op branded packaging easy to recycle as part of our **Action on Plastics plan** when we launched our **Future of Food ambition in 2018.** Packaging has a place, it protects our food and keeps it fresher and safe for longer. But we want to keep it in the economy and out of the oceans by using less and making our products easy to recycle. Our approach to recycling is about looking at the entire chain, from manufacture to waste management, taking into account the impact on shelf-life, to minimise the impact overall (39).
Additional comments		Plastic trays are being removed from asparagus and sweetcorn (144 tonnes); cream pots (114 tonnes); tomatoes (102 tonnes); carrots (38 tonnes); and herb pots (18 tonnes). Plastic has already been removed from organic bananas, easy peeler citrus fruit and single loose cauliflowers and brassicas (8). PVC and polystyrene trays will be replaced with recyclable alternatives (1213 tonnes) Plastic film on fruit and vegetables will be replaced with a recyclable alternative (2518 tonnes) by end 2020 (8).	Packaging plays a vital role in protecting goods and keeping food fresh for as long as possible. But increasingly, consumers want to see fewer single-use plastics, especially when it comes to fresh produce (14).	Recognise the role packaging plays in preventing food waste, and states replacing plastic with another material should not result in an overall increase in carbon (16).	"in january 2021 Aldi became the first UK supermarket to replace all plastic on its soft drinks cans with 100% recyclable FSC certified cardboard sawing nearly 11 million pieces of plastic a year (90 tonnes)" - Note - this is not in line with plastics pact and the packaging related waste and carbon emissions will most likely have gone up.		
Produce bags	Removed in 2020 (51).	No lightweight plastic bags (9) - byo or recycled reusable @30p, paper for bakery products (7)	Option to buy reusable (14)	Paper (17)	-	-	-

Table A10 Detailed Retailer Spreadsheet 4/6

	Lidl	Iceland	Waitrose	Ocado
3. **70%** of plastics packaging effectively **recycled or composted**	no real mention of this in particular	n/a	No mention.	Take carrier bags back for recycling
4. **30% average recycled content** across all plastic packaging.	" By 2021, 30% of own label plastic packaging to contain recycled content (Complete)." (21) (note - this is an ambiguous statement)	n/a	Not much on recycled content - ready meal trays are now recycled from PET bottles	We frequently review our own-label range and make continual improvements to its recyclability and recyclable content.
Differences to UKPP		Aim is to eliminate all plastic	A small number of compostable wrappers were observed during the audit - not in main policy though.	Very little info other than part of UKPP
Strategy	'Circular motion' strategy - **Reduce, Recycle, Reuse, Engage, Collaborate (21)**	**#TooCoolForPlastic**	Plan Plastic (fund). 'Taking Action on Plastics' (44),	
Additional comments	When making packaging decisions, our buying teams carefully balance shelf life (and in turn customer safety ,product protection and food waste) and carbon miles ,with the negative consequences associated with plastic product on and waste (22).	.4 Minimise or remove packaging without creating more food waste or compromising food safety (25)	Aware of and discuss in the Unpacked report (41). "In 2019 we will work further with our customers to determine which plastic packaging can be removed without decreasing quality and reducing shelf life to make sure that we don't increase food waste." (42)	
Produce bags	First retailer to introduce reusable produce bags in 2019 (and also to eliminate black plastic from fruit and veg in 2018 (21).	-	We are replacing loose fruit and veg bags with home compostable alternatives by spring 2019 (42)	

Table A10 Detailed Retailer Spreadsheet 5/6

	Tesco	Sainsbury's	Asda	Morrisons	Aldi	M&S	Co-op
Acknowledges packaging prevents food waste?							
Black Plastic / PVC / PS	Don't use.	Working on, making progress (48)					
	Tesco	**Sainsbury's**	**Asda**	**Morrisons**	**Aldi**	**M&S**	**Co-op**
Other running themes							
Plastic / Packaging reduction target	50% packaging weight by 2025.	50% Plastic by 2025	3bn pieces removed by 2025	50% of plastic by 2025 (set in 2017).	Plastic 50% by 2025 (set in 2019). packaging 50% by 2025 (set in 2015).	30% in volume plastic 2027; 5% yoy target (28)	15% by the end of 2022 (2018) (39)
Other initiatives	Removal of meatpads (6).	Investigating 'prevented ocean plastic' (48)				Working with the Plastic Bank (28)	
Food Waste							
Courtauld 2030 signatory? Food Waste: To deliver against UN SDG 12.3: a 50% per capita reduction in food waste by 2030 vs the UK 2007 baseline (covering manufacture, retail, hospitality and food service, and household).	Y	Y	Y	Y	Y	Y	Y
Own policies	Member of Champions 12.3 , and actively working on projects own, suppliers, customers (10) report food waste annually (11) Engaged with Hubbub (12).	Reduce food waste by 50 per cent by 2030 (12) Support 12.3 and the WRAP food waste road map (48).	Reduce it (food waste) by 20% by 2025 and halve it by 2030	By 2030, we aim to have cut it by 50% against a 2016 baseline (18). Across the supply chain. Redistribution, field, Milk. Unsold Food Programme (19).	Food waste is an urgent environmental and social issue. We have committed to reduce food waste by 20% by 2025, and halve it by 2030 (relative to 2017 baseline). partners, we are also committed to the UN Sustainable Development Goal 12.3 to halve, per capita, global food waste by 2030. This goal has vital importance to reduce the environmental impact of wasted food, and to help alleviate food poverty (21).	We have committed to reduce food waste by 50% by 2030 relative to a 2017/18 baseline in our M&S operated stores in the UK and to redistribute 100% of edible surplus food by 2025. We are also signatories to Courtauld 2025 where tackling food waste across the industry is one of its priorities. We are signatories to UN sustainable development goal 12.3, where we are committed to reducing our food waste by 50% by 2030 against a 2017/18 baseline. (33,34)	2021 target - We will reduce food waste generated in our stores and depots by 50% by 2030 compared to 2015 (39).
Document number in:Greenwood, Sarah. 2024. "Fresh Produce on the Loose." OSF. May 11. osf.io/m72un	1,3,4,6,10,11,12,46,47, 51, 94,102	7-9, 12a, 13, 48, 49, 76	14, 15, 60, 61, 86, 89	16-19, 83, 95, 101	20, 20a, 65, 72, 74	27-34, 50, 69, 77, 82, 85, 87, 88	35-39a, 70, 73, 75, 79, 80, 91, 92

Table A10 Detailed Retailer Spreadsheet 6/6

	Lidl	Iceland	Waitrose	Ocado
Acknowledges packaging prevents food waste?				
Black Plastic / PVC / PS				
	Lidl	**Iceland**	**Waitrose**	**Ocado**
Other running themes				
Plastic / Packaging reduction target	Plastic 40% - own label products by 2025 (set in 2017) Packaging - 25% ol by 2025 (set in 2019)	Plastic 100% by 2023	Plastic 50% by 2025	
Other initiatives			Remove plastic toys from our Christmas crackers by 2020. - eliminate glitter from our own-brand cards, tags, wraps, crackers and flowers by Christmas 2020	Ocado own brand packaging overhaul will avoid 27 tonnes of plastic a year, including removal of nets
Food Waste				
Courtauld 2030 signatory? Food Waste: To deliver against UN SDG 12.3: a 50% per capita reduction in food waste by 2030 vs the UK 2007 baseline (covering manufacture, retail, hospitality and food service, and household).	Y	Y		Y
Own policies	Reduce food waste per store by 25% by 2020 and 50% by 2030, in line with SDG 12.3 (By 2020 ensure all major suppliers adopt a target, measure, act approach to reduce food waste and commit to a 50% reduction by 2030.) Launch a dedicated campaign to inspire our customers to reduce food waste in the home) (23)	We are proud signatories to the Courtauld Commitment 2030, which has brought together organisations across the food industry to reduce the environmental impact of food and drink, with the shared target of reducing the UK's food and drink waste by 50% by 2030. Iceland is also a signatory to the WRAP/IGD Food Waste Roadmap, and we signed the Government's 'Step Up To The Plate' pledge in May 2019. In line with the UN's Sustainable Development Goal SDG 12.3, we have set ourselves a target to achieve a 50% reduction of food waste in our own operations by 2030, with 2017/18 asour baseline year (26).	We will halve food waste in own-brand supply chains and help halve customers' food waste, both by 2030. (45) By 2030 Waitrose will reduce operational food waste by 50% against a 2018 baseline .	Boast low levels already but working towards Zero - tends to be focussed around own operations
Document number in:Greenwood, Sarah. 2024. "Fresh Produce on the Loose." OSF. May 11. osf.io/m72un	21-23, 53-55, 62, 97-99	24-26, 56-59	40-45, 78, 90, 93, 103	52, 63-64, 71, 96, 104

Table A11 Acknowledgement of hygiene, safety, protection, convenience and food waste by retailers

Retailer	Hygiene	Safety	Protection	Convenience	Food waste		Ref (Downloaded documents)*
Aldi	-	-	Y	-	**Y**	Plastic packaging plays an important role in protecting products from damage, making sure that they can be transported easily, and helps reduce waste by preserving food for longer.	20, 20a, 65, 72, 74
Asda	-	(Y)	Y	(Y)	**Y**	Protect from damage - Our sustainability commitments; Packaging is used to protect, preserve and present; Packaging plays a vital role in protecting goods and keeping food fresh for as long as possible. And 'our sustainability commitments' suplier pdf. products so that they get to our customers in the best condition. It also helps us to reduce food waste, as part of our commitments to Courtauld 2025*. - Plastic Unwrapped. Safetly and **convenience** only in relation to carriers (Waste Better Planet), hence '(Y)' (but also mentioned in Wells 2008)	14, 15, 60, 61, 86, 89
Co-op	'-	**Y**	Y	-	(Y)	Packaging has a place, it protects our food and keeps it fresher and safe for longer 'packaging and recycling'	35-39a, 70, 73, 75, 79, 80, 91, 92
Iceland	-	**Y**	-	-	**Y**	We commit to ....Minimise or remove packaging without creating more food waste or compromising food safety. (Doing it right, commitment 4)	24-26, 56-59
Lidl		**Y**	Y	-	**Y**	We are acutely aware of the important role that packaging plays protecting food, keeping it safe and minimising food waste. Equally, we have long been committed to tackling the important issue of plastic waste and the detrimental impact that this is having on the environment; In addition to primary packaging, we use plastic packaging to ensure the safe and efficient transport of our products. (Plastics and Packaging Webpage); When making packaging decisions, our buying teams carefully balance shelf life (and in turn customer safety, product protection and food waste) and carbon miles, with the negative consequences associated with plastic production and waste. ('The Purpose of Packaging' webpage)	21-23, 53-55, 62, 97-98
M&S	Y	(Y)	Y	-	Y	All packaging must be sourced from suppliers who are cost effective, innovative and technically competent. UK Packaging suppliers must be accredited to the BRC/IOP 'Hygiene Standard for Packaging Suppliers'. "We need packaging to help us get our products to our stores, and to ourcustomers, safely. Packaging plays a significant role in keeping our food fresh,reducing waste...." (27)	27-34, 50, 69, 77, 82, 85, 87, 88
Morrisons	-	**Y**	Y	(Y)	Y	The purpose of packaging is to contain and protect the product throughout its life. Food safety, protecting the products from damage and preserving shelf life is the priority of the packaging; (Plastic and Packaging policy). 4.2. Packaging optimisation - Good packaging uses the minimum amount of material required to protect the product and present it **in a format suitable to meet the customer's needs.**	16-19, 83, 95, 101
Ocado	-	-	-	Y	-	"It's so important to us that we are able to delight customers through our range, value and **convenience** but we also recognise the importance of ensuring our impact on people, animals and the environment is positive and sustainable in the long term," said Laura Harricks, chief customer officer at Ocado Retail.	52, 63-64, 71, 96, 104
Sainsbury's	-	-	(Y)	-	(Y)	Packaging helps us deliver fresh, undamaged produce, but we know that it can have a negative impact on our planet. (Plastic - Sainsburys.pdf)	7-9, 12a, 13, 48, 49, 76
Tesco	-	-	Y	-	**Y**	We recognise the importance of packaging to protect the quality of our products(reducing the environmental impact of our packaging), Packaging plays an important role in protecting products and reducing food waste. (packaging factsheet)	1,3,4,6,10,11,12,46,47, 51, 94,102
Waitrose	-	-	Y	-	Y	Plastic serves several important functions in retail, including protecting products from damage in transit and helping preserve food for longer.	40-45, 78, 90, 93, 103

*Document number in: Greenwood, Sarah. 2024. "Fresh Produce on the Loose." OSF. May 11. osf.io/m72un