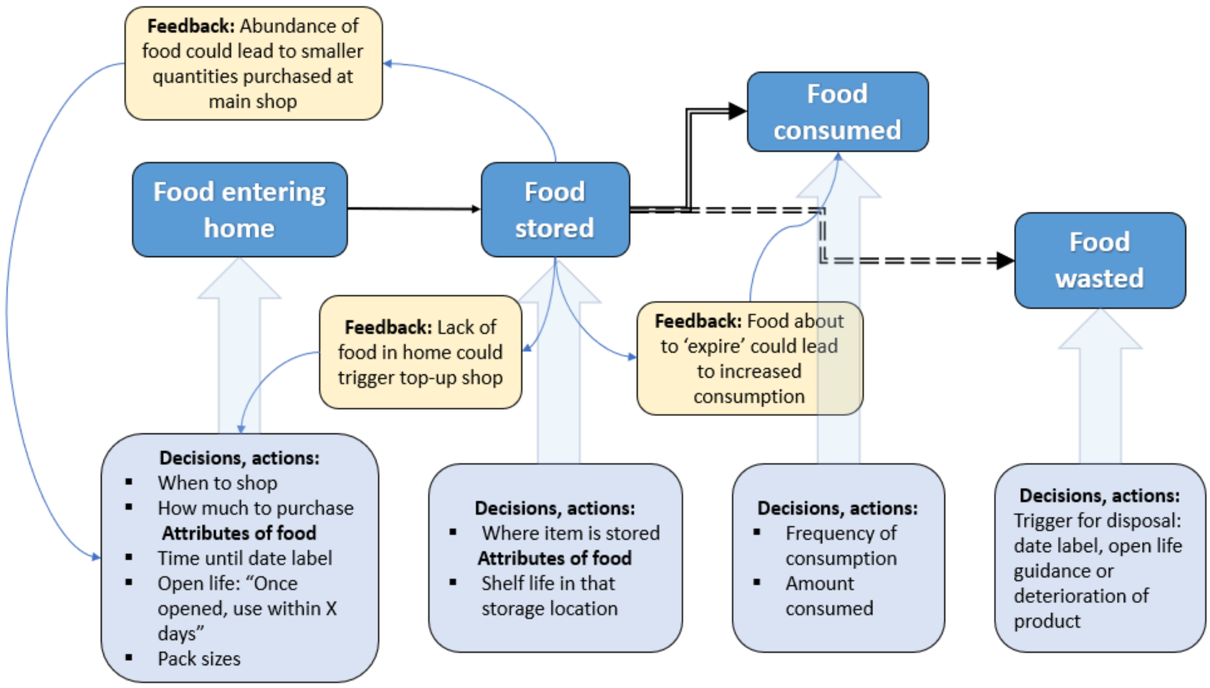
Final Report

Helping people to reduce fresh-produce waste: **Modelling the impact of selling products loose or in packaging**



Investigation into the impacts on food waste in the home from selling fresh fruit and vegetables loose or in packaging

Project code: POS102-002

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Written by: Tom Quested, Rachel Devine, Estelle Herszenhorn, Helen White, Griff Palmer, Jake Jasper (WRAP)

Front cover photography: Schematic of the household simulation model

Executive summary

This report is one of three describing a programme of research which investigated how the selling of fresh fruit and vegetables loose or in packaging can impact household food waste (HHFW).

This report focuses on modelling that seeks to answer the central research question of this work: how is food waste in the home impacted by selling fruit and vegetables in packaging or loose?

Why are we doing this research?

Plastic pollution and food waste are prominent environmental issues that have each risen up the social and political agendas in recent years. Plastic pollutes nearly every ecosystem on the planet, damaging wildlife and our life-support systems. With up to 40% of global food production being wasted, food waste is also an important challenge of our time. Producing food that becomes wasted takes agricultural land equivalent in area to China. The food that is wasted has a greenhouse gas footprint larger than any country bar the USA or China. Furthermore, in nearly every country with accurate data, *households* are the single largest source of food waste. Data for the United Kingdom (UK), where this research focuses, indicates that approximately 70% of post-farm gate food waste comes from households.

One of the barriers to removing plastic packaging from items is that this change could impact on levels of food waste. Packaging has the potential to extend the shelf life of certain food items and thereby reduce food waste. Conversely, selling some fresh produce items loose (and at appropriate price points) could reduce food waste, by enabling people, such as those who live in single-person or smaller households, to buy the quantity they need.

So, does packaging increase or decrease food waste in the home? Until now, this has been a substantial evidence gap. This report tackles this, investigating whether selling certain fresh-produce items loose would lead to a rise or decline in food waste in the home and provides a basis to update WRAP/Defra/FSA Food labelling guidance on this subject. It is important to note that this report does not quantify the effects of selling loose on any changes in food waste, packaging or emissions in the supply chain.

What research did we do?

This research used innovative modelling – using the Household Simulation Model developed by WRAP and the University of Sheffield – to estimate the effects of selling packaged or loose fresh produce on household food waste (HHFW). This modelling uses an approach called discrete event simulation to simulate the journey of food through the home, including how much is wasted. It can investigate how actions and decisions by households, alongside attributes to the food, impact the amount of food waste.

In addition, the modelling was able to evaluate the relative contribution of individual factors associated with the removal of packaging: change in shelf life, removal of the date labels; and changes in the quantities that can be purchased.

Building on these results, quantitative estimates of the greenhouse gas (GHG) emissions relating to the food waste and packaging were made. This involved collating data from the literature and previously published reports. Other environmental impacts associated with the food waste and packaging were discussed qualitatively.

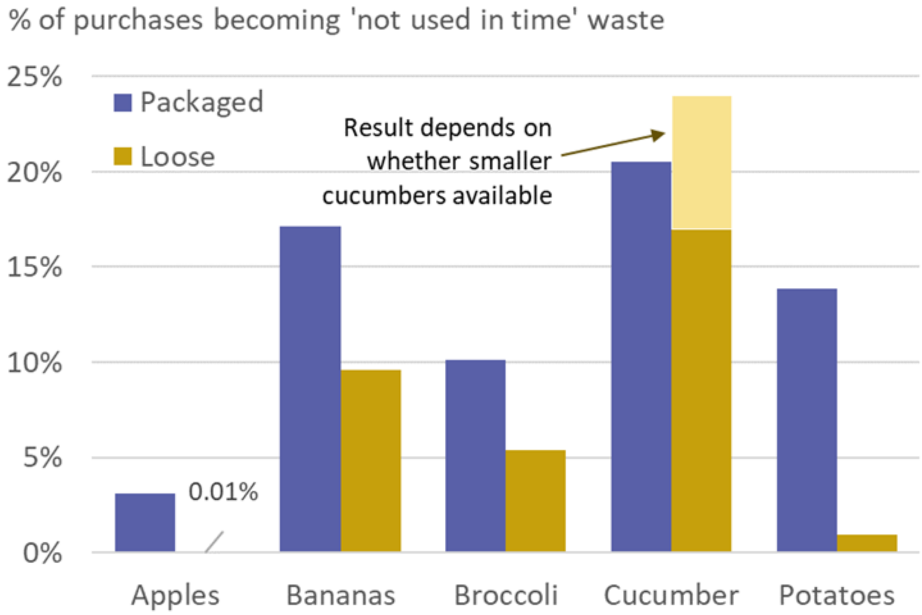
The research focuses on fresh, uncut fruit and vegetables – frequently sold packaged in the UK, but with the potential to be sold loose. Five types of fruit and vegetable were modelled: apples, banana, broccoli, cucumber and potatoes. These were chosen as they contribute greatly to HHFW in the UK and show diverse characteristics relevant to this project: for example, a range of shelf lives, pack sizes and consumption patterns in the home.

New data collection was undertaken, specifically designed to support the modelling. This included experiments to determine the shelf life of relevant food items, and how the shelf life is influenced by packaging. A second report investigates how people interact with date labels and the presence of packaging, and the extent to which they influence when people choose to dispose of the five types of fresh produce modelled in this report. The research also benefited from an in-store survey providing a snapshot of how these products are currently sold in the UK, as presented in this report. In addition, the research drew heavily from extensive HHFW research in the UK over the last 15 years undertaken by WRAP and other organisations.

What did the research find?

The modelling predicts that selling four of the five products loose, rather than packaged, would reduce HHFW (Figure ES1). **For apples, bananas, broccoli and potatoes, the predicted level of 'not used in time' HHFW for loose is substantially lower than for packaged items.** For cucumber, the result is less clear cut and depends on whether smaller cucumbers (half-sized or cut half-cucumbers) are available when cucumbers are sold loose. If these smaller cucumbers are available, the research predicts a modest decrease in HHFW; if not available, a modest increase.

Figure ES1: Comparison of model predictions for packaged and loose items: level of 'not used in time' household food waste (expressed as a percentage of purchase)



The modelling focuses on 'not used in time' food waste, i.e., the food waste resulting from people throwing away food items due to either the level of deterioration they exhibit or because of a date label (or a combination of the two). It is assumed that waste of these products due to other reasons (e.g., personal preference, preparing or serving too much, accidents) would not be influenced by the presence or absence of packaging.

Three factors were considered in the project in relation to removal of packaging. Their effects and scale are illustrated in Table ES1:

- **Changes in shelf life**: this is the least important of the three factors modelled. For three of the five products (apples, cucumbers and potatoes), shelf-life experiments suggested no detectable difference in shelf life between the loose and packaged variants of the product. Therefore, for these products, there is no change in HHFW as a result. For bananas and broccoli, the loose products did have slightly shorter shelf lives than the packaged products, which increases modelled HHFW by around a fifth in each case.

  Therefore, a key finding of this research is **that the preservation qualities that might have been previously believed to have been important for HHFW prevention are small compared to other factors**.

- **Removal of Best Before (BB) dates**: this factor decreases HHFW for all products except for bananas, which rarely carry a BB date in the UK. The magnitude of the impact on HHFW is remarkable, given that – in line with results from recent research with citizens – we have assumed that a small minority of the population use the BB date as a disposal date. Although there is uncertainty about the exact prevalence of this behaviour, these results demonstrate that a change affecting a small proportion of the population can have a significant impact on HHFW.

Therefore, one of the key findings of this research is that **the removal of Best Before dates has the potential to reduce food waste, irrespective of whether the item is packaged or not**. This recommendation should be considered in conjunction with the limitations of the research, as discussed in Section 8.4.

- **Change in pack-size options**: for apples, bananas and potatoes, **allowing people to buy an amount appropriate for their needs (rather than the smallest currently available pack) greatly reduces HHFW, and has the largest impact on HHFW for these three products**. This disproportionately benefits single-occupancy households: for packaged items, the smallest pack size was often much greater than a single-occupancy household generally consumes before the items start to deteriorate in quality. For broccoli, it was assumed that amounts purchased are not affected by whether the product is loose or packaged. For cucumbers, it depends on the size range of cucumbers available, as mentioned above.

  While HHFW could be reduced by providing smaller pack sizes for smaller households, this would not take the opportunity to reduce the environmental impacts relating to the removal of packaging.

Table ES1: Predicted impact on 'not used in time' HHFW of selling loose (final row), and effects of individual changes (first three rows), percentage point difference

Change:	Difference in HHFW compared to packaged, expressed as percentage-point difference				
	Apples	Bananas	Broccoli	Cucumber	Potatoes
Change in shelf-life from packaging removal	0.0 pp	+3.3 pp	+1.9 pp	0.0 pp	0.0 pp
Removal of BB date	-0.8 pp	0.0 pp	-7.1 pp	-3.5 pp	-4.5 pp
Change in pack-size options	-2.7 pp	-9.9 pp	0.0 pp	0.0 pp (or +7.2 pp)*	-8.8 pp
Selling loose (All three changes combined)**	**-3.1 pp**	**-7.5 pp**	**-4.7 pp**	**-3.5 pp (or +4.0 pp)***	**-13.0 pp**

*0 pp / -3.5 pp if smaller (half-sized) cucumbers available loose; +7 pp / +4.0 pp if no smaller cucumbers available

**This is not simply the sum of the three changes above: this scenario includes interactions between all three changes

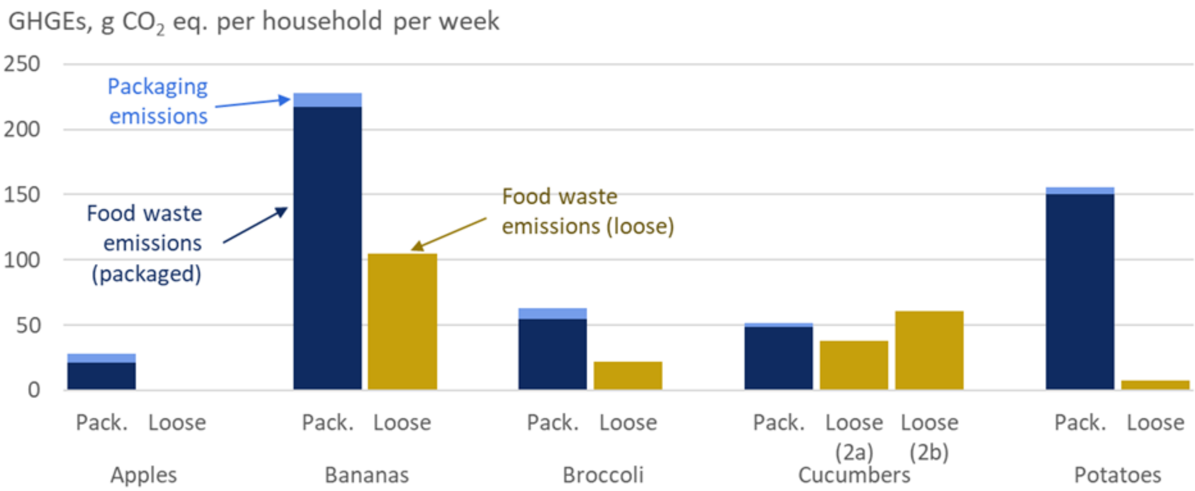
What are the environmental impacts of packaging and HHFW?

There are a range of environmental impacts relating to food and packaging. This report investigates greenhouse gas (GHG) emissions quantitatively, and explores other impacts qualitatively.

Figure ES2 illustrates the lack of trade-off for greenhouse gas emissions between packaging and HHFW. For most of the products, the GHG emissions associated with

HHFW are much higher for the packaged scenarios. The exception is for cucumbers: specifically comparing the packaged scenario with the loose scenario in which smaller cucumbers are not available (scenario 2b). In this case, total emissions are higher for the loose scenario, even when accounting for packaging emissions in the packaged scenarios. Therefore, selling the apples, bananas, broccoli and potatoes loose would reduce HHFW, while also removing single-use plastic packaging. Both of these elements would contribute to lower GHG emissions, alongside other environmental benefits.

Figure ES2: Estimated Greenhouse Gas (GHG) emissions for packaged and loose scenarios, splitting emissions relating to packaging and HHFW



The estimates of GHG emissions indicated that, where a product is packaged, the contribution of the packaging is relatively minor in comparison to any HHFW. From the average of all the scenarios modelled in this report across all the products, the packaging contributed approximately 10% of the GHG emissions; HHFW contributed 90%. Therefore, the scenario with the lowest combined GHG emissions was – in the cases modelled – that with the lowest HHFW (Figure ES2).

For loose items, the GHG emission calculations assume that these items will be carried home using existing bags (or other receptacles). Therefore, if additional bags or other receptacles are required to transport these items to people's homes, this would increase the GHG-emission estimates for the loose scenarios. However, as the GHG emissions from packaging are much lower than for the food itself, this is unlikely to affect the conclusions.

In addition to GHG emissions, there are other substantial environmental impacts associated with food waste and packaging. Food waste is associated with land and water use, biodiversity loss and eutrophication of water bodies and acidification. Plastic packaging is associated with aquatic and terrestrial pollution, disrupting ecosystems and threatening the life-support systems we rely on. As for GHG emissions, because of the nature of the results, there is no trade-off relating to these impacts for apples, bananas, broccoli and potatoes.

This analysis (as with the HHFW analysis in Table ES1 and Figure ES1) does not consider differences in the supply chain between scenarios. For instance, selling loose versus packaged could lead to different levels of food waste in the supply chain and different amounts of supply-chain packaging required. It is important that the environmental impacts of these elements are also considered in decisions relating to selling packaged or loose. When viewed through a lens of GHG emissions, reducing the overall food waste (supply chain and household) will likely minimise overall emissions. However, plastic pollution is also important, so designing product and packaging systems that also eliminate plastic pollution while keeping levels of food waste low would be ideal.

Can we infer anything for fruit and vegetable products not modelled here?

Quantitative results would require relevant input data and modelling. However, understanding whether HHFW is likely to increase or decrease when a product is sold loose, rather than packaged, is possible. This can be achieved by considering the three effects presented in Table ES1. The report considers oranges as an example, concluding that – when combining these effects – HHFW for oranges would likely decrease if they were sold loose because, like many fresh produce items, household waste levels will be influenced by the quantity that suits a household being available. The removal of any Best Before date from oranges would also help lower the amount wasted.

The five items selected for modelling were chosen in order to help provide a representative range of features of many products in the fresh produce category, in order that the findings help identify useful principles for the category. Given this, the findings indicate that, for many types of fresh produce, selling loose is unlikely to increase HHFW, so, there is an opportunity to reduce the use of single-use plastic without the unintended negative consequences of increasing HHFW. However, there will be exceptions: for instance, berries and other soft fruits were not modelled in this study and the conclusions above are unlikely to apply to this sub-category.

What are the limitations of the study and what further research is planned?

This project is underpinned by innovative modelling and new data. These combine to provide novel insights. Nevertheless, the research has its limitations.

Firstly, the Household Simulation Model captures many of the behavioural dynamics of real households with regard to food purchasing, storage, consumption and waste. However, it cannot capture *all* of the nuances of real households with regard to their actions and decision making. Therefore, comparing scenarios allows assessment of the *approximate* effect on HHFW of the differences between the scenarios.

Secondly, the modelling is based upon input data. This has been sourced from a range of datasets, each providing the most appropriate data available. In some cases, the data required transformation to obtain inputs for the model. This could introduce uncertainty. For instance, the process of converting survey results into the proportion of the population influenced by Best Before dates in their disposal decisions required subjective judgement. In this instance, we cross-checked the information from multiple sources; in most cases, the two sets of results were consistent. Nevertheless, there is uncertainty in this key input data.

Some of the input data was for a specific variety of fruit or vegetable, specifically, shelf life data was obtained for Royal Gala apples and Estima potatoes. These varieties were chosen to be typical of a wider range of products. Other data was from snapshot studies: for example, data on types of packaging in-store came from November 2020, and the results could have been influenced by changes relating to the Covid-19 pandemic.

To explore the extent to which these limitations affect the conclusions drawn from the research, sensitivity analyses were conducted for several important factors to assess the degree to which the results depend on decisions made in the project. These analyses suggest that the results may be influenced to a small degree by assumptions made and uncertainty in input data. However, given the large differences seen between packaged and loose scenarios for four of the five products, the conclusions presented in this report are unlikely to be influenced by these limitations.

What are the implications of these results?

Given these results, should businesses increase their offering of fresh, uncut fruit and vegetables sold loose? What other changes should be made on the basis of this new research?

The results suggest that selling uncut fresh produce loose, could decrease HHFW and eliminate single use plastic packaging of these items, simultaneously. However, there are some important provisos relating to this change:

Firstly, the decision-making process should consider waste and material use *in the supply chain*. As mentioned above, substantial increases in supply-chain food waste could lead to higher overall environmental impacts. Therefore, measurement of waste in supply chains is important, with this evidence analysed alongside estimates of HHFW.

Furthermore, to sell more fresh produce loose would require changes throughout the supply chain. As with any change in a complex system, there would be challenges to overcome. Changes in the supply chain could include to the varieties of fruit and vegetables sold and how they are transported from producer to stores. Challenges in-store include ensuring products can be identified in the absence of packaging and managing stock-rotation.

The relationship with customers is also central: ensuring that there is an appropriate range of fruits and vegetables that can be purchased in a way that is convenient and meets their needs. In particular, consideration of how customers can transport loose fresh produce to their homes easily, without introducing damage, and using receptacles that are reusable.

Finally, there may be some products – not modelled here – where there *is* considerable shelf-life extension relating to the packaging. For instance, modified atmosphere packaging for bagged salad and ethylene inhibitors for strawberries. There are also cases where the packaging performs an important protection function to delicate items, for instance, berries. In such situations, the packaging may reduce food waste to a degree that the overall environmental impact is lower compared to loose. In such cases, the packaging should be designed to be readily reusable or recyclable within current systems.

Trials undertaken by Morrisons and Waitrose, discussed in the main body of the report, illustrate how many of these challenges can be overcome.

The results show that the presence of a BB date significantly affects a minority of people's decisions on whether to eat items of fresh produce. However, the modelling in this report indicates that, although affecting a small proportion of the population, disposal decisions based on the BB date can contribute greatly to HHFW. Therefore, the results suggest that selling uncut fresh produce without any date label could reduce food waste.

However, an important consideration relating to removing Best Before dates from fresh, uncut produce is whether date labels significantly influence when and how much people consume items. People may use date labels to a greater or lesser extent for a whole range of decisions. For example, on the one hand, people may use these dates to manage the food within their homes, helping them to eat up items before they go off. This dynamic could mean the Best Before date helps people to reduce household food waste in these instances. On the other hand, for some people, seeing an item in the home with a Best Before date in the near future could lead people to consider the quality deteriorating and reduce consumption, leading to more household food waste in these instances. Without reliable information on the extent of mechanisms such as these, these were omitted from the modelling.

The presence of the Best Before date could also influence how people purchase items in store. In addition, there could also be challenges relating to stock management in grocery stores. These points are discussed in Section 8.4 and were also examined in previous interrogation of evidence around fresh produce and date labels[1].

Removal of BB dates goes alongside other important ways to prevent fresh produce waste in the home. This includes taking advantage of longer shelf lives of products stored in optimal conditions. The scale of some of the opportunities for this are covered in one of the reports published alongside this one (The impact of packaging and refrigeration on shelf life).

For changes discussed in this section, updated WRAP/Defra/FSA Food labelling guidance for selling fresh, uncut fruit and vegetables will be available later in 2022, and will be developed with FSA and Defra and with input from industry via the Courtauld Commitment 2030 and the UK Plastics Pact. This builds on previous versions of the guidance to reflect the new research to maximise the reduction in HHFW and single-use plastic packaging. Therefore, in updating the recommendations on uncut fresh produce, consideration has been given to:

- For HHFW prevention: which products would give most benefit from retailing loose and removal of Best Before dates
- For reduction in single-use plastics: what is the best way to approach this and what might the scale and pace of change be

[1] *https://wrap.org.uk/resources/report/evidence-and-insights-informing-updated-guidance-aimed-reducing-fresh-produce*

https://wrap.org.uk/resources/case-study/evidence-review-plastic-packaging-and-fresh-produce

- For implementation of any change: what would need to be considered to enable changes, for retail supply chains and customers and where further information is needed on the impact of packaging and changes to date-labelling on supply chain waste and logistics
- In what situations it is not currently realistic to sell uncut fresh produce loose (e.g., certain berries).

What is next in this area?

As discussed in this report, decisions on whether to sell fruit and vegetables loose need to consider the impacts in the supply chain, as well as the home. This report provides some much-needed data on the potential impacts relating to HHFW. WRAP encourages businesses to measure supply-chain food waste and packaging use. Together with information on the impact of selling packaged or loose on household food waste, this supply-chain information can be used by businesses to make decisions that are best for the environment overall.

The research methods used in this report could be applied to other types of fresh fruit and vegetables in the UK, especially those where there are significant differences from the products included in the current report (e.g., soft fruit). As part of future research, comparison of different packaging formats and functionality could be investigated. For example, the "Reducing plastic packaging and food waste through product innovation simulation" project[2] is using the Household Simulation Model, supported by a range of data gathering and research, to investigate situations in which plastic packaging can play a role in reducing food waste in the supply chain and the home.

Furthermore, the research could be applied to fresh fruit and vegetables in other countries where the issues in this report are also relevant. This could help to create tools that help a wider range of organisations around the globe to navigate these decisions, supporting plastic reduction and minimisation of food waste.

[2] *https://gtr.ukri.org/projects?ref=NE%2FV010654%2F1*

Contents

Glossary

Best Before (BB) date: "The best before date is about quality and not safety. The food will be safe to eat after this date but may not be at its best. Its flavour and texture might not be as good."[3] Importantly for this project, BB dates are not legally required on fresh, uncut produce. However, many such products do carry BB dates in the UK.

Fresh produce: fresh fruit and vegetables

GHG: greenhouse gas

Household food waste (HHFW): within the Household Simulation Model, household food waste is any food item purchased for human consumption but not consumed by humans. Therefore, it covers any food disposed of via the following routes: the general waste bin (residual waste), separate food-waste collections, mixed food and garden collections, via the sewer and home composting. The model also includes food fed to animals as a destination, which makes up a very low proportion of food not eaten as intended but is not classified as household food waste.

Household Simulation Model (HHSM): a modelling approach used in this report. It was developed by WRAP and is used to understand how food waste is influenced by a range of decisions and actions by householders alongside attributes of food, such as shelf life. The model simulates the journey of food into and through a home, focusing on 'not used in time' food waste (below). More details of the model can be found in Section 2.2.

Household (HH) archetypes: In the HHSM, there are seven HH archetypes, which are used to help account for the variation between households in the UK. These archetypes vary in number of occupants, age of occupants (and therefore amounts consumed), shopping habits, factors affecting disposal decisions and levels of risk relating to food. More details can be found in Section 2.2.3.

National Diet and Nutrition Survey (NDNS): a continuous programme of fieldwork designed to assess the diet, nutrient intake and nutritional status of the UK population aged 1.5 years and over.

Not used in time: food that has been thrown away because it has gone off (e.g., mouldy, mushy or rotten) or because it has passed a date label (e.g., 'use by' or 'best before').

Shelf life: as used in this report, the length of time after purchase that an item is still consumed. This varies by product, by storage location and between people (i.e., the point in the deterioration of a product when it is no longer consumed varies between people).

Unfulfilled requirements: a termed used in the Household Simulation Model whereby a householder would like to consume a food item, but there is none of that item in the household.

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[3] Food Standard Agency: https://www.food.gov.uk/safety-hygiene/best-before-and-use-by-dates, accessed 14th July 2021.

This report was published alongside two other closely related pieces of research, both on the topic of helping people to reduce fresh produce and dairy waste:

- **Citizen insights on the influence of packaging and date labels on disposal decisions**. Referred to as "The Citizen Disposal Decision Report" for short.
- **The impact of packaging and refrigeration on shelf life**. Referred to as "The Shelf-Life Report" for short.

These two reports can be accessed, alongside this report at: https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste

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We would also like to thank members of the industry task force, who provided valuable input to support this project. It should be noted that this report was not reviewed or approved by members of this group prior to publication.

We would also like to thank members of a previous project for development of the Household Simulation Model, without which, the research in this report would not have been possible: Christian Reynolds, Cansu Kandemir, David Evans, Lenny Koh (all Sheffield University at the time) and Karen Fisher (WRAP) – alongside current authors Tom Quested, Rachel Devine and Estelle Herszenhorn.

1.0 Introduction

1.1 What's driving this project?

Plastic pollution and food waste are prominent environmental issues that have each risen up the social and political agendas in recent years. Since the airing of the BBC documentary series *Blue Planet II* in late 2017, images of plastic – often plastic packaging – polluting and damaging almost every ecosystem on our planet have been burnt on to the public consciousness. In parallel, the issue of food waste has been gaining global prominence since the publication of the 2011 United Nations report[4]. It is estimated that up to 40% of food produced is wasted[5,6]. Of note for this report, in nearly every country with accurate data, households are the single largest source of food waste[7]. Data for the UK, where this research focuses, indicates that approximately 70% of post-farmgate food waste comes from households[8].

Reflecting these challenges, programmes are in place to deliver solutions. In the United Kingdom, the UK Plastics Pact is transforming the way that the UK makes, uses and disposes of plastic, moving away from a linear plastics economy towards a circular system where we capture the value of plastics material – keeping plastic in the economy and out of the oceans. Launched in 2018, the UK Plastics Pact brings together governments, businesses, local authorities, citizens and NGOs behind a common vision and commitment to a set of ambitious targets:

- Eliminate problematic or unnecessary single-use packaging through redesign, innovation or alternative (re-use) delivery models
- 100% of plastics packaging to be re-usable, recyclable or compostable
- 70% of plastics packaging effectively recycled or composted
- 30% recycled content across all plastic packaging

In parallel, the UK has committed to achieving Sustainable Development Goal (SDG) 12.3, and, to reflect that, Courtauld 2030 has a target to reduce food waste (post-farm gate) by 50% per person by 2030 against a 2007 baseline. The Courtauld Commitment brings together organisations from across the UK food system to make food and drink production and consumption more sustainable. At the heart of this voluntary agreement is a commitment to identify priorities, develop solutions and implement change to cut the waste and greenhouse gas emissions associated with food and drink, and protect critical water resources. To help deliver the Courtauld food waste target, WRAP and IGD have developed and led the Food Waste Reduction Roadmap, which is an industry-wide

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[4] Global food losses and food waste: extent, causes and prevention. FAO (2011) http://www.fao.org/3/i2697e/i2697e.pdf

[5] *Driven to Waste: Global Food Loss on Farms, WWF and Tesco. https://wwf.panda.org/discover/our_focus/food_practice/food_loss_and_waste/driven_to_waste_global_food_loss_on_farms/*

[6] *UNEP Food Waste Index Report, 2021. https://www.unep.org/resources/report/unep-food-waste-index-report-2021*

[7] UNEP Food Waste Index Report 2021, UNEP (2021) https://www.unep.org/resources/report/unep-food-waste-index-report-2021

[8] Food surplus and waste in the UK – key facts, WRAP (updated 2021): https://wrap.org.uk/resources/guide/waste-prevention-activities/food-love-waste-data

programme of work to equip food businesses to work towards UN Sustainable Development Goal 12.3.

Eliminating plastic pollution and reducing the amount of food that is wasted would have profound positive impacts: for our ecosystems, the climate and for our own health. Reflecting this, efforts around the world to tackle these two problems are ramping up. However, one common narrative suggests there may be a trade-off between the two issues under certain circumstances: specifically, that plastic packaging can extend the shelf life of food items and thereby reduce food waste.

Until now, there has been a substantial evidence gap relating to this narrative: how plastic packaging influences food waste in the home. This reflects the challenges in undertaking trials and evaluating the impact of interventions on household food waste (HHFW). This report tackles this evidence gap: building on new data on the shelf life of packaged and unpackaged products, and estimating the impact on food waste in the home using an innovative modelling approach.

The influence of packaging will vary between different types of food. This report focuses on fresh fruit and vegetables sold in the United Kingdom (UK), where there is the potential for the trade-off described above. We concentrate on five items: apples, bananas, broccoli, cucumbers and potatoes. These five represent foods that are highly wasted in UK homes and have different 'dynamics' associated with them: they are purchased in different quantities, have different lengths of shelf life and are used in different ways in the home. The results are discussed with regard to what they can tell us about other fresh-produce items not investigated here (e.g., oranges and onions).

The results not only illustrate the impact of selling loose but the research also is able to illustrate the impact of each individual effect relating to the presence or absence of packaging. Food waste in the home could be influenced by changes in shelf life influenced by the packaging, information provided on the packaging (including date labels) and the pack sizes available for packaged products. Although the results focus on packaging and food waste in the UK, many of the findings in this report will be applicable to other countries.

This report discusses previous research and activity in this area (Section 1.2). The evidence gaps found from that review are described in Section 1.3, alongside an overview of the elements of the project (Section 1.4).

Chapter 2.0 details the methodological approach adopted for this report, including the rationale for the choice of products, an overview of the Household Simulation Model, the data sources used for the modelling and the calculations relating to greenhouse gas emissions.

Chapters 3.0 to 7.0 present background information, specific methodological points, results, discussion and conclusions for each of the five products investigated: apples, bananas, broccoli, cucumber and potatoes. Appendix 2 presents the results of the greenhouse-gas-emission calculations and discussion of the results with regard to environmental issues.

Chapter 8.0 summarises the results from the five products, drawing overarching conclusions and the implications for the sale of fresh fruit and vegetables with regard to packaging.

1.2 What do we already know?

This section summarises previous research and other activity relating to the intersection household food waste (HHFW) and packaging. It covers previous research on the links between packaging and HHFW (Section 1.2.1), life cycle assessments (LCAs) on this topic (Section 1.2.2) and results of previous trials by UK supermarkets to sell fresh produce loose (Section 1.2.3).

1.2.1 Previous research on links between packaging and HHFW

There are several *potential* mechanisms by which packaging could influence HHFW. These relate to many of the primary functions of packaging. The WRAP evidence review on plastic packaging and fresh produce[9] lists the following relevant factors:

- reducing deterioration and extending shelf-life
- preventing access to foreign bodies that would render food inedible
- protecting it from physical damage during transport and storage, and
- providing product dispensing or collating functions e.g. multi-pack.

The packaging can also be used to provide information for citizens purchasing these products, including storage advice and date labels. This section discusses the most relevant of these for this project.

To understand the general scale of packaging's influence on HHFW, Williams et al. (2012)[10] and Williams et al. (2020)[11] attempted to quantify the proportion of HHFW in Swedish households that is related to packaging, in the broader sense. In both studies households completed a questionnaire, food waste diary and were then interviewed about their food waste behaviours. Food items across several categories were included in both studies ranging from meat, fish, dairy and fresh produce (including apples, bananas and cucumbers in the 2020 study).

Williams et al. (2012) found that around 20-25% of households' food waste was related to packaging, pack sizes and information on packaging. In their 2020 study, this rose to 36% though more fresh produce items were included compared to the 2012 research. The top reasons for food waste related to packaging were: 1) packages that were too big, 2) packages that were difficult to empty and 3) food that was past its best before date. In the 2020 study, 76% of fruit and vegetable waste occurred because the 'food has gone bad' and this originated from participants purchasing more than they needed.

The proportion of UK HHFW associated with different reasons has been documented in detail. This includes results from kitchen diaries in which people could record the reason

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[9] *Evidence Review: Plastic Packaging and Fresh Produce, WRAP (2019): https://wrap.org.uk/resources/case-study/evidence-review-plastic-packaging-and-fresh-produce*

[10] *Williams, H. et al. (2012). Reasons for household food waste with special attention to packaging. Journal of Cleaner Production. 24. 141-148. https://doi.org/10.1016/j.jclepro.2011.11.044*

[11] *Williams, H. et al. (2020). Avoiding food becoming waste in households – The role of packaging in consumers' practices across different food categories. Journal of Cleaner Production. 265. 121775. https://doi.org/10.1016/j.jclepro.2020.121775*

food waste wasted[12]. The single largest reason for wasting food that could have been eaten is 'not used in time', where food has not been used before it has gone rotten, mouldy or has been thrown away because of a date label, accounting for 41% of edible HHFW in the UK. It is not possible to split out the root causes of this: it could relate to people purchasing more than they need, sub-optimal storage of items and/or how people use date labels. A proportion of this will relate to packaging (e.g., pack sizes, shelf-life extension, information on the packaging).

With specific regard to date labels, 16% of 'avoidable' food waste included mention of a date label of some type[12]. The value was 5% for fresh fruit and 10% for fresh vegetables and salad, both of which normally carry a Best Before date in the UK[13]. It may be that these values are under-estimates of the actual influence of date labels on disposal decisions: i.e., date labels influence disposal decisions for items recorded in the food-waste diaries where dates were not explicitly mentioned.

This topic was further explored in one of the accompanying reports[14]. This found that the presence of date labels on fresh produce greatly influenced the proportion of people disposing of items past that date. This, and previous research, indicates that a sizeable minority of the UK population use the Best Before date as a disposal date, incorrectly using it as a marker of food safety beyond which food should not be consumed. Similar results have been found for other countries where research of this nature has been conducted[14].

Wikström et al. noted that food waste for fresh produce could be influenced via the pack sizes available[15]. This is supported by analysis by WRAP that showed levels of food waste were highest – per person – for single-occupancy households[16]. Furthermore, more of the avoidable food waste from single-occupancy households was associated with 'not used in time' waste. This is consistent with qualitative research that suggests that a higher proportion of food waste in smaller households could be attributed to the pack sizes available, and how they are priced and promoted. For example, in 2019, bread sold in UK supermarkets was found to be 74% more expensive per kilogram for small loaves (400 grams) compared to larger loaves (800 gram)[17].

In the shelf-life experiment report published alongside this report, the literature review identified some information relating to the shelf life for loose and packaged products. These indicated that, for the five products included in this report, packaged versions of the product usually lasted longer. However, for some of the literature found, the

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[12] Household Food and Drink Waste: A Product Focus, WRAP (2014). https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf

[13] A Best Before date provides an indication as to how long a product will remain at its best quality, whereas a Use By date communicates how long a product is safe to consume. The same date labels are also used in the European Union.

[14] Citizen insights on the influence of packaging and date labels on disposal decisions, WRAP, 2022: https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste

[15] Wikström, F., Williams, H., Trischler, J., & Rowe, Z. (2019). The Importance of Packaging Functions for Food Waste of Different Products in Households. Sustainability 2019, Vol. 11, Page 2641, 11(9), 2641. https://doi.org/10.3390/SU11092641

[16] Household Food and Drink Waste: A People Focus, WRAP (2014): https://wrap.org.uk/sites/default/files/2021-02/WRAP-Household-food-and-drink-waste-A-people-focus-Report_0.pdf

[17] Retail Survey 2019, WRAP (2019): https://wrap.org.uk/sites/default/files/2020-08/Retail-Survey-2019.pdf

varieties of fresh produce, packaging and storage conditions were dissimilar to products sold in the UK. Furthermore, in most cases, the data presented was on a proxy measure for whether it would be eaten or rejected (e.g., moisture loss). Therefore, there was a need to undertake the shelf-life experiments described in that research report, designed to support the research in the current report. These found a different picture: for the six out of the ten combinations of product and condition tested, packaging provided no discernible shelf-life extension. For the other four combinations tested, packaging provided extensions to shelf life that ranged from modest (8% extension for refrigerated apples) to large (54% for refrigerated potatoes). Potential reasons for the apparent differences between the published literature and these more recent shelf-life experiments are discussed in *The impact of packaging and refrigeration on shelf life* (Section 4.1.1).

1.2.2 Life Cycle Assessments of packaging and food waste

Understanding the relative benefits and trade-offs between plastic packaging and food waste is crucial to be able to make informed decisions about selling fresh produce loose rather than packaged. To understand the environmental impact of food packaging, Life Cycle Assessments (LCAs) are often undertaken. However, food waste is rarely acknowledged and modelled in packaging LCA studies, nor is it considered in the packaging design phase[18]. This means that a packaging format that causes high food waste, but otherwise has a lower environmental impact, can appear to be more favourable than a packaging format that has high environmental impact but reduces food waste[19]. Fundamentally, LCAs often overlook the primary role of food packaging, which is to protect and preserve food.

Over the past few decades, the academic literature has demonstrated through specific case studies the importance of including food waste in environmental impact assessments of the food packaging system[20,21,22]. Since *household* food waste accounts for the greatest amount of food waste in the food system in most countries with reliable data[23], several authors have focussed on including consumer-level food waste within their LCA models[24].

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[18] *De Gama, L. (2019). Managing the incorporation of consumer food waste into the packaging development process: a cross case analysis of the UK packaged food sector. University of Portsmouth. PhD Thesis.*

[19] *Wikström, F et al. (2014). The influence of packaging attributes on consumer behaviour in food-packaging LCA studies—A neglected topic. Journal of Cleaner Production. 73. 100–108. https://doi.org/10.1016/j.jclepro.2013.10.042*

[20] *Williams, H., Wikström, F. (2011). Environmental impact of packaging and food losses in a life cycle perspective: a comparative analysis of five food items. Journal of Cleaner Production. 19. 43-48. https://doi.org/10.1016/j.jclepro.2010.08.008*

[21] *Hanssen, O. J. (1998). Environmental impacts of product systems in a life cycle perspective: a survey of five product types based on life cycle assessments studies. Journal of Cleaner Production. 6. 299-311. https://doi.org/10.1016/S0959-6526(98)00031-6*

[22] *Wikström, F., Williams, H., Venkatesh, G. (2016). The influence of packaging attributes on recycling and food waste behaviour – An environmental comparison of two packaging alternatives. Journal of Cleaner Production. 137. 895-902. https://doi.org/10.1016/j.jclepro.2016.07.097.*

[23] *UNEP Food Waste Index Report 2021,* UNEP (2021) *https://www.unep.org/resources/report/unep-food-waste-index-report-2021*

[24] *Wikström, F., Williams, H. (2010). Potential environmental gains from reducing food losses through development of new packaging–a life-cycle model. Packaging Technology and Science. 23 (7). 403-411. https://doi.org/10.1002/pts.906*

The most recent and comprehensive overview of LCAs for packaged food items that includes food waste is by Heller *et al.* (2018)[25]. The authors model the packaging of multiple food items including meat, dairy, salad leaves and some vegetables. The study evaluates all GHGs associated with the food, including production and processing, primary and tertiary packaging production, distribution, retail, transport to home, home refrigeration, packaging production, packaging waste disposal and wasted food and associated inedible parts. Their results demonstrate that the ratio of food production GHGs to packaging production GHGs differs for each product. Where the ratio is highest (e.g., cereals, meat, seafood and dairy) there is greater opportunity to reduce GHGs via packaging that is specifically designed to reduce food waste. Where the ratio is lowest (e.g., potatoes, spinach and ready-to-eat lettuce) there may be greater scope to remove packaging but *only* if there is no subsequent increase in HHFW.

The second phase of the study by Heller *et al.* (2018) is a scenario model that includes a hypothetical 10% reduction in food waste across all food items. This scenario demonstrates two things: 1) the need to include food waste in LCAs of food packaging, and 2) for some products, reducing food waste by just 10% would have a greater impact on reducing GHGs than simply removing plastic packaging (and the GHGs associated with producing the plastic packaging) from the equation. However, that study does not evaluate whether food waste would increase or decrease if items were instead sold unpackaged, and what the associated impact on GHGs would be.

In short, previous LCA studies on this topic have been hindered by the lack of quantitative information about the degree to which packaging – including pack sizes and on-pack information – influences food waste, especially in the home.

1.2.3 Retailer plastic-free trials

In response to the recent increase in citizen awareness and demand for more sustainable packaging options, there has been an increase in the number of retailers trialling "plastic-free aisles". These have mostly centred on fresh produce and dried goods such as cereals and pasta, though some retailers have also offered refill options for liquids such as cooking oil and household cleaning products. Two examples of packaging-free trials are those by Morrisons in 2018 and Waitrose in 2019. These are summarised below.

Morrisons trial: In 2018, Morrisons launched a 10-month packaging-free trial for fresh produce in their Skipton store in North Yorkshire[26]. The project was supported by WRAP and Defra and aimed to understand the impact on customer demand, costs, and waste by examining customer, colleague and supplier opinion. The trial involved several significant changes including increasing the number of fresh produce lines sold loose, displaying fresh produce in wooden crates, replacing plastic bags with recyclable brown paper bags for loose fresh produces and removing the plastic wrapping from cucumbers during the summer season.

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[25] *Heller et al. (2018). Mapping the Influence of Food Waste in Food Packaging Environmental Performance Assessments. Journal of Industrial Ecology. 23 (2). 480-495. https://doi.org/10.1111/jiec.12743*

[26] *Evaluation of a plastic-free/loose fresh produce trial. Morrisons Supermarkets - member of The UK Plastics Pact and Courtauld Commitment 2025. https://wrap.org.uk/sites/default/files/2021-03/morrisons_plastic_free_aisle_case_study_0_0.pdf*

Customer satisfaction was high and 72% of Skipton customers surveyed said that they preferred to buy loose rather than packaged fresh produce. The top three reasons stated by customers who preferred loose fresh produce were:

- Ability to choose the size/condition (95.5% agreed/strongly agreed)
- Buying the exact quantity needed (93.8% agreed/strongly agreed)
- It doesn't have plastic packaging (86.1% agreed/strongly agreed)

Overall, customers that participated in the research believed that they had less food waste in their homes when they purchased loose fresh produce. When asked about tomatoes, carrots, apples, onions, potatoes and broccoli, 59.4% of respondents who said they preferred to purchase fresh produce loose said they wasted none of the produce they purchased. Whereas 55% of customers who said they preferred to purchase packaged fresh produce also claimed to waste nothing.

Waitrose trial: In June 2019, Waitrose launched an 11-week "Unpacked" test in their Botley Road store in Oxford. The store removed packaging from more than 200 products moving to a "reduce, reuse, refill" model[27]. More than half of the product lines were fresh produce items, although several varieties of dried goods, frozen fruits and liquid cleaning products were also included in the trial. The aim of the project was to evaluate which products could be switched to packaging-free and to test if customers would be prepared to change their shopping habits. During the trial customer satisfaction was high and 72% said they were 'very satisfied' shopping Unpacked and 80% said they would be 'very likely' to shop Unpacked again.

Waitrose also gained further insight from customers about factors that are known to influence HHFW:

- In the absence of on-pack storage guidance and shelf-life information, many customers re-educated themselves on the best ways to prolong shelf-life of their food items through better food storage and increased planning.
- It was found that whilst customers care about reducing plastic packaging, one of the primary motivators for change was saving money, for example by buying the exact quantities.
- Anecdotally, food waste reduced at home as customers had the flexibility to buy what they needed.
- However, some customers highlighted that additional handling could spoil the fruit and vegetables.

The trial did not investigate whether the shelf life of fresh produce items is extended or reduced when sold Unpacked, and no specific comment was made on whether customers missed seeing the best before date.

Another finding was that in-store food waste increased at the start of the project when trying to understand the demand for loose produce compared to packaged. One

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[27] *Ethics and Sustainability Unpacked Report 2019/20, John Lewis and Partners.* *https://www.johnlewispartnership.co.uk/content/dam/cws/pdfs/Juniper/ethics-and-sustainability/John-Lewis-Partnership-Unpacked-Report-January-2021.pdf*

product with high levels of waste was soft fruits where more customers made the switch to Unpacked than was originally anticipated, which led to a surplus of pre-packaged items.

Both trials found evidence that selling a wide range of products – including most fresh fruit and vegetables – loose was a positive experience for most of their customers. There were challenges in the supply chain due to the changes made. There was no direct assessment made of the impact of food waste in the home, although self-reported information suggested that selling items loose may help people to buy the right amount for their needs and consequently waste less.

1.3 Evidence gaps and research questions

Previous research described in the above sections has demonstrated that packaging can influence food waste in the home, as well as in the supply chain. Existing LCA studies indicate that the degree to which packaging influences food waste could be one of the most important effects for many environmental indicators, most notably greenhouse gas emissions. However, as noted by Wikström et al.[15], the strength of this influence between packaging and food waste, especially food waste in the home, is not well understood for fresh produce (or most other products). No empirical measurement of the changes in HHFW during a change from selling packaged to loose (or *vice versa*) have been identified in the literature. Therefore, the magnitude of change or even the direction of change are not well understood. However, indirect information suggests that packaging-related factors could influence a sizable portion of HHFW.

Studies focusing solely on the potential shelf-life extension associated with packaging suggest that food waste in the home could *decrease* due to packaging. Other studies looking at a wider range of packaging-relating factors – such as pack sizes and presence of date labels – suggest that food waste in the home could *increase* due to packaging. Understanding the direction and magnitude of these effects is, therefore, of practical importance when understanding the full impacts of packaging.

This represents a large evidence gap, and this project seeks to provide the evidence to fill this gap, specifically: **what is the effect on household food waste of selling fresh produce loose and packaged?** Furthermore, the research investigates the environmental impacts for food waste and packaging, comparing loose and packaged scenarios.

As identified in previous studies and trials, the category of fresh fruit and vegetables is of particular interest. It represents a high proportion of HHFW in the UK. Most lines are currently packaged, but there is the potential for most items to be sold loose – indeed, many already are.

Previous research suggests that the effects may differ between various types of fruit and vegetables. Therefore, a range of fresh, uncut fruit and vegetables were selected for further investigation. The choice of fruit and vegetables studied in this report is discussed in Section 2.1.

In an ideal world, this research question would be investigated using trials, whereby items previously sold packaged would be sold loose (or *vice versa*) and the resultant change in household food waste measured. However, given the available budget, they were investigated via modelling, using the Household Simulation Model (HHSM). The HHSM was developed as a tool for analysing the impact of changes to product attributes and / or human behaviour on household food waste (HHFW). In particular, it focuses on 'not used in time' HHFW – that which has been thrown away because it has deteriorated in quality, felt to be unsafe or because of a date label. It is therefore well suited to this project. More details of the HHSM can be found in Section 2.2.

The preliminary stages of the project identified several mechanisms whereby packing could influence food waste in the home. These include:

- Pack size: influencing the minimum amount that can be purchased
- Shelf life: the length of time before the product starts to deteriorate
- Product damage: accrual of damage in the supply chain and in the home
- Best Before date: present on some packaged products, general absent on loose products
- Storage information: present on many packaged products, but absent from loose products

For the mechanisms in black (pack size, shelf life and Best Before date), there was a clear mechanism for these to influence food waste in the home. Furthermore, relevant data was either available or it was possible to obtain during the course of the project.

For product damage, data in the public domain is rare. In some cases, businesses in the supply chain have measured product damage. Supermarkets have records of their customers' complaints, in some cases being able to disaggregate those relating to product damage. Therefore, while it would be problematic for this project to include product damage, supermarkets may hold the relevant information, which they can include their decision-making.

At present, there is limited evidence to suggest that citizens have different storage behaviours when apples are sold packaged or loose. Whilst a large majority of citizens claim to read and follow food-storage guidance at home at least part of the time[28,29], when asked unprompted why they store foods the way they do, on-pack storage guidance is an uncommon answer[30]. Instead, storage habits are usually influenced by a range of factors including learned behaviours, common sense, and social norms such as storing fruit in a fruit bowl because it serves as a reminder to eat it[31]. Therefore, for the modelling in this report, we have assumed that the removal of packaging (and the

[28] *Helping Consumers Reduce Fruit and Vegetable Waste: Final Report, WRAP, 2008:* https://wrap.org.uk/sites/default/files/2020-10/WRAP-RTL044-001%20Final%20report.pdf

[29] *Reducing Food Waste Through the Chill Chain. Insights Around the Domestic Refrigerator and its Uses, WRAP, 2010:* https://wrap.org.uk/sites/default/files/2020-12/Reducing-food-waste-through-the-chill-chain-Insights-around-the-domestic-refigerator.pdf

[30] *Research into consumer behaviour in relation to food packaging, WRAP, 2008:* https://wrap.org.uk/sites/default/files/2020-12/Research-into-consumer-behaviour-in-relation-to-food-dates-and-portion-sizes.pdf

[31] *Consumer insights: date labels and storage guidance, WRAP, 2011:* https://wrap.org.uk/sites/default/files/2020-12/Consumer-insight-date-labels-and-storage-guidance.pdf

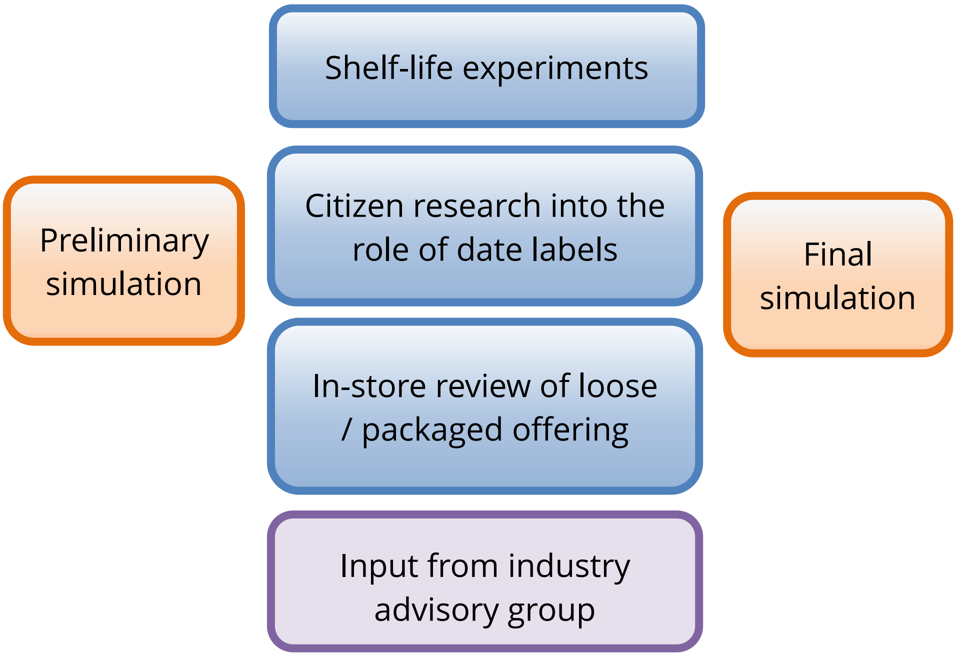
associated storage information) is unlikely to greatly alter where items are stored in the short term. Indeed, the previous trials (Section 1.2.3) demonstrated that selling items loose was an opportunity to communicate information in a different way: for example, using blackboards in-store. Therefore, selling items loose could be a 'moment of change': an opportunity to shift long-standing habits in a direction that helps minimise food waste.

For the reasons presented above, this research investigates three potential links between household food waste and packaging: via pack sizes, shelf lives and Best Before dates.

1.4 Project overview

Given the wide range of impacts of packaging on food waste, this project contains many elements. The project was run in three phases, illustrated in Figure 1.

Figure 1: Elements of this project



The project started with preliminary simulation using the Household Simulation Model (HHSM). This phase had two purposes:

- To assess whether the HHSM was capable of simulating the five products chosen to sufficient accuracy for the project
- To determine the data needs of the rest of the project: which input parameters required more accurate data.

The preliminary modelling demonstrated that the products could be adequately modelled but important data was lacking for many important inputs. These included the actual shelf life of the products, how this was influenced by the presence or absence of packaging and how people used Best Before dates. We could not find existing data that was sufficiently relevant and accurate for these inputs. Furthermore, we could demonstrate that the results were greatly affected by these input factors.

The modelling would also benefit from an up-to-date assessment of how fresh fruit and vegetables were sold: how much was sold packaged and loose, what the packaging was and what information was contained on it. These requirements led to three separate, but related activities:

- **Shelf-life experiments**: taking products from UK supermarkets and storing them in a range of conditions, some loose and some packaged. Sensory assessment was undertaken to measure their deterioration, allowing comparison between the loose and packaged variants. This is the subject of a separate report: *Helping people to reduce fresh produce and dairy waste: The impact of packaging and refrigeration on shelf life*
- **Citizen research into the use of date labels**: this research used standard survey questions alongside Implicit Association Testing to understand how date labels affect people's decisions around consumption and disposal of food. This is the subject of a separate report: *Helping people to reduce fresh produce and dairy waste: citizen insights on the influence of packaging and date labels on disposal decisions*.
- **In-store review of loose and packaged offering:** this involved an in-store survey, undertaken by the British Growers Association as part of their Produce View survey. Further details of this can be found in this report (Section 2.3.3).

In addition, the project team received input to the project from an industry group composed of major supermarket retailers and producers of fresh produce.

Following these data-gathering sub-projects, final modelling was undertaken using updated input values based on the additional research undertaken. Chapter 2.0 presents the methodology for this final modelling and the input values used. The results are presented in Chapters 3.0 to 7.0, and summarised in Section 8.1.

Wikström and co-authors propose five main issues to overcome so that packaging design can fully contribute to food-waste prevention[32]:

1. Identify and obtain specific data of packaging functions that influence food waste;
2. Understand the total environmental burden of product/package by considering the trade-off between product protection and preservation and environmental footprint;
3. Develop understanding of how these functions should be treated in environmental footprint evaluations;
4. Improve packaging design processes to also consider reducing food waste; and
5. Analyse stakeholder incentives to reduce food loss and waste.

The research within the current report focuses on an important evidence gap, directly contributing to points 1 and 2 in the above list.

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[32] *Wikström, F., Verghese, K., Auras, R., Olsson, A., Williams, H., Wever, R., Grönman, K., Pettersen, M. K., Møller, H., & Soukka, R. (2019). Packaging Strategies That Save Food: A Research Agenda for 2030. Journal of Industrial Ecology, 23(3), 532–540. https://doi.org/10.1111/JIEC.12769*

2.0 Methodology

This section describes the different elements of the methodology used in this project.

The rationale for the products studied within this project is given in Section (2.1). The reasons for using the Household Simulation Model are presented in Section 2.2, alongside an overview of the model itself.

Section 2.3 presents the data sources used for the project and how this information was used to inform the inputs for the Household Simulation Model.

2.1 Choice of products

The influence of packaging on food waste in the home will vary for different types of fresh fruit and vegetables. Items last different lengths of time, the packaging will extend shelf life by different amounts, and they are sold and consumed in different quantities. Therefore, specific products needed to be investigated. This section details the products selected and describes why they were chosen.

The first criterion for selection was that the item needed to be wasted in sufficiently large amounts in UK homes to warrant investigation. For this, the most up-to-date UK household food waste (HHFW) statistics were used[33].

Secondly, a range of fruit and vegetables that are consumed in different ways in the home was useful, to help explore the different dynamics at play. Therefore, at least two types of fruit and two types of vegetable were sought. It was useful to have some items that are eaten as single items (e.g., bananas) and some items for which part of the item is eaten at individual occasions (e.g., cucumbers). At least one salad item and one other type of vegetable were sought.

The third criterion was to pick at least one item for which we thought that food waste in the home would be decreased by the presence of packaging and one where it would be increased[34]. For these reasons, the products selected were:

- Apples
- Bananas
- Broccoli
- Cucumber
- Potatoes

In general, we modelled the dynamics for these products irrespective of the variety: e.g., the modelling for apples draws on data for consumption of all raw apples. However, for some pieces of data – specifically the shelf-life experiments – we needed to generate data for specific varieties. The varieties chosen for these are listed in Section 2.3.2. The

[33] Household food waste: restated data for 2007-2015, WRAP (2018): *https://wrap.org.uk/sites/default/files/2021-03/WRAP-Household-food-waste-restated-data-2007-2015_0.pdf*

[34] *It transpired that these initial predictions were proved wrong by the subsequent research.*

rationale for these choices is presented in Section 2.1 of the report published alongside this one: *The impact of packaging and refrigeration on shelf life*.

2.2 Household Simulation Model

This section provides the rationale for using the Household Simulation Model for this project, followed by an overview of the model and the elements of interest for this project.

2.2.1 Background to HHSM

Understanding the wasting of food in homes is not straightforward. The amounts and types of food wasted are the result of many interactions within a household: how household members manage and consume food, alongside the attributes of the food that they bring into the home[35,36]. This makes it challenging to understand how a change to this 'system' (e.g., selling specific foods loose rather than packaged) influenced the amount of food waste.

In an ideal world, trials would be undertaken to increase our understanding of these relationships. For this project, this could involve measuring waste in the home of specific food products over the duration of a change to how these products are sold: e.g., while the offering of fresh fruit and vegetables being sold changes from packaged to loose. A control group – with no change to how fruit and vegetables are sold – should also be monitored to ensure that any results are due to the removal of packaging, rather than a general trend in levels of food waste or due to the monitoring method.

While such trials are possible, they are relatively expensive to conduct and require precise co-ordination with supermarkets prepared to make a change to how they sell fresh fruit and vegetables. Although the research presented in this report does not include such empirical trials, we hope that the results may help to unlock the funding and the determination for such a project.

Given the rarity of such trials in general[37,38,39], the Household Simulation Model (HHSM) was developed as a solution to this type of problem. It is designed to understand how changes to how food is purchased, stored and consumed in the home affect the levels

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[35] Quested T., Marsh, E., Stunell, D., Parry, A., (2013), Spaghetti soup: The complex world of food waste behaviours, Resources, Conservation and Recycling, 79, pp. 43-51: https://doi.org/10.1016/j.resconrec.2013.04.011

[36] Schanes, K., Dobernig, K., Gözet, B. (2018), Food waste matters - A systematic review of household food waste practices and their policy implications, J. Cleaner Production, 182(1) pp. 978-991: https://doi.org/10.1016/j.jclepro.2018.02.030

[37] Porpino, G. (2016). Household Food Waste Behavior: Avenues for Future Research., Journal of the Association for Consumer Research, pp. 41–51. https://doi.org/10.1086/684528

[38] Stöckli, S., Niklaus, E., & Dorn, M. (2018). Call for testing interventions to prevent consumer food waste. Resources, Conservation and Recycling, 136, pp. 445–462. https://doi.org/10.1016/J.RESCONREC.2018.03.029

[39] Reynolds, C. et al. (2019). Review: Consumption-stage food waste reduction interventions – What works and how to design better interventions. Food Policy, 83, 7–27. https://doi.org/10.1016/J.FOODPOL.2019.01.009

of food waste in the home. It can also model how attributes of the product (such as its shelf life) and changes to how people interact with the product influence food waste.

The HHSM uses an approach called Discrete Event Simulation (DES) to model the journey of food into and through individual homes. This journey is impacted by the attributes of the food in question, and the actions and decisions of people in the household. By changing the inputs (e.g., increasing the shelf life), it is able to assess the impact of that change in the context of that household.

The HHSM was first developed from a previous model (The Milk Model), which simulated milk in the United Kingdom[40]. The Milk Model was extended, generalised and refined during 2018 and 2019 to create the HHSM. The details and operation of the model are documented in Kandemir et al. (2020)[41]. The application of discrete event simulation to the issue of HHFW has also been performed – adapting the Milk Model to the context of the USA[42].

Other modelling of food waste in the home has been undertaken. However, to the best of the authors' knowledge, none is suitable for the research problem at hand. Grainger et al. (2019) developed an agent-based model linked to Bayesian Networks for application to European HHFW[43]. This does not have the functionality to assess how specific changes to a product influence food waste. Other models have been created to investigate the relationship between food waste and packaging[44,45,46]. However, due to the limited methodological information in the public domain, these could not be considered as potential approaches for this project.

2.2.2 Overview of HHSM

The HHSM was developed as part of a previous project between WRAP and Sheffield University. As mentioned above, the HHSM is based around the journey of food through the home. The main elements of this journey are illustrated in Figure 2. Food enters the

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[40] The Milk Model, WRAP (2013): *https://wrap.org.uk/resources/report/milk-model-simulating-food-waste-home*

[41] Kandemir et al. (2020), Using discrete event simulation to explore food wasted in the home, Journal of Simulation: https://doi.org/10.1080/17477778.2020.1829515

[42] Stankiewicz, S. K., Auras, R., & Selke, S. (2019). Modeling American Household Fluid Milk Consumption and their Resulting Greenhouse Gas Emissions. *Sustainability 2019, Vol. 11, Page 2152*, *11*(7), 2152. https://doi.org/10.3390/SU11072152

[43] Grainger, M., Piras, S., Righi, S., Setti, M., Stewart, G., Vittuari, M., 2018: Behavioural economics: Linking Bayesian and agent-based models to assess consumer food waste. REFRESH Deliverable 4.4: https://eu-refresh.org/behavioural-economics-consumer-food-waste

[44] denkstatt, G. (2015, May). Vermeidung vonLebensmittelabfällendurch Verpackung. Presented at the denkstatt, Vienna, Austria.

[45] OVAM. (2015). Food loss and packaging (p. 116). Mechelen: OVAM. https://www.ovam.be/sites/default/files/atoms/files/2015-Report-OVAM-Food-loss-and-packaging-DEF.pdf

[46] Pack4Food. (2019). Over- vs. onderverpakken: Wat is de optimale barrière voor de verpakking van mijn levensmiddel?. Pack4Food. Retrieved October 17, 2019, from https://www.pack4food.be/project/optibarrier

home, usually via a shopping trip. Food is then stored in the home, with different conditions possible (fridge, freezer and ambient temperatures). This food is available for consumption, up to the point where the household is no longer prepared to eat it.

Figure 2: Schematic of elements of 'journey' of food through the home in the HHSM

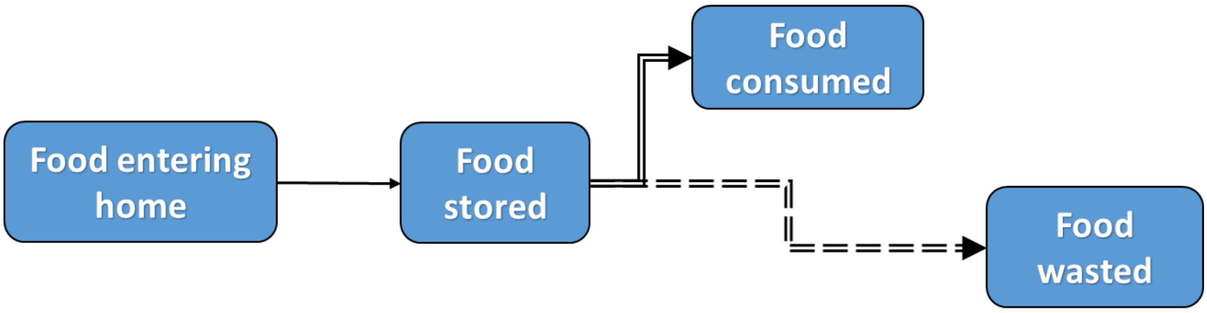
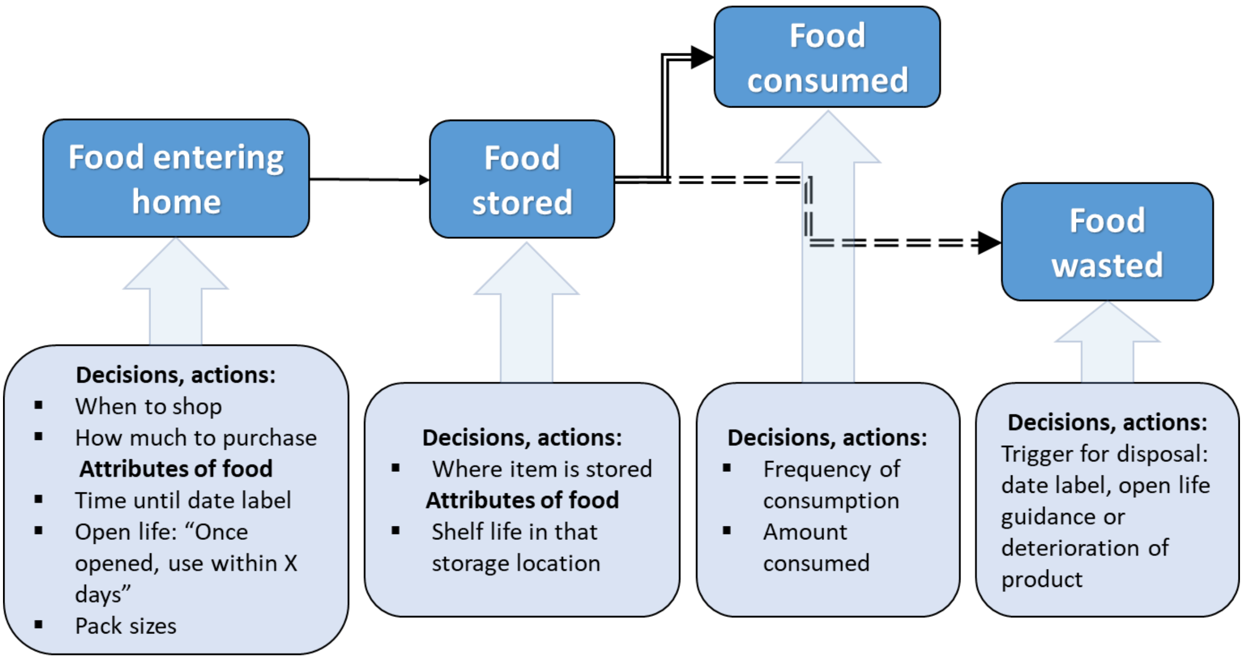


Figure 3 illustrates some of the influences on this journey that can be modelled in the HHSM. Householders' decisions and actions can influence the flow of material into and through the home. Similarly, the attributes of the food can impact on this flow. This decisions and actions of people, and the attributes of food are inputs to the HHSM: they can be adjusted by the modeller to understand their impact on food waste in different modelled households.

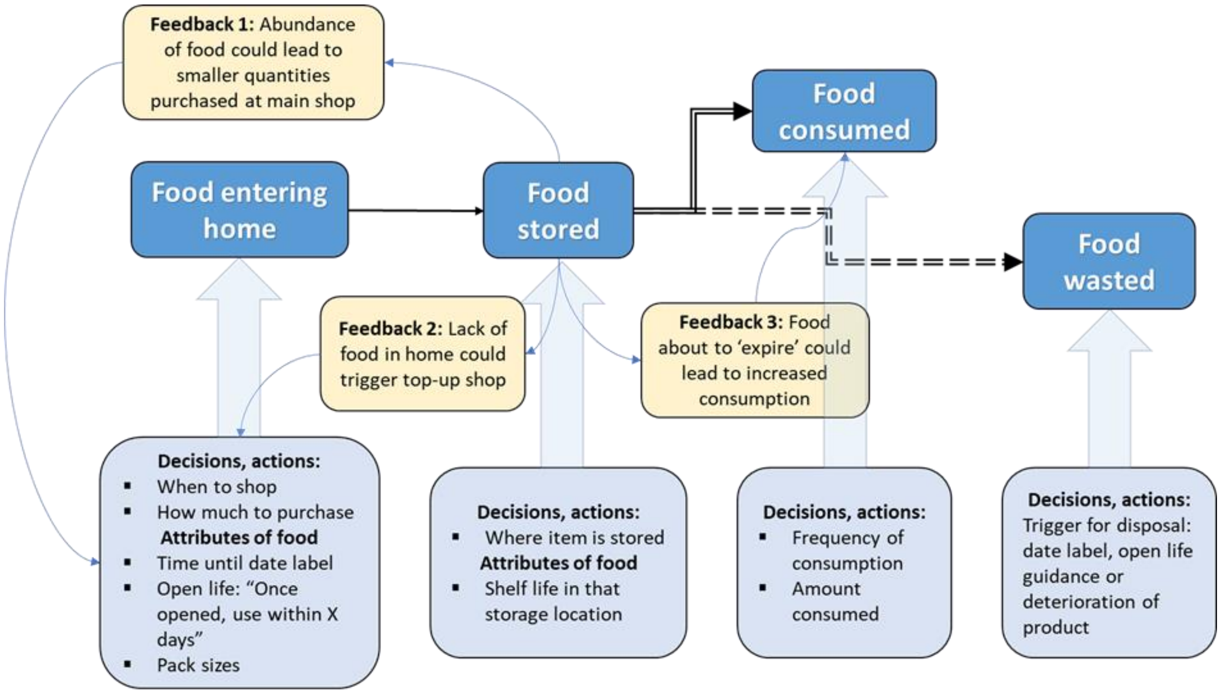
Figure 3: Schematic of the HHSM with examples of decisions, actions and attributes of food linked to elements of journey



The HHSM also contains many feedback loops. A non-exhaustive selection of these loops is included on the schematic in Figure 4. In these examples, the amount of food present in the home can affect how much is purchased in main shops, whether a top-up shop occurs and can influence the amount of the food consumed. Full details of the

HHSM can be found in Kandemir et al. (2020)[47]. The model was created and run in a specialist discrete-event-simulation software package: Arena (version 16.0).

Figure 4: Schematic of the HHSM with example feedback loops added



The HHSM focuses on food waste in the home that is thrown away because it has not 'been used in time'. This includes food that has been thrown away because it has deteriorated in quality, is felt to be unsafe, or because of a date label. Kitchen diaries suggest that, in the UK, this is the largest single reason for HHFW. For fresh fruit it accounts for 87% of edible food waste (260,000 tonnes in 2012), and for fresh vegetables and salad 38% (490,000 tonnes)[48]; specific values for the five types of fruit and vegetable studies in this report can be found in Section 2.3.4). It does not estimate food waste relating to other reasons: too much cooked or served, personal preference (e.g., fussy eating), accidents in the kitchen or failure of a fridge of freezer. For this project, the vast majority of the impacts of selling packaged or loose will influence this 'not used in time' element of food waste.

[47] Kandemir et al. (2020), Using discrete event simulation to explore food wasted in the home, Journal of Simulation: https://doi.org/10.1080/17477778.2020.1829515

[48] Household food waste: restated data for 2007-2015, WRAP (2018): https://wrap.org.uk/sites/default/files/2021-03/WRAP-Household-food-waste-restated-data-2007-2015_0.pdf

2.2.3 Household Archetypes

The HHSM also uses 'household (HH) archetypes' to help account for the variation (on factors relevant to HHFW) between households in the UK. Following the previous work[49], seven household archetypes were used in this project. These vary in number of occupants, age of occupants (and therefore amounts consumed), shopping habits, factors affecting disposal decisions and levels of risk relating to food.

The seven HH archetypes are:

- Aspirational-Discoverer (AD) Family
- Functional Fueller, single-occupancy (FF single)
- FF couple
- Spontaneous Creative single-occupancy (SC single)
- SC Family with one child (SC one child)
- Ideal Advocate (IA) couple
- Pressured Provider (PP) Family

The household archetypes draw on a wide range of information collected by WRAP on food decisions, behaviours and habits. The names of the HH archetypes derive from segmentation work undertaken by WRAP in 2016[50]. However, there are important differences between the HH archetypes and food-waste segments. Most importantly, they apply at different scales: the segments group similar *individual people*, whereas the HH archetypes represent groups of *households*, often made up of multiple people.

2.2.4 Factors of interest to this project

As discussed in Section 1.3, of interest for this project are the following elements:

- The shelf life of the item: in particular, if the shelf life changes due to the presence or absence of packaging.
- The trigger for disposal: what proportion of households use the date label (in the case of fresh produce, the Best Before date) as a disposal date and no longer are prepared to eat that item.
- The pack sizes available to households for that item, e.g., the pack sizes typically on sale in UK supermarkets.

The data sources for these are described in the following section, alongside other data useful to the modelling.

[49] Kandemir et al. (2020), Using discrete event simulation to explore food wasted in the home, Journal of Simulation: https://doi.org/10.1080/17477778.2020.1829515

[50] *Information for segments can be found on the Love Food Hate Waste website: e.g.,: https://www.lovefoodhatewaste.com/article/functional-fueller*

2.3 Information sources for modelling

This section describes the data sources used and how they have been used to create the inputs for the modelling in this project. This includes food-consumption data (Section 2.3.1), shelf-life data (Section 2.3.2) and data on the size of packs available at UK supermarkets for these food items (Section 2.3.3).

2.3.1 Food consumption

The model requires input data for consumption patterns within a household. These are referred to in the model as 'requirements': these requirements will only be fulfilled (i.e., food consumed) if there is food of that type available in the modelled household. If there is, these requirements lead to consumption of the food. Otherwise, the requirements become 'unfulfilled requirements', and are recorded separately.

There are two pieces of information that the model needs to calculate the requirements of a given food:

- The probability that a person or household consumes this food on a given day
- The distribution of how much of this food is eaten on days when it is consumed

The methods used follow that of Kandemir et al. (2020)[51] and are summarised below. Both of these pieces of information are derived from National Diet and Nutrition Survey (NDNS) datasets[52]. The NDNS dataset is a four-day diary of consumption, itemising items consumed for breakfast, lunch, dinner, and snacks. Data from the 2015/16 wave of the survey was used.

The NDNS contains information for three age groups:

- Adults
- Children between 7 and 17 years old inclusive
- Children between 0 and 6 years old inclusive (referred to as infants)

Analysis of the NDNS data was performed for each of these age groups separately. The NDNS data was also filtered by product to create separate datasets containing data for people who consumed the food item on at least one day of the four-day survey. The total amount consumed across all four days of the survey and the number of days that the person consumed the item were calculated for each data entry.

The analysis was also performed for participants with 'typical' levels of consumption of that food for their age group. To do this, the total consumption amounts for each respondent in an age group were ranked from highest to lowest. For most combinations of product and age group, the central 25% (between the 37.5 and 62.5 centiles) of cases were selected for further analysis.

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[51] *Kandemir et al. (2020), Using discrete event simulation to explore food wasted in the home, Journal of Simulation: https://doi.org/10.1080/17477778.2020.1829515*

[52] *MRC Elsie Widdowson Laboratory & NatCen Social Research. (2019). National diet and nutrition survey years 1-9, 2008/09-2016/17. UK Data Service.*

For broccoli (all age groups) and for children aged 0 - 6 that ate cucumber, the sample size for this central 25% would have been low (n < 40). In these cases, the central 50% (from the 25th to 75th centile) was instead used to increase the sample size. This approach means that across all food items the average sample size across all age categories is greater than 70[53].

The first piece of information that the model requires is the probability that the food item is consumed each day, as a percentage. The 'typical' cases (the central 25% or 50%) were used to calculate this probability. This was achieved by dividing the number of days this sub-set of participants ate the food in question by the total number of days surveyed for this sub-set of participants. For example, for apples, 'typical' adults found to eat an apple on at least one of the days in the survey, an apple was eaten on an average of 1.8 days out of 4 survey days. This translates to a consumption probability of 45% (= 1.8 days / 4 days).

The second piece of information that the model requires is the distribution of amounts of the food item that the household consumes in a day. A distribution is used – rather than just using the average amount each day – as actual levels of consumption of a product will fluctuate over time. This allows the modelling to be more realistic. This was created from the central 25% (or 50%) of cases, creating a distribution of the daily amounts consumed on given days of the food item in question. Separate distributions were created for each combination of product and age category.

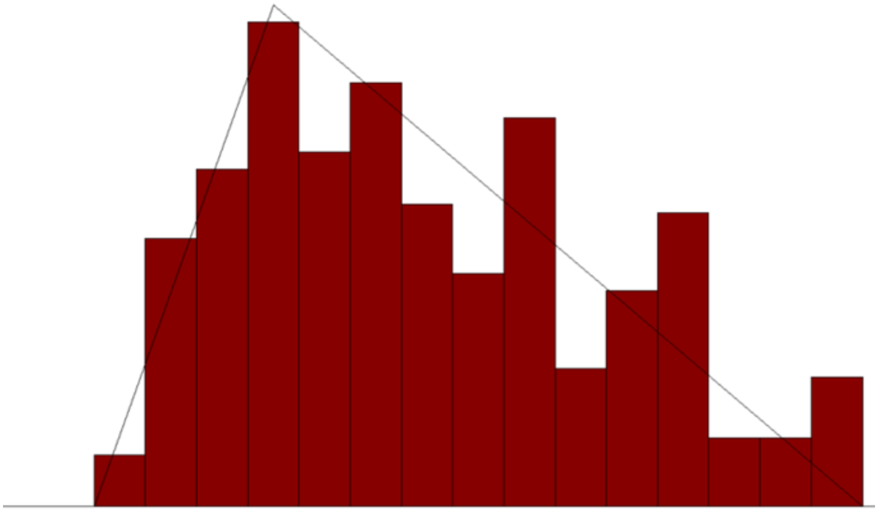
For most products (broccoli, cucumber and potatoes), the resulting distribution for each food item and age group was then fitted with a curve using the least squares method using the 'Input Analyzer' function in the Arena software. This function could then be used as input for the modelling.

The Input Analyzer uses the least squares method to produce a list of distributions or "curves" that can be used to represent the data. The distributions are ordered from best fit to worse fit according to the least squared value. In every instance the best fit was chosen, unless the best fit was the normal distribution, in which case the next best fit was chosen. Normal distributions were not used to avoid the occurrence of negative consumption values, which are not possible and would cause problems in the model.

The distributions and their fitted lines are provided in the Appendix 3. Figure 5 shows an example of the distribution of consumption values for adults that consumed potatoes. The consumption values are presented as a histogram and the curve that best fits the data (in this instance, a triangular distribution) is overlain on the histogram.

[53] *Average sample sizes from the NDNS database are as follows: Apples = 71, Bananas = 100, Broccoli = 106, Cucumber = 88, Potatoes = 146.*

Figure 5: Example curve fitting for consumption of potatoes: red bars = NDNS data, black line = best fit line (triangular distribution)



For two of the products (apples and bananas), it was assumed that households ate either whole or half items, based on the NDNS distributions.

Where households have more than one person, there are two ways in which the above information can be used to provide consumption levels for the whole household:

Household members modelled separately: For foods that are eaten uncooked (apples, bananas and cucumbers), it is assumed that household members consume independently of each other – i.e., if one person eats an apple on a given day, other household members are not affected by this decision (i.e., their probability of consumption and consumption amounts are unaffected).

Household modelled as a single unit: For broccoli and potatoes, it was assumed that, if one household member consumes these items, then the other household members would also consume it. For instance, these items could form part of a main meal that is served to all members. In such cases, each household is modelled as a single unit with regard to consumption, with a single probability. Consumption amounts are determined by adding together the consumption distributions of individual household members.

The above choices assume that foods that are cooked (or require longer preparation times) are more likely to be cooked (and eaten) for other household members. To put it another way, if someone is cooking potatoes or broccoli in multi-person household, they are less likely to cook just for themselves; they are likely to cook them for all household members who eat that type of food.

In contrast, items that can be quickly prepared (or need no preparation) allow for consumption by household members to be more independent of other household members.

The input data for food requirements calculated from the procedure described in this section can be found in the chapters for each food item: apples (3.2.1), bananas (0), broccoli (0), cucumber (6.2.1) and potatoes (02.3.1).

2.3.2 Shelf-life data

An important input to the Household Simulation Model is the length of time between an item being purchased and when it will no longer be consumed by members of the household. In this modelling, we distinguish two groups of households:

- Households in which the food item will be consumed up to the point of observable deterioration
- Households in which the food item will be consumed up until the Best Before date

This sub-division is based on the observations in previous research. Studies of UK citizens have shown that some people treat Best Before dates as disposal dates, while others do not seem to be influenced by them[54]. Research published alongside this report confirmed this, suggesting that for fresh fruit and vegetables a minority of people were heavily influenced by the date[55]. Two types of information were available:

- Asking people the extent to which they used their judgement or the date label in making disposal decisions; and
- A 'rapid-fire' Implicit Association Test, in which research participants were asked to say whether they would use or dispose of products. One group of people saw images of food in various states of deterioration without a date label, a second group saw the same images with a date label. The difference between the two allowed the influence of the date labels to be assessed.

In general, there was broad agreement between the two types of information about the proportion of the population for whom disposal decisions were heavily influenced by the date label. The exact values vary for each product and the stage of decay, but are somewhere in the region of 20% of the population. Specific values for each product are given in Chapters 0 to 7.0.

For those households using the Best Before date as a disposal date, the length of time between purchase and the Best Before date was taken from supermarket websites. For these items, the typical length of time between the purchase date and the Best Before date were obtained from a range of sources. These are detailed in Table 1.

For households using their judgement to make disposal decisions (i.e., consume the product until observable deterioration of the item), information for the shelf life was obtained from bespoke experiments in the Shelf-Life report[56]. These experiments held samples of the five types of fruit and vegetables being studied in controlled conditions, some in packaging, others loose. Full details of the methodology can be found in that report.

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[54] *Consumer insight: Date labels and storage guidance, WRAP (2011): https://wrap.org.uk/resources/report/consumer-insight-date-labels-and-storage-guidance*

[55] *Citizen insights on the influence of packaging and date labels on disposal decisions, WRAP, 2022: https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

[56] *The impact of packaging and refrigeration on shelf life, WRAP, 2022: https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

Table 1: Typical length of time between purchase date and Best Before date

Product	Length of time between purchase date and BB date*	Notes
Apple (Gala)	8 days	
Banana (Cavendish)	4 days	Not used in modelling: BB dates rarely present on bananas (Section 4.2.3)
Broccoli (Calabrese)	3.5 days	
Cucumber (slicing)	5 days	
Potato	5 days	Slightly longer than data from WRAP Retail Survey (2019)

* UK Supermarket Morrison's website: typical shelf life. Accessed on 30th June 2020

The Household Simulation Model requires input data on the 'shelf life', defined here as the length of time between an item being purchased and the point when people in a household are no longer prepared to consume that item. This is entered into the model as a distribution to reflect the variability in the shelf life between individual items. The distribution also accounts for the differences between people in terms of the condition of an item they are prepared to eat.

To extract the shelf-life data from the Shelf-Life Report, firstly, a typical condition had to be chosen as representative of the UK population. For apples, bananas and potatoes, this was ambient conditions; for broccoli and cucumber, these were assumed to be refrigerated. In both cases, these reflect self-reported data from the UK population on where they store these items[57].

Table 2: Conditions used for the modelling

Product	Condition used for estimating shelf life
Apple (Gala)	Ambient
Banana (Cavendish)	Ambient
Broccoli (Calabrese)	Refrigerated, 4°C
Cucumber (slicing)	Refrigerated, 4°C
Potato (Estima)	Ambient, dark

For items typically refrigerated (broccoli and cucumbers), data for a 4°C fridge was used. Data for 9°C was also available from the shelf-life experiments. The cooler fridge was

[57] *Unpublished WRAP food-waste trackers.*

chosen as it is closer to empirical measurement of fridge temperatures in the UK: Bigila et al. (2018) found the average temperature of fridges in England to be 5.3°C[58], while Evans et al. (2014) found the average temperature in UK fridges to be 4.4°C[59].

To transform the data in the Shelf-Life Report into a distribution suitable to use as input for the HHSM, the following procedure was applied:

- To determine **the average shelf life**: Identify the length of time corresponding to a deterioration score[60] of 0.3. This marks the mid-point between the onset of noticeable deterioration (where the deterioration score first increases above zero) and a score of 0.6, where most people would no longer consume the item. The length of time between the date of purchase and when the line fitted to the data reaches 0.3 is set as the average shelf life.
- To determine **the standard-deviation of the shelf life**: Record the length of time between the deterioration score first increasing above zero and a score of 0.6. This represents the range in which most people would start to reject the item. So that most of the shelf-life values fall within this range, the standard deviation is set to one-quarter of this range. This means the range represents two standard deviations either side of the mean: approximately 95% of shelf-life values will fall within this range.

Table 3: Shelf life of items derived from the shelf-life report, expressed as days since purchase for a deterioration score of 0.3. Expressed to two significant figures

Product	Loose / Packaged	Average (mean, days)
Apple (Gala)	L & P	31
Banana (Cavendish)	L	5.0
	P	6.8
Broccoli (Calabrese)	L	17
	P	24
Cucumber (slicing)	L & P	11
Potato (Estima)	L & P	24

[58] *Biglia A, Gemmell A.J., Foster H.J., Evans J.A., Temperature and energy performance of domestic cold appliances in households in England,International Journal of Refrigeration, 87, pp 172-184 (2018).* https://doi.org/10.1016/j.ijrefrig.2017.10.022.

[59] *Evans J.A., Foster A.M., Brown T., Temperature control in domestic refrigerators and freezers. 3rd IIR International Cold Chain Conference, Twickenham UK, 2014:* https://openresearch.lsbu.ac.uk/download/8370819afc6aae9e8184e30692960587dd466461328374e2cadbe15c04e17c7b/357885/130_Temperature%20control%20in%20domestic%20refrigerators%20and%20freezers%20%2801.05.14%29.pdf

[60] *The deterioration score is a measure of level of deterioration of the item, based on sensory evaluation of the item by trained assessors. A score of zero represents all assessors scoring all replicates as 'green' (perfect or near perfect). A score of one represents all assessors scoring all replicates 'red' (unacceptable to the majority of the population). More details can be found in the shelf-life report.*

The results of this process can be found in a Table 3. These show that there is a shelf-life extension associated with the packaging for apples, bananas and broccoli, but none for cucumber and potatoes.

2.3.3 Pack-size data

Data for common pack sizes was obtained by an in-store survey of products commissioned by WRAP as part of this project and conducted by Produce View. The modelling primarily uses pack sizes that were commonly available for the majority of retailers. The aim of the work was to record the product lines available in large-format UK supermarkets for apples, bananas, broccoli, cucumbers and potatoes. Information recorded about the lines included:

- Whether sold loose or packaged.
- List of containers / bags available for customers to take products home in.
- Information provided at point of sale.
- Other general information displayed in store

For packaged items, the following was recorded:

- Whether Best Before date present
- Other date wording (e.g., "Display Until")
- Advice on home storage, including whether a blue-fridge icon was present (the symbol used to indicate that shelf life is extended by storing in the fridge)
- Packaging type

Data was collected from ten large-format supermarkets – one for each of the ten largest supermarket chains in the UK[61]. Data collection occurred on the 2nd of November 2020 – providing a snapshot immediately prior to the Covid-19-related lockdown that started on the 5th of November 2020.

Typical pack sizes for each of the types of fruit and vegetables are described in Chapters 3.0 to 7.0.

2.3.4 HHFW data

This project uses a wide range of data relating to HHFW. Key information used to check the modelling results is discussed in this section. This focuses on data to assess whether the modelled levels of 'not used in time' food waste were within realistic bounds.

The most relevant data includes information on the percentage of purchases that are wasted in UK households, based on data collected in 2012 and published in 2014[62].

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[61] *ASDA, Aldi, Co-op, Iceland, Lidl, Marks and Spencer's, Morrisons, Sainsbury's, Tesco and Waitrose*

[62] Household food and drink waste: A product focus, WRAP, 2014: https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf. Since the publication of this data, WRAP has updated the classification of household food waste, moving from the term 'avoidable' to 'wasted food' (i.e., the edible parts that are thrown away), with

Relevant data was available for the UK from 2012[62]. This involved combining data on the percentage of purchases that become 'avoidable' food waste (Table 4 – highlighted column) with data on the reasons for food being thrown away in the home (Table 5 – highlighted column. The results are shown in Table 6.

Table 4: Percentage of purchases brought into the home that become waste, 2012 data

Food item	**Percentage of purchases wasted**			
	Avoidable	**Possibly avoidable**	**Unavoidable**	**Total**
Apples	13%	3%	8%	24%
Bananas	9%	0%	34%	44%
Fresh vegetables & salads*	21%	15%	6%	42%
Cucumber	24%	3%	4%	30%
Potatoes	20%	26%	0%	46%

*used as a proxy for broccoli

Table 5: Percentage of avoidable food waste for priority items wasted relating to 'not being used in time', 2012 data

Food Item	**Reason wasted: 'Not used in time'**		
	Date label not cited	**Date label cited**	**Total**
Apples	71%	7%	78%
Bananas	90%	3%	93%
Cucumber	76%	7%	83%
Fresh vegetables & salads*	52%	10%	62%
Potatoes	43%	6%	49%

*used as a proxy for broccoli

slight difference in definition between the two classifications. Given the evidence needs of the current project, we have used data from before this reclassification. Hence, the term 'avoidable' is used in places in the report. This does not influence the results: More details can be found in: Household food waste: restated data for 2007-2015, WRAP (2018): *https://wrap.org.uk/sites/default/files/2021-03/WRAP-Household-food-waste-restated-data-2007-2015_0.pdf*

Table 6: Percentage of purchases that end up as 'not used in time' food waste in UK homes, 2012 data

Food Item	% of purchases not used in time
Apples	10.2%
Bananas	8.7%
Fresh vegetables & salads*	13.0%
Cucumber	19.5%
Potatoes	9.9%

*used as a proxy for broccoli

Data for broccoli was not available, so all fresh vegetables and salads was used as a proxy, which indicated that 13% of purchases would become 'not used in time' food waste (Table 6). Using cabbage as a proxy was also considered. Had we used this, the result would have been similar to the 13% used.

3.0 Apples

This section covers the following for apples:

- Background information about apples in the UK, focusing on household food waste (Section 3.1)
- The apple-specific inputs used for the modelling (Section 0)
- A summary of the scenarios modelled for apples (Section 3.3)
- The results of these scenarios modelled for apples, alongside discussion of the implications (Section 3.4)
- Apple-specific conclusions (Section 3.5)

3.1 Apples: background information

In the UK, an average of 122 grams of apples were purchased per person per week in 2018/19[63] equating to approximately 420,000 tonnes per year[64]. Of these, around 285,000 tonnes are produced in the UK[65], with the remainder imported. Apple sales are largely unaffected by the seasons and remain relatively stable throughout the year[66]. The most popular apple varieties consumed in the UK are: Braeburn, Gala, Golden Delicious, Granny Smith, Jazz, Queen Cox and Pink Lady[67].

The most detailed breakdown of household apple waste in the UK is based on 2012 data. This suggests that approximately 24% of all apple purchases were wasted, with 13% of purchases becoming 'avoidable' waste, the remainder being cores, stalks and peel. This equates to 59,000 tonnes of avoidable apple waste per year at a total cost of £130 million[68]. Around half of all instances of apple waste are whole apples (Figure 6).

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[63] *Family Food datasets 2018/2019, Department for Environment, Food, & Rural Affairs, 2020: https://www.gov.uk/government/statistical-data-sets/family-food-datasets*

[64] *Estimated using the average UK population in 2019 (66.797 million), Office of National Statistics.*

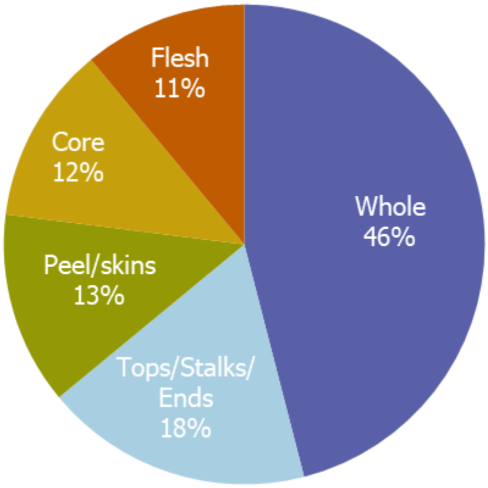
[65] *UK Horticulture Statistics, Department for Environment, Food, & Rural Affairs, 2019: https://www.gov.uk/government/collections/horticultural-statistics*

[66] *Methods used for Household Food and Drink Waste in the UK. WRAP. 2012: https://wrap.org.uk/sites/default/files/2020-12/Methods-used-for-Household-Food-and-Drink-Waste-in-the-UK-2012.pdf*

[67] *Fruit and vegetable resource maps: Final report. WRAP Cymru. 2011. Currently unpublished.*

[68] *Household food and drink waste: A product focus, WRAP, 2014: https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf*

Figure 6: Breakdown of household apple waste in the UK in 2012, by weight. Covers waste collected by local authorities: residual waste and collections targeting food waste.



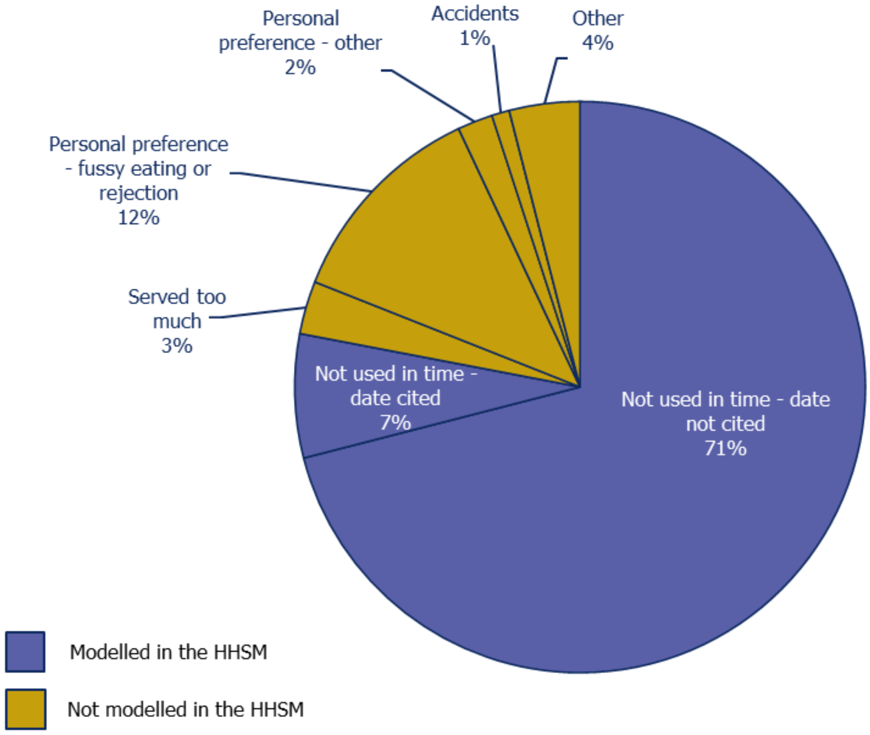
Source: Household Food and Drink Waste: A Product Focus[69]

The most common reason for apples to be wasted was due to them not being used in time, accounting for 78% of 'avoidable'[70] apple waste (Figure 7). The remaining avoidable waste was due to personal preferences, serving too much and accidents. The Household Simulation Model focuses on food waste that is 'not used it time', thus investigating 78% of 'avoidable' household apple waste.

[69] *Household food and drink waste: A product focus, WRAP, 2014:* https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf

[70] Since the publication of *Household food and drink waste: A product focus* in 2014, WRAP has updated the classification of household food waste, moving from the term 'avoidable' to 'edible'. This report uses details that were calculated before this change. Refer to Section 2.3.4 for more details.

Figure 7: Reasons for avoidable apple waste in UK households in 2012, by weight



Source: Household Food and Drink Waste: A Product Focus[71]

Of the 78% of waste that was not used in time, participants in research involving food-waste diaries rarely cited a date label when recording why they discarded the apple (7% of the total avoidable waste; Figure 7). This is consistent with other WRAP research that suggests date labels play a larger role in people's decisions when there is a perceived safety risk, such as for meat and dairy products[72]. For fresh produce items, most citizens tend to rely on their own senses and judgement when deciding whether to eat or discard an item. However, research published alongside this report suggests that a substantial minority of people are heavily influenced in their disposal decisions by the Best Before date, as discussed in 2.3.2.

In early November 2020, Produce View conducted a review of several large format supermarkets in the UK to understand the range of apples (and other products included in this report) that were available. (Methodological details can be found in Section 2.3.3.) The survey included details on the varieties of apples sold loose and in packaging, packaging material and formats, date label type and prevalence, as well as on-pack storage guidance.

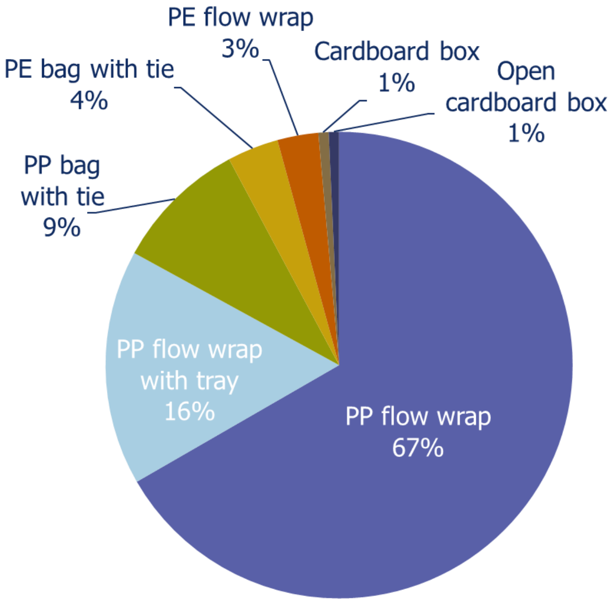
According to the survey, 27 varieties of apple were sold packaged whereas eight varieties were sold loose. Across all supermarkets that were visited, 98% of apple lines sold in packaging were contained within plastic packaging. The most common type of packaging

[71] *Household food and drink waste: A product focus, WRAP, 2014: https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf*

[72] *Consumer insight: date labels and storage guidance, WRAP (2011): https://wrap.org.uk/sites/default/files/2020-12/Consumer-insight-date-labels-and-storage-guidance.pdf*

was polypropylene flow wrap and 67% of packaged apple lines were sold in this format. The full breakdown of packaging types is shown in Figure 8.

Figure 8: Packaging types for apples sold in large-format UK supermarkets, Nov. 2020



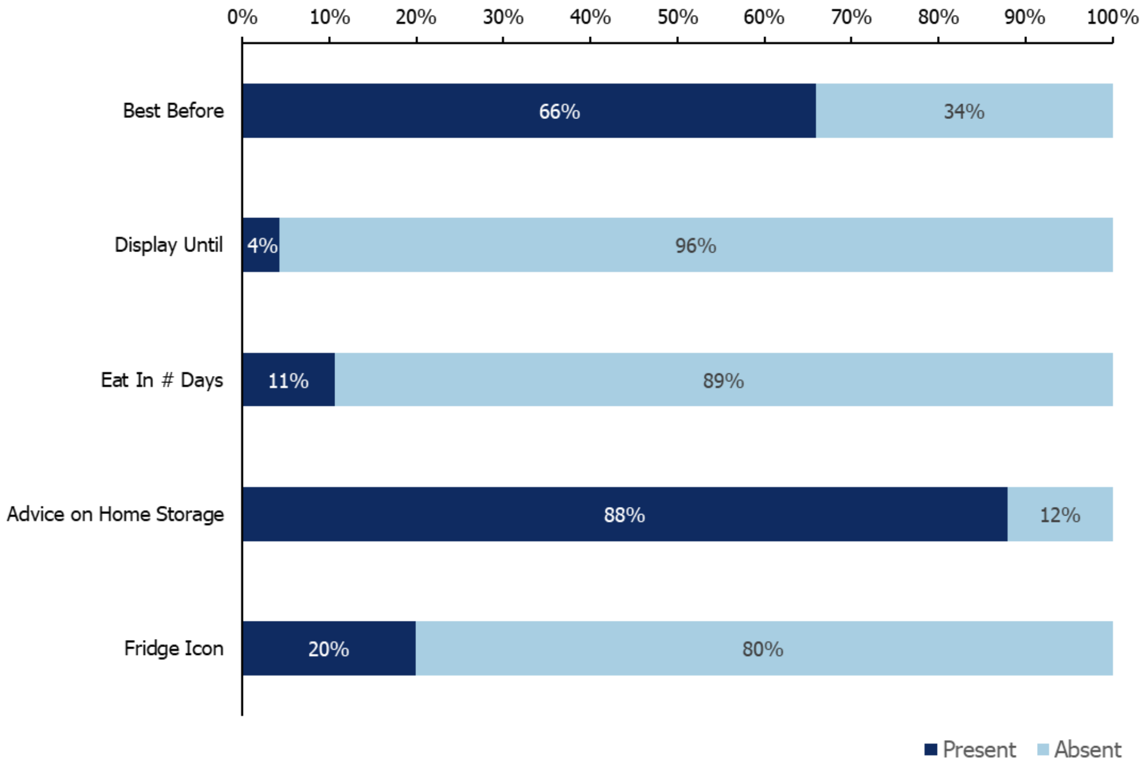
Source: Produce View in-store survey

Information displayed on-pack that is relevant to this study include date labels and storage information. Focussing on date labels, 66% of packaged apple lines had a 'Best Before' date, 4% a 'Display Until' date, and 11% a 'Eat in X number of days' label. In terms of storage information, 88% of packaged apples contained advice on home storage and 20% have a fridge icon displayed on-pack (Figure 9).

WRAP's recommendation when selling apples packaged is to use the Little Blue Fridge icon, and the advice 'At home store below 5°C'. When offering apples loose, WRAP's recommendation is to provide at-home storage information at point of purchase and via other channels[73].

[73] *Fresh uncut fruit and vegetable guidance. WRAP, 2019: https://wrap.org.uk/sites/default/files/2020-07/WRAP-food-labelling-guidance-uncut-fruit-and-vegetable.pdf*

Figure 9: Other on-pack information for apples sold in large-format UK supermarkets, November 2020



Source: Produce View in-store survey

WRAP citizen-facing storage guidance for apples is 'The fridge is the best place to store Apples'[74]. Shelf-life experiments conducted alongside this research suggest that apples stored in the fridge last two to three months longer than apples stored at ambient temperatures[75]. Previous research also found that only 26% of citizens claimed that they store apples in the fridge, which was corroborated by fridge audits: 25% of respondents stored apples in the fridge[76].

At present, there is limited evidence to suggest that citizens have different storage behaviours when apples are sold packaged or loose.

Before being sold to the public, apples can spend a long time in storage. The post-harvest life of apples ranges from 0-365 days and is influenced by variety and storage conditions. Across all apple varieties, the mean storage time is 50 days, but if stored correctly certain varieties can be stored for up to 12 months (e.g., Bramley's Seedling).

[74] *Love Food Hate Waste A-Z storage guidance.* *https://lovefoodhatewaste.com/article/food-storage-a-z*

[75] *The impact of packaging and refrigeration on shelf life, WRAP, 2022:* *https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

[76] *Helping Consumers Reduce Fruit and Vegetable Waste: Final Report, WRAP, 2008:* *https://wrap.org.uk/sites/default/files/2020-10/WRAP-RTL044-001%20Final%20report.pdf*

3.2 Apples: model inputs

This section details the input data used for the Household Simulation Model (HHSM) specific to apples. Data sources common to all products can be found in section 2.3. This section includes details on:

- Levels and patterns of consumption
- Pack sizes
- Shelf life

3.2.1 Levels and patterns of apple consumption

Section 2.3.1 describes the general approach for determining the amount of an individual food required by a household each day in the HHSM. The current section describes information specific to apples.

For apples, estimates of the amount required each day were built up from individual household members. This assumes that members of the household eat apples independently from each other – i.e., if one person eats an apple, the other members are no more or less likely to eat an apple that day. This assumption does not have a large influence on the results.

Data on apple consumption was based on the NDNS dataset (refer to Section 2.3.1). The distributions fitted to the NDNS data are found in Appendix 3. For people in all three age groups, there are peaks in the graphs, corresponding to the weight of a single apple. This suggests that, on days when people consume apples, they generally eat a single, whole apple. For infants (0-6 years of age), there was evidence of smaller quantities being consumed.

For these reasons, the apple requirements were set to the following for days when apples are consumed:

- Adults: 1 apple
- Children (7-17 years): 1 apple
- Infants (0-6 years): 45% chance of eating half an apple, 55% chance of eating a whole apple (based on the splits in the NDNS)

The probability that people consume apples was also calculated from the NDNS dataset. These are:

- Adults: 45%
- Children (7-17 years): 47%
- Infants (0-6 years): 39%

For the modelling of apples, it was not necessary to modify people's requirements for apples depending on whether apples were present in the home. This was largely due to apples being present most of the time in most simulated households: unfulfilled requirements were low.

These modelled consumption patterns average out at around three apples per person per week, higher than the levels of apples purchased recorded in Defra's Family Food statistics, quoted in Section 3.1. The main reason for this difference is that, in this research, we are modelling households that consume apples regularly; the Defra statistics average apple purchases over the whole population, including households that never eat apples.

3.2.2 Pack sizes for apples

This section describes the decisions around the number of apples purchased in the modelling. Data obtained from the Produce View survey of UK supermarkets (Section 2.3.3) revealed that packaged apples were most frequently found in packs of six in all major supermarkets surveyed. The next most common pack size was four, present in most (but not all) UK supermarkets. Therefore, these pack sizes were used as the pack sizes for the 'packaged' scenarios.

With packs of four and six apples available, households purchased a number of apples close to their needs for the time between shops. For instance, for the FF Single household, it was assumed that they would consume three apples a week if available to them in the home. Therefore, if purchasing packaged apples, a single pack of four apples is the closest to their needs. Similarly, the PP family would consume an average of 12.7 apples a week; hence they buy two packs of six.

The slight exceptions to this rule are the AD Family and SC One Child households, which each buy slightly more than their needs: due to the 'foodie' nature of these households, they would like to buy different types of apple at each shop, so buy two packs of four. These purchased amounts are slightly higher than the 6.0 and 5.5 apples respectively they typically consume in the four days between their main shops.

Table 7: Input data relating to purchasing of packaged apples

	AD Family	FF Single	FF Couple	SC Single	SC One Child	IA Couple	PP Family
Package Size (number of apples)	4	4	6	4	4	6	6
No. packages purchased at each main shop	2	1	1	1	2	1	2
No. packages purchased at each top-up shop	1	n/a	n/a	n/a	n/a	1	1
Average gap between main shops (days)	4	7	7	4	4	7	7

Apples were purchased on all main and top-up shops, unless there were a high number of apples already present in the household and the household adjusted their purchases accordingly (Feedback Loop no.1 in Figure 4).

For loose apples, the numbers purchased were determined from the requirements from earlier runs of the model. For those households with weekly main shops, three apples are purchased for *each person* in the household at each shop. For households with more frequent shops, fewer apples are purchased at each shop per person. For both of the 'foodie' household archetypes mentioned previously (AD Family and SC One Child), their aspiration to buy different types of apples can be accommodated when purchasing loose.

Table 8: Input data relating to purchasing of loose apples

	AD Family	FF Single	FF Couple	SC Single	SC One Child	IA Couple	PP Family
No. of apples purchased loose per main shop	6	3	6	2	6	6	12
No. of apples purchased loose per top-up shop	6	n/a	n/a	n/a	n/a	6	6
Average frequency of main shop (days)	4	7	7	4	4	7	7

3.2.3 Shelf life for apples

One of the important pieces of data for the modelling is the time between a product being purchased and when a given household is no longer prepared to eat it (referred to as the 'shelf life'). This will differ significantly depending on whether a household is influenced in their decision by the Best Before date or not, as discussed in Section 2.3.2.

To estimate the proportion of the population that use the Best Before date as the date upon which to disposal of apples, we used data from the one of the reports published alongside this one[77]. This report found that a minority of people used the Best Before date for apples. In answer to the question: *"Please indicate on the scale below how you make decisions about when to eat or throw away the following foods"*:

- 4% stated "Entirely on the date"
- 6% "Mostly on the date" and
- 22% "A mixture of the date and judgment".

[77] *Citizen insights on the influence of packaging and date labels on disposal decisions, WRAP, 2022: https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

To use this data to inform the modelling in the current report, it was assumed that all the people giving the first two responses and half those stating "A mixture of the date and judgment" dispose of their apples on the Best Before date. This is approximately 21% (4% + 6% + half of 22%). The value varies by household archetype, from 13% for Ideal Advocates to 43% for Aspirational Discovers.

It is possible that these figures used are an underestimate, based on the Implicit Association Test (IAT) documented in the same study (add reference). For apples, the uplift in disposal due to the date being present was around 40% for conditions 2 and 3 (apples that, while not perfect, were still deemed edible by most people in the absence of a date label). This suggests that more people may be strongly influenced by the date than indicated by the responses to the question on how they make decisions quoted above. Therefore, the impact of the presence of a Best Before date on food waste in the results (Section 3.4) may be an underestimate of the true impact for apples.

For those people who use the Best Before date as a disposal date, the average shelf life is assumed to be eight days after purchase. This is taken from data from Morrison's website (refer to Section 2.3.2).

For the remaining 79% of the population, it was assumed that people would consume apples until they started to deteriorate in quality. Data from the shelf-life experiment report was used to inform this input. Following the method use for all products (Section 2.3.2), the average shelf life for apples was found to be:

- Loose apples: 31.5 days
- Packaged apples: 31.3 days

As there was so little difference between the packaged and loose shelf lives (<1 day, <1%), the same value was used for both shelf lives (31 days). This will have minimal impact on the results. Given this assumption, the proportion of the population that depackages apples (58%[78]) does not affect the shelf-life in the modelling. However, it does affect the number of households for whom the Best Before date is available. Furthermore, only 66% of packaged apples in the UK carry a Best Before date[79]. We have assumed that the Best Before date is only available for 28% of households (66% x 42% not depackaging), of which, an average of 21% use this Best Before date as a disposal date. This means approximately 6% of households use the Best Before date as a disposal date for apples. This assumption is explored in the sensitivity analysis (Section 9.2).

The standard deviations used (6 days, derived from data for loose apples) means that 95% of apples in the model would have a shelf life ± 12 days of the average, reflecting the length of time that apples stored at ambient conditions take to deteriorate and differences in the stage of deterioration people are prepared to eat apples.

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[78] *Consumer Attitudes to Food Waste and Food Packaging*, WRAP (2013): https://wrap.org.uk/sites/default/files/2020-12/Consumer-attitudes-to-food-waste-and-packaging.pdf

[79] *Produce View data in Section 2.3.3.*

3.3 Apples: summary of modelling runs

Five scenarios were modelled in the final phase of modelling:

- Scenario 1: Packaged
- Scenario 2: Loose
- Scenario 3: Packaged but same shelf life as loose
- Scenario 4: Packaged but no Best Before date
- Scenario 5: Packaged but same pack size options as loose

Scenarios 3 to 5 are the same as packaged, but with one factor changed at a time to be the same as loose. This allows the effect of that single factor on the levels of waste to be assessed.

Scenario 1, Packaged: Households buy apples in packs of four or six. The number of packs bought is determined by their consumption levels, type of shop (main or top-up), and frequency of shop (Section 3.2.2). The shelf life is determined by the Best Before for around 6% of households (refer to Section 3.2.3); the remaining households use their judgement. For apples thrown away because they have reached their Best Before date, the average shelf life is eight days. For those using judgement, the average is 31 days.

Scenario 2, Loose: Households buy the number of apples appropriate for their needs (refer to Section 3.2.2). It is assumed that all apples are sold without packaging and no Best Before date. The average shelf life is therefore assumed to be 31 days.

Scenario 3, Packaged but same shelf life as loose: Unlike for most other products, this has no impact on the shelf life (refer to Section 3.2.3). Therefore, the modelling inputs and results are the same as scenario 1.

Scenario 4, Packaged no Best Before date: The same as scenario 1, except that the 21% of households that previously used the Best Before date as a disposal date now use their judgement for when to dispose of apples. For these households, this increases the average shelf life from eight days to 31 days. There is no change for the other 79% of households.

Scenario 5, Packaged, but same size options as loose: This scenario is the same as scenario 1, but the number of apples purchased is the same as in the loose scenario: households buy the number of apples appropriate to their needs. The Best Before date is still used for 21% of the population as a disposal date.

The results of these scenarios can be found in the following section (3.4).

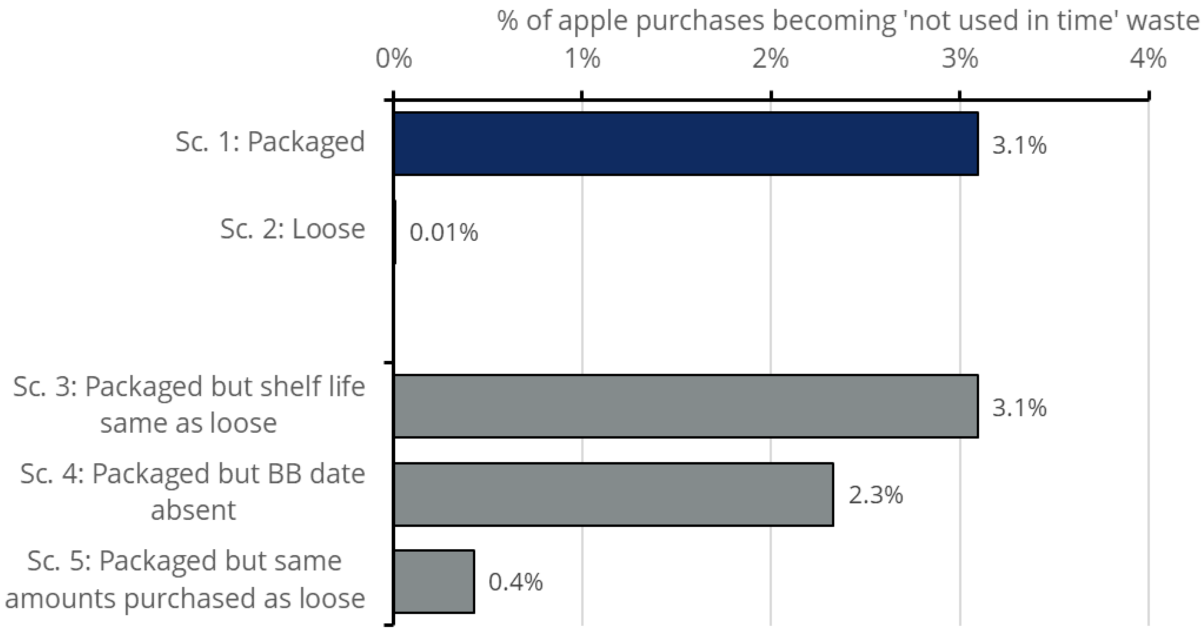
3.4 Apples: results and discussion

This section contains the results of scenarios described in the previous section. The differences between scenarios are discussed to demonstrate how various factors relating to the selling of apples impact the levels of food waste.

Figure 10 provides the estimates of 'not used in time' apple waste for the five scenarios previously described. **The main finding is that predicted levels of 'not used in time'**

food waste are considerably lower for loose apples (close to 0% of purchases) compared to packaged apples (3.1% of purchases).

Figure 10: Comparison of levels of 'not used in time' apple waste for scenarios modelled, expressed as % of purchases that are wasted because they are not used in time



This stark difference between the results of the loose and packaged scenarios should be viewed in the context of the assumptions of the modelling. It is likely that both the packaged and loose estimates are slight under-estimates, as neither account for apples coming into the home with some form of defect that is not visible on purchase but could lead to the apple being thrown away (e.g., internal rot). However, this is likely to affect packaged and loose apples to a similar degree, so using the *difference* between the two scenarios is still valid.

For both scenarios, it is assumed that people have a good understanding of the number of apples that they typically consume within their household and purchase accordingly. For some household archetypes, we have assumed that selling loose means that people will take the opportunity presented to them to purchase a more appropriate number of apples for their needs. It is possible that people continue to over-purchase to the same degree, despite the opportunity afforded to smaller households where loose items are available. The evidence from the Morrisons' trial (Section 1.2.3) suggests that many people do take the opportunity to adjust their purchasing habits.

It is also assumed that removal of the Best Before date will lead to people using their judgement on when to dispose of apples. While this is likely for many people, there could still be households who hold a view that the shelf life of apples is much shorter than the reality and still dispose of apples after a relatively short period of time, an action exacerbated perhaps if they buy apples each week and dispose of any remaining.

Scenarios 3 to 5 help to understand the differences between the packaged and loose scenarios. This is achieved comparing each to scenario 1 (packaged), allowing the impact of each factor to be assessed (Table 9).

Table 9: Summary of the impact on 'not used in time' apple waste of changes relating to elements of selling apples packaged

Change in...	Impact on food waste		Derived from which scenarios:	Notes
	Percentage-point change	Relative change (%)		
Shelf-life	0.0%	0%	3 minus 1	Shelf lives assumed to be the same
BB date (removed)	-0.8%	-25%	4 minus 1	Shelf life increases from 8 to 31 days for 6% of population
Pack-size options	-2.7%	-86%	5 minus 1	Reduces food waste in smaller households
All three changes simultaneously*	**-3.1%**	**-99.7%**	2 minus 1	Reduction driven by BB date removal and pack-size options

*This is not simply the sum of the three changes above: this scenario includes interactions between all three changes

Comparing scenarios 1 and 3 illustrates the effect of updating the packaged shelf life to be the same as the loose. As both packaged and loose shelf lives are assumed to be the same (average of 31 days), this makes no impact on the results.

Removing the Best Before date from packaged apples and assuming people consume apples up to the point that they start to deteriorate makes a substantial difference to levels of apple waste, falling from 3.1% of purchases (scenario 1) to 2.3% of purchases (scenario 4). This is despite the change only affecting around 6% of apple purchases (c. 21% of household use the date if present, 58% of households de-package and 66% of packaged apples have a Best Before date). This is because the level of apple waste is predicted to be high if people use the Best Before date as a disposal date: if all households used the Best Before date as a disposal date, 17% of apple purchases would be wasted[80] – around seven times higher than if all people use their judgement (2.3% of purchases, scenario 4).

The largest single effect comes from people buying the number of apples appropriate for their needs. This reduces apple waste from 3.1% of purchases (scenario 1) to 0.4% of purchases (scenario 5). The biggest changes are for single-occupancy households – these households benefit from being able to buy two or three apples on a shopping trip. These are the households that – under the 'packaged' scenario – wasted the highest proportion of their apple purchases. Therefore, this change disproportionately helps the households with the most waste to reduce the amount wasted.

[80] *This is not a scenario reported in Figure 10*

3.5 Apples: conclusions

The evidence presented in this report suggests that selling apples loose could lead to fewer being thrown away in the home.

The packaging does not greatly increase shelf life in the home for the varieties studied, and therefore has limited direct impact on household food waste. Even in situations where the packaging did extend shelf life (e.g., if it has an impact for varieties of apples not tested), 58% of the population de-package their apples, negating much of the potential benefit.

In contrast, the removal of the Best Before date and allowing households – especially smaller households – to purchase amounts of apples appropriate for their needs should greatly reduce food waste in the home. Even though the magnitude of these effects is contingent on some of the modelling assumptions, there would still be an overall reduction in apple waste in the home if more conservative assumptions were used.

These results suggest the following for reducing the number of apples thrown away in the home:

- Ensuring that apples last as long as possible after their purchase date: e.g., by ensuring that apples are kept in optimal conditions in the supply chain and in the home. The Shelf-Life Report[81] suggests that a very long shelf life can be achieved in the home by storing apples in the fridge.
- Encouraging citizens to purchase an appropriate number of apples for their needs, e.g., by only selling apples individually.
- Removing Best Before dates from apples, so that the date label cannot lead to premature disposal. Furthermore, encourage people to use their judgement and senses to make disposal decisions.

[81] *The impact of packaging and refrigeration on shelf life, WRAP, 2022:* *https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

4.0 Bananas

This section covers the following for bananas:

- Background information about bananas in the UK, focusing on household food waste (Section 4.1)
- The banana-specific inputs used for the modelling (Section 4.2)
- A summary of the scenarios modelled for bananas (Section 4.3)
- The results of these scenarios modelled for bananas, alongside discussion of the implications (Section 4.4)
- Banana-specific conclusions (Section 4.5)

4.1 Bananas: background information

In the UK, an average of 217 grams of bananas were purchased per person per week in 2018/19[82], equating to approximately 750,000 tonnes[83]. Bananas sold in the UK are mostly sourced from Central and South America and are easily available throughout the year[84]. In the UK, Cavendish is the main variety making up 98% of banana fruit sold[85]

The most detailed breakdown of household banana waste in the UK is based on 2012 data. This suggests that approximately 44% of all banana purchases were wasted. Most of this is peel (Figure 11), with 9% of purchases becoming 'avoidable' waste (whole bananas or flesh), the remainder being banana peel[86]. This equates to 67,000 tonnes of avoidable banana waste per year at a total cost of £63 million[87].

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[82] *Family Food datasets 2018/2019, Department for Environment, Food, & Rural Affairs, 2020: https://www.gov.uk/government/statistical-data-sets/family-food-datasets*

[83] *Estimated using the average UK population in 2019 (66.797 million), Office of National Statistics.*

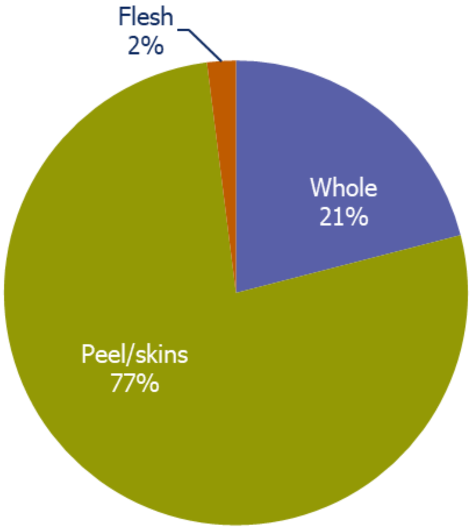
[84] *UK Horticulture Statistics, Department for Environment, Food, & Rural Affairs, 2019: https://www.gov.uk/government/collections/horticultural-statistics*

[85] *Fruit and vegetable resource maps: Final report. WRAP Cymru, 2011. Currently unpublished.*

[86] *Household food and drink waste: A product focus, WRAP, 2014: https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf*

[87] *Household Food and Drink Waste in the UK 2012, WRAP (2013): https://wrap.org.uk/sites/default/files/2020-12/Household-Food-and-Drink-Waste-in-the-United-Kingdom-2012.pdf*

Figure 11: Breakdown of household banana waste in the UK in 2012, by weight. Covers waste collected by local authorities: residual waste and collections targeting food waste.

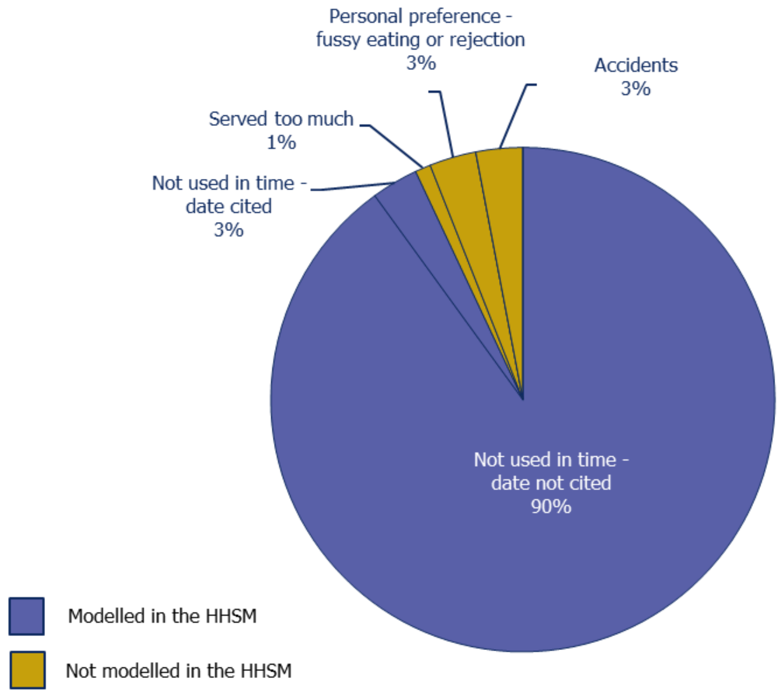


Source: Household Food and Drink Waste: A Product Focus[88]

The most common reason for discarding bananas was when they were not used in time (Figure 12). Of the banana waste that could have been eaten (whole and part bananas, but not peel), 93% was classified as 'not used in time'. The Household Simulation Model focuses on food waste that is 'not used it time', thus investigating 93% of total household banana waste.

[88] *Household food and drink waste: A product focus, WRAP, 2014:* [*https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf*](https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf)

Figure 12: Reasons for avoidable banana waste in UK households in 2012, by weight



Source: Household Food and Drink Waste: A Product Focus[89]

Of the 93% of waste that was not used in time, participants in research involving food-waste diaries rarely cited a date label when recording why they discarded the banana (3% of the total avoidable waste; Figure 12). This is consistent with other WRAP research that suggests date labels play a larger role in people's decisions when there is a perceived safety risk such as for meat and dairy products[90]. For fresh produce items, most citizens tend to rely on their own senses and judgement when deciding whether to eat or discard an item. However, research published alongside this report suggests that a substantial minority of people are heavily influenced in their disposal decisions by the Best Before date, as discussed in 2.3.2.

In early November 2020, Produce View conducted a review of several large format supermarkets in the UK to understand the range of bananas (and other products included in this report) that were available. (Methodological details can be found in Section 2.3.3.) The survey included details on the types of banana sold loose and in packaging, packaging material and formats, date label type and prevalence, as well as on-pack storage guidance.

According to the survey, eight lines of bananas were sold loose across the ten supermarkets surveyed. In contrast, 33 lines of packaged bananas were found in the same supermarkets: these fell into 5 categories: Fairtrade, Organic, Small size, Regular size (not organic) and 'Ripen at home'. When sold loose, only two types were offered by UK retailers: Fairtrade and Regular size (not organic).

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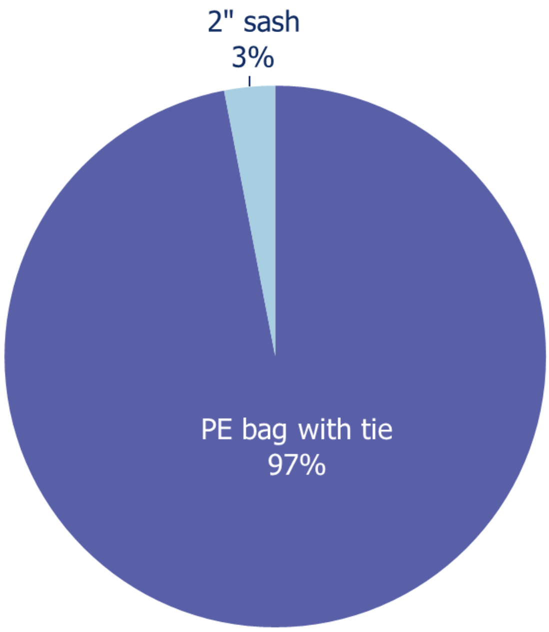
[89] *Household food and drink waste: A product focus, WRAP, 2014:* https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf

[90] *Consumer insight: date labels and storage guidance, WRAP (2011):* https://wrap.org.uk/sites/default/files/2020-12/Consumer-insight-date-labels-and-storage-guidance.pdf

Across all supermarkets that were visited, bananas were sold in two types of packaging. The most common type of packaging was a polyethylene tied bag and 97% of packaged banana lines were sold in this format.

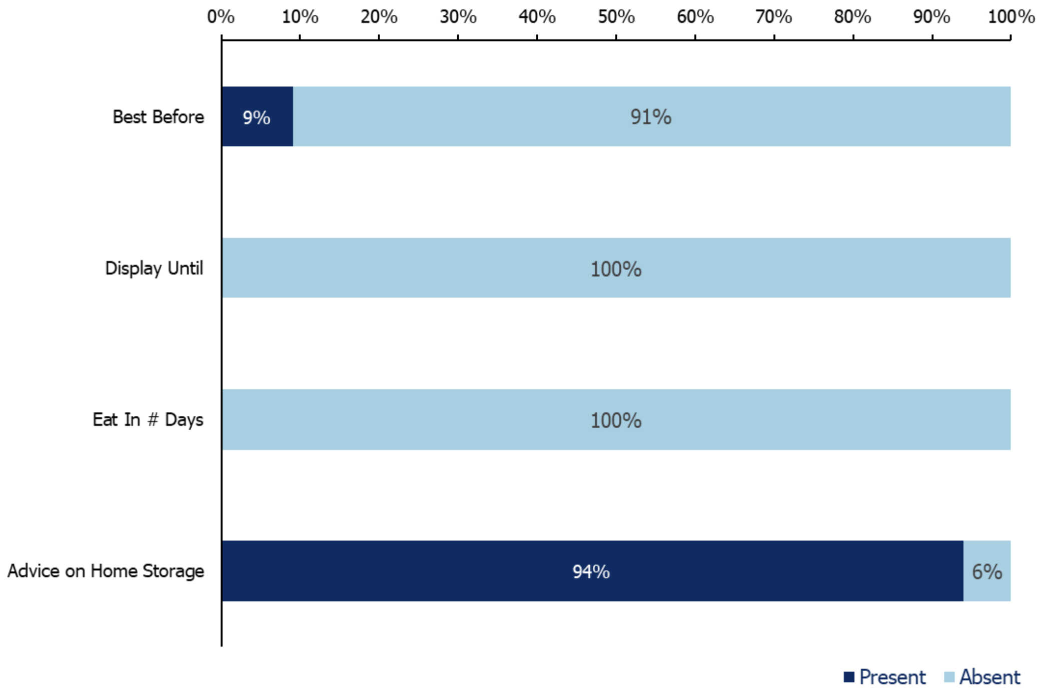
Figure 13: Packaging types for bananas sold in large-format UK supermarkets, Nov. 2020



Source: Produce View in-store survey

Information displayed on-pack that is relevant to this study include date labels and storage information. Focussing on date labels, only 9% of packaged bananas had a 'Best Before' date, the lowest percentage for any of the five products investigated in this report. No packaged bananas had a 'Display Until' date or an 'Eat in X number of days' label. In terms of storage information, 94% of packaged bananas contained advice on home storage (Figure 14).

Figure 14: Other on-pack information for bananas sold in large-format UK supermarkets, November 2020



Source: Produce View in-store survey

WRAP storage guidance for bananas states: 'At home, store in a cool, dry place'. Laboratory experiments showed that there was no benefit in storing bananas in the fridge as the skins will blacken. The experiments also demonstrated that bananas stored at 22°C lost their visual quality within 4 days, whereas bananas kept at 15°C remained visually acceptable for 7-17 days[91]. This research also found that 84% of citizens claimed that they never store bananas in the fridge, which was corroborated by fridge audits: 94% of respondents stored bananas outside of the fridge.

At present, there is limited evidence to suggest that citizens have different storage behaviours when bananas are sold packaged or loose.

4.2 Bananas: model inputs

This section details the input data used for the Household Simulation Model (HHSM) specific to bananas. Data common to all products can be found in section 2.3. This section includes details on:

- Levels and patterns of consumption
- Pack sizes
- Shelf life

[91] *Helping Consumers Reduce Fruit and Vegetable Waste: Final Report, WRAP, 2008: https://wrap.org.uk/sites/default/files/2020-10/WRAP-RTL044-001%20Final%20report.pdf*

4.2.1 Levels and patterns of banana consumption

Section 2.3.1 describes the general approach for determining the amount of an individual food required by a household each day in the HHSM. The current section describes information specific to bananas.

For bananas, estimates of the amount required each day were built up from individual household members. This assumes that members of the household eat bananas independently from each other – i.e., if one person eats a banana, the other members are no more or less likely to eat a banana that day. This assumption does not have a large influence on the results.

Data on banana consumption was based on the NDNS dataset (refer to Section 2.3.1). The distributions fitted to the NDNS data are found in Appendix 3. For people in all three age groups, there is a peak in the graphs, which is especially prominent for older children (7-17 years of age) and adults. This suggests that, on days when people consume bananas, they generally eat a single, whole banana. For infants (0-6 years of age), there was evidence of smaller quantities being consumed.

For these reasons, the banana requirements were set to the following for days when bananas are consumed:

- Adults: 1 banana
- Children (7-17 years): 1 banana
- Infants (0-6 years): 36% chance of eating ½ banana, 64% chance of eating a whole banana (based on the splits in the NDNS)

The probability that people consume bananas was also calculated from the NDNS dataset. These are:

- Adults: 52%
- Children (7-17 years): 45%
- Infants (0-6 years): 50%

In the preliminary modelling, banana requirements were not based on the presence of bananas in the household. This led to relatively high levels of waste and / or high levels of unfulfilled requirements. Therefore, it was decided to use the more advanced functionality of the HHSM in the final modelling: to allow the probability that bananas are required for consumption on a given day is increased (10 percentage points) when banana are present in the household: a more realistic assumption that led to more realistic levels of modelled waste.

These consumption patterns modelled average out at around three bananas per person per week, higher than the levels of banana purchases recorded in Defra's Family Food statistics, quoted in Section 4.1 (approximately 2 bananas per person per week). The main reason for this difference is that, in this research, we are modelling households that consume bananas regularly; the Defra statistics average bananas purchases over the whole population, including households that never eat bananas.

4.2.2 Pack sizes for bananas

This section describes the decisions around the number of bananas purchased in the modelling.

Data obtained from the Produce View survey of UK supermarkets (Section 2.3.3) revealed that packaged bananas were most frequently found in packs of five. Therefore, this was used as the pack size for the 'packaged' scenarios.

Larger households (those with 3 or 4 occupants) were modelled to buy two packs of bananas on main shops (Table 10). All other households purchased one pack on the main shop. For those households where top-up shops were possible, one pack was purchased during these shops.

Table 10: Input data relating to purchasing of packaged banana

	AD Family	FF Single	FF Couple	SC Single	SC One Child	IA Couple	PP Family
Package Size (no. bananas)	5	5	5	5	5	5	5
No. packages purchased at each main shop	2	1	1	1	2	1	2
No. packages purchased at each top-up shop	1	n/a	n/a	n/a	n/a	1	1
Average gap between main shops (days)	4	7	7	4	4	7	7

Table 11: Input data relating to purchasing of packaged banana

	AD Family	FF Single	FF Couple	SC Single	SC One Child	IA Couple	PP Family
No. of bananas purchased loose per main shop	7	4	5	3	7	5	10
No. of bananas purchased loose per top-up shop	7	n/a	n/a	n/a	n/a	3	5
Average gap between main shops (days)	4	7	7	4	4	7	7

Bananas were purchased on all main and top-up shops, unless there were a high number of bananas already present in the household and the household adjusted their purchases accordingly (refer to Feedback Loop no.1 in Figure 4).

For loose bananas, the numbers purchased were determined from the requirements from earlier runs of the model. This sees reductions in the number of bananas purchased for a main shop for AD families (from ten to seven), FF single (from five to four), SC Single (from five to three) and for SC one child (from ten to seven).

4.2.3 Shelf life for bananas

One of the important inputs for the modelling is the time between a product being purchased and when a given household is no longer prepared to eat it (referred to as the 'shelf life'). This will differ significantly depending on whether a household is influenced in their decision by the Best Before date or not, as discussed in Section 2.3.2.

In reference to Citizen Disposal Decision Report[92], it was found that a minority of people used the Best Before date for bananas. In answer to the question: *"Please indicate on the scale below how you make decisions about when to eat or throw away the following foods"*, 4% stated "*Entirely on the date"*, 5% *"Mostly on the date"* and 19% *"A mixture of the date and judgment"*.

However, from the Produce View report, only 9% of packaged bananas carry a Best Before date. Furthermore, previous research indicates that the majority of UK citizens (63%) depackaged their bananas on return from their shopping trip[93], effectively removing the Best Before date. If we combined these percentages, assuming that they are independent, the proportion of the population using Best Before dates as disposal dates would be around 1%. Therefore, it is assumed that the Best Before date do not inform disposal decisions of bananas in UK households.

It was thus assumed that people would consume bananas until they started to deteriorate in quality. Data from the Shelf-Life Report[94] was used to inform this input. Following the method use for all products (Section 2.3.2), the average shelf life for bananas was found to be:

- Loose bananas: 5.0 days, with a standard deviation of 1.5 days.
- Packaged bananas: 6.8 days with a standard deviation of 1.5 days.

This means that those bananas that are packaged – and remain in their packaging in the home – have a shelf life of around 1.8 days longer than loose bananas or bananas that have been depackaged.

[92] *Citizen insights on the influence of packaging and date labels on disposal decisions, WRAP, 2022:* *https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

[93] *Consumer Attitudes to Food Waste and Food Packaging*, WRAP (2013): https://wrap.org.uk/sites/default/files/2020-12/Consumer-attitudes-to-food-waste-and-packaging.pdf

[94] *The impact of packaging and refrigeration on shelf life, WRAP, 2022: https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

The standard deviations means that 95% of bananas in the model would have a shelf life ± 3 days of the average, reflecting the length of time that bananas stored at ambient conditions take to deteriorate and differences in the stage of deterioration people are prepared to eat bananas.

4.3 Bananas: summary of modelling runs

Five scenarios were modelled in the final phase of modelling:

- Scenario 1: Packaged
- Scenario 2: Loose
- Scenario 3: Packaged but same shelf life as loose
- Scenario 4: Packaged but no Best Before date
- Scenario 5: Packaged but same pack size options as loose

Scenarios 3 to 5 are the same as packaged, but with one factor changed at a time to be the same as loose. This allows the impact of individual factors to be assessed.

Scenario 1, Packaged: Households buy bananas in packs of five. The number of packs they buy is determined by their consumption levels and the type of shop (main or top-up). It is assumed that 63% of the population depackage bananas on return from home. For bananas that are depackaged, the shelf life is 5.0 days, for those still in packaging it is 6.8 days. It is also assumed that Best Before dates do not inform disposal decisions.

Scenario 2, Loose: Households buy the number of bananas appropriate to their needs. All bananas are sold loose. It is assumed that Best Before dates are not present and therefore not used. The average shelf life is 5.0 days.

Scenario 3, Packaged but same shelf life as loose: All packaged bananas have a shelf-life of 5.0 days. This is the same as assuming that 100% of the population depackage their bananas after shopping.

Scenario 4, Packaged no Best Before date: As scenario 1 assumes no-one uses the Best Before date, this scenario has the same inputs and results as scenario 1.

Scenario 5, Packaged but same size options as loose: This scenario is the same as scenario 1 except that the number of bananas purchased is the same as in the loose scenario: households buy the number of bananas appropriate to their needs. 63% of households are still assumed to depackaged their bananas.

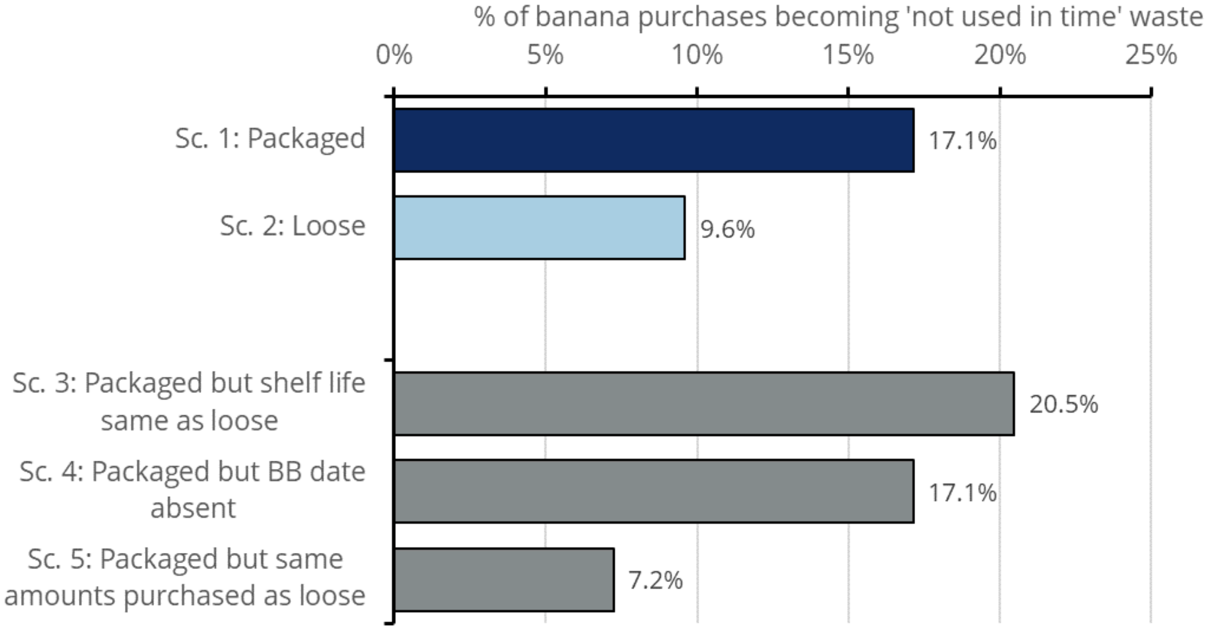
The results of these scenarios can be found in the following section (4.4).

4.4 Bananas: results and discussion

This section contains the results of scenarios described in the previous section. The differences between scenarios are discussed to demonstrate the impact on food waste of different changes to how bananas are sold.

Figure 15 provides the levels of 'not used in time' banana waste modelled for the five scenarios previously described. Predicted levels of waste are considerably lower for loose bananas (9.6% of purchases) compared to packaged bananas (17.1%).

Figure 15: Comparison of levels of 'not used in time' banana waste for scenarios modelled



Scenarios 3 to 5 help to understand the differences between the packaged and loose scenarios. This is achieved comparing each to scenario 1 (packaged), allowing the impact of each factor to be assessed (Table 12).

Table 12: Summary of the impact on 'not used in time' banana waste of changes relating to elements of selling bananas packaged

Change in...	Impact on food waste		Derived from which scenarios:	Notes
	Percentage-point change	Relative change (%)		
Shelf-life	+3.3%	19%	3 minus 1	1.8 days less shelf life for 37% of population keeping bananas packaged
BB date (removed)	0%	0%	4 minus 1	No change (assumed BB dates not used for bananas)
Pack-size options	-9.9%	-58%	5 minus 1	Purchases need not be in multiples of five
All three changes simultaneously*	**-7.5%**	**-44%**	2 minus 1	Overall, decrease in HHFW due to pack-size options

*This is not simply the sum of the three changes above: this scenario includes interactions between all three changes

Comparing scenarios 1 and 3 illustrates the effect of reducing the packaged shelf life to be the same as the loose. This change applies to the 37% of the population who, when bananas are packaged, keep them in the packaging after purchase. For this group of the population, this increases the shelf life by 1.8 days. Overall, the change in shelf life of selling loose is predicted to increase banana waste by 3.3% of purchases (from 17.1% of purchases to 20.5%). There would be a larger difference from this effect if a greater proportion of the UK population kept their bananas in packaging after purchase.

Comparing scenarios 1 and 4 illustrates the predicted impact of the removal of Best Before dates from the few bananas that carry this information. This is estimated at zero, as so few bananas carry Best Before dates, most people claim not to use them if they are present and most people depackage bananas after purchase, effectively removing the Best Before date.

Comparing scenarios 1 and 5 illustrates the predicted impact of allowing people to purchase bananas in the pack size that best fits their needs (i.e., the same number of as in the loose scenario). Although this change only affects four of the seven household archetypes, it has the largest single impact on the level of food waste, reducing it from 17% to 7% of banana purchases. This illustrates that allowing people to purchase any number of items could greatly help prevent waste.

4.5 Bananas: conclusions

The evidence presented in this report suggests that selling bananas loose could lead to fewer being thrown away in the home. Despite the shelf life being extended by the presence of packaging by 1.8 days, most people depackage their bananas when they return from the shops and therefore this shelf-life extension is not realised for most people. Therefore, the effect relating to changes in shelf life is relatively modest. It is smaller in magnitude than the impact of allowing people to buy the appropriate number of bananas for their needs. This effect reduces food waste in the home and is of greater magnitude than the effects of shelf life. Therefore, selling bananas loose has the potential to reduce household food waste *and* reduce the amount of plastic packaging.

Other findings from the modelling suggest the following for reducing the number of bananas thrown away in the home:

- Ensuring that bananas last as long as possible after their purchase date: e.g., by ensuring that bananas are kept in optimal conditions in the supply chain and in the home. Previous research has suggested cooler conditions (but not the fridge) can extend bananas' shelf life.
- Encouraging citizens to purchase an appropriate number of bananas for their needs, e.g., by only selling bananas individually.
- For the small number of retailers still using Best Before dates on bananas, removing these so that they cannot influence people's disposal decisions.

5.0 Broccoli

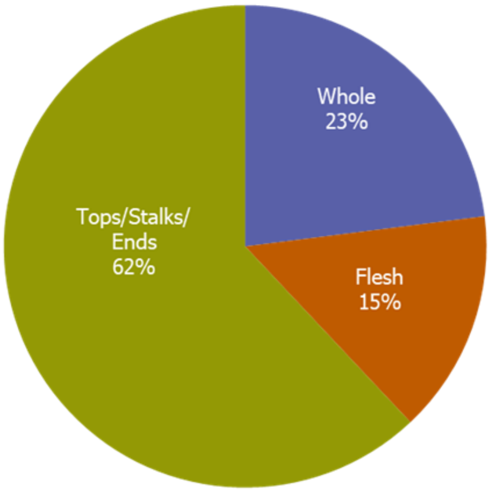
This section covers the following for broccoli:

- Background information about broccoli in the UK, focusing on household food waste (Section 5.1)
- The broccoli-specific inputs used for the modelling (Section 5.2)
- A summary of the scenarios modelled for broccoli (Section 5.3)
- The results of these scenarios modelled for broccoli, alongside discussion of the implications (Section 5.4)
- Broccoli-specific conclusions (Section 5.5)

5.1 Broccoli: background information

In the UK, an average of 173 grams of fresh green vegetables were purchased per person per week in 2018/19, of which, approximately 73 grams was headed broccoli and cauliflower[95]. This equates to approximately 250,000 tonnes per year of broccoli and cauliflower purchases[96]. Around 60,000 tonnes of broccoli are produced in the UK and around 133,000 tonnes of broccoli and cauliflower are imported[97]. UK production is from June to October with Spain the main exporter of broccoli to the UK. In the UK, Calabrese is the main variety.

Figure 16: Breakdown of household broccoli waste in the UK in 2012, by weight. Covers waste collected by local authorities: residual waste and collections targeting food waste



Source: Household Food and Drink Waste: A Product Focus[98]

The most detailed breakdown of household broccoli waste in the UK is based on 2012 data. This suggests that around 42,000 tonnes of broccoli were wasted by UK

[95] *Family Food datasets 2018/2019, Department for Environment, Food, & Rural Affairs, 2020: https://www.gov.uk/government/statistical-data-sets/family-food-datasets*

[96] *Estimated using the average UK population in 2019 (66.797 million), Office of National Statistics.*

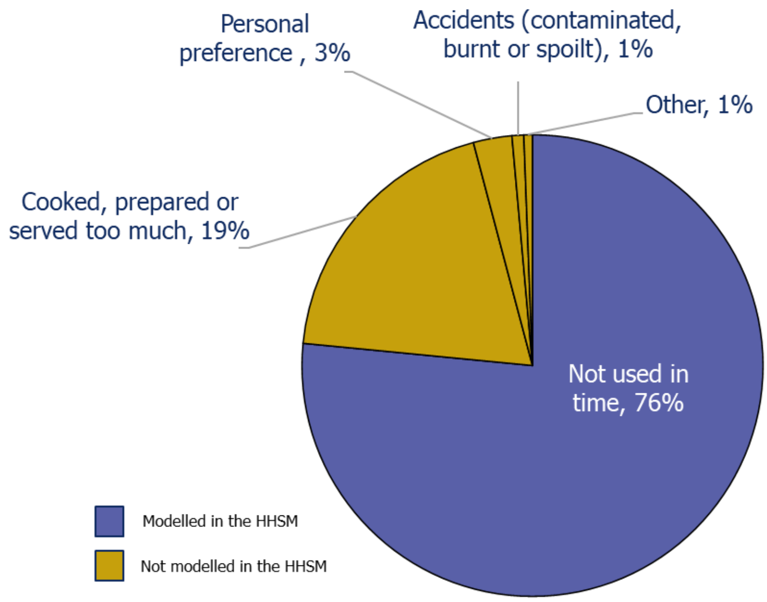
[97] *UK Horticulture Statistics, Department for Environment, Food, & Rural Affairs, 2019: https://www.gov.uk/government/collections/horticultural-statistics*

[98] *Household food and drink waste: A product focus, WRAP, 2014: https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf*

households annually, of which 15,000 tonnes was classified as 'avoidable' (whole or flesh of broccoli, excluding the stalk)[99].

The most common reason for discarding broccoli was because it was not used in time. Of the avoidable waste, 11,000 tonnes (76%) was classified as 'not used in time'. The remaining avoidable waste was due to personal preference, serving too much and accidents (Figure 17)[100]. The Household Simulation Model focuses on food waste that is 'not used it time', thus investigating 76% of total broccoli waste.

Figure 17: Reasons for avoidable broccoli waste in UK households in 2012, by weight



Source: Household Food and Drink Waste in the UK 2012[100]

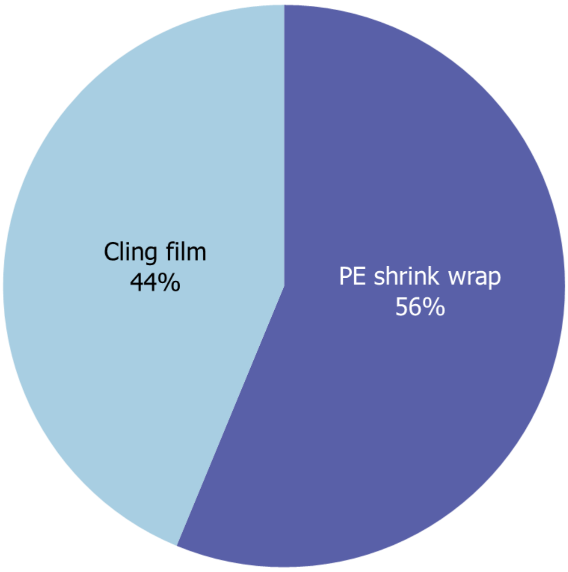
In early November 2020, Produce View conducted a review of several large format supermarkets in the UK to understand the range of broccoli (and other products included in this report) that were available. (Methodological details can be found in Section 2.3.3.) The survey included details on the types of broccoli sold loose and in packaging, packaging material and formats, date label type and prevalence, as well as on-pack storage guidance.

According to the survey, both organic and non-organic broccoli are sold in packaging, whereas only non-organic broccoli is sold loose. The most common type of packaging was polyethylene shrink wrap and 56% of packaged broccoli lines were sold in this format. The remaining 44% of lines were sold in cling film (Figure 18).

[99] Since the publication of *Household food and drink waste: A product focus* in 2014, WRAP has updated the classification of household food waste, moving from the term 'avoidable' to 'edible'. This report uses details that were calculated before this change. Refer to Section 2.3.4 for more details.

[100] *Household Food and Drink Waste in the UK 2012, WRAP (2013): https://wrap.org.uk/sites/default/files/2020-12/Household-Food-and-Drink-Waste-in-the-United-Kingdom-2012.pdf*

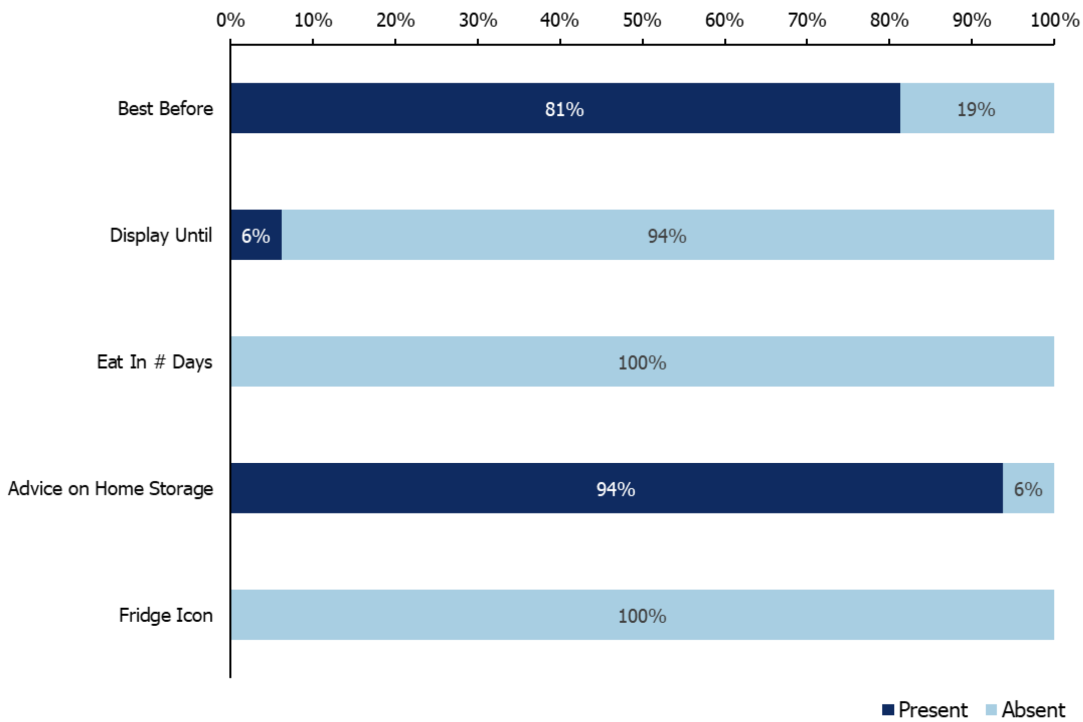
Figure 18: Packaging types for broccoli sold in large-format UK supermarkets, Nov. 2020



Source: Produce View in-store survey

Information displayed on-pack that is relevant to this study include date labels and storage information. Focussing on date labels, 81% of packaged broccoli lines had a 'Best Before' date, 6% had a 'Display Until' date. No broccoli lines had an 'Eat in X number of days' label. In terms of storage information, 94% of packaged broccoli lines had advice on home storage and none had a fridge icon (Figure 19).

Figure 19: Other on-pack information for broccoli sold in large-format UK supermarkets, November 2020



Source: Produce View in-store survey

WRAP storage guidance for broccoli is 'Broccoli should be stored in the fridge in its original packaging, to keep it at its best.'[101]. Laboratory experiments demonstrated that broccoli is highly perishable if not refrigerated[102]. Broccoli stored at 22°C developed significant browning, off-odours and fungal growth after only 4 days, whereas broccoli stored in the fridge was acceptable after 7 days but unacceptable after 11 days. This research also found that 92% of citizens claimed that they store broccoli in the fridge, which was corroborated by fridge audits: 90% of respondents stored broccoli in the fridge.

At present, there is limited evidence to suggest that citizens have different storage behaviours when broccoli is sold packaged or loose.

5.2 Broccoli: model inputs

This section details the input data used for the Household Simulation Model (HHSM) specific to broccoli. Data common to all products can be found in section 2.3. This section includes details on:

- Levels and patterns of consumption
- Pack sizes
- Shelf life

5.2.1 Levels and patterns of broccoli consumption

Section 2.3.1 describes the general approach for determining the amount of an individual food required by a household each day in the HHSM. The current section describes information specific to broccoli.

For broccoli, the amount required each day was estimated for the whole household, built up from data for individual household members. This assumes that members of the household eat broccoli at a similar time, for example, as part of a main meal.

Data on broccoli consumption was based on the NDNS dataset (refer to Section 2.3.1). The distributions fitted to the NDNS data are found in Appendix 3. These show an increase with age for the amount of broccoli eaten in a given day:

- Adults: 76 grams
- Children (7-17 years): 60 grams
- Infants (0-6 years): 33 grams[103]

[101] *Love Food Hate Waste A-Z storage guidance.* *https://lovefoodhatewaste.com/article/food-storage-a-z*

[102] *Helping Consumers Reduce Fruit and Vegetable Waste: Final Report, WRAP, 2008:* *https://wrap.org.uk/sites/default/files/2020-10/WRAP-RTL044-001%20Final%20report.pdf*

[103] The distributions used were for inputs to the model were: Adults: TRIANGULAR(6, 83.4, 125), Children (7-17 years): 15 + WEIBULL(49.8, 2.27), Infants (0-6 years): TRIANGULAR(1, 44.9, 55)

The probability that people consume broccoli was also calculated from the NDNS dataset. These probabilities are:

- Adults: 31%
- Children (7-17 years): 28%
- Infants (0-6 years): 31%

An average value of 30% was used for the basic probability of consumption on a given day. To represent actual dynamics in the household more accurately, the probability that broccoli was required on a given day varied depending on whether there was broccoli available to consume or not. If there was no broccoli in the household, the value used was 25%. If there was broccoli present, this probability was 35%, 10 percentage points higher. This is a more realistic dynamic, as the presence of broccoli could be a trigger for consumption. This modification helped to ensure that outputs of the model (levels of broccoli waste and unfulfilled requirements) were realistic.

5.2.2 Pack sizes for broccoli

This section describes the decisions in the modelling around the amount of broccoli purchased.

Data obtained from the Produce View survey of UK supermarkets (Section 2.3.3) revealed that packaged broccoli was most likely to be in packs of 350 grams. It was assumed that 200 grams of this was typically eaten by a household. The remaining 150 grams was assumed to be stalk that most households usually do not eat (Nicholes et al. 2019)[104].

On a main shop, the following household archetypes were assumed to buy two packs of broccoli: AD Family, FF Couple, SC One Child, PP Family. The other three archetypes buy a single pack (Table 13). For those households where broccoli was purchased at a top-up shop (AD Family, IA Couple), one pack was purchased.

It was further assumed that all households purchased broccoli on every shopping trip unless they had broccoli already and checked their stocks beforehand (refer to Feedback Loop no.1 in Figure 4).

It was assumed that the same amounts of broccoli were purchased irrespective of whether the broccoli was packaged or loose. This assumes that loose and packaged heads of broccoli are approximately the same size and that the presence of packaging does not greatly influence purchasing habits.

[104] Nicholes et al. (2019) *Surely you don't eat parsnip skins? Categorising the edibility of food waste.* Resources, Conservation and Recycling 147, pp. 179-188. https://doi.org/10.1016/j.resconrec.2019.03.004. It should be noted that the population was relatively evenly split between those who 'never' or 'occasionally' eat broccoli stalks (total = 47%) and those who 'always' and 'often' (total = 43%). Eating this fraction of broccoli can help prevent food waste in the home: https://www.lovefoodhatewaste.com/dont-just-eat-it-compleat-it

Table 13: Input data relating to purchasing of packaged broccoli

	AD Family	FF Single	FF Couple	SC Single	SC One Child	IA Couple	PP Family
Package Size (g)	200	200	200	200	200	200	200
No. packages purchased at each main shop	2	1	2	1	2	1	2
No. packages purchased at each top-up shop	1	n/a	n/a	n/a	n/a	1	n/a
Probability of buying the item at main shop	100	100	100	100	100	100	100
Probability of buying the item at top-up shop	100	n/a	n/a	n/a	n/a	100	100

5.2.3 Shelf life for broccoli

The time between a product being purchased and when a given household is no longer prepared to eat it (referred to as the 'shelf life') is an important input to the model. This will differ significantly depending on whether a household is influenced in their decision by the Best Before date or not, as discussed in Section 2.3.2.

In reference to Citizen Disposal Decision Report[105], it was found that a minority of people used the Best Before date for broccoli. In answer to the question: *"Please indicate on the scale below how you make decisions about when to eat or throw away the following foods"*:

- 4% stated "Entirely on the date",
- 6% "Mostly on the date", and
- 23% "A mixture of the date and judgment".

This data from the Citizen Disposal Decision Report was used to inform the modelling inputs. It was assumed that all the people giving the first two responses and half those stating "A mixture of the date and judgment" dispose of their broccoli on the Best Before date. This is approximately 21% (4% + 6% + half of 23%). The value varies by household archetype, from 17% for Ideal Advocates to 42% for Aspirational Discovers.

This average value is similar to the uplift in broccoli disposal due to the presence of a date label found in the implicit test – for condition 2, there was an uplift of 33%, for condition

[105] *Citizen insights on the influence of packaging and date labels on disposal decisions, WRAP, 2022: https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

3, the uplift was 8%. The values suggests that an average of around an additional 20% of the population would throw away their broccoli if there is a date label present.

From data from the in-store survey (Section 5.2.3), 81% of packaged broccoli lines had a Best Before date. We have assumed that, for the Best Before date to influence the disposal decision, the Best Before date must be present and people use it. We have therefore multiplied this by the 21% of people influenced by the Best Before date with the 81% of packs with the date: therefore, approximately 16% of disposal decisions are informed by the Best Before date.

For the remaining 84% of the population, it was assumed that people would consume their broccoli until it started to deteriorate in quality. Data from the Shelf-Life Report[106] was used to inform this input. Following the method use for all products (Section 2.3.2), the average shelf life for broccoli in a fridge at 4°C was found to be:

- Loose broccoli: 17 days, with a standard deviation of 2.5 days.
- Packaged broccoli: 24 days with a standard deviation of 2.5 days.

This means that for broccoli that is packaged – and remains in its packaging when in the home – has a shelf life of around seven days longer than loose broccoli or broccoli that has been de-packaged.

For this modelling, it is assumed that broccoli is not de-packaged at home. We were unable to find data on the degree of de-packaging for broccoli. The only data for vegetables that we were aware of was for carrots, for which 34% are de-packaged[107]. We investigate the importance of this assumption in the sensitivity analysis (Section 9.2).

The standard deviations mean that 95% of broccoli in the model would have a shelf life ± 5 days of the average, reflecting the variability in time that broccoli takes to deteriorate and different people's willingness to eat broccoli at different states of deterioration.

5.3 Broccoli: summary of modelling runs

Five scenarios were modelled for broccoli in the final phase of modelling:

- Scenario 1: Packaged
- Scenario 2: Loose
- Scenario 3: Packaged but same shelf life as loose
- Scenario 4: Packaged but no Best Before date
- Scenario 5: Packaged but same pack size options as loose

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[106] *The impact of packaging and refrigeration on shelf life, WRAP, 2022:* https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste

[107] *Consumer Attitudes to Food Waste and Food Packaging*, WRAP (2013): https://wrap.org.uk/sites/default/files/2020-12/Consumer-attitudes-to-food-waste-and-packaging.pdf

Scenarios 3 to 5 are the same as packaged, but with one factor changed at a time to be the same as loose. This allows the impact of that single factor on the levels of waste to be assessed.

Scenario 1, Packaged: Households buy broccoli in packs weighing 350 grams, with 200 grams used by the household (the rest being stalk that is typically not eaten). Households buy either one or two packs on shopping trips (Table 13). With regard to the length of time people are prepared to eat broccoli after purchase, c. 16% of the population use the Best Before date: for these households, the shelf-life is an average of 3.5 days. For the remaining 84% of the population, the broccoli remains in packaging and people use their judgement to decide when to dispose: an average shelf-life of 24 days.

Scenario 2, Loose: Households buy the same amount of broccoli as for the packaged scenario. It is assumed that heads of broccoli are the same size. The average time after purchase that people dispose of broccoli is 17 days for all households.

Scenario 3, Packaged but same shelf life as loose: For this scenario, 16% of the population still use the Best Before date. However, for the remining 84% of the population, the shelf life change from 24 days to 17 days.

Scenario 4, Packaged no Best Before date: In this scenario, for the 16% of the population using the Best Before date, the shelf life of broccoli is increased from 3.5 days to 24 days.

Scenario 5, Packaged, but same size options as loose: As it is assumed that people buy the same amount of broccoli whether packaged or loose, there is no difference in the inputs or results between this scenario and the packaged scenario (number 1).

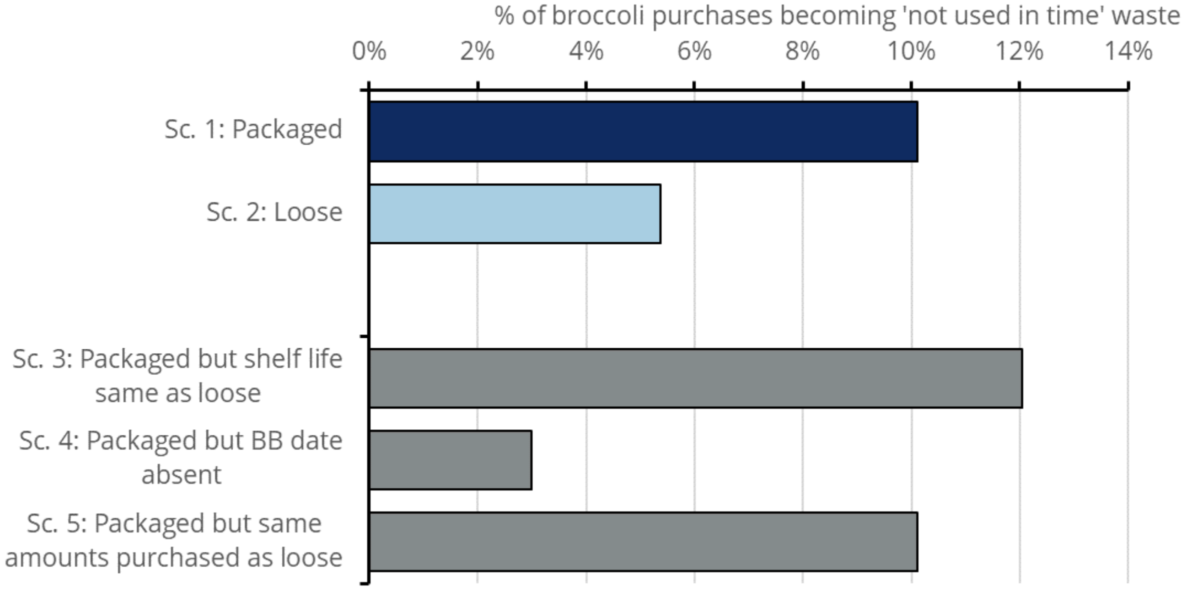
The results of these scenarios can be found in the following section (5.4).

5.4 Broccoli: results and discussion

This section contains the results of scenarios described in the previous section for broccoli. The scenarios are compared to demonstrate the impact on broccoli waste of factors relating to the presence or absence of packaging.

Figure 20 illustrates the estimates of 'not used in time' broccoli waste modelled for the five scenarios previously described. **The main finding is that predicted levels of waste are considerably lower for loose broccoli (5.4% of purchases) compared to packaged broccoli (10.1%).**

Figure 20: Comparison of levels of 'not used in time' broccoli waste for scenarios modelled



Scenarios 3 to 5 help to understand the differences between the packaged and loose scenarios. This is achieved comparing each to scenario 1 (packaged), allowing the impact of each factor to be assessed (Table 14).

Comparing scenarios 1 and 3 illustrates the effect of decreasing the packaged shelf life by seven days for the 86% of the population assumed to keep their broccoli in packaging and use their judgement for when to throw broccoli away. Although difference in shelf life is relatively large (from 24 days to 17 days), both shelf lives are relatively long and consequently levels of broccoli waste are low: for the sub-section of the population that use their judgement, broccoli waste is:

- 3.0% of purchases for the 24-day shelf life, and
- 5.4% for the 17-day shelf life.

The reason that this change is not having more effect in scenario 3 is that most of the food waste is coming from a sub-section of the population that uses the Best Before date as a disposal date. For this group, 43% of broccoli purchases are wasted. This sub-section is unaffected by the change in scenario 3.

Comparing scenarios 1 and 4 illustrates the impact of the removal of Best Before dates. This is pronounced, even though only 16% of the population are affected by this change: the level of broccoli waste reduced from 10.1% to 3.0%, illustrating the large impact of premature disposal. This is the single largest effect on selling broccoli loose, far outweighing the slight decrease in shelf-life illustrated by scenario 3.

There is no change in inputs between scenarios 1 and 5: the same amounts of broccoli are assumed to have been purchased in each.

Table 14: Summary of the impact on 'not used in time' broccoli waste of changes relating to elements of selling broccoli packaged

Change in…	Impact on food waste		Derived from which scenarios:	Notes
	Percentage-point change	Relative change (%)		
Shelf-life	+1.9%	19%	3 minus 1	7 days less shelf life for 45% of population who keep broccoli packaged and use judgement for disposal decisions
BB date (removed)	-7.1%	-70%	4 minus 1	For 16% of population, shelf life increases from 3.5 to 24 days
Pack-size options	0.0%	0%	5 minus 1	Same size options as loose
All three changes simultaneously*	**-4.7%**	**-47%**	2 minus 1	Overall, the Best Before date has largest effect

*This is not simply the sum of the three changes above: this scenario includes interactions between all three changes

5.5 Broccoli: conclusions

These results suggest that selling broccoli loose could lead to lower levels of broccoli waste in the home.

Most importantly, broccoli waste is being driven by the relatively small proportion of the population who are influenced by the Best Before date. The presence of this date suggests to citizens that broccoli has a much shorter shelf life than it really does. The difference between the two is stark – Best Before dates are typically 3 or 4 days after broccoli is purchased from supermarkets. The shelf-life experiments indicate that broccoli in a fridge at the recommended temperature (4°C) shows no significant signs of deterioration for a further three days and is still in a condition that most people would eat up to 17 days past the day of purchase.

The removal of the Best Before date appears the most effective way of reducing broccoli waste in the home. This would remove the influence of the date on people's disposal decisions, encouraging them to use their senses to assess whether broccoli is still edible. Other alternatives – e.g., a mass education programme on the differences between Best Before and Use By dates – would be costly and unlikely to be as effective as the removal of Best Before dates.

Aside from the removal of date labels, the impact on broccoli waste in the home of selling broccoli loose – compared to packaged – is slight. Selling broccoli loose is unlikely to affect the amounts of broccoli purchased at each shopping trip, as heads of broccoli are usually similar in size. Although the packaging does appear to increase the shelf life of broccoli at 4°C (although not in warm fridges at 9°C), this additional shelf life does not influence broccoli waste levels greatly as the shelf life of broccoli is relatively long already.

The modelling also demonstrates that broccoli waste in the home can be minimised by ensuring that broccoli lasts as long as possible after its purchase date. This can be achieved by minimising delays in the supply chain and keeping broccoli in optimal conditions in the supply chain and in the home. Ensuring fridges run at the recommended temperature (below 5°C) would help greatly, as the shelf life of broccoli is highly temperature dependent.

6.0 Cucumber

This section covers the following for cucumbers:

- Background information about cucumbers in the UK, focusing on household food waste (Section 6.1)
- The cucumber-specific inputs used for the modelling (Section 6.2)
- A summary of the scenarios modelled for cucumbers (Section 6.3)
- The results of these scenarios modelled for cucumbers, alongside discussion of the implications (Section 6.4)
- Cucumber-specific conclusions (Section 6.5)

6.1 Cucumber: background information

In the UK, an average of 54 grams of cucumbers were purchased per person per week in 2018/19[108] equating to approximately 188,000 tonnes per year[109]. Nearly all cucumbers in the UK have been imported, with the majority imported from Europe[110].

The most detailed breakdown of household cucumber waste in the UK is based on 2012 data. This suggests that approximately 30% of all cucumber purchases were wasted[111], equating to 50,000 tonnes per year at a total cost of £77 million[112]. Figure 21 shows the types of cucumber waste produced by UK households[111].

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[108] *Family Food datasets 2018/2019, Department for Environment, Food, & Rural Affairs, 2020:* https://www.gov.uk/government/statistical-data-sets/family-food-datasets

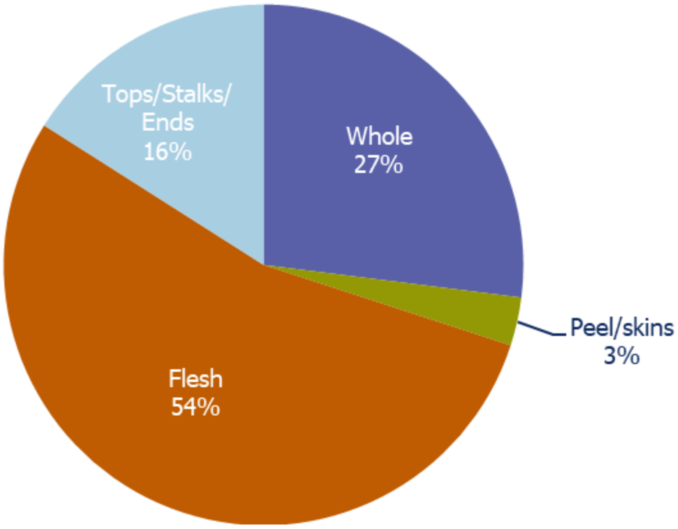
[109] *Estimated using the average UK population in 2019 (66.797 million), Office of National Statistics.*

[110] *UK Horticulture Statistics, Department for Environment, Food, & Rural Affairs, 2019:* https://www.gov.uk/government/collections/horticultural-statistics

[111] *Household food and drink waste: A product focus, WRAP, 2014:* https://wrap.org.uk/sites/files/wrap/Product-focused%20report%20v5_3.pdf

[112] *Household food waste: restated data for 2007-2015, WRAP, 2018:* https://www.wrap.org.uk/sites/files/wrap/Household%20food%20waste%20restated%20data%202007-2015%20FINAL.pdf

Figure 21: Breakdown of household cucumber waste in the UK in 2012, by weight. Covers waste collected by local authorities: residual waste and collections targeting food waste



Source: Household Food and Drink Waste: A Product Focus[113]

The most common reason for discarding cucumbers was not used in time. Of the cucumber waste that could have been eaten, 83% was classified as 'not used in time'. The remaining avoidable waste was due to personal preferences, serving too much and accidents (Figure 22). The Household Simulation Model focuses on food waste that is due to 'not used it time', allowing this research to investigate 83% of total household cucumber waste.

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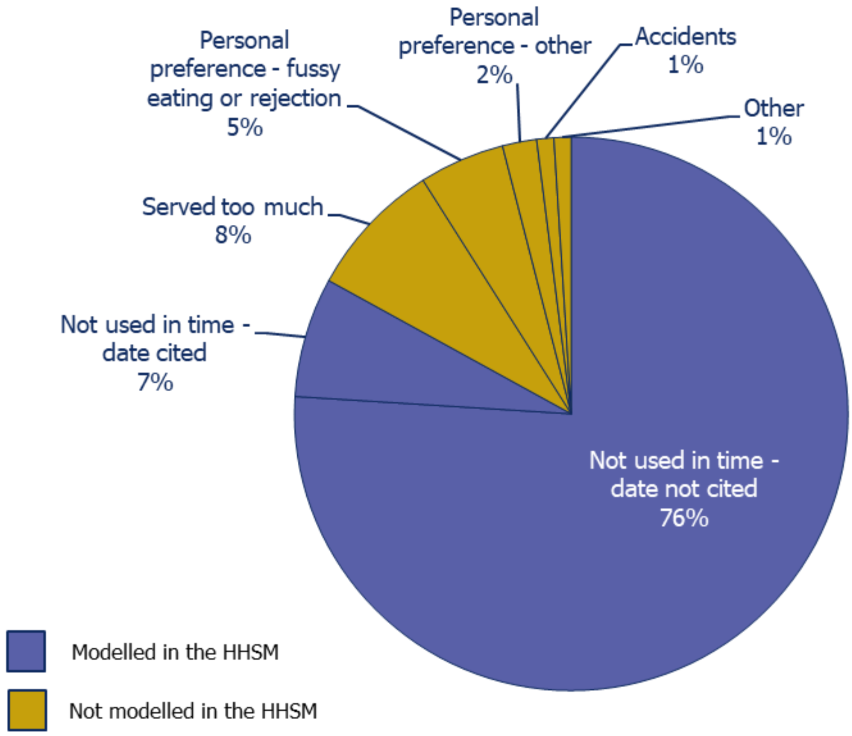
[113] *Household food and drink waste: A product focus, WRAP, 2014:* *https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf*

Figure 22: Reasons for avoidable cucumber waste in UK households in 2012, by weight



Source: Household Food and Drink Waste: A Product Focus[114]

Of the 83% of waste that was not used in time, participants in research involving food-waste diaries rarely cited a date label when recording why they discarded the cucumber (7% of the total avoidable waste; Figure 22). This is consistent with other WRAP research that suggests date labels play a larger role in people's decisions when there is a perceived safety risk such as for meat and dairy products[115]. For fresh produce items, most citizens tend to rely on their own senses and judgement when deciding whether to eat or discard an item. However, research published alongside this report suggests that a substantial minority of people are heavily influenced in their disposal decisions by the Best Before date, as discussed in 2.3.2.

In early November 2020, Produce View conducted a review of several large format supermarkets in the UK to understand the range of cucumber (and other products included in this report) that were available. (Methodological details can be found in Section 2.3.3.) The survey included details on the types of cucumber sold loose and in packaging, packaging material and formats, date label type and prevalence, as well as on-pack storage guidance.

According to the survey, whole cucumbers were sold both packaged and unpackaged, whereas half cucumbers were only sold packaged. For packaged cucumbers, organic,

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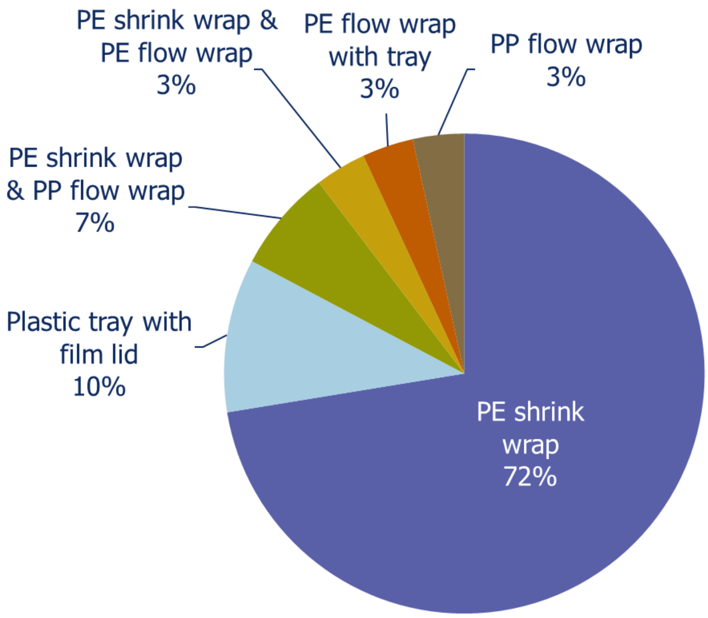
[114] *Household food and drink waste: A product focus, WRAP, 2014: https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf*

[115] Consumer insight: date labels and storage guidance, WRAP (2011): https://wrap.org.uk/sites/default/files/2020-12/Consumer-insight-date-labels-and-storage-guidance.pdf

non-organic, whole, half and baby sizes were sold, whereas for unpackaged cucumbers only organic ones were sold.

100% of packaged cucumber lines were sold in plastic packaging, and the various types are shown in Figure 23. The most common type of packaging was polyethylene shrink wrap: 72% of packaged cucumber lines were sold in this format.

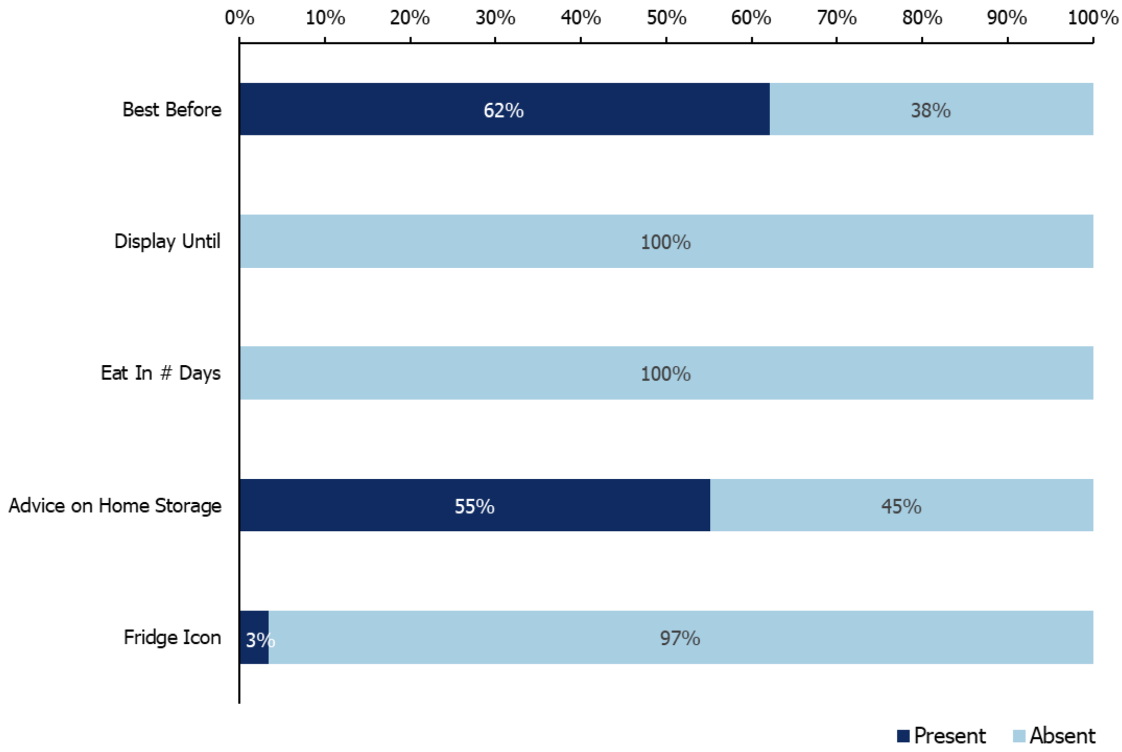
Figure 23: Packaging types for cucumbers sold in large-format UK supermarkets, Nov. 2020



Source: Produce View in-store survey

62% of packaged cucumber lines currently contain a 'Best Before' date, and no lines of packaged cucumber currently contain a 'Display Unit' date or an 'Eat in X number of days' label. In terms of storage information, 55% of packaged cucumber lines contain advice on home storage and only 3% contain a fridge icon (Figure 24).

Figure 24: Other on-pack information for cucumber sold in large-format UK supermarkets, November 2020



Source: Produce View in-store survey

Previous WRAP research suggests that only 2% of citizens claim they never store cucumber in the fridge - the same research found that during fridge audits 64% of respondents stored cucumber in the fridge[116].

At present, there is limited evidence to suggest that citizens have different storage behaviours when cucumber are sold packaged or loose.

6.2 Cucumber: model inputs

This section details the input data used for the Household Simulation Model (HHSM) specific to cucumbers. Data common to all products can be found in section 2.3. This section includes details on:

- Levels and patterns of cucumber consumption
- Amount of cucumber purchases
- Shelf life and when cucumbers are disposed of

[116] Helping Consumers Reduce Fruit and Vegetable Waste: Final Report, WRAP, 2008: https://wrap.org.uk/sites/default/files/2020-10/WRAP-RTL044-001%20Final%20report.pdf

6.2.1 Levels and patterns of cucumber consumption

Section 2.3.1 describes the general approach for determining the amount of cucumber required by a household each day in the HHSM. The current section describes information specific to cucumbers.

For cucumbers, estimates of the amount required each day were built up from individual household members. This assumes that members of the household eat cucumber independently from each other – i.e., if one person eats cucumber, the other members are no more or less likely to eat it. This assumption does not have a large influence on the results.

Data on cucumber consumption was based on the NDNS dataset (refer to Section 2.3.1). The distributions fitted to the NDNS data are found in Appendix 3. These similar average amounts of cucumber eaten in a given day for the three age groups:

- Adults: 24 grams
- Children (7-17 years): 28 grams
- Infants (0-6 years): 25 grams

The probability that people consume cucumber was also calculated from the NDNS dataset. These probabilities are:

- Adults: 38%
- Children (7-17 years): 34%
- Infants (0-6 years): 38%

The probability that people consume cucumbers was also calculated from the NDNS dataset. The values for cucumbers varied between 34-38% for the different age groups for people who consumed cucumbers in at least one of the four days surveyed as part of the NDNS research.

In the preliminary modelling, it was found that using these probabilities in a 'simple' way to calculate cucumber requirements led to high levels of waste and / or high levels of unfulfilled requirements. Therefore, it was decided to use the more advanced functionality of the HHSM: to allow the probability that cucumber is required for consumption on a given day is increased when cucumber is present in the household. In practice, this was achieved by halving the 'base' requirement frequency for each age group (so that people were half as likely to desire cucumber if not present – 17% to 19% of days, depending on age group) and then approximately triple this low level if cucumber was present (to 55% to 57% of days, depending on age group). The resultant consumption patterns for these two situations averaged out at a realistic level of cucumber consumption.

6.2.2 Pack sizes for cucumber

Data was obtained from supermarket websites, which suggested that large cucumbers were approximately 500 grams and 'standard' cucumbers around 340 grams. Half cucumbers were assumed to be half the weight of a standard cucumber: i.e., 170 grams.

It was assumed that 10 grams at each end of the cucumber is not consumed as this is widely discarded in the UK. This makes the edible portion of a standard cucumber 320 grams and a half cucumber 160 grams.

During the preliminary modelling process, the amount and frequency of cucumber purchases was adjusted to ensure that household dynamics were within realistic bounds. The amounts and frequencies detailed in (Table 15) were found to meet this aim. These gave levels of waste similar to those measured in UK households: 20.5% modelled for the packaged scenario, 19.5% for measured 'not used in time' cucumber waste (refer to Section 2.3.4).

Table 15: Input data relating to purchasing of packaged cucumbers

	AD Family	FF Single	FF Couple	SC Single	SC One Child	IA Couple	PP Family
Package Size (g)	320	160	320	160	320	320	320
No. packages purchased at each main shop visit	1	1	1	1	1	1	1
Probability of buying the item at main-shop visit	100	50	75	50	75	75	100

For single-occupancy household archetypes (FF single and SC single), half cucumbers were assumed to be purchased, while 'standard' cucumbers were assumed to be purchased for all other archetypes.

For loose scenarios, two variants were modelled. In one (scenario 2a), it was assumed that smaller, half-sized cucumbers – sometimes referred to as midi-cucumbers – were available, replacing wrapped half cucumbers. In the second loose scenario (2b), it was assumed that these smaller cucumbers were *not* available, and smaller households could only purchase whole cucumbers. This was to investigate the importance of half-sized cucumbers on levels of waste and support decision making on this subject.

It was further assumed that not all households purchased cucumbers on every shopping trip: single-occupancy households had a 50% probability of purchasing cucumbers on a main shop, and households containing two people had a 75% probability. Households were also able to adjust their purchases if they had a cucumber in the fridge (refer to Feedback Loop no.1 in Figure 4).

In initial modelling, it was assumed that two household archetypes bought cucumbers in top-up shops (AD Family and IA couple). To ensure the amount of cucumber bought was realistic, these top-up shops were de-activated for the final modelling. Therefore, for the purposes of the modelling, it was assumed that no household archetypes purchased cucumbers during top-up shops.

6.2.3 Shelf life for cucumbers

One of the important inputs for the modelling is the time between a product being purchased and when a given household is no longer prepared to eat it (referred to as the 'shelf life'). This will differ significantly depending on whether a household is influenced in their decision by the Best Before date or not, as discussed in Section 2.3.2..

In reference to Citizen Disposal Decision Report[117], it was found that a minority of people used the Best Before date for cucumbers. In answer to the question: *"Please indicate on the scale below how you make decisions about when to eat or throw away the following foods"*:

- 4% stated "Entirely on the date",
- 7% "Mostly on the date", and
- 22% "A mixture of the date and judgment".

For the purposes of the modelling, it was assumed that all the people giving the first two responses and half those stating *"A mixture of the date and judgment"* dispose of their cucumbers on the Best Before date. This is approximately 22% (4% + 7% + half of 22%). This is similar to the uplift in cucumber disposal due to the presence of a date label found in the implicit test – for condition 2, an additional 19% of people discarded the cucumber when there was a date label present.

The values used in the modelling varied for different household archetypes, as determined from the Citizen Disposal Decision Report. This varies from 45% for Aspirational Discovers to 15% Ideal Advocates.

It was not assumed that cucumbers were depackaged. However, the in-store research (Section 2.3.3) indicated that 62% of cucumbers carry Best Before dates. It was assumed that this reduces the number of households using the Best Before date as a disposal date. Consequently, the 22% of households potentially using the date was multiplied by 62% to obtain 14% of disposal decisions influenced by the Best Before date.

For those using the Best Before date, it was assumed that the average time from purchase to disposal was 5 days. This information was obtained from Morrisons website for the average shelf-life of a cucumber. A standard deviation of 1 day was modelled to account for variability (e.g., to account for different lengths of time the cucumbers spend in the supply chain before purchase).

For the rest of the population – those who do not use Best Before dates to inform disposal decisions and for situations where there is no Best Before date – it was assumed that people would consume cucumbers until they started to deteriorate in quality. Data from the Shelf-Life Report[118] was used to inform this input.

Following the method use for all products (Section 2.3.2), the average shelf life for cucumbers was found to be 11 days, with a standard deviation of 2.5 days, irrespective of whether it was shrink wrapped or not. This means that 95% of cucumbers simulated in the model would have a shelf life between 6 days and 16 days, a wide range, reflecting

[117] *Citizen insights on the influence of packaging and date labels on disposal decisions, WRAP, 2022: https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

[118] *The impact of packaging and refrigeration on shelf life, WRAP, 2022: https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

the length of time that cucumbers stored at 4°C take to deteriorate and differences in the stage of deterioration people are prepared to eat cucumbers.

6.3 Cucumber: summary of modelling runs

Unlike all other products in this report, there were six scenarios for cucumber. This reflects the uncertainty in whether smaller, half-sized cucumbers would be offered by supermarkets in the future. The six scenarios modelled are:

- Scenario 1: Packaged
- Scenario 2a: Loose (smaller cucumbers available)
- Scenario 2b: Loose (no smaller cucumbers available)
- Scenario 3: Packaged but same shelf life as loose
- Scenario 4: Packaged but no Best Before date
- Scenario 5: Packaged but same size options as loose (scenario 2a)

Scenarios 3 to 5 are the same as packaged, but with one factor changed at a time to be the same as loose. This allows the impact of that single factor on the levels of waste to be assessed.

Scenario 1, Packaged: Households buy whole cucumbers, except for single-occupancy households, which buy half cucumbers (also packaged). It is assumed that c. 14% of the population use the Best Before date as a disposal date (an average of 5 days after purchase), with the remaining 86% are prepared to consume until the cucumber starts to deteriorate in quality (an average of 11 days after purchase).

Scenario 2a, Loose (smaller cucumbers available): All households buy whole cucumbers, except for single-occupancy households, which buy smaller (half-sized) cucumbers (assumed to be loose). It is assumed that Best Before dates are absent, so that the point of disposal for all households is as the cucumber deteriorates in quality (11 days after purchase).

Scenario 2b, Loose (no smaller cucumbers available): As for Scenario 2a, except that including single-occupancy households buy whole cucumbers. In this scenario, it is assumed that no smaller (half-sized) cucumbers are available loose.

Scenario 3, Packaged but same shelf life as loose: As the packaged and loose shelf lives were found to be the same in the shelf-life experiments, no change is made to the shelf life. Therefore, the inputs and the results for this scenario (no. 3) are the same as scenario 1 (packaged).

Scenario 4, Packaged no Best Before date: This is the same as scenario 1 (packaged) except that it assumes that there is no Best Before date. It is therefore assumed that the point of disposal for all households is as the cucumber deteriorates in quality (an average of 11 days after purchase).

Scenario 5, Packaged, but same size options as loose (scenario 2a): This scenario takes the packaged scenario (number 1) and adjusts the product size options to be the same as loose (scenario 2a). For the case of cucumbers, there are no differences in size options between scenarios 1 and 2a, so the inputs for scenario 5 are unchanged from scenario 1.

The results of these scenarios can be found in the following section (6.4).

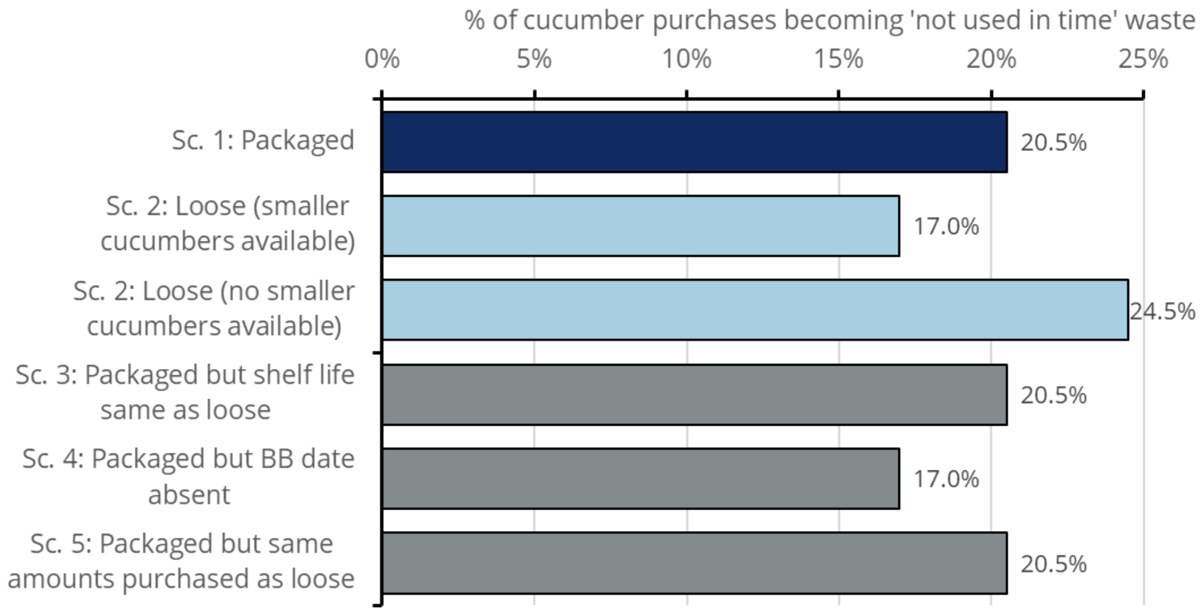
6.4 Cucumber: results and discussion

This section contains the results of scenarios described in the previous section. The differences between scenarios are discussion to demonstrate the impact on food waste of different changes to how cucumbers are sold.

Figure 25 provides the levels of 'not used in time' cucumber waste modelled for the six scenarios previously described. Predicted levels of waste are similar for packaged cucumbers (21% of purchases) and loose cucumbers (17% for scenario 2a and 24% for scenario 2b).

The difference between scenarios 2a and 2b illustrates the impact of the availability of smaller (half-sized) cucumbers. Where available, these smaller cucumbers allow smaller households (or households with low cucumber requirements) to purchase an appropriate amount for their needs. This would help reduce waste irrespective of whether the cucumbers are packaged or loose.

Figure 25: Comparison of levels of 'not used in time' cucumber waste for scenarios modelled



Scenarios 3 to 5 help to understand the differences between the packaged and loose scenarios. This is achieved comparing each to scenario 1 (packaged), allowing the impact of each factor to be assessed Table 16).

Comparing scenarios 1 and 3 illustrates the effect of updating the packaged shelf life to be the same as the loose (for people not using the Best Before date). However, as the packaged and loose shelf lives were found to be the same in the shelf-life experiments, this results in no change to the shelf life. Hence the levels of cucumber waste are the same in scenarios 1 and 3.

Table 16: Summary of the impact on 'not used in time' cucumber waste of changes relating to elements of selling cucumbers packaged

Change in...	Impact on food waste		Derived from which scenarios:	Notes
	Percentage-point change	Relative change (%)		
Shelf-life	0.0%	0%	3 minus 1	Assumed no change in shelf-life
BB date (removed)	-3.5%	-17%	4 minus 1	For 17% of population, shelf life increased from 5 to 11 days
Pack-size options	0.0% (or +7.2%)**	0% (or +35%)**	5 minus 1	Depends on whether smaller cucumbers are available (1st values) or not (2nd)
All three changes simultaneously*	**-3.5% (or +4.0%)****	**-17% (or +19%)****	2 minus 1	Depends on whether smaller cucumbers are available (1st values) or not (2nd)

*This is not simply the sum of the three changes above: this scenario includes interactions between all three changes

**0% / -17% if smaller (half-sized) cucumbers available loose; +35% / +19% if no smaller cucumbers available

Comparing scenario 1 (21%) and scenario 4 (17%) illustrates the impact of a minority of the population using Best Before dates as a disposal date. Although the percentage of people using the Best Before date is assumed to be small (c. 14%), it still reduces the level of food waste by four percentage points. Indeed, if everyone used the Best Before date as a disposal date, the level of cucumber waste is estimated to be 43% (scenario not shown on graph), around two and a half times the level where people use their judgement. Therefore, ensuring that people are not using the Best Before date as a disposal date would help reduce cucumber waste, irrespective of whether the cucumber is packaged or loose.

Comparing scenarios 1 and 5 illustrates the impact of changing the size options. However, as the size options for packaged and loose (in scenario 2a) are the same, there is no change in cucumber waste between scenarios 1 and 5. As discussed previously in this section, the difference in scenarios 2a and 2b illustrates the impact of the product sizes available, specifically smaller cucumbers.

Figure 26: Comparison of packaged (scenario 1, amber) and loose (scenario 2, blue) cucumber waste, illustrating differences between household archetypes

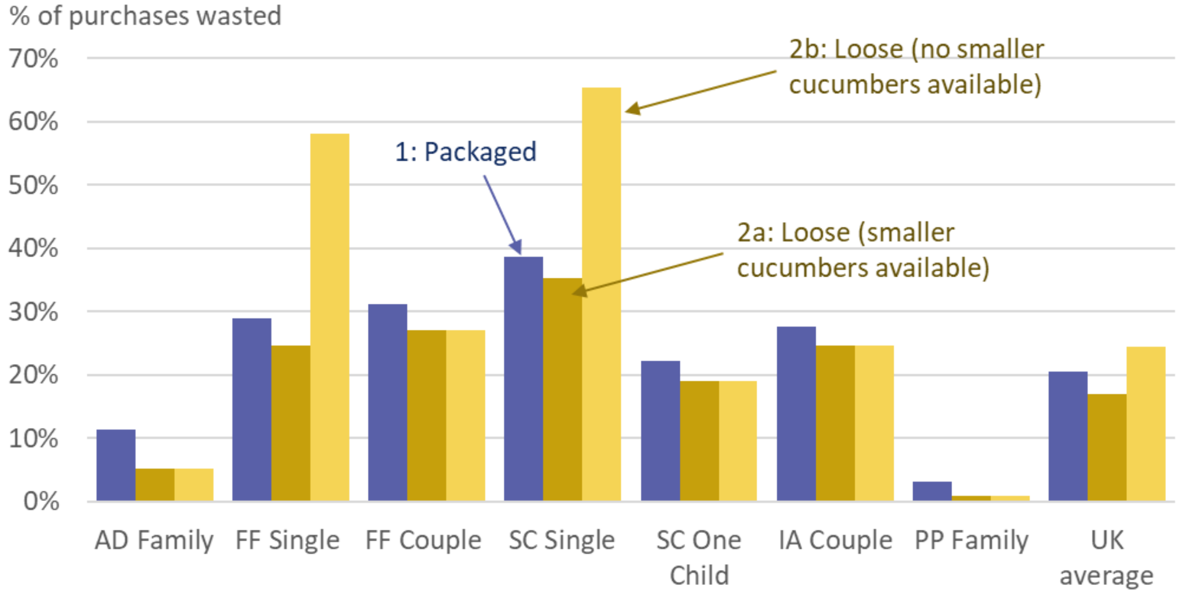


Figure 26 illustrates the cucumber waste for the three main scenarios for the seven household archetypes used in this modelling. Comparing scenarios 1 and 2a shows the impact of not using Best Before dates as disposal dates. This is most pronounced for the 'AD Family' assumed to be the most likely to use Best Before dates in this way. For the other household archetypes, the difference is smaller.

Comparing scenarios 2a and 2b illustrates for which households the availability of smaller, half-sized cucumbers has the most impact. This is for the single-occupancy households (FF single and SC single), who were assumed to purchase these smaller cucumbers in scenario 2a. Where these smaller cucumbers are not available (scenario 2b), the levels of cucumber waste are high: over 50% of purchases for each scenario.

These levels of waste are sufficiently high that, in real households, they may trigger a change in how people purchase or consume cucumbers. Even in these cases, the modelling still illustrates the challenges for smaller households of managing food in the home if only products too large for their needs are available.

6.5 Cucumber: conclusions

These results suggest that there are many changes that could lead to lower levels of cucumber waste in the home:

- Ensuring that cucumbers last as long as possible after their purchase date: e.g., by ensuring there are no delays in the supply chain, cucumbers are kept in optimal conditions in the supply chain and in the home.
- Supporting citizens so that cucumbers are consumed until they start to deteriorate in quality, e.g., by removing Best Before dates
- Having smaller cucumbers or half-cucumbers available for smaller households and / or those that require smaller amounts.

- Encouraging citizens to purchase an appropriate amount of cucumber for their needs, e.g., by ensuring that smaller and half cucumbers have a similar price per kilogram as larger cucumbers.

The impact on household food waste (HHFW) of selling cucumbers loose and packaged is not clear cut, unlike the other four products. Crucially, whether HHFW is lower for loose or packaged cucumbers depends on the range of sizes of cucumbers available. The important factor is the availability of smaller cucumbers for households with low levels of cucumber consumption.

Currently, most supermarket retailers sell wrapped half cucumbers. As a transition, these could continue to be made available. However, it could also be possible that the necessary smaller cucumber products could simply be smaller cucumbers (i.e., 100 to 200 grams) sold loose – this would be necessary to achieve a packaging-free cucumber range.

The evidence gathered for this project suggested that there is no increase in shelf life relating to the packaging – which, as noted in the Shelf-Life Report[119], is not consistent with other information in the public domain. If further experiments demonstrate a difference in shelf life between packaged and loose cucumbers, then this could change this conclusion of the report.

[119] *The impact of packaging and refrigeration on shelf life, WRAP, 2022: https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

7.0 Potatoes

This section covers the following for fresh potatoes:

- Background information about potatoes in the UK, focusing on household food waste (Section 7.1)
- The potato-specific inputs used for the modelling (Section 7.2)
- A summary of the scenarios modelled for potatoes (Section 7.3)
- The results of these scenarios modelled for potatoes, alongside discussion of the implications (Section 7.4)
- Potato-specific conclusions (Section 7.5)

7.1 Potatoes: Background information

In the UK, an average of 379 grams of fresh potatoes were purchased per person per week in 2018/19[120], equating to approximately 1.32 million tonnes[121]. Potato sales are largely unaffected by the season and remain relatively stable throughout the year[122], although the varieties sold vary. In the UK over 500 varieties of potato are grown and sold. Each variety is grown for sale into retail or into processing (e.g. for crisps and chips), and the varieties used for each are different. In the UK the most popular variety of potato is Maris Piper[123].

The most detailed breakdown of household fresh potato waste in the UK is based on 2012 data. This suggests that approximately 46% of all potato purchases were wasted, equating to 710,000 tonnes per year, worth £555 million[124]. Most of this is peel or skin (55%, Figure 27), with the remainder being whole or part potatoes.

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[120] *Family Food datasets 2018/2019, Department for Environment, Food, & Rural Affairs, 2020: https://www.gov.uk/government/statistical-data-sets/family-food-datasets*

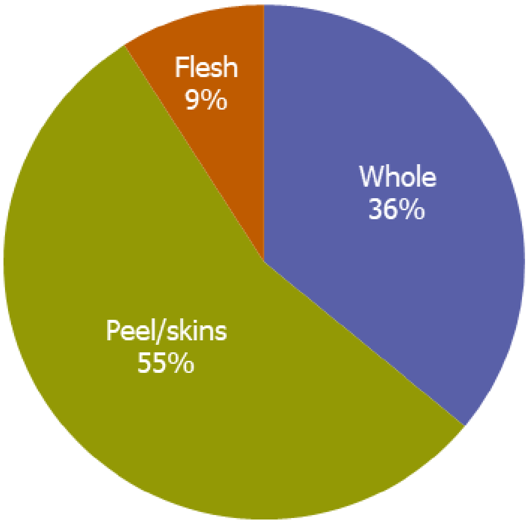
[121] *Estimated using the average UK population in 2019 (66.797 million), Office of National Statistics.*

[122] *Methods used for Household Food and Drink Waste in the UK. WRAP. 2012: https://wrap.org.uk/sites/default/files/2020-12/Methods-used-for-Household-Food-and-Drink-Waste-in-the-UK-2012.pdf*

[123] *The variety with the largest planted area in the UK is Maris Piper https://ahdb.org.uk/potato/planted-area-variety .It should be noted that potato yield will vary by variety, and this is not a direct indicator of sales/consumption. Data on the most popular variety that is sold or consumed in the UK was not available.*

[124] Household food waste: restated data for 2007-2015, WRAP (2018): *https://wrap.org.uk/sites/default/files/2021-03/WRAP-Household-food-waste-restated-data-2007-2015_0.pdf*

Figure 27: Breakdown of household fresh potato waste in the UK in 2012, by weight. Covers waste collected by local authorities: residual waste and collections targeting food waste



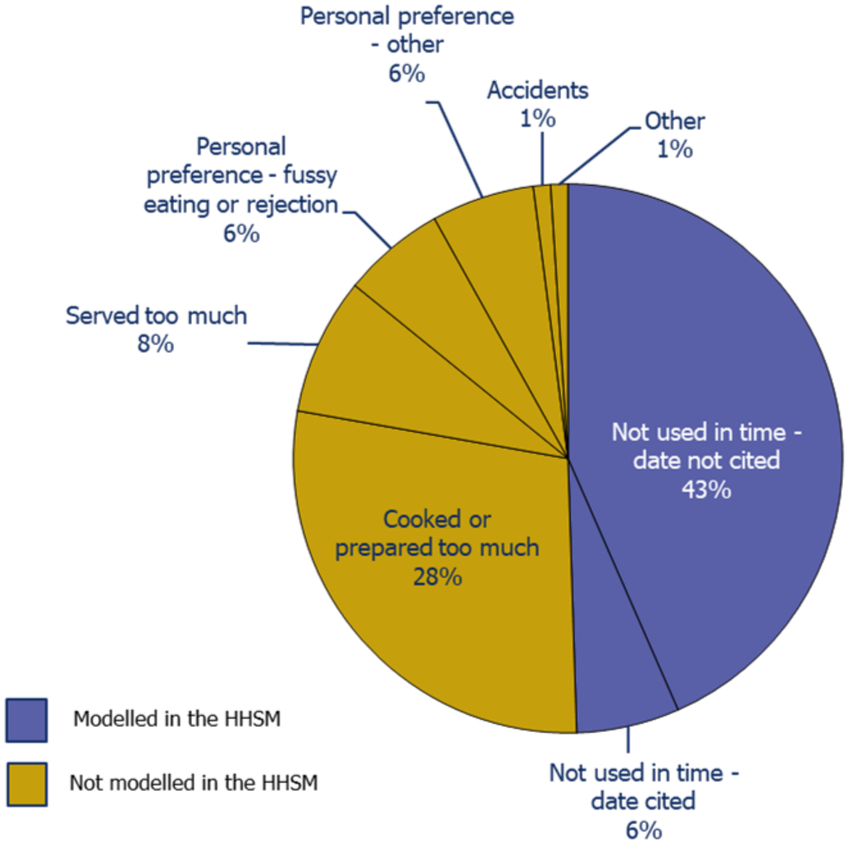
Source: Household Food and Drink Waste: A Product Focus[125]

The most common reason for 'avoidable' potato waste due to them not being used in time (49% of avoidable potato waste[126], Figure 28). The Household Simulation Model focuses on food waste that is due to 'not used it time', thus investigating 49% of total household potato waste. This is the lowest percentage for the five products studies in this project. This reflects the fact that many potatoes are not eaten due to too much being cooked or served, or personal preference.

[125] *Household food and drink waste: A product focus, WRAP, 2014:* https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf

[126] Since the publication of *Household food and drink waste: A product focus* in 2014, WRAP has updated the classification of household food waste, moving from the term 'avoidable' to 'edible'. This report uses details that were calculated before this change. Refer to Section 2.3.4 for more details.

Figure 28: Reasons for avoidable fresh potato waste in UK households in 2012, by weight



Source: Household Food and Drink Waste: A Product Focus[127]

Of the 49% of waste that was not used in time, participants in research involving food-waste diaries rarely cited a date label when recording why they discarded potato (6% of the total avoidable waste; Figure 28). This is consistent with other WRAP research that suggests date labels play a larger role in people's decisions when there is a perceived safety risk, such as for meat and dairy products[128]. For fresh produce items, most citizens tend to rely on their own senses and judgement when deciding whether to eat or discard an item. However, research published alongside this report suggests that a substantial minority of people are heavily influenced in their disposal decisions by the Best Before date, as discussed in 2.3.2.

In early November 2020, Produce View conducted a review of several large format supermarkets in the UK to understand the range of potatoes (and other products included in this report) that were available. (Methodological details can be found in Section 2.3.3.) The survey included details on the types of potatoes sold loose and in packaging, packaging material and formats, date label type and prevalence, as well as on-pack storage guidance.

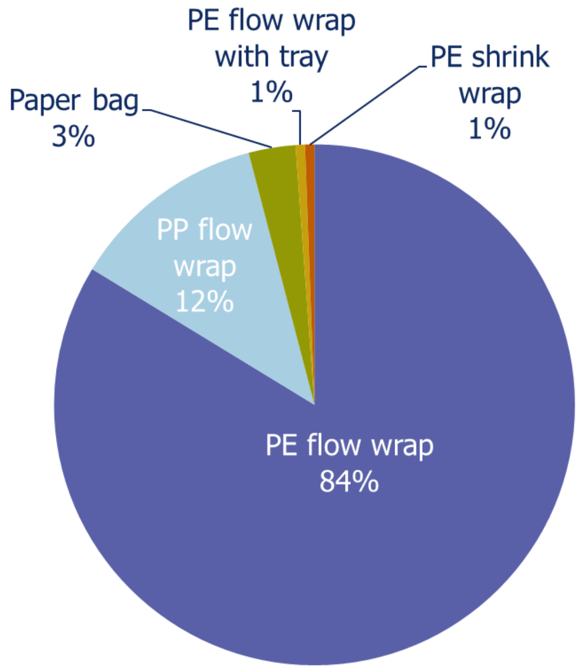
[127] *Household food and drink waste: A product focus, WRAP, 2014: https://wrap.org.uk/sites/default/files/2020-10/WRAP-Product-focused%20report%20v5_3.pdf*

[128] *Consumer insight: date labels and storage guidance, WRAP (2011): https://wrap.org.uk/sites/default/files/2020-12/Consumer-insight-date-labels-and-storage-guidance.pdf*

According to the survey, 50 varieties of potatoes were sold packaged whereas only four varieties were sold loose. This is broadly consistent of sales data, which suggests that upwards of 90% of potatoes sold in retail are packaged[129].

97% of packaged potatoes were sold in plastic packaging, with the remaining 3% sold in paper bags. The breakdown of different packaging types is shown in Figure 29. The most common packaging type was polyethylene flow wrap and 84% of potato lines were sold in this format.

Figure 29: Packaging types for fresh potatoes sold in large-format UK supermarkets, Nov. 2020.

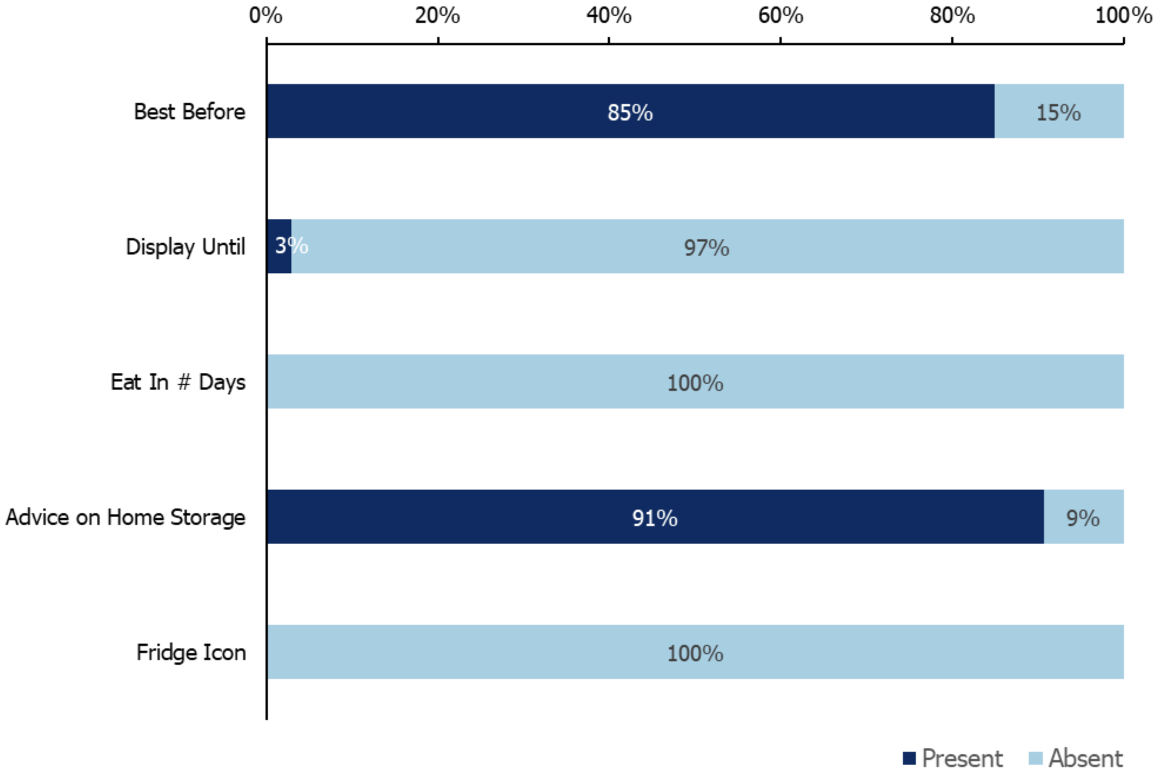


Source: Produce View in-store survey

85% of packaged potato lines currently contain a 'Best Before' date, 3% contain a 'Display Until' date and no lines of packaged potatoes contain an 'Eat in X number of days' label. In terms of storage information, 91% of packaged potatoes contain advice on home storage (Figure 30).

[129] https://ahdb.org.uk/news/consumer-insight-pre-packed-potatoes-gain-during-pandemic-year

Figure 30: Other on-pack information for potatoes sold in large-format UK supermarkets, November 2020



Source: Produce View in-store survey

WRAP storage guidance for potatoes: 'At home, store in a cool, dark, dry place' and ideally away from strong-smelling food like onions[130]. Laboratory experiments demonstrated that potatoes stored in the light at 15°C and 22°C developed significant greening after only four days, whereas potatoes kept in the dark did not develop any greening over a 21-day period[131]. This research also found that 48% of citizens claimed to store potatoes in the cupboard and 21% in the fridge. The findings were corroborated by fridge audits: 84% of respondents stored potatoes outside of the fridge.

At present, there is limited evidence to suggest that citizens have different storage behaviours when potatoes are sold packaged or loose.

7.2 Potatoes: Model inputs

This section details the input data used for the Household Simulation Model (HHSM) specific to potatoes. Data common to all products can be found in section 2.3. This section includes details on:

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[130] *Love Food Hate Waste A-Z storage guidance.* *https://lovefoodhatewaste.com/article/food-storage-a-z*

[131] *Helping Consumers Reduce Fruit and Vegetable Waste: Final Report, WRAP, 2008:* *https://wrap.org.uk/sites/default/files/2020-10/WRAP-RTL044-001%20Final%20report.pdf*

- Levels and patterns of consumption
- Pack sizes
- Shelf life

7.2.1 Levels and patterns of potato consumption

Section 2.3.1 describes the general approach for determining the amount of an individual food required by a household each day in the HHSM. The current section describes information specific to potatoes.

For potatoes, the amount required each day was estimated for the whole household, built up from data for individual household members. This assumes that members of the household eat potatoes at a similar time, for example, as part of a main meal.

Data on potato consumption was based on the NDNS dataset (refer to Section 2.3.1). The distributions fitted to the NDNS data are found in Appendix 3. These show an increase with age for the amount of potatoes eaten in a given day:

- Adults: 143 grams
- Children (7-17 years): 131 grams
- Infants (0-6 years): 78 grams

The probability that people consume potatoes was also calculated from the NDNS dataset. These probabilities are:

- Adults: 46%
- Children (7-17 years): 36%
- Infants (0-6 years): 42%

An average value of 41% was used for the basic probability of consumption on a given day. To represent actual dynamics in the household more accurately, the probability that potatoes were required on a given day varied depending on whether there were potatoes available to consume or not. If there were no potatoes in the household, the value used was 10 percentage points lower (31%). If there were potatoes present, this probability was 52%: 20 percentage points higher. This is a more realistic dynamic, as the presence of potatoes could be a trigger for consumption. This modification helped to ensure that outputs of the model (levels of potato waste and unfulfilled requirements) were realistic.

7.2.2 Pack sizes for potatoes

This section describes the decisions around the amount of potatoes purchased in the modelling.

Data obtained from the Produce View survey of UK supermarkets (Section 2.3.3) revealed that the minimum size of packaged white or baking potatoes was either four baking potatoes or 2 kilograms. Assuming a typical baking potato is 250 grams, this indicates that the minimum pack size is 1 kg. Therefore, for purchases of *packaged* potatoes, it was assumed that potatoes could be bought in 1 kg increments[132].

The amounts purchased in the model are listed in Table 17. For all household archetypes, except for PP Family, 1 kg of potatoes is sufficient (or more than sufficient) for their average potato requirements between main shops.

Table 17: Input data relating to purchasing of packaged potatoes

	AD Family	FF Single	FF Couple	SC Single	SC One Child	IA Couple	PP Family
Package Size (g)	1000	1000	1000	1000	1000	1000	1000
No. packages purchased at each main shop	1	1	1	1	1	1	2
No. packages purchased at each top-up shop	1	n/a	n/a	n/a	n/a	1	1

It was further assumed that all households purchased potatoes on every shopping trip, unless they had potatoes present and checked their stocks beforehand. If this were the case, then potatoes purchases may be reduced (refer to Feedback Loop No.1 in Figure 4).

For loose potatoes, it was assumed that potato purchases could be adjusted in 250 g increments (approximately the weight of one baking potato)[133]. This only affects FF Single and SC household archetypes.

Table 18: Input data relating to purchasing of loose potatoes

	AD Family	FF Single	FF Couple	SC Single	SC One Child	IA Couple	PP Family
Amount purchased loose (g)	1000	500	1000	250	750	1000	2000

[132] *In addition to white and baking potatoes, smaller salad potatoes are also available. This model focuses on the pack sizes of the former as their sales are higher in the UK. Were salad potatoes to be included, this would mean that smaller pack sizes (often 750 grams) would also be available. If these were included – and assumed to be interchangeable with old potatoes and baking potatoes – the level of waste in the packaged scenario would be lower.*

[133] *For the IA couple and PP Family archetypes, the increment was 500 grammes. Due to how the Household Simulation Model adjusts the regular amount of purchases, this provided the most flexibility for those simulated household.*

7.2.3 Shelf life for potatoes

The time between a product being purchased and when a given household is no longer prepared to eat it (referred to as the 'shelf life') is an important input to the model. This will differ significantly depending on whether a household is influenced in their decision by the Best Before date or not, as discussed in Section 2.3.2..

In reference to Citizen Disposal Decision Report[134], it was found that a minority of people used the Best Before date for potatoes. In answer to the question: *"Please indicate on the scale below how you make decisions about when to eat or throw away the following foods"*:

- 3% stated "Entirely on the date",
- 5% "Mostly on the date", and
- 22% "A mixture of the date and judgment".

This data from the Citizen Disposal Decision Report was used to inform the modelling inputs. It was assumed that all the people giving the first two responses and half those stating "A mixture of the date and judgment" dispose of their potatoes on the Best Before date. This is approximately 19% (3% + 5% + half of 22%). The value varies by household archetype, from 14% for Ideal Advocates to 30% for Aspirational Discovers.

The average is similar to the uplift in potato disposal due to the presence of a date label indicated by the Implicit Association Test in the Citizen Disposal Decision Report. For conditions 2 to 5, the uplifts in disposal when a Best Before date was present were, respectively, 23%, 27%, 21% and 11% of the respondents. These values suggests that the use of 19% as an estimate of the percentage of the population who throw away potatoes as if it were a disposal date is reasonable.

Not all of these households will have access to a date label. In-store research (Section 2.3.3) indicated that 85% of potato lines sold in the UK carry Best Before dates. Therefore, similar to other products, 19% and 85% were multiplied together: 16% of disposal decisions were informed by Best Before dates.

For the remaining 84% of the population, it was assumed that people would consume their potatoes until they started to deteriorate in quality. Data from the Shelf-Life Report[135] was used to inform this input. Following the method outlined in Section 2.3.2, the average shelf life for potatoes was found to be 24 days (with a standard deviation of 6 days). This was for dark, ambient conditions (in a cupboard). The average shelf life was not influenced by the presence or type of packaging in these conditions. Therefore, the average shelf life of 24 days was used for both the packaged and loose conditions.

The standard deviations mean that 95% of potatoes in the model would have a shelf life ± 12 days of the average. This reflects the variability of potatoes stored in ambient conditions and differences in willingness to eat potatoes in different states of deterioration.

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[134] *Citizen insights on the influence of packaging and date labels on disposal decisions, WRAP, 2022: https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

[135] *The impact of packaging and refrigeration on shelf life, WRAP, 2022: https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

As the shelf life is the same for loose and packaged potatoes, no assumption needs to be made about the proportion of people who de-package potatoes.

7.3 Potatoes: summary of modelling runs

Five scenarios were modelled for potatoes in the final phase of modelling:

- Scenario 1: Packaged
- Scenario 2: Loose
- Scenario 3: Packaged but same shelf life as loose
- Scenario 4: Packaged but no Best Before date
- Scenario 5: Packaged but same pack size options as loose

Scenarios 3 to 5 are the same as packaged, but with one factor changed at a time to be the same as loose. This allows the impact of that single factor on the levels of waste to be assessed.

Scenario 1, Packaged: Households buy potatoes in packs weighing 1 kilogram, with one or two packs being purchased depending on the needs of the household. c. 16% of the population use the Best Before date as a disposal date: for these households, the shelf-life is an average of five days. The remaining 84% of the population use their judgement to decide when to dispose: an average shelf life of 24 days.

Scenario 2, Loose: Single-occupancy households purchase small amounts of potatoes, more suited to their needs. It is assumed that there is no Best Before date and all households use their judgement with regard to disposal: the average shelf life is 24 days (as for packaged).

Scenario 3, Packaged but same shelf life as loose: As the shelf life of packaged and loose potatoes is the same, this is the same as scenario 1.

Scenario 4, Packaged no Best Before date: As for scenario 1, but all people use their judgement, increasing the shelf life from 5 to 24 days for 16% of the population.

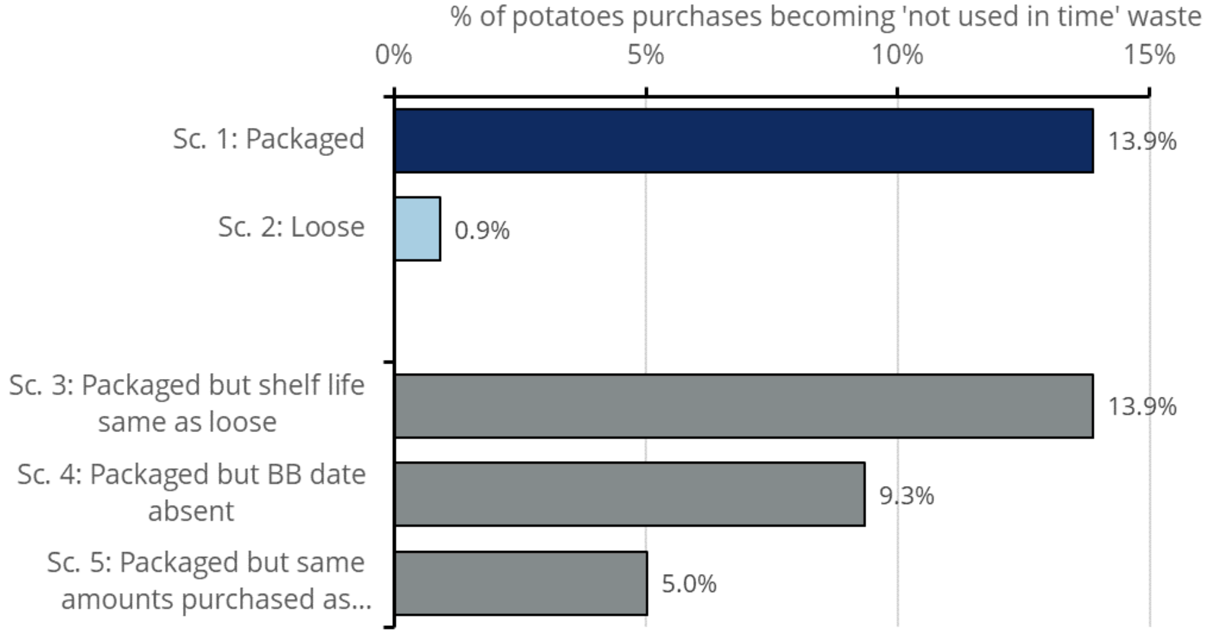
Scenario 5, Packaged, but same size options as loose: As for scenario 1, but the amounts purchased are the same as for loose (i.e., small amounts purchased for single-occupancy households). The Best Before date is still used by 16% of the population as a disposal date, with 84% using their judgement.

The results of these scenarios can be found in the following section (7.4).

7.4 Potatoes: results

This section contains the results of scenarios described in the previous section for potatoes. The scenarios are compared to illustrate the impact on potato waste of factors relating to the presence or absence of packaging. Figure 31 illustrates the results of the modelling: **the main finding is that predicted levels of waste are considerably lower for loose potatoes (0.9% of purchases) compared to packaged potatoes (13.9%).**

Figure 31: Comparison of levels of 'not used in time' potato waste for scenarios modelled



Scenarios 3 to 5 help to understand which factors are contributing to the low level of waste in the home associated with the loose scenario. By comparing each of scenarios 3 to 5 with scenario 1, the effect of the shelf life, the Best Before date and the pack sizes can be assessed (Table 19).

Table 19: Summary of the impact on 'not used in time' potato waste of changes relating to elements of selling potatoes packaged

Change in...	Impact on food waste		Derived from which scenarios:	Notes
	Percentage-point change	Relative change (%)		
Shelf-life	0.0%	0%	3 minus 1	No change in shelf life between loose and packaged
BB date (removed)	-4.5%	-33%	4 minus 1	For 16% of population, shelf life increases from 5 to 24 days
Pack-size options	-8.8%	-64%	5 minus 1	Purchases can occur in multiples of 250 g, rather than 1 kg
All three changes simultaneously*	**-13%**	**-93%**	2 minus 1	Overall, pack-size options have the largest impact

*This is not simply the sum of the three changes above: this scenario includes interactions between all three changes

Comparing scenarios 1 and 3 illustrates the effect of altering the shelf life for the 84% of the population who use their judgement when deciding when to dispose of potatoes (i.e., those not using the Best Before date as a disposal date). As the shelf-life experiments indicated that the shelf life was unaffected by whether the packaging was present, this leads to no change in the model inputs. Therefore, the resulting waste for scenario 3 is the same as scenario 1.

Comparing scenarios 1 and 4 illustrates the impact of the removal of Best Before dates: waste levels drop from 13.9% to 9.3% of purchases. This is pronounced, even though only 16% of the population are affected by this change. Indeed, if all households used the Best Before date as a disposal date, 29% of potato purchases would become 'not used in time waste'. This illustrates the large impact of a Best Before date that is much shorter (five days) than the shelf life if potatoes is kept in a dark cupboard (an average of 24 days).

For the modelling, we assumed that this period of time was an average of five days, based on data from a supermarket website (Section 2.3.2). However, other evidence suggests that this period of time could be even shorter: an average of 3.9 days was found in the WRAP Retail Survey 2019[136]. If this lower value was placed in the model, the impact of the Best Before date on food waste in the home would have been found to be more pronounced.

Comparing scenarios 1 and 5 illustrates the impact of the increased flexibility in the amount purchased from selling loose. This allows people to purchase a multiple of 250 grams of potatoes that is closest to their needs. For the packaged scenario, people were constrained to buying in multiples of 1 kilogram. This single change makes the largest difference, reducing potato waste from 13.9% to 5.0% of purchases. This makes the largest difference for people in single-occupancy households, who can much more easily buy the amount of potatoes they need.

7.5 Potatoes: Discussion and conclusions

These results suggest that selling potatoes loose could substantially reduce fresh potato waste in the home. This result is being driven by effects relating to pack size and the influence of the Best Before dates on disposal decisions.

The modelling demonstrates that fresh potato waste in the home can be minimised by ensuring that potatoes last as long as possible after their purchase date. This can be achieved by minimising delays in the supply chain, keeping potatoes in optimal conditions in the supply chain and in the home.

The results also suggest that the presence of a Best Before date influences a sufficient proportion of the population to make a considerable difference to levels of fresh potato waste in households. Therefore, the removal of the Best Before date appears the most effective way of reducing fresh potato waste in the home. This would remove the

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[136] https://wrap.org.uk/resources/report/retail-survey-2019

influence of the date label on disposal decisions, encouraging people to use their senses to assess whether the potatoes are still edible. Other alternatives – e.g., a mass education programme on the differences between Best Before and Use By dates – would be costly and unlikely to be as effective as the removal of Best Before dates.

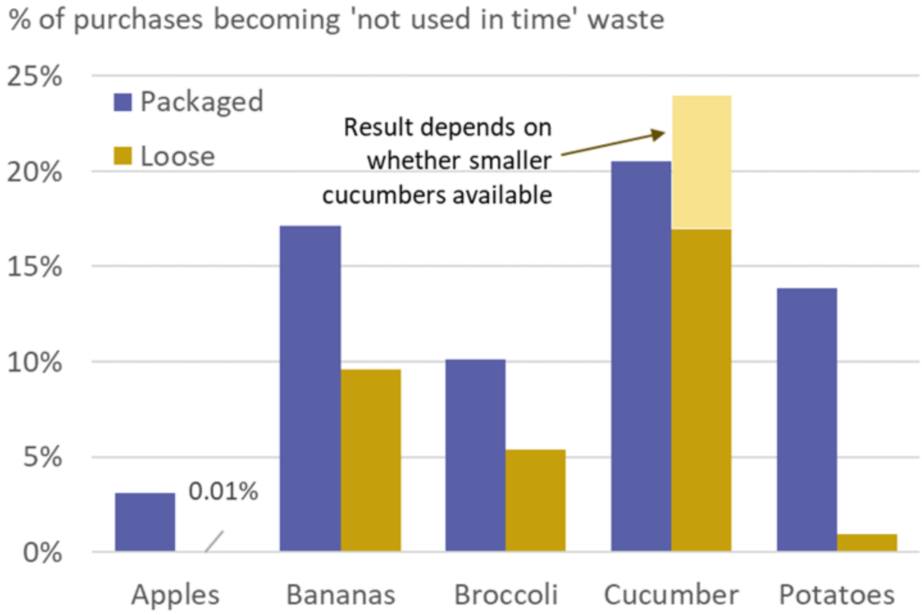
8.0 Key results and conclusions

This section draws together the results presented in Chapters 3.0 to 7.0, illustrating common themes between the five products studied. It also discusses how widely the results can be applied (Section 8.2), the practical implications of the results (Section 8.3), limitations of the research (Section 8.4) and future research that would benefit this topic (Section 8.5).

8.1 Summary of results

This research predicts that, for four of the five products investigated, selling loose – rather than packaged – reduces 'not used in time' household food waste (HHFW) (Figure 32, Table 20). For the fifth product, cucumber, levels of HHFW could decrease or increase depending on whether smaller (half-sized) cucumbers are available in the loose scenario.

Figure 32: Model predictions for level of 'not used in time' household food waste, comparing packaged and loose items



The modelling focuses on 'not used in time' food waste: that resulting from people throwing away food items due to either the level of deterioration they exhibit or because of a date label (or a combination of the two). It is assumed that waste of these products due to other reasons (e.g., personal preference, preparing or serving too much, accidents) would not be influenced by the presence or absence of packaging.

Table 20: Predicted levels of 'not used in time' household food waste for the five scenarios modelled for each of the five products

Scenario	Food waste (as % of purchases)				
	Apples	Bananas	Broccoli	Cucumber	Potatoes
Packaged	3.1%	17.1%	10.1%	20.5%	13.9%
Loose	0.01%	9.6%	5.4%	17.0-24.5%*	0.9%
Packaged, but shelf life same as loose	3.1%	20.5%	12.0%	20.5%	13.9%
Packaged, but BB date removed	2.3%	17.1%	3.0%	17.0%	9.3%
Packaged, but pack-size options same as loose	0.4%	7.2%	10.1%	20.5-27.8%*	5.0%

*Results depend on assumption relating to availability of smaller cucumbers.

Table 21 and Table 22 also helps understand why there is a predicted reduction in household food waste from selling loose:

- **Changes in shelf life**: this is the least important of the three factors modelled. For three of the five products (apples, cucumbers and potatoes), shelf-life experiments suggested no detectable difference in shelf life between the loose and packaged variants of the product. Therefore, for these products, there is no change in HHFW as a result. For bananas and broccoli, the loose products did have slight shorter shelf lives than the packaged products, which increases modelled HHFW around a fifth in each case.

  Therefore, a key finding of this research is **that the preservation qualities that might have been previously believed to have been important for HHFW prevention are small compared to other factors**.

- **Removal of Best Before (BB) dates**: this factor decreases HHFW for all products except for bananas, which rarely carry a BB date in the UK. The magnitude of the impact on HHFW is remarkable, given that – in line with results from recent research with citizens – we have assumed that a small minority of the population use the BB date as a disposal date. Although there is uncertainty about the exact prevalence of this behaviour, these results demonstrate that a change affecting a small proportion of the population can have a significant impact on HHFW.

  Therefore, one of the key findings of this research is that **the removal of Best Before dates has the potential to reduce food waste, irrespective of whether the item is packaged or not**. This recommendation should be considered in conjunction with the limitations of the research, as discussed in Section 8.4.

- **Change in pack-size options**: for apples, bananas and potatoes, **allowing people to buy an amount appropriate for their needs (rather than the smallest currently available pack) greatly reduces HHFW, and has the largest impact on HHFW for these three products**. This disproportionately affects single-occupancy households: for packaged items, the smallest pack size was often much greater than a single-occupancy household generally consumes before the items start to deteriorate in quality. For broccoli, it was assumed that amounts purchased are not affected by whether the product is loose or packaged. For cucumbers, it depends on the size range of cucumbers available, as mentioned above.

  While HHFW could be reduced by providing smaller pack sizes for smaller households, this would not take the opportunity to reduce the environmental impacts relating to the removal of packaging.

Table 21: Predicted impact on 'not used in time' household food waste of selling loose (final row), and effects of individual changes (first three rows), percentage point difference

Change:	Difference in HHFW compared to packaged, expressed as percentage-point difference				
	Apples	**Bananas**	**Broccoli**	**Cucumber**	**Potatoes**
Change in shelf-life from packaging removal	0.0 pp	+3.3 pp	+1.9 pp	0.0 pp	0.0 pp
Removal of BB date	-0.8 pp	0.0 pp	-7.1 pp	-3.5 pp	-4.5 pp
Change in pack-size options	-2.7 pp	-9.9 pp	0.0 pp	0.0 pp (or +7.2 pp)*	-8.8 pp
Selling loose (All three changes combined)**	**-3.1 pp**	**-7.5 pp**	**-4.7 pp**	**-3.5 pp (or +4.0 pp)***	**-13.0 pp**

*0 pp / -3.5 pp if smaller (half-sized) cucumbers available loose; +7 pp / +4.0 pp if no smaller cucumbers available

**This is not simply the sum of the three changes above: this scenario includes interactions between all three changes

Table 22: Predicted impact on 'not used in time' household food waste of selling loose (final row), and effects of individual changes (first three rows), relative difference

Change:	Difference in HHFW compared to packaged (relative %)				
	Apples	Bananas	Broccoli	Cucumber	Potatoes
Change in shelf-life from packaging removal	0%	+19%	+19%	0%	0%
Removal of BB date	-25%	0%	-70%	-17%	-33%
Change in pack-size options	-86%	-58%	0%	0% (or 35%)	-64%
Selling loose (All three changes combined)**	**-99.7%**	**-44%**	**-47%**	**-17% (or +19%)**	**-93%**

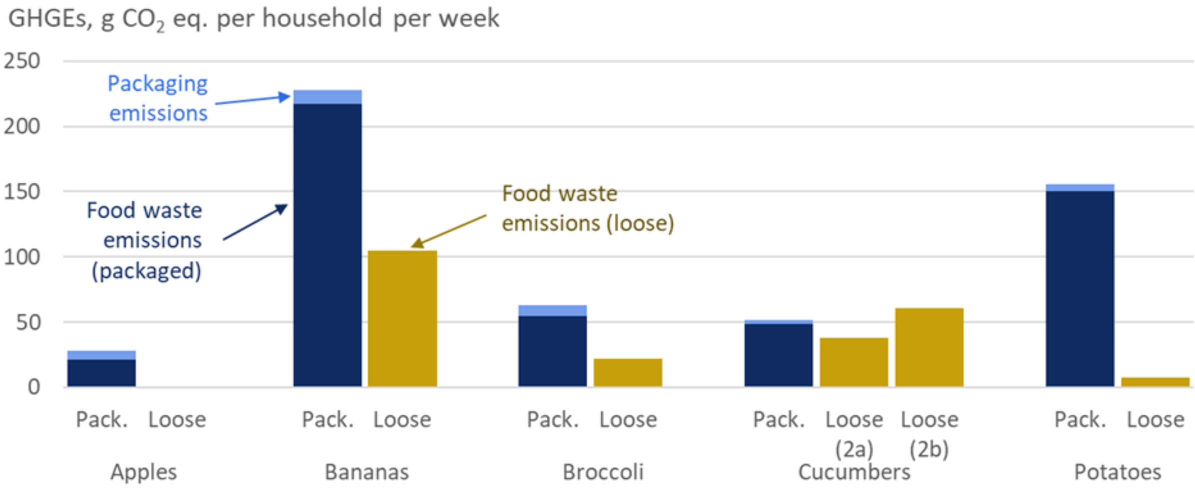
*0% / -17% if smaller (half-sized) cucumbers available loose; +35% / +19.0% if no smaller cucumbers available

**This is not simply the sum of the three changes above: this scenario includes interactions between all three changes

There are a range of environmental impacts relating to food and packaging. This report investigates greenhouse gas (GHG) emissions quantitatively, and explores other impacts qualitatively (Chapter 10.0).

Figure 33 illustrates the lack of trade-off for greenhouse gas emissions between packaging and HHFW. For most of the products, the GHG emissions associated with HHFW are much higher for the packaged scenarios. The exception is for cucumbers: specifically comparing the packaged scenario with the loose scenario in which smaller cucumbers are not available (scenario 2b). In this case, total emissions are higher for the loose scenario, even when accounting for packaging emissions in the packaged scenarios. Therefore, selling the apples, bananas, broccoli and potatoes loose would reduce HHFW, while also removing single-use plastic packaging. Both of these elements would contribute to lower GHG emissions, alongside other environmental benefits.

Figure 33: Estimated Greenhouse Gas (GHG) emissions for packaged and loose scenarios, splitting emissions relating to packaging and HHFW



The estimates of GHG emissions indicated that, where a product is packaged, the contribution of the packaging is relatively minor in comparison to any HHFW. From the average of all the scenarios modelled in this report across all the products, the packaging contributed approximately 10% of the GHG emissions; HHFW contributed 90%. Therefore, the scenario with the lowest combined GHG emissions was – in the cases modelled – that with the lowest HHFW (Figure ES2).

In addition to GHG emissions, there are other substantial environmental impacts associated with food waste and packaging. Food waste is associated with land and water use, biodiversity loss and eutrophication of water bodies and acidification. Plastic packaging is associated with aquatic and terrestrial pollution, disrupting ecosystems and threatening the life-support systems we rely on. As for GHG emissions, because of the nature of the results, there is not a trade-off relating to these impacts for four of the five products.

This analysis does not consider any differences in the supply chain between scenarios. For instance, selling loose versus packaged could lead to different levels of food waste in the supply chain and different amounts of supply-chain packaging required. It is important that the environmental impacts of these elements are also considered in decisions relating to selling packaged or loose. When viewed through a lens of GHG emissions, reducing the overall food waste (supply chain and household) will likely minimise overall emissions. However, plastic pollution is also important, so designing product and packaging systems that also eliminate plastic pollution while keeping levels of food waste low would be ideal.

8.2 How widely can these conclusions be applied?

This is a key question for interpreting these research findings. Can they be used to infer anything for types of fruit and vegetables not included in the research, such as oranges, onions and carrots? Furthermore, given that some of the data comes from specific varieties of products (e.g., Royal Gala for apples) and from a particular season, can the data for apples even be applied to all apples?

Strictly speaking, the results presented are the product of the input data used. For some of the data, notably the shelf-life data, this is for a particular variety at a given time of year. For banana, broccoli and cucumbers, the variety chosen is widespread, dominating the UK market. For apples and potatoes, a popular variety was chosen (Royal Gala and Estima, respectively). Nevertheless, these varieties account for less than half of apple and potato sales.

Furthermore, supply chains vary throughout the year. Produce may come from the UK during the relevant season and be imported for the rest of the year. For potatoes and apples, these may be stored for many months before reaching our shelves – the length of time depends on the variety, the season and where they are sourced from.

For the data on the presence of Best Before dates and pack sizes, it was taken for all varieties of that product on the market, albeit from a snapshot in November 2020. The products on the market may have been influenced by Covid-19: cases were increasing in the UK at the time, with a lockdown in England starting three days after the in-store fieldwork.

Where there are a range of varieties of one product in the UK market, and the supply chain changes throughout the year, the question becomes whether these differences will *materially* impact on the results seen in this study. This can be answered by considering the three factors that influence food waste in the home:

- Do common pack sizes vary over the year? Do pack sizes not modelled here (for example, three-packs of apples) predominate at other times of the year?
- Is the difference in shelf life between packaged and loose *substantially* different for varieties not modelled here, or at different times of year?
- Is there a substantial difference in the prevalence of Best Before dates at different times of year?

If the answer to any of these questions is yes, then the information gathered can be used to update the modelling for those specific circumstances. For most of the products modelled (all but cucumber), there would need to be a substantial change – compared to what has been modelled – for the loose variety to result in more food waste in the home than the packaged variety.

Can anything be said of other fruit and vegetable products not modelled here? *Quantitative* results – such as those found in Table 20 – require input data to be acquired and modelling to be undertaken. However, understanding *qualitatively* whether household food waste is likely to increase or decrease when a product is sold loose, rather than packaged, is possible. This can be achieved by considering the first three rows in Table 21. If we take the example of oranges:

- The packaging prevalent in the UK (a net) is unlikely to increase shelf life over and above loose oranges. Therefore, it is unlikely that there is going to be any effect on HHFW from this factor.
- Similar to bananas and apples, the minimum pack size could be substantially increasing HHFW, especially for smaller households. The magnitude of this effect

depends on orange-specific information: frequency or orange consumption, typical pack sizes for orange and how long householders are prepared to consumer oranges for.

- If Best Before dates are present, this factor could have a similar impact to apples. Removal of the Best Before date could greatly reduce food waste for a minority of the population. The exact extent depends on data specific to oranges: how many people keep them in the packaging, the proportion of oranges with a Best Before data on the market, how many people are influenced by BB dates for oranges and the difference in time between the Best Before date and when the orange would be consumed if people used their judgement around disposal decisions.

Therefore, we could tentatively but reasonably conclude that – when combining these three effects – household food waste for oranges might decrease if they were sold loose.

For some fresh produce categories – for example, summer fruit and berries – there could be different dynamics present, which were not relevant to the five products investigated and therefore not modelled. For assessment of these, further investigation would be required.

Similarly, where organisations in other countries are grappling with the same issues, in the first instance they could use the information in this report to create a qualitative estimate applicable to their context. For instance, if fresh produce does not carry a Best Before date in that country but pack sizes are similar to the UK, the results can be reinterpreted to understand if it is likely that packaging is contributing to household food waste in that given situation. This could be followed by detailed modelling, where it would support decision making and positive changes.

8.3 Implications of the results

For the first time, detailed estimates of the impact on household food waste from the removal of packaging are available to businesses, as summarised in Section 8.1. Given the discussion in the previous section, this research strongly suggests that **UK supermarkets could sell many types of fresh fruit and vegetables loose without leading to increased food waste <u>in the home</u>.** For some products – apples, bananas, broccoli and potatoes – changing to selling loose could lead to a *substantial reduction* in household food waste. Therefore, there is a path for businesses to navigate that would make progress simultaneously on the issues of reducing plastic pollution and food waste in the home.

It is important to note other considerations when making business decisions. As noted in the calculations of greenhouse gas emissions, food waste contributes more to the total emissions than packaging. In addition to *household* food waste, items being wasted in the *supply chain* will therefore also be important. Therefore, the decision on whether to remove packaging should consider waste and packaging (and other sources of emissions) throughout the supply chain as well as households.

Previously, the piece of evidence on the impact of packaging on household food waste was missing from this jigsaw. Supermarkets can use this information alongside data they hold on their supply-chain waste and packaging to make decisions whether to sell items loose.

A second clear finding of this research is that the interaction between packaging and food waste in the home is not all about shelf life, as per the many previous discussions on this subject. Other factors are also vitally important: indeed, for three out of the five products investigated, the minimum pack size was more important. In addition, the removal of Best Before dates was more important than shelf-life for four out of the five products.

One of the ways to prevent HHFW is to stop the Best Before date heavily influencing disposal decisions. For fresh fruit and vegetables, the simplest (and likely the most effective) way could simply be to remove this. There is no legislative barrier to doing so. This would remove the influence of the date on people's disposal decisions, encouraging them to use their senses to assess whether produce is still edible. Other alternatives – e.g., a mass education programme on the differences between Best Before and Use By dates – would be costly and unlikely to be as effective as the removal of Best Before dates. This would need to weighed up against other uses of the date: e.g., helping people to manage food in the home (see limitations of the research in Section 8.4).

Previous research has shown that single-occupancy households generate more waste from fruit and vegetables, and more waste because it was not used in time[137]. The current research has illustrated the challenges for single-occupancy households in buying the appropriate amounts for typical consumption levels if fruit and vegetables are sold packaged, especially for apples, bananas and potatoes.

Many of the products in this report are already sold loose in many supermarkets – most notably apples, bananas and potatoes. However, the number of lines sold loose is relatively low, and, where market-share data is available, this reveals that loose commands a low percentage of sales[138]. Therefore, the question to ask is not whether supermarkets should sell these products packaged or loose; rather it is whether they should work towards substantially shifting the balance between packaged and loose, with most products sold loose where there is a net reduction in food waste, considering both the supply chain and the home. This will be further expanded in the Food labelling guidance, to be published later in 2022.

This research indicates changes other than selling loose that could also be made to reduce food waste in the home:

- Simply put, the presence of a Best Before date on fresh fruit and vegetables increases household food waste. Removal should reduce household food waste markedly, especially in households where the Best Before date heavily influences disposal decisions. If they are not needed on bananas – with the shortest shelf life of all the products studied here – why are dates needed on products with longer and less predictable shelf lives?

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[137] *Household food and drink waste: A people focus, WRAP (2014), section 2.3.2: https://wrap.org.uk/sites/default/files/2021-02/WRAP-Household-food-and-drink-waste-A-people-focus-Report_0.pdf*

[138] *https://ahdb.org.uk/news/consumer-insight-pre-packed-potatoes-gain-during-pandemic-year*

- Helping citizens to buy an amount appropriate to their needs. Over-purchasing in the simulations greatly increases household food waste. In real life, it would either increase household food waste or require householders to work hard to avoid the additional items from becoming waste (for example, cooking and freezing them, sharing with friends and neighbours). Therefore, it is vital that there are appropriate pack sizes and loose offerings for *all* households – including single-occupancy households. Furthermore, pricing, promotions, positioning and other tools at the retailers' disposal should be used to guide people to the appropriate products and pack sizes for their needs.
- Ensuring products last as long as possible. The modelling has illustrated that the length of time that people are prepared to eat an item after purchase has a strong influence on household food waste. Actions that increase this length of time should support food-waste prevention. These include optimal storage of food in the supply chain and in the home, avoiding damage in the supply chain and on the journey home. Removal of date labels should also help this aim.

8.4 Limitations of research

The research in this project has used the most relevant modelling tool available for assessing the impact on household food waste and drawn upon up-to-date data sources to develop inputs. However, there are considerations and limitations of all research. This section describes these.

There are two main groups of limitations:

Firstly, the Household Simulation Model models simplified households. The simulation captures many of the dynamics of real households with regard to food purchasing, storage, consumption and waste. However, the modelling cannot capture all of the nuance of real households. Therefore, the results are approximate. Comparing scenarios allows assessment of the *approximate* impact on food waste of the differences between the scenarios. Therefore, only large differences between scenarios should be the basis of decisions – where the differences seen in the modelling results are likely to be a good representation of the real world.

Secondly, the modelling is based upon input data. This has been sourced from a range of datasets, each providing the most appropriate data available. In some cases, the data required transformation to obtain inputs for the model. This could introduce uncertainty. For instance, the process of converting survey results into the proportion of the population influenced by Best Before dates in their disposal decisions required subjective judgement. In this instance, we cross-checked the information used against data from other relevant survey questions. In most cases, the two sets of results were consistent.

Some of the input data was for a specific variety of fruit or vegetable, specifically, shelf-life data was obtained for Royal Gala apples and Estima potatoes. These varieties were chosen to be typical of a wider range of products. The implications of this are discussed in Section 8.2 and suggest that, although the results could change *slightly* if these snapshots are not fully representative of the whole 'picture', the conclusions made are unlikely to be influenced.

For the input data relating to shelf life, this came from a dedicated study resigned to get the most appropriate information for varieties sold in the UK, conditions in UK homes and UK-relevant packaging[139] . It also focused on sensory analysis as a primary method for assessing the deterioration of products, a suite of metrics most aligned to decisions in the home relating to whether to consume or disposed of a food item. However, it should be noted that the results of this study were different in nature from those in the literature: packaging was found to have less impact on shelf life than prior studies suggested. The potential reasons for this are discussed in Section 4.1 of the Shelf-Life report[139]. While the authors of this report believe that the shelf-life data used in this current study is the most appropriate available, some circumspection is recommended in interpreting the results in light of this apparent discrepancy.

Other data was from snapshot studies: for example, data on types of packaging in-store came from November 2020, and the results could have been influenced by changes relating to the Covid-19 pandemic.

For some items – notably apples - it is likely model predictions for both the packaged and loose variants are underestimates, as neither account for items coming into the home with some form of defect that is not visible on purchase but could lead to the apple being thrown away (e.g., internal rot). However, this is likely to affect both packaged and loose apples to a similar degree, so using the *difference* between the two scenarios is still valid.

For both scenarios, it is assumed that people have a good understanding of the number of items that they typically consume within their household and purchase accordingly. For some household archetypes, we have assumed that selling loose means that people will take the opportunity presented to them to purchase a more appropriate number of items for their needs. It is possible that people continue to over-purchase to the same degree, despite being able to purchase smaller amounts. However, the evidence from the Morrisons's trial (Section 1.2.3) suggests that many people do take the opportunity to adjust their purchasing habits when food is presented loose.

It also assumed that removal of the Best Before date will lead to people using their judgement relating to when to dispose of items. While this is likely for many people, there could still be households in which items are still disposed of after a relatively short period of time. Given that this would mean throwing away food that has no visible signs of deterioration, this seems implausible.

Best Before dates could also influence food waste in other ways. For instance, some people use them for selecting items in store with the greatest possible shelf life. However, this may be a zero-sum game: while the people in question may bring home longer lasting items, other shoppers will be left with the remaining items in store, so (unknowingly) bring home shorter shelf-life items than they otherwise would. As a result, the net effect on food waste across the whole UK from this particular mechanism is likely to be small and has not been included in the study.

[139] *The impact of packaging and refrigeration on shelf life, WRAP, 2022: https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste*

Furthermore, Best Before dates could help people manage the stock of items in the home. Where people have multiples packs of a given item, they could identify and use the oldest items first. Similarly, it could also prompt people to use up a range of items in an appropriate order to minimise food waste: short-shelf-life fresh produce (e.g., berries) soon after a shop, leaving items with a longer shelf life until later. For modelling purposes, this would mean increased consumption of items of items with a BB date (up to that date). All else being equal, this would reduce food waste.

It is also conceivable that an opposing mechanism occurs in some households: in the days leading up to the BB date, the presence of the date could cause people to perceive a lowering in quality (or increase in risk), and consequently reduce their consumption of the items in question. The authors of this report are unaware of any studies that have determined whether consumption is increased or decreased due to the presence of a date label.

Given this uncertainty, these dynamics – of BB dates influencing levels of consumption of within-date products – were not included in the modelling. However, with more information about whether these practices occur and their magnitude, their impact on food waste could be modelled.

In an ideal world, we would also have information from real-world situations (e.g., in-home observation) or from surveys in which people are able to interact with a product in a more natural way. Due to the timings of this project with regard to the Covid-19 pandemic, these types of social research were not possible. If data from these were to become available in the future suggesting a different fraction of the population being influenced by Best Before dates, the modelling results could easily be adapted to reflect this new knowledge.

As a result of these limitations, the results will not perfectly reflect the real world. The assumptions inherent within the modelling and the input data could influence the results. Sensitivity analysis was conducted for a several important factors to assess the degree to which the results depend on decisions made in the project (Section 9.0). These analyses suggest that the results may be influenced to a small degree by these decisions. However, given the large differences seen between packaged and loose scenarios for four of the five products, the conclusions presented in this report are unlikely to be influenced by these limitations.

Only five types of fruit and vegetables were modelled in this research. However, the research was able to uncover common mechanisms whereby the presence or absence of packaging could influence HHFW. Moreover, the research was able to understand the circumstances that would lead to that mechanism being important. Therefore, the findings in this research can be extended to help understand the impact of packaging on HHFW for a wider range of products, allowing best-practice guidance to be refined.

8.5 Future work / research

This research has provided new evidence on the link between packaging and household food waste. While it answers many research questions and supports practical recommendations, further research in this area would be useful.

Firstly, while we believe that the evidence presented in this report is sufficient for action, this field would benefit from real-world trials: the removal of packaging on specific products with accompanied measurement of supply-chain and **household** food waste. These trials may be expensive and have logistical challenges, but they would demonstrate the degree to which the modelling predictions in this report are accurate. This would also help to improve the modelling, refining the dynamics included in the simulation. Ultimately, it could – depending on the results – provide more compelling evidence for businesses to act.

As discussed in Section 8.3, decisions on whether to package fruit and vegetables need to consider the impacts in both the supply chain and in the home. This report provides much-needed data on the impacts relating to household food waste. Working with businesses, future research could incorporate data on the impacts within the supply chain to provide a more complete picture. This could help to understand whether there are trade-offs: for example, between supply-chain and household food waste.

There is also further research that could be useful to understanding the role of Best Before dates on HHFW. It could be useful to undertake both qualitative and quantitative research to better understand the role date labels can play, not only on disposal decisions, but also whether the presence or absence of the BB date influences how frequently people consume these key foods. This new data could then be used to refine further modelling. This research may be complex and costly to get meaningful results, so it may be appropriate to carefully consider any options and determine where insights could support the greatest potential for food waste prevention.

Finally, the research could be applied to other products in the UK, and to other countries where the issues in this report are also relevant. For example, the "Reducing plastic packaging and food waste through product innovation simulation" project[140] is using the Household Simulation Model, supported by a range of data gathering and research, to investigate situations in which plastic packaging can play a role in reducing food waste in the supply chain and the home. This could help create tools to help a wider range of organisations around the globe to navigate these decisions, reducing plastic use and minimising food waste.

[140] https://gtr.ukri.org/projects?ref=NE%2FV010654%2F1

9.0 Appendix 1: Sensitivity analyses

9.1 Introduction to sensitivity analyses

The results in the main report represents our best efforts to model the effect of selling packaged and loose. However, we were not always able to obtain all the desired information to inform the input factor. Furthermore, some data was open to interpretation. This section presents sensitivity analyses, in which additional runs of the HHSM are undertaken to assess whether uncertainties identified around key inputs alter the conclusions of the report.

9.2 Sensitivity analysis: depackaging

For apples and bananas, we had data on the proportion of the population who claim to depackage apples and bananas after they purchase the items in packaging. This was often to facilitate storage and consumption from a fruit bowl.

There was no data available for broccoli, cucumbers and potatoes. In the main report, it was assumed that these weren't depackaged when returned from the home, mainly because these would be unlikely to be placed in a fruit bowl. None the less, a minority of the population (34%) indicated that they would depackage carrots[141].

A sensitivity analysis was performed for broccoli. Broccoli was chosen because the impact of depackaging is likely to be more pronounced than for the other two vegetables. This is for two reasons:

- Broccoli's shelf life is dependent on the presence of packaging, unlike for potatoes and cucumber.
- There is a large difference in shelf life for those using the Best Before date compared to those using their judgement.

The results of the sensitivity analysis are presented in Table 23. The first column presents the results found in the main report, assuming 0% of households depackage broccoli. The second column presents the results for a situation in which 34% of households depackage broccoli. (34% is used, taking data for carrots as a proxy.) This depackaging has two effects:

1. It removes the Best Before date for these households, meaning that households could use it for a disposal decision, even if they wanted to
2. The change reduces the shelf life for those not using their judgement, from an average of 24 days to 17 days.

The values for some of the scenarios change: levels of waste are lower for scenarios 1, 3 and 5 due to the first effect mentioned above. Whereas the level of broccoli waste increases for scenario 4 due to the second effect.

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[141] *Consumer insights: date labels and storage guidance, WRAP, 2011: https://wrap.org.uk/sites/default/files/2020-12/Consumer-insight-date-labels-and-storage-guidance.pdf*

Table 23: Estimates of broccoli waste, illustrating the impact of assumptions around depackaging

Scenario	Broccoli waste (as % of purchases)	
	0% depackaged	34% depackaged
1: Packaged	10.1%	8.5%
2: Loose	5.4%	5.4%
3: Packaged, but shelf life same as loose	12.0%	9.8%
4: Packaged, but BB date removed	3.0%	3.8%
5: Packaged, but pack-size options same as loose	10.1%	8.5%

Table 24 presents the differences between scenarios, which allows comparison of 0% and 34% of households depackaging. There are some modest differences between the two scenarios, most noticeable the impact of BB date removal. However, although the magnitudes of the differences have changed, the conclusions in the main report would still be valid if 34% of broccoli were depackaged in the home.

Table 24: Differences between waste in broccoli scenarios, comparing two levels of depackaging

Change	Broccoli waste (as % of purchases)	
	0% depackaged	34% depackaged
Change in shelf-life from packaging removal	1.9%	1.3%
Removal of BB date	-7.1%	-4.7%
Change in pack-size options	0.0%	0.0%
All three changes combined	**-4.7%**	**-3.1%**

9.3 Sensitivity analysis: interaction between depackaging and BB date

In the model, it is assumed that around 60% of households depackage apples and bananas. This has two effects in the model, affecting:

- the shelf life of those using their judgement to determine the disposal point of an item,
- the availability of the Best Before date for households using this to inform disposal

In the main report, we have interpreted the percentage of households influenced by the Best Before date to be that they are influenced by it *assuming it is available*. For some of the households potentially influenced by the Best Before date, we have assumed that they have depackaged the item and it is no longer available.

In this sensitivity analysis, we repeat the modelling *assuming that the Best Before date is available to all who state they are influenced by it*. This would be the case if people who use the Best Before date don't depackage items, for instance because they want the Best Before date to be available to them. We take the example of apples, as Best Before dates are rarely found on bananas in the UK.

Table 25: Estimates of apple waste, illustrating the impact of assumptions around depackaging and Best Before dates

Scenario	Apple waste (as % of purchases)	
	BB date available only to those not depackaging	BB date available to all
1: Packaged	3.9%	5.0%
2: Loose	0.004%	0.004%
3: Packaged, but shelf life same as loose	3.9%	5.0%
4: Packaged, but BB date removed	3.0%	3.0%
5: Packaged, but pack-size options same as loose	0.4%	1.0%

The results show that there would be slightly more apple waste for scenarios 1, 3 and 5 (Table 25). This is because the Best Before date is available to more households, and therefore influences more disposal decisions. Changing this assumption increases the impact of the Best Before date (Table 26): removing the Best Before date makes more of a difference with this new assumption. Overall, selling loose is predicted to have more of an impact with the modified assumption than the original. Therefore, the conclusions in the main report are not affected by this assumption.

Table 26: Differences between waste in apple scenarios, comparing assumptions around depackaging and Best Before dates

Scenario	Apple waste (as % of purchases)	
	BB date available only to those not depackaging	BB date available to all
Change in shelf-life from packaging removal	0.0%	0.0%
Removal of BB date	-0.8%	-2.0%
Change in pack-size options	-3.4%	-4.0%
All three changes combined	**-3.9%**	**-5.0%**

10.0 Appendix 2: Environmental-impact calculations

One of the key drivers of this research is to minimise the environmental impact of the food we buy and its packaging. There are many ways in which food and packaging can impact on the environment, including via greenhouse gas (GHG) emissions, the amount of land required to produce food and pollution of marine and terrestrial environments by packaging. This appendix discusses these impacts of the environment, including calculations relating to GHG emissions.

Previous research suggests that packaging makes up a relatively small component of the overall GHG footprint of food products (i.e., that taking into account food production, transportation and any processing, storage, cooking and waste disposal). The exact value is dependent on the food in question as well as the packaging material and the amount used[142]. In this appendix, comparison is made between the GHG emissions of the food *waste* and packaging from key scenarios from the modelling found in the report (Chapters 3.0 to 7.0). This uses the calculations presented in Section 10.1 and the results are presented in Section 10.2. Impacts other than GHG emissions are discussed in Section 10.3.

10.1 Methods for calculating GHG emissions

This section outlines the methods used for quantifying greenhouse gas (GHG) emissions associated with food waste and packaging from key scenarios from the rest of the report. This allows the GHG emissions relating to food waste in the home and packaging to be compared for the scenarios modelled in this report.

These are approximate calculations to provide an indication of the relative magnitudes of GHG emissions. They also use average values for emissions; for some products, the production methods used can greatly influence emissions (e.g., use of heated versus unheated greenhouses).

The emissions relating to food waste were the total of the following process / stages of the supply chain:

- Primary production
- Transport to processor or retailer
- Processing (where applicable)
- Retail environment
- Transport - retail to home
- Packaging (where applicable)
- Disposal (landfill and compost)

[142] *e.g. Heller et al. (2018). Mapping the Influence of Food Waste in Food Packaging Environmental Performance Assessments. Journal of Industrial Ecology. 23 (2). 480-495. https://doi.org/10.1111/jiec.12743*

The data for production and transport were taken from Poore and Nemecek (2018)[143]. The data for retail to landfill was taken from data sources collated for Household Food and Drink Waste in the UK (WRAP, 2009)[144]. The primary source for the emissions associated with the packaging polymers was Brizga et al., (2020)[145].

The data collated and used in further calculations can be found in Table 27. This indicates that the total GHG emissions for each of the five products are similar, varying from 0.90 to 1.28 kg CO_2 eq. per kg of product.

Table 27: GHG emissions (kg CO_2 eq. per kg product) associated with food, split by stage of the supply chain

Produce	**GHG emissions (kg CO_2 eq. per kg product)**					
	Primary production + transport to retailer	Processing	Retail + transport to home	Waste (landfill & compost)	Packaging	**Total**
Apples	0.325		0.076	0.545	0.0054	**0.95**
Bananas	0.617		0.102	0.545	0.012	**1.28**
Broccoli	0.373	0.15	0.113	0.545	0.018	**1.20**
Cucumber	0.398		0.102	0.545	0.018	**1.06**
Potato	0.194	0.025	0.130	0.545	0.006	**0.90**

For most products, there are two hotspots: primary production and waste processing. To estimate the GHG emissions associated with household food waste (HHFW), the sum of the factors relating to all stages except for packaging (to avoid double counting) was multiplied by the amount of food waste in each scenario. This was compared to the packaging GHG emissions, calculated as described below.

The emissions for food waste relate to the complete journey of food from agricultural production, through the supply chain and at home, to waste disposal. The use of these factors in this way makes the implicit assumption that preventing HHFW will reduce all of these emissions – i.e., waste prevention leads to lower levels of production and throughput within the supply chain than if no waste were to occur. If HHFW prevention

[143] *J. Poore, T. Nemecek (2018), Reducing food's environmental impacts through producers and consumers, Science, Vol. 360, Issue 6392, pp. 987-992, https://science.sciencemag.org/content/360/6392/987*

[144] Household Food and Drink Waste in the UK, WRAP (2009): *https://wrap.org.uk/sites/default/files/2020-12/Household-Food-and-Drink-Waste-in-the-UK-2009.pdf*

[145] *Brizga J., et al. (2020), The Unintended Side Effects of Bioplastics: Carbon, Land, and Water Footprints, One Earth, 3(1), pp. 45-53, https://doi.org/10.1016/j.oneear.2020.06.016*

does not impact production and the supply chain in this way, then the reduction in GHG emissions may be more limited. In the most extreme case, HHFW prevention could have no influence on the supply chain, and therefore HHFW prevention would only mitigate the waste-disposal emissions. These GHG emissions from waste disposal are approximately half of the total emissions. Further research – beyond the scope of this report – is required to understand the impacts of HHFW prevention on GHG emissions within the supply chain.

The amount and material of packaging associated with each type of produce are shown in Table 28. The data on packaging material comes from the in-store research discussed in Section 2.3.3 (results presented in the 'Background Information' sections of Chapters 3.0 to 7.0). The weight of packaging comes from a range of sources, as indicated in the table.

Table 28: Types and weights of packaging for products in this study

Produce	Packaging	Weight of packaging
Apples	PP flow wrap	2.7 g per 6 pack of apples (1 kg)[146]
Bananas	PE bag	3 g per 750 g bag of bananas (estimated)
Broccoli	PE shrink wrap	3 g per 350 g of broccoli (estimated)
Cucumber	PE shrink wrap	1.5 g per 300 g cucumber[147]
Potato	PE bag	5 g per 2.5 kg bag (measured by author)

Where there were no published values for the weight of packaging the values were estimated from the apple, packaging, and potato values. Furthermore, to calculate the GHG emissions associated with packaging, the percentage of packaging for a particular product was multiplied by the weight of that product purchased. This assumes that the ratio of packaging to food is the same, irrespective of the pack size. As will be seen in the results, the contribution from packaging is small and conclusions drawn are not particularly sensitive to the amount of packaging used.

The carbon factor used for PP flow wrap and both forms of PE (film bag and shrink WRAP) is taken from the UK Government GHG Conversion Factors for Company Reporting 2020[148]. The average value for average plastic films is used (2,574 kg CO_2 eq. /

[146] *M. Boschiero, et al., (2019), Greenhouse gas emissions and energy consumption during the post-harvest life of apples as affected by storage type, packaging and transport, J. Cleaner Production, 220, pp. 45-56, https://doi.org/10.1016/j.jclepro.2019.01.300*

[147] *A. White, S. Lockyer, (2020), Removing plastic packaging from fresh produce – what's the impact?, Nutrition Bulletin, 45(1), pp. 35-50, https://doi.org/10.1111/nbu.12420*

[148] *https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/891105/Conversion_Factors_2020_-_Condensed_set__for_most_users_.xlsx*

tonne material). Values from other sources were considered: these had similar magnitude and were in the range 2,000 – 3,500 kg CO2 eq. / tonne material.

10.2 Results of GHG emission calculations

This section details the GHG emissions associated with food waste and packaging modelled in this report, using the methodology detailed in the previous section. These are presented separately for the five products.

It should be noted that the results of this section are approximate, as average values have been used for the GHG emissions associated with different foods and packaging materials: values will vary, for example, according to the details of food production (e.g., the use of heated vs. unheated greenhouses).

Furthermore, for loose items, the GHG emission calculations assume that these items will be carried home using existing bags (or other receptacles). Therefore, if additional bags or other receptacles are required to transport these items to people's homes, this would increase the GHG-emission estimates for the loose scenarios. However, as the GHG emissions from packaging are much lower than for the food itself, this is unlikely to affect the conclusions.

The results tables show the emission factors and the values these have been multiplied by: i.e., amount of food waste in the scenario and amount of packaging purchased.

10.2.1 Apples

For the packaged scenario (Table 29), the modelling estimated that 23 g of apples were wasted per week, producing c. 21 g of GHG emissions (CO_2eq.). In this scenario, c. 3 g of packaging were required, contributing 7 g CO_2eq.

For the loose scenario, there was only 0.1 g of food waste per week, equating to 0.1 g CO_2eq. and no primary packaging was used.

Therefore, the total GHG emissions associated with the packaged scenario (28 g CO_2eq. / week) are much higher than the loose scenario (0.1 g CO_2eq. / week). It should be remembered that these figures do not consider GHG emissions relating to supply-chain food waste, supply chain packaging or any other factor which could be influenced by whether produce is sold packaged or loose.

Approximately one quarter of the GHG emissions associated with the packaged-apples scenario is from the packaging. Therefore, emissions from this scenario are dominated by the food-waste component, due to the relatively small weight of packaging involved in the scenario. Therefore, any changes that can be made to prevent food waste – whether in the home or in the supply chain – will help reduce GHG emissions relating to apples.

Table 29: Greenhouse gas (GHG) emissions of apples for packaged and loose modelling scenarios

Quantity	Scenario 1 (packaged)	Scenario 2 (Loose)
Food waste (g/week)	22.7	0.1
GHG emission factor for FW (g CO_2 eq. / g FW)	0.95	
GHG emission for FW (g CO_2eq. / week)	21.5	0.1
Packaging required for all purchases (g / week)	2.7	0.0
GHG emission factor for packaging (g CO_2 eq. / g packaging)	2.6	
GHG emission for packaging (g / week) g CO_2eq.	6.8	0.0
Total GHG emission (FW + packaging) g CO_2eq.	**28.3**	**0.1**

10.2.2 Bananas

For the packaged scenario, it was estimated that 172 g of bananas were wasted per week (Table 30). This produced c. 218 g CO_2eq. / week. In this scenario, 4 grammes of packaging contributed a further 10 g CO_2eq. / week.

Table 30: Greenhouse gas (GHG) emissions of bananas for packaged and loose modelling scenarios

Quantity	Scenario 1 (packaged)	Scenario 2 (Loose)
Food waste (g/week)	172.0	83.2
GHG emission factor for FW (g CO_2 eq. / g FW)	1.26	
GHG emission for FW (g CO_2eq. / week)	217.5	105.2
Packaging required for all purchases (g / week)	4.0	0.0
GHG emission factor for packaging (g CO_2 eq. / g packaging)	2.6	
GHG emission for packaging (g / week) g CO_2eq.	10.2	0.0
Total GHG emission (FW + packaging) g CO_2eq.	**227.7**	**105.2**

For bananas sold loose, the model estimated lower levels of waste (83 g per week), leading to 105 g CO_2eq. / week. Therefore, the loose scenario had slightly less than half of the total GHG emissions compared to the packaged scenario.

It should be remembered that these figures do not consider GHG emissions relating to supply-chain food waste, supply chain packaging or any other factor which could be influenced by whether produce is sold packaged or loose.

For the packaged scenario, c. 4% of the total emissions are associated with packaging and 95% with food waste.

10.2.3 Broccoli

For the packaged scenario, it was estimated that 46 g of broccoli were wasted per week. This produced c. 55 g CO_2eq. / week (Table 31). In this scenario, c. 3 grams packaging contributed a further 8 g CO_2 eq. / week.

For broccoli sold loose, the model estimated lower levels of waste (18.5 g per week), leading to 22 g CO_2eq. / week. Therefore, the loose scenario had around one third of the total GHG emissions compared to the packaged scenario. In the packaged scenario, the packaging contributed 13% of the total GHG emissions.

It should be remembered that these figures do not consider GHG emissions relating to supply-chain food waste, supply chain packaging or any other factor which could be influenced by whether produce is sold packaged or loose.

Table 31: Greenhouse gas (GHG) emissions of broccoli for packaged and loose modelling scenarios

Quantity	Scenario 1 (packaged)	Scenario 2 (Loose)
Food waste (g/week)	46.3	18.5
GHG emission factor for FW (g CO_2 eq. / g FW)	1.18	
GHG emission for FW (g CO_2eq. / week)	54.7	21.9
Packaging required for all purchases (g / week)	3.2	0.0
GHG emission factor for packaging (g CO_2 eq. / g packaging)	2.6	
GHG emission for packaging (g / week) g CO_2eq.	8.1	0.0
Total GHG emission (FW + packaging) g CO_2eq.	**62.8**	**21.9**

10.2.4 Cucumber

For the packaged scenario, it was estimated that 46 g of cucumber were wasted per week, producing c. 48 g CO_2eq. / week (Table 32). In this scenario, packaging contributed a further 3 g CO_2eq. / week.

For cucumber sold loose, there were two scenarios. In scenario 2a, smaller (half-sized) cucumbers are available. In this, 37 g of cucumbers were wasted per week, equating to 38 grammes CO_2eq. Waste levels were higher (58 g / week, 61 g CO_2 eq.) where smaller cucumbers are not available (scenario 2b).

There is a low amount of GHG emissions associated with packaging, due to small amounts of material being used. In the packaged scenario, 7% of GHG emissions are associated with the packaging. Therefore, the total GHG emissions of each scenario are largely determined by the level of food waste and is consequently lowest for scenario 2a.

Table 32: Greenhouse gas (GHG) emissions of cucumber for packaged and loose modelling scenarios

Quantity	Scenario 1 (packaged)	Scenario 2a (Loose, small cucumbers available)	Scenario 2b (Loose, small cucumbers not available)
Food waste (g/week)	46.2	36.7	58.1
GHG emission factor for FW (g CO_2 eq. / g FW)	1.05		
GHG emission for FW (g CO_2eq. / week)	48.3	38.3	60.8
Packaging required for all purchases (g / week)	1.3	0.0	0.0
GHG emission factor for packaging (g CO_2 eq. / g packaging)	2.6		
GHG emission for packaging (g / week) g CO_2eq.	3.4	0.0	0.0
Total GHG emission (FW + packaging) g CO_2eq.	**51.7**	**38.3**	**60.8**

It should be remembered that these figures do not consider GHG emissions relating to supply-chain food waste, supply chain packaging or any other factor which could be influenced by whether produce is sold packaged or loose.

10.2.5 Potatoes

For the packaged scenario, it was estimated that 170 g of potatoes were wasted per week. This produced c. 150 g CO_2eq. / week (Table 33). In this scenario, packaging contributed a further 5.5 g CO_2eq. / week.

For potatoes sold loose, the model estimated lower levels of waste (9 g per week), leading to 8 g CO_2eq. / week. Therefore, the loose scenario had around 5% of the GHG emissions compared to the packaged scenario.

In the packaged scenario, the packaging contributed 4% of the total GHG emissions. It should be remembered that these figures do not consider GHG emissions relating to supply-chain food waste, supply chain packaging or any other factor which could be influenced by whether produce is sold packaged or loose.

Table 33: Greenhouse gas (GHG) emissions of potatoes for packaged and loose modelling scenarios

Quantity	Scenario 1 (packaged)	Scenario 2 (Loose)
Food waste (g/week)	170	8.9
GHG emission factor for FW (g CO_2 eq. / g FW)	0.88	
GHG emission for FW (g CO_2eq. / week)	150	7.9
Packaging required for all purchases (g / week)	2.1	0.0
GHG emission factor for packaging (g CO_2 eq. / g packaging)	2.6	
GHG emission for packaging (g / week) g CO_2eq.	5.5	0.0
Total GHG emission (FW + packaging) g CO_2eq.	**155.8**	**7.9**

10.3 Other environmental indicators

In addition to the emission of greenhouse gases, there are numerous environmental impacts associated with both food waste and packaging. This section highlights some of the important impacts, and their link to the current research.

For food waste, these include:

- **Land use**: The production of food for the world's population requires large amounts of land. It has been estimated that half of the habitable land of the world is used for agriculture[149]. Therefore, substantial amounts of land are used to produce food that is subsequently wasted.

- **Water use:** Agriculture uses more water than any other sector: approximately 70 percent of global freshwater withdrawals are for agriculture[150]. This can lead to water stress and the risk of water scarcity.
- **Biodiversity loss**: biodiversity refers to the number, variety and genetic variability of species in an area. It is essential to the functioning of our planet's ecosystems. Even small losses can have disastrous effects. The use of land for agriculture can fragment habitats, reduce water available for ecosystems and introduce chemicals into the environment harmful to a wide range of organisms. This is exacerbated by producing food that is later wasted.
- **Acidification**: the process in which soil or water environment becomes more acidic. Acidification can often be linked back to farming activities and to the production of key inputs, such as fertilisers and pesticides. This can reduce soil fertility, meaning the land has reduced potential to grow crops. Aquatic ecosystems are also negatively impacted.
- **Eutrophication**: where bodies of water become over-enriched by nutrients, e.g., nitrogen and phosphorus. This process often involves the run-off from agricultural activities, such as fertiliser application. This impacts aquatic ecosystems, placing local biodiversity at risk[151].

For plastic, the environmental impacts are wide ranging. This section looks at those likely from the types of plastic film used for fruit and vegetable packaging in the UK (PE and PP), and systems related to this. In addition to the GHG emissions related to the production of the polymer and the manufacturing of the packaging (as detailed in the previous section), there are also considerable environmental impacts associated with the end of life.

Currently in the UK, the minority of film is collected for recycling. The remainder is either collected in residual waste or enters the environment as litter.

For the plastic film collected as part of the residual waste in the UK, the majority of this will end up being burnt within an energy-from-waste plant, rather than going to landfill[152]. From a greenhouse gas perspective, being burnt, even with energy recovery is a worse outcome than going to landfill, and much worse than being recycled.

Where plastic film enters the environment, plastics disrupt ecosystems, either as large pieces or the microplastics that it breaks down into. Marine animals are particularly

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[149] *https://ourworldindata.org/global-land-for-agriculture*

[150] *Gleick,P.H et al. (2014). The World's Water: The Biennial Report on Freshwater Resources. Washington, DC: Island Press): https://link.springer.com/book/10.1007/978-1-59726-228-6*

[151] *Driven to waste: the global impact of food loss and waste on farms: WWF-UK (2021): https://wwf.panda.org/discover/our_focus/food_practice/food_loss_and_waste/driven_to_waste_global_food_loss_on_farms/*

[152] *https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/966114/Statistics_on_waste_managed_by_local_authorities_in_England_in_2019v3_accessible.pdf*

affected. From the largest – whales have been found with stomachs full of plastic[153] – to the smallest: plankton are being contaminated with microplastic. These tiny plants and animals play an important role in sequestering carbon dioxide from the ocean's surface, transporting it into the deep oceans, preventing it from re-entering the atmosphere. Laboratory experiments suggest microplastic pollution reduces the ability of plankton to sequester carbon, and that the plastic pollution reduces the metabolic rates, reproductive success, and survival of plankton[154]. This could reduce the ability of oceans to act as a carbon sink, exacerbating the climate emergency.

Where plastic is collected for recycling, this does not always mean that it is recycled. Since China stopped importing much of the plastic waste globally, the disrupted supply chains have led to cases of plastic being dumped on land, making their way into the marine ecosystems and being incinerated, leading to toxic gases being released and associated health issues for those living nearby[155].

Careful management and recycling of the plastic film used for food packaging could greatly reduce the end-of-life impacts detailed above. However, there is a high degree of 'leakage' of these types of plastics into the environment: therefore, opportunities to reduce plastic use – as discussed in this report – are also important.

10.4 Conclusions relating to environmental impacts

At the outset of this project, the authors believed that there might be situations in which there were trade-offs between packaging and household food waste, consistent with prominent narratives on this subject. However, as demonstrated in this project, this is not the case for most of the products investigated: generally, removal of packaging is predicted to lead to less food waste in the home.

Figure 34 illustrates this lack of trade-off for greenhouse gas emissions. For most of the products, the GHG emissions associated with HHFW are higher for the packaged scenarios. The exception is for cucumbers: specifically comparing the packaged scenario with the loose scenario in which smaller cucumbers are not available (scenario 2b). In this case, total emissions are higher for the loose scenario, even when accounting for packaging emissions in the packaged scenarios.

For packaged scenarios, the contribution of the packaging is relatively minor in comparison to any HHFW; from the average of all the scenarios modelled in this report across all the products, the packaging contributed approximately 10% of the GHG emissions; HHFW contributed 90%. Therefore, the scenario with the lowest combined GHG emissions was – in the cases modelled – that with the lowest HHFW.

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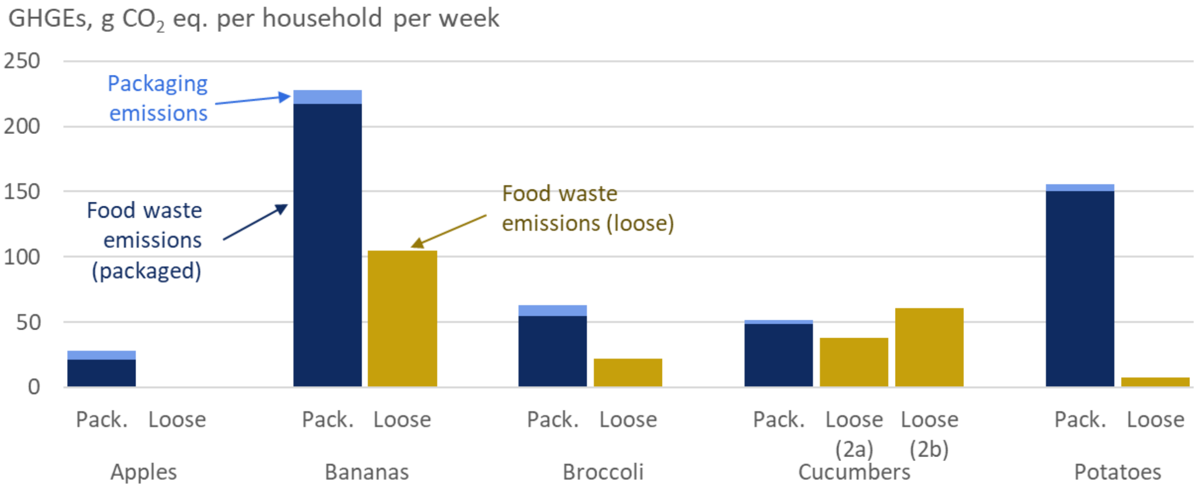
[153] https://www.nationalgeographic.com/environment/article/whale-dies-88-pounds-plastic-philippines

[154] https://www.ciel.org/wp-content/uploads/2019/05/Plastic-and-Climate-FINAL-2019.pdf

[155] https://www.nrdc.org/stories/single-use-plastics-101

Figure 34: Estimated Greenhouse Gas (GHG) emissions for packaged and loose scenarios, splitting emissions relating to packaging and household food waste

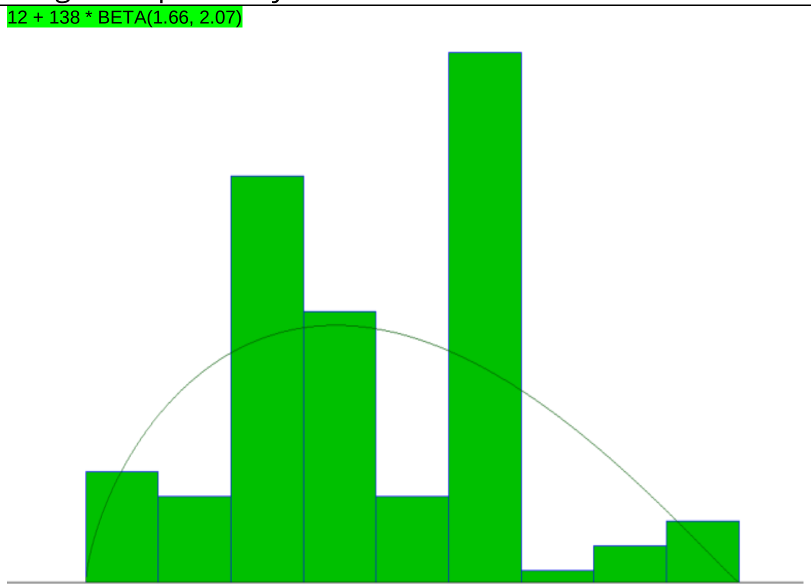
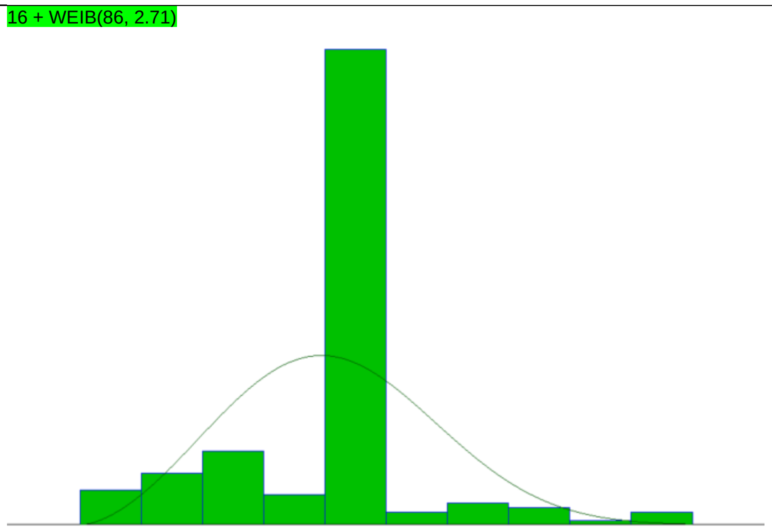
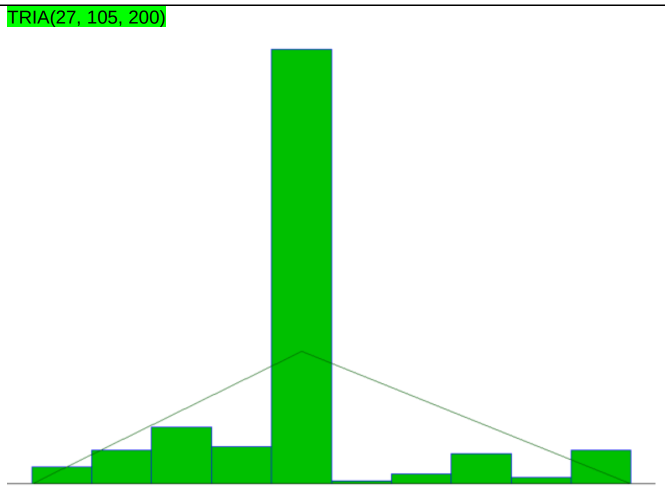


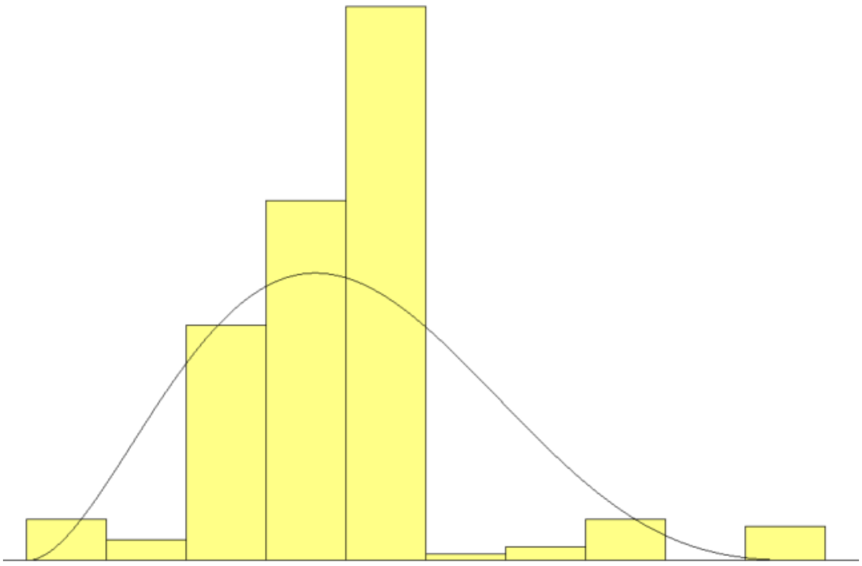
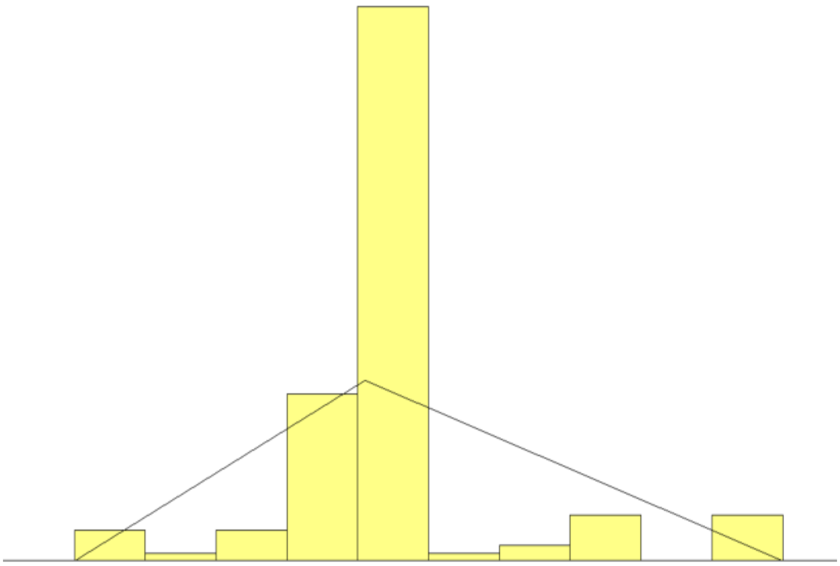
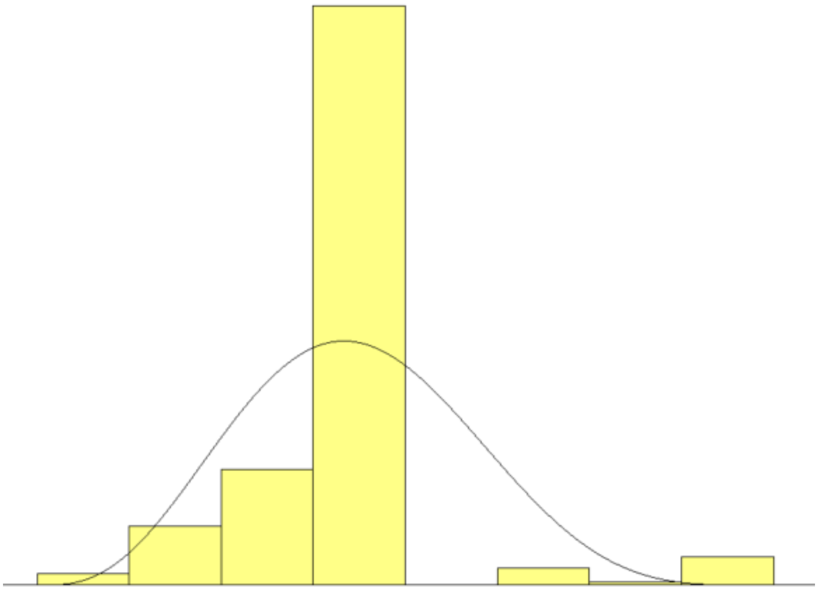
This leads to the general point: when viewed through the lens of GHG emissions, it is important to minimise food waste through reasonable and proportionate means. Although not explicitly included in the modelling, it logically follows that this would include food waste in the supply chain, as well as that in the home.

However, as discussed in Section 10.3, GHG emissions are important, but not the only important impact on the environment. For the topic of whether fresh fruit and vegetables should be sold packaged or loose, consideration should be given to the potential for any packaging used to pollute the natural environment, and the harm that it can cause there. In situation where it can be demonstrated that 'leakage' of packaging into the natural environment is low (e.g., through effective and comprehensive collection and recycling schemes), its use as a packaging material *might* be justified. However, where this cannot be demonstrated, removal of packaging appears to be an opportunity to reduce environmental harm from both the packaging and household food waste for many products.

11.0 Appendix 3: use of NDNS data to determine consumption patterns

This section provides the distributions of consumption from the National Diet and Nutrition survey, as outline in Section 2.3.1. The distributions are displayed alongside the fit used, replicated for each type of fruit and vegetable, and each age group. The distribution was fitted using the Input Analyzer function in the Arena Software.

<u>Apples Infants</u> **Distribution: Beta** Expression: 12 + 138 * BETA(1.66, 2.07) Square Error: 0.074413 **Chi Square Test** Number of intervals = 7 Degrees of freedom = 4 Test Statistic = 74 Corresponding p-value < 0.005 **Kolmogorov-Smirnov Test** Test Statistic = 0.152 Corresponding p-value < 0.01 **Data Summary** Number of Data Points = 130 Min Data Value = 12 Max Data Value = 150 Sample Mean = 73.5 Sample Std Dev = 31.5 **Histogram Summary** Histogram Range = 12 to 150 Number of Intervals = 8	
<u>Apples Children</u> **Distribution: Weibull** Expression:16 + WEIB(86, 2.71) Square Error: 0.246574 **Chi Square Test** Number of intervals = 6 Degrees of freedom = 3 Test Statistic = 207 Corresponding p-value < 0.005 **Kolmogorov-Smirnov Test** Test Statistic = 0.327 Corresponding p-value < 0.01 **Data Summary** Number of Data Points = 170 Min Data Value = 16.7 Max Data Value = 200 Sample Mean = 93.4 Sample Std Dev = 29.1 **Histogram Summary** Histogram Range = 16 to 200 Number of Intervals = 10	
<u>Apples Adults</u> **Distribution: Triangular** Expression: TRIA(27, 105, 200) Square Error: 0.269749 **Chi Square Test** Number of intervals = 8 Degrees of freedom = 6 Test Statistic = 300 Corresponding p-value < 0.005 **Kolmogorov-Smirnov Test** Test Statistic = 0.399 Corresponding p-value < 0.01 **Data Summary** Number of Data Points = 197 Min Data Value = 27.7 Max Data Value = 200 Sample Mean = 101 Sample Std Dev = 31.7 **Histogram Summary** Histogram Range = 27 to 200 Number of Intervals = 10	

Bananas Infants **Distribution: Beta** Expression: 5+195*BETA(2.95, 4.43) Square Error: 0.088717 **Chi Square Test** Number of intervals = 6 Degrees of freedom = 3 Test Statistic = 105 Corresponding p-value <0.005 **Kolmogorov-Smirnov Test** Test Statistic= 0.182 Corresponding p-value < 0.01 **Data Summary** Number of Data Points = 189 Min Data Value = 5 Max Data Value = 200 Sample Mean = 82.9 Sample Std Dev = 33 **Histogram Summary** Histogram Range = 5 to 200 Number of Intervals = 10	5 + 195 * BETA(2.95, 4.43) 
Bananas Children **Distribution: Triangular** Expression: TRIA(5, 85, 200) Square Error: 0.230997 **Chi Square Test** Number of intervals = 7 Degrees of freedom = 5 Test Statistic = 159 Corresponding p-value <0.005 **Kolmogorov-Smirnov Test** Test Statistic = 0.26 Corresponding p-value < 0.01 **Data Summary** Number of Data Points = 119 Min Data Value = 5 Max Data Value = 200 Sample Mean = 96.7 Sample Std Dev = 34.6 **Histogram Summary** Histogram Range = 5 to 200 Number of Intervals = 10	TRIA(5, 85, 200) 
Bananas Adults **Distribution: Beta** Expression: 15+185*BETA(4.16, 5.43) Square Error: 0.240723 **Chi Square Test** Number of intervals = 5 Degrees of freedom = 2 Test Statistic = 274 Corresponding p-value < .005 **Kolmogorov-Smirnov Test** Test Statistic= 0.325 Corresponding p-value < 0.01 **Data Summary** Number of Data Points = 288 Min Data Value = 15.1 Max Data Value = 200 Sample Mean = 95.2 Sample Std Dev = 28.2 **Histogram Summary** Histogram Range = 15 to 200 Number of Intervals = 8	15 + 185 * BETA(4.16, 5.43) 

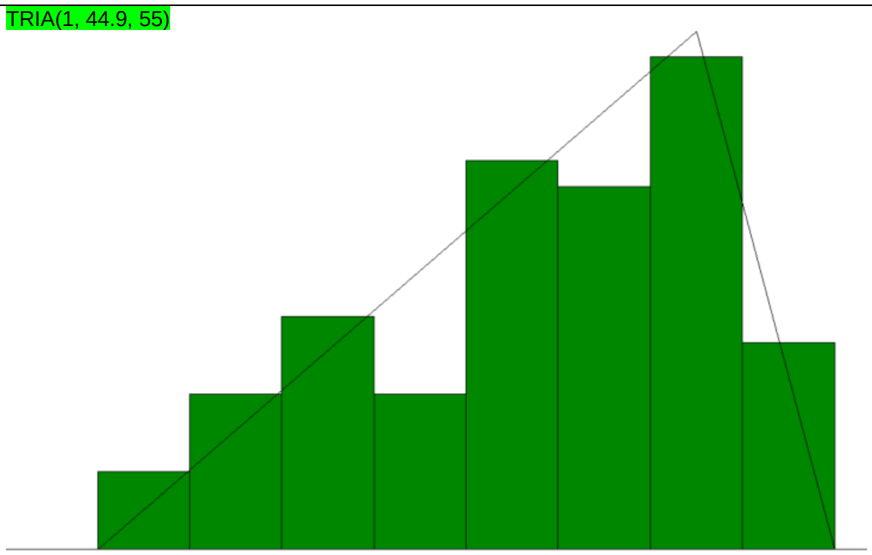
Broccoli Infants
Distribution: Triangular
Expression: TRIA(1, 44.9, 55)
Square Error: 0.006448

Chi Square Test
Number of intervals = 5
Degrees of freedom = 3
Test Statistic = 4.25
Corresponding p-value = 0.24

Kolmogorov-Smirnov Test
Test Statistic = 0.129
Corresponding p-value= 0.132

Data Summary
Number of Data Points = 80
Min Data Value = 1.7
Max Data Value = 54.1
Sample Mean = 32.6
Sample Std Dev = 13.5

Histogram Summary
Histogram Range = 1 to 55
Number of Intervals = 8



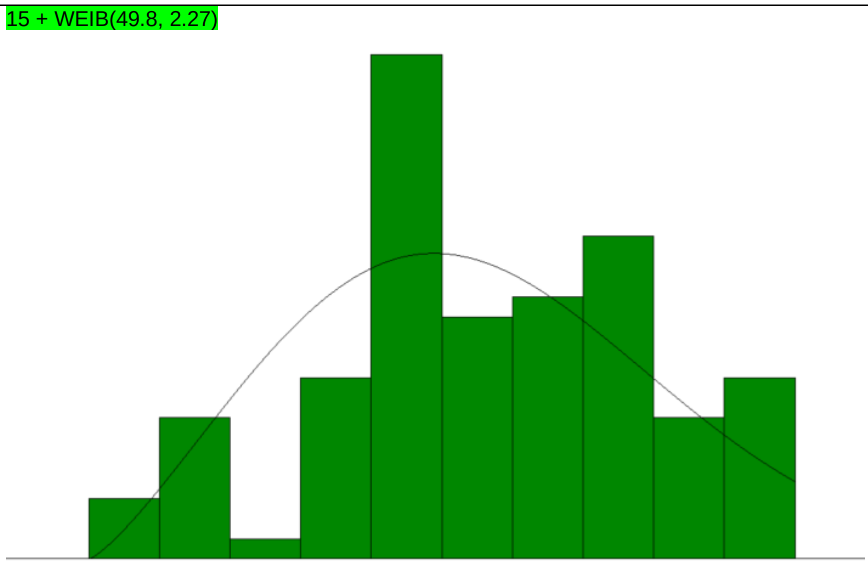
Broccoli Children
Distribution: Weibull
Expression: 15 + WEIB(49.8, 2.27)
Square Error: 0.024983

Chi Square Test
Number of intervals = 7
Degrees of freedom = 4
Test Statistic = 15
Corresponding p-value < .005

Kolmogorov-Smirnov Test
Test Statistic = 0.112
Corresponding p-value = .145

Data Summary
Number of Data Points = 102
Min Data Value = 15
Max Data Value = 93.7
Sample Mean = 60.2
Sample Std Dev = 18.9

Histogram Summary
Histogram Range = 15 to 94
Number of Intervals = 10



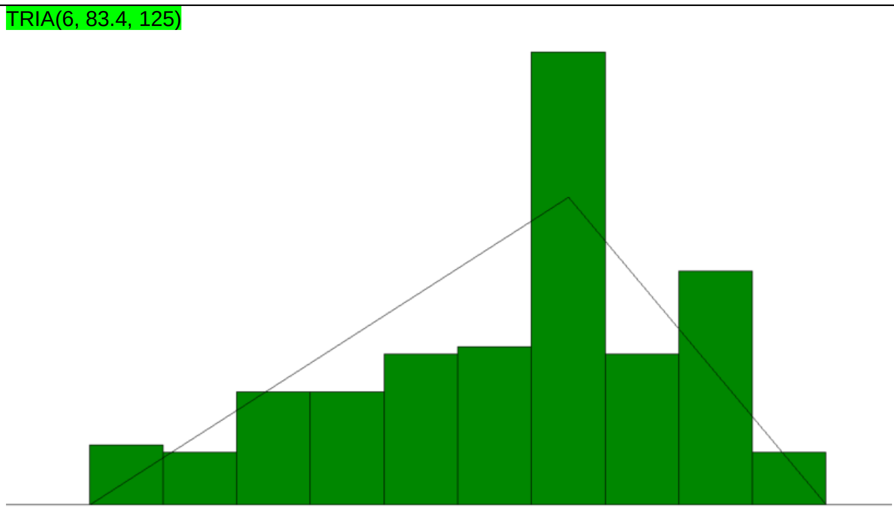
Broccoli Adults
Distribution:Triangular
Expression:TRIA(6, 83.4, 125)
Square Error:0.025393

Chi Square Test
Number of intervals = 8
Degrees of freedom = 6
Test Statistic = 44.9
Corresponding p-value < .005

Kolmogorov-Smirnov Test
Test Statistic = 0.241
Corresponding p-value < 0.01

Data Summary
Number of Data Points = 204
Min Data Value = 6.5
Max Data Value = 125
Sample Mean = 76.1
Sample Std Dev = 27.7

Histogram Summary
Histogram Range = 6 to 125
Number of Intervals = 10



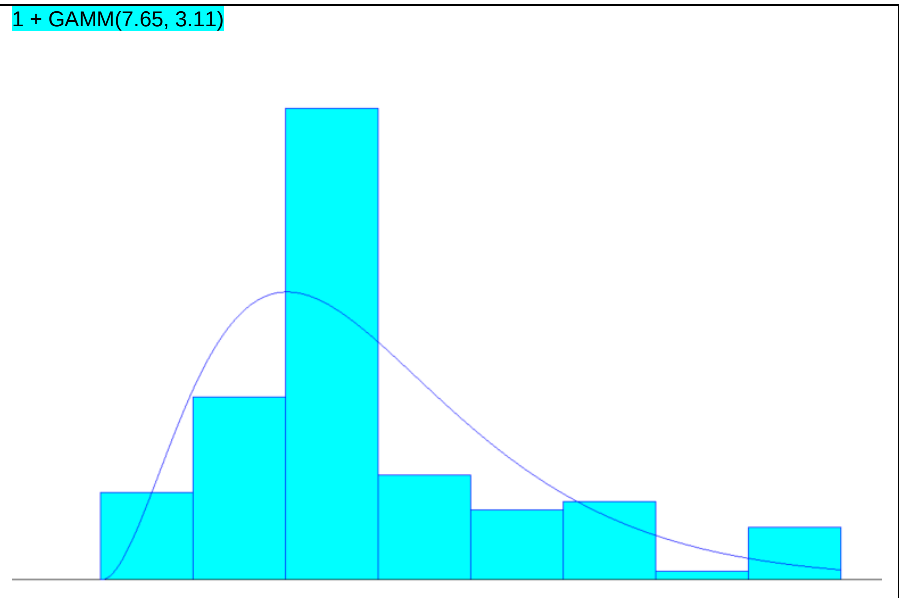
Cucumber Infants
Distribution:Gamma
Expression:1 + GAMM(7.65, 3.11)
Square Error:0.052520

Chi Square Test
Number of intervals = 5
Degrees of freedom = 2
Test Statistic = 26.7
Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
Test Statistic = 0.125
Corresponding p-value = 0.0429

Data Summary
Number of Data Points = 121
Min Data Value = 1.6
Max Data Value = 64.4
Sample Mean = 24.8
Sample Std Dev = 13.4

Histogram Summary
Histogram Range = 1 to 65
Number of Intervals = 8



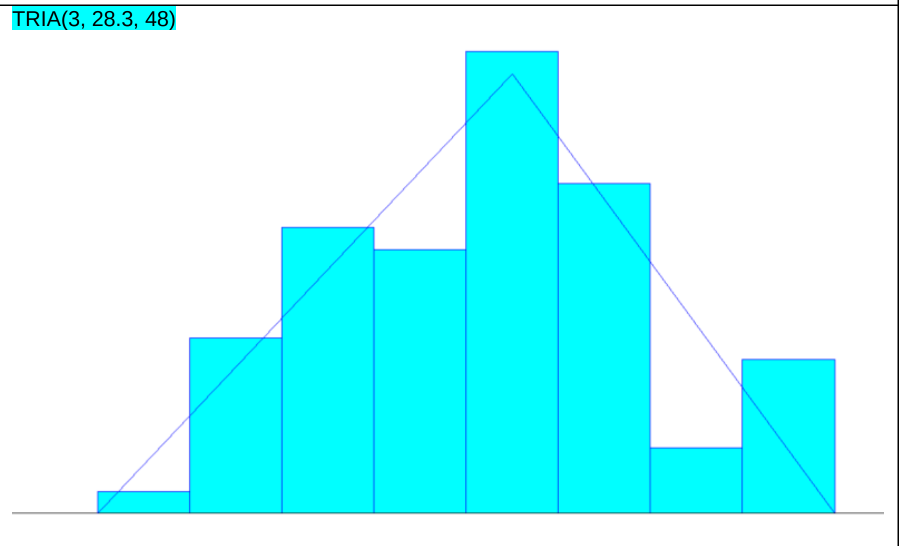
Cucumber Children
Distribution: Triangular
Expression: TRIA(3, 28.3, 48)
Square Error: 0.011461

Chi Square Test
Number of intervals = 6
Degrees of freedom = 4
Test Statistic = 5.25
Corresponding p-value = 0.267

Kolmogorov-Smirnov Test
Test Statistic = 0.134
Corresponding p-value = 0.103

Data Summary
Number of Data Points = 80
Min Data Value = 3
Max Data Value = 48
Sample Mean = 27.5
Sample Std Dev = 10.1

Histogram Summary
Histogram Range = 3 to 48
Number of Intervals = 8



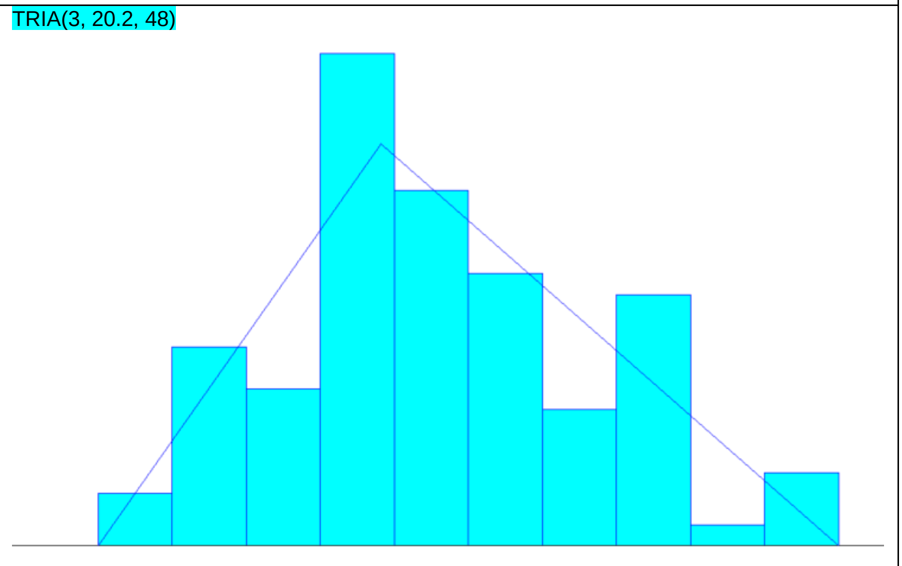
Cucumber Adults
Distribution: Triangular
Expression: TRIA(3, 20.2, 48)
Square Error: 0.013147

Chi Square Test
Number of intervals = 8
Degrees of freedom = 6
Test Statistic = 18.2
Corresponding p-value =0.00591

Kolmogorov-Smirnov Test
Test Statistic = 0.132
Corresponding p-value < 0.01

Data Summary
Number of Data Points = 192
Min Data Value = 3.6
Max Data Value = 48
Sample Mean = 23.7
Sample Std Dev = 9.67

Histogram Summary
Histogram Range = 3 to 48
Number of Intervals = 10



<u>Potatoes Infants</u>
Distribution: Weibull
Expression: 12 + WEIB(73.4, 1.76)
Square Error: 0.019444

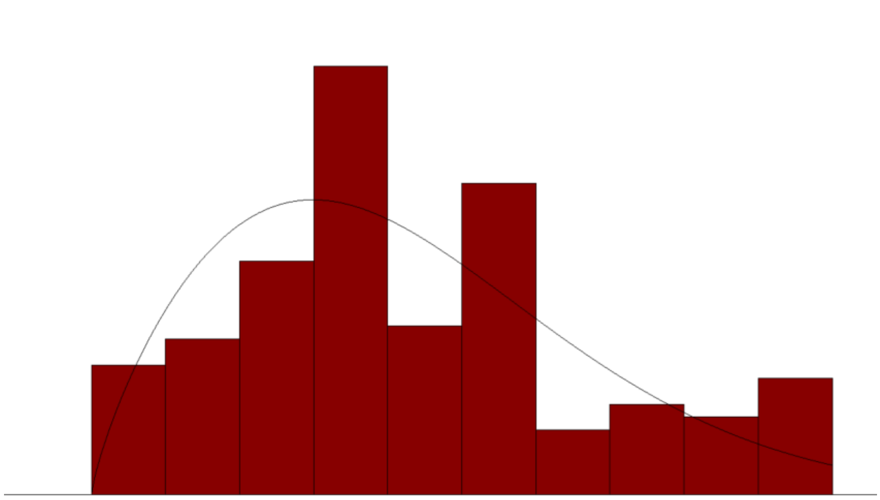
Chi Square Test
Number of intervals = 7
Degrees of freedom = 4
Test Statistic = 19.3
Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
Test Statistic = 0.0804
Corresponding p-value > 0.15

Data Summary
Number of Data Points = 137
Min Data Value = 12.6
Max Data Value = 164
Sample Mean = 77.8
Sample Std Dev = 37.3

Histogram Summary
Histogram Range = 12 to 165
Number of Intervals = 10

12 + WEIB(73.4, 1.76)



<u>Potatoes Children</u>
Distribution Beta
Expression: 6 + 231 * BETA(1.67, 1.43)
Square Error: 0.017082

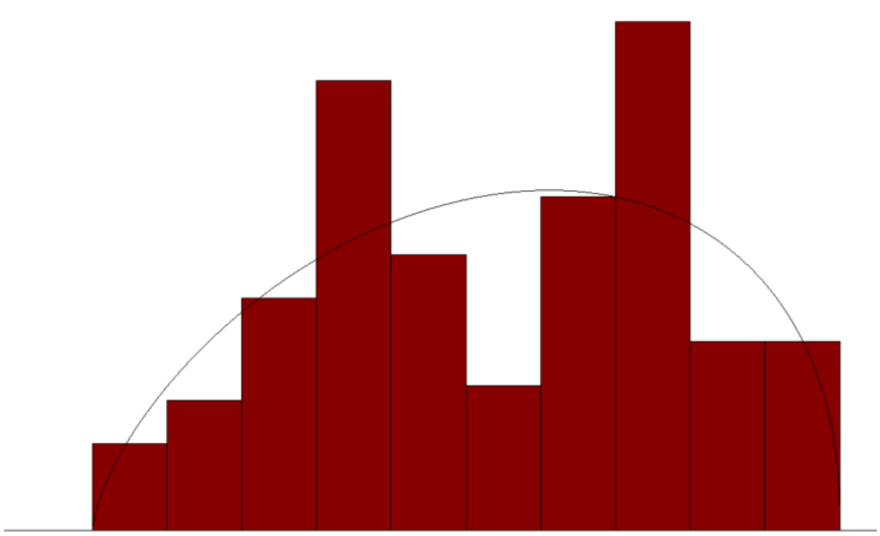
Chi Square Test
Number of intervals = 9
Degrees of freedom = 6
Test Statistic = 24.3
Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
Test Statistic = 0.113
Corresponding p-value = 0.022

Data Summary
Number of Data Points = 175
Min Data Value = 6.8
Max Data Value = 237
Sample Mean = 131
Sample Std Dev = 56.9

Histogram Summary
Histogram Range = 6 to 237
Number of Intervals = 10

6 + 231 * BETA(1.67, 1.43)



<u>Potatoes Adults</u>
Distribution:Triangular
Expression: TRIA(9, 81.6, 320)
Square Error: 0.005863

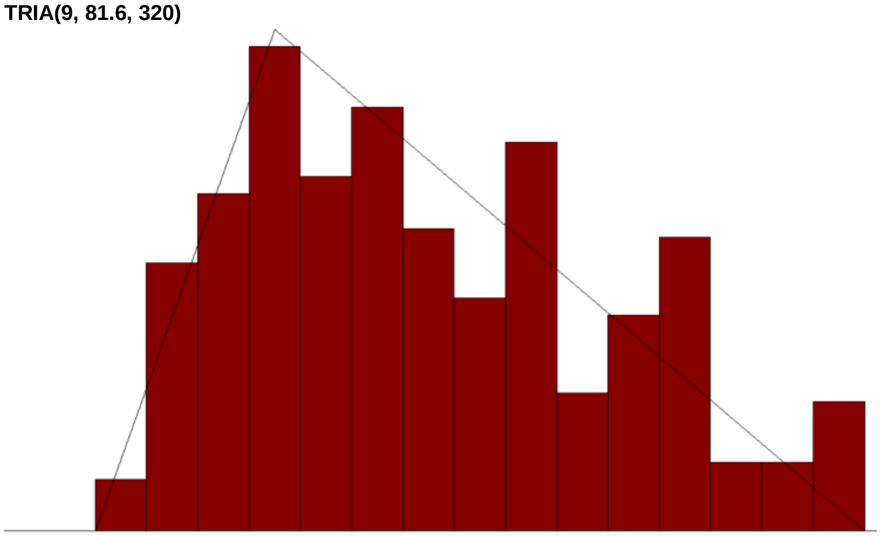
Chi Square Test
Number of intervals = 13
Degrees of freedom = 11
Test Statistic = 51
Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
Test Statistic = 0.0697
Corresponding p-value = 0.0284

Data Summary
Number of Data Points = 435
Min Data Value = 9.6
Max Data Value = 320
Sample Mean = 143
Sample Std Dev = 73.4

Histogram Summary
Histogram Range = 9 to 320
Number of Intervals = 15

TRIA(9, 81.6, 320)



Below are the data relating to the fit of distributions for products where the distribution was used (broccoli, cucumber and potatoes). For apples and bananas, a different approach was used, as summarised in Sections 3.2.1 and 4.2.1.

The “Fit All Summaries” were generated in the Input Analyzer function of Arena. Normal distributions were not used since the Household Simulation Model will not function if the level of consumption is negative. The next best fit was chosen and is highlighted for each dataset. These are highlighted in Table 34 to Table 36.

Table 34: Ranked summary of fitted distributions for consumption levels, with best-fit values (sum of squares): **Broccoli**

	Infants	**Children**	**Adults**
Best fit	Triangular 0.00645	Normal 0.0209	Triangular 0.0254
	Beta 0.0118	Weibull 0.025	Normal 0.03
	Normal 0.0209	Beta 0.025	Beta 0.0307
	Weibull 0.0267	Triangular 0.0295	Weibull 0.0348
	Uniform 0.0325	Erlang 0.0353	Erlang 0.049
	Erlang 0.0398	Gamma 0.039	Gamma 0.0501
	Gamma 0.0404	Uniform 0.0407	Uniform 0.0541
	Lognormal 0.0553	Lognormal 0.0766	Lognormal 0.066
Worst fit	Exponential 0.0914	Exponential 0.0831	Exponential 0.0983

The distributions used for **broccoli** were:

- Infants (0-6 years): Triangular (Minimum = 1 g, Mode = 44.9 g, Maximum = 55 g)
- Children (7-17 years): 15 + Weibull distribution (49.8, 2.27)
- Adults: Triangular (Minimum = 6 g, Mode = 83.4 g, Maximum = 125 g)

Table 35: Ranked summary of fitted distributions for consumption levels, with best-fit values (sum of squared): **Cucumber**

	Infants	**Children**	**Adults**
Best fit	Gamma 0.0525	Triangular 0.0115	Triangular 0.0131
	Erlang 0.0532	Normal 0.0133	Weibull 0.0153
	Lognormal 0.0581	Weibull 0.0149	Erlang 0.0167
	Weibull 0.0597	Beta 0.0195	Gamma 0.017
	Triangular 0.0732	Erlang 0.0238	Normal 0.0176
	Beta 0.0733	Gamma 0.0279	Beta 0.0186
	Normal 0.0745	Uniform 0.0472	Lognormal 0.0244
	Uniform 0.133	Lognormal 0.0826	Uniform 0.0478
Worst fit	Exponential 0.134	Exponential 0.0943	Exponential 0.0763

The distributions used for **cucumbers** were:

- Infants (0-6 years): 1 + Gamma distribution (7.65, 3.11)
- Children (7-17 years): Triangular (Minimum = 3 g, Mode = 28.3 g, Maximum = 48 g)
- Adults: Triangular (Minimum = 3 g, Mode = 20.2 g, Maximum = 48 g)

Table 36: Ranked summary of fitted distributions for consumption levels, with best-fit values (sum of squared): **Potatoes**

	Infants	**Children**	**Adults**
Best fit	Weibull 0.0194	Beta 0.0171	Triangular 0.00586
	Triangular 0.0196	Triangular 0.0216	Gamma 0.00629
	Normal 0.0216	Weibull 0.0242	Weibull 0.0064
	Gamma 0.023	Normal 0.0252	Erlang 0.00675
	Beta 0.0245	Uniform 0.0269	Beta 0.00706
	Erlang 0.0253	Gamma 0.0273	Lognormal 0.00814
	Lognormal 0.0368	Erlang 0.0274	Normal 0.0114
	Uniform 0.0382	Lognormal 0.0367	Uniform 0.0184
Worst fit	Exponential 0.0574	Exponential 0.0666	Exponential 0.0318

The distributions used for input to the HHSM for **potatoes** were:

- Infants (0-6 years): 12 + Weibull distribution (73.4, 1.76)
- Children (7-17 years): 6 + 231 * Beta distribution (1.67, 1.43)
- Adults: Triangular distribution (Minimum = 9 g, Mode = 81.6 g, Maximum = 320 g)

12.0 Appendix 4: Estimates of impact on UK Household Food Waste

12.1 Introduction

This appendix provides calculations to estimate the approximate scale of changes to household food waste if the five items studied in this report were to be sold loose. The calculations are described, alongside the assumptions within them. Given the nature of the assumptions, these calculations merely provide an order of magnitude relating to this issue, rather than precise estimates.

12.2 Method

For each of the five products, the calculations multiply together the amount of 'not used in time' (NUIT) household food waste[156] by the change in this waste associated with three changes, as modelled in this report (Table 22):

- Shelf-life extension of the packaging
- Removal of Best Before date
- Ability to buy what you need

In addition, these estimates are multiplied by factors taking into account:

1. **The approximate scale of the grocery market currently sold pre-packaged**. This is based on information obtained from in-store research conducted by Produce View (Section 2.3.3). It has been assumed the number of loose and pre-packaged lines reflects the proportion of sales. For bananas, the proportion of pre-packed sales has been down-weighted to reflect the importance of the loose lines[157].
2. **The proportion of people depackaging items on returning from shopping.** (63% for bananas[158]). This feeds into the calculations relating to the shelf-life extension of packaging (Table A4.1). This factor is not used for the calculations relating to the removal of BB date (Table A4.3) as it has already been taken into account within the modelling calculations relating to BB date removal (Sections 3.2.3, 4.2.3, etc.)
3. **Whether people who buy packaged items are more or less likely to dispose of food due to the Best Before date.** This is an assumption such that, if there were an interaction, this estimate if conservative. This is included in the 'adjustment for interaction' term.

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[156] *Household food waste: restated data for 2007-2015, WRAP 2018,* *https://wrap.org.uk/sites/default/files/2021-03/WRAP-Household-food-waste-restated-data-2007-2015_0.pdf*

[157] *The grocery retail industry indicated that most banana sales are loose, suggesting that although most lines are packaged, these are outsold by their loose counterparts. For this reason, an approximate estimate of 25% has been used for packaged sales.*

[158] *Consumer Attitudes to Food Waste and Food Packaging*, WRAP (2013): https://wrap.org.uk/sites/default/files/2020-12/Consumer-attitudes-to-food-waste-and-packaging.pdf

4. **Whether those needing smaller amounts already buy loose items.** This factor helps to ensure the results do not overstate the amount of household food waste that could be prevented from selling loose. This is included in the 'adjustment for interaction' term.
5. **That some NUIT waste will be unaffected by changes to BB date and amount purchased:** specifically, that some items purchased will contain internal defects that will be disposed of irrespective of whether they are purchased pre-packaged or loose. This is included in the 'adjustment for interaction' term.

In addition to calculating the potential reduction in household food waste, expressed by weight, calculations were also performed to calculate the change in greenhouse gas (GHG) emissions and amount spent on food associated with this reduction in food waste for the UK as a whole. The factors used for converting weight to GHG emissions and monetary value of the food waste are given the table below:

Food type	GHG emissions (tonnes CO_2 eq. / tonnes food waste)	£ / kg
Apple	0.95	£2.00
Banana	1.26	£1.01
Broccoli	1.18	£1.42
Cucumber	1.05	£1.31
Fresh potato	0.88	£0.83

GHG factors come from Appendix 2, covering food production, transport, processing, retail and waste disposal (but excluding packaging). Cost factors are derived from Defra's Family Food Datasets for 2018/19 data (the most recent available), by dividing the weight of purchases by the expenditure. For broccoli, for which no disaggregated data exists in the Family Food dataset, an average of costs from supermarket websites was taken.

12.3 Results: Weight

All results in this section are approximate, to obtain the order of magnitude of the impact of the associated changes.

Selling items loose would decrease the shelf life of bananas and broccoli, thus increasing the NUIT food waste associated with them (Table A4.1). The estimate for impact in the UK is around 3,000 tonnes each year.

Table: A4.1: Estimate of change in annual 'not used in time' household food waste when selling loose for **change in shelf life**

Food type	Amount of NUIT waste (tonnes)	% change in NUIT	% market currently packaged	Adjustment for depackaging	Estimate of change in shelf life (tonnes)
Apple	40,000	0.0%	n/a	n/a	-
Banana	44,000	19.4%	25%	37%	791
Broccoli	14,000	19.2%	76%	100%	2,043
Cucumber	26,000	0.0%	n/a	n/a	-
Fresh potato	180,000	0.0%	n/a	n/a	-
Total	**290,000**				**2,834**

Selling items loose would allow people to buy the right amount for their needs more easily. This would affect the food waste of apples, bananas and potatoes. The total reduction in food waste is estimated at approximately 64,000 tonnes each year in the UK (Table A4.2).

Table: A4.2: Estimate of change in annual 'not used in time' household food waste when selling loose for **buying the rights amount**

Food type	Amount of NUIT waste (tonnes)	% change in NUIT	% market currently packaged	Adjustment for interaction	Estimate of change in shelf life (tonnes)
Apple	40,000	-86%	80%	25%	-6,901
Banana	44,000	-58%	25%	50%	-3,177
Broccoli	14,000	0%	n/a	n/a	-
Cucumber	26,000	0%	97%	50%	-
Fresh potato	180,000	-64%	94%	50%	-54,160
Total	**290,000**				**-64,239**

Taking the data in Tables A4.1 and A4.2 together, the net change in selling loose is approximately a reduction in household food waste of 61,000 tonnes each year. Given the assumptions within the calculations, this estimate of the impact of selling loose would best be expressed as "around 60,000 tonnes" (i.e., to one significant figure). This does not include the impact of removing BB dates from products, which is provided in Table A4.3.

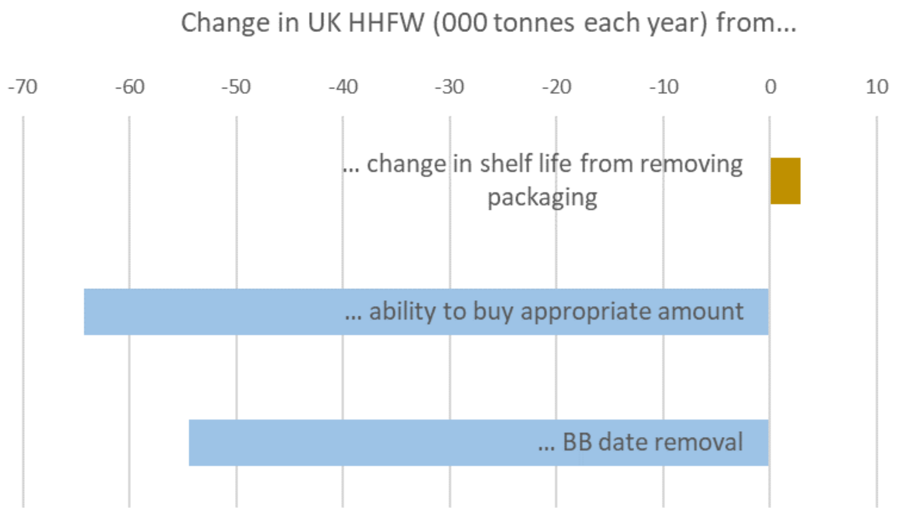
Removing the date label is estimated to reduce NUIT food waste for four of the products studies, with an annual impact in the UK of 54,000 tonnes (Table A4.3). Given the assumptions within the calculations, this would best be expressed to one significant figure: around 50,000 tonnes.

Table: A4.3: Estimate of change in annual 'not used in time' household food waste when selling loose for **removal of BB date**

Food type	Amount of NUIT waste (tonnes)	% change in NUIT	% market currently packaged	Adjustment for interaction	Estimate of change in shelf life (tonnes)
Apple	40,000	-25%	80%	50%	-3,942
Banana	44,000	0%	n/a	n/a	-
Broccoli	14,000	-70%	76%	75%	-5,620
Cucumber	26,000	-17%	97%	75%	-3,255
Fresh potato	180,000	-33%	94%	75%	-41,575
Total	**290,000**				**-54,392**

Figure A4.1 illustrates the relative magnitude of the impacts on HHFW relating to the three elements modelled, as described above. It can be seen that changes to the shelf life have a much smaller impact on HHFW than either giving people the ability to buy an appropriate amount or removing the BB date.

Figure A4.1: Estimates of changes in UK household food waste for the three elements modelled



If items were to be sold loose and BB dates were removed, the total impact would likely be slightly less than the sum of the two separate impacts due to interactions between the two. Therefore, the likely impact of both together would be approximately 100,000 tonnes (to one significant figure).

12.4 Results: GHG emissions

Overall, the potential changes to GHG emissions (in tonnes of CO_2 eq.) from these changes is similar in magnitude to the change in food waste (in tonnes), Table A4.4. This results from the average intensity factor of GHG emissions, weighted by the amount of waste for each of the five products, being just under 1 kg CO_2. Eq. per tonne of good waste.

Therefore, the change to GHG emissions is around 50,000 tonnes CO_2 eq. each year for selling loose (sum of first two columns in Table A4.4) and the removal of the BB date (third column).

Table: A4.4: Estimate of change in annual **GHG emissions** relating to removal of packaging and BB date removal (tonnes, CO_2 eq.)

Food type	Change in shelf life from packaging removal	Change from ability to buy the right amount	Change from BB date removal
Apple	-	-6,556	-3,745
Banana	997	-4,003	-
Broccoli	2,410	-	-6,631
Cucumber	-	-	-3,417
Fresh potato	-	-47,661	-36,586
Total	**3,407**	**-58,221**	**-50,380**

If items were sold loose and the BB dates were removed, the total impact would likely be slightly less than the sum of the two separate impacts due to interactions between the two. Therefore, the likely impact of both together would be approximately 100,000 tonnes CO_2 eq.

12.5 Results: Cost savings

The average of the cost per kg (weighted for the amount of waste produced) is close to £1 / kg. Therefore, the potential annual cost savings across all UK citizens is around £60 million for selling loose (sum of first two columns in Table A4.5) and £50 million the removal of the BB date (third column).

Table: A4.5: Estimate of change in annual **cost saving for citizens** relating to removal of packaging and BB date removal (£ million)

Food type	Change in shelf life from packaging removal	Change from ability to buy the right amount	Change from BB date removal
Apple	-	-£14	-£7.9
Banana	£0.8	-£3.2	-
Broccoli	£2.9	-	-£8.0
Cucumber	-	-	-£4
Fresh potato	-	-£45	-£34
Total	**£3.7**	**-£62**	**-£54**

If items were sold loose and the BB dates were removed, the total impact would likely be slightly less than the sum of the two separate impacts due to interactions between the two. Therefore, the likely impact of both together would be approximately £100 million each year.

https://wrap.org.uk/resources/report/helping-people-reduce-fresh-produce-waste