Minimising Plastic Packaging and Household Food Waste: A New Approach using Discrete Event Simulation

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Abstract

Reducing both food waste and food plastic packaging waste in the household has major environmental and economic benefits. However, due to the high cost and resources required, limited empirical research has been conducted on this topic. This paper provides a new modelling strategy for incorporating complicated household behaviours to answer trade-offs between food waste and food plastic packaging waste. This research proposes a novel modelling technique accounting for complex household behaviours integrating the link between resilience and the circular economy. It investigates how the circular economy boosts social-ecological resilience, delves into possible trade-offs, and underlines the variation in the household behaviour required for both circular and resilient economy. The paper makes suggestions based on these results to assist firms, governments, and educators in developing and implementing circular economy policies that improve resilience.

Keywords: Circularity in Plastic Food Packaging, Household Food Waste Digital Simulation, Resilient Plastic Supply Network

Introduction

Plastic packaging waste is a major issue that has recently entered public consciousness. Around 41% of plastic packaging is used for food (Schweitzer et al., 2018). Currently, consumers expect retailers to cut plastic packaging in order to reduce plastic waste. However, this has the potential to increase food waste (and foodborne illness risk) due to decreased shelf life (Recoup, 2018). In the UK, approximately 10 million tonnes of food are wasted every year, with the average family (i.e. a household containing children) spending £700 a year on food that is wasted. 31% of avoidable household food waste (1.3 million tonnes), is caused by a mismatch of packaging, pack and portion size, and household food habits (Quested et al., 2013).

Both waste from plastic packaging and food waste can be reduced through product redesign and other household behaviour interventions. However, it is time consuming and costly to empirically test every intervention to determine and quantify the best solutions that reduce plastic pollution and food waste.

This study aims to contribute towards a new circular-to-resilient supply network paradigm shift (see Rajesh 2018, Bagm Gupta and Foropon 2018). This will be achieved by further developing the digital decision support tool called the Household Simulation Model (HHSM) through qualitative studies, empirical data and life cycle analyses (LCA). The effects of using such digital technologies on developing circular and resilient supply chains can be found in Koh et al., (2020). The HHSM was previously piloted by the University of Sheffield and WRAP (Waste and Resources Action Programme) to estimate and reduce food waste in UK households. It is a digital representation of household dynamics and is adaptable to various household types, so that it can model the impacts of food product innovation quickly and enable manufacturers to select the best innovations and interventions, and to prioritise their development and deployment (Kandemir et al., 2020).

WRAP is a circular economy charity, it works with businesses, individuals and communities to reduce waste, develop sustainable products and use resources in an efficient way. WRAP has used the previous version of the HHSM to provide an evidence base for changes to on-pack information (for use by and best before dates please see (Food date labelling | WRAP, 2022) to reduce food waste as part of action under the The Courtauld Commitment 2030: a voluntary agreement focused on reducing food waste, cutting carbon and protecting critical water resources (The Courtauld Commitment 2030 | WRAP, 2022). However, the UK Plastics Pact, which is another voluntary agreement led by WRAP (The UK Plastics Pact | WRAP, 2022), has not yet used the HHSM as an evidence base due to the lack of packaging information related to the simulation.

In this paper, updates to the HHSM are detailed, and it is used to generate evidence concerning reducing both food wasted and food plastic packaging waste, taking into account trade-offs with cost and environmental impacts. Although the HHSM has the flexibility to model several food items/packaging types, this paper focuses on exploring the impact of different packaging options for chicken breast pieces as currently sold and consumed in the UK.

Methodology

This study presents a new application of Discrete Event Simulation (DES) to model complex household behaviour integrating the link between resilient and circular economy. The key feature of the modelling tool (HHSM) is that it can incorporate empirical data (from qualitative anthropological and social science research and from quantitative product and consumer research) on how food is purchased, stored, used in the home, and wasted. The qualitative insight was provided by a study of 28 households which investigated packaging interactions and practices related to food waste and involved a combination of qualitative semi-structured interviews and diary research informed by Practice Theory (Schanes et al, 2018). This was used alongside data on plastic packaging options and composition (such as recycled, compostable, antimicrobial packaging), further insights around packaging (single and reuse options) and food, with specific fresh produce data (such as shelf life), and plastic packaging in the supply chain also included from a wide variety of sources. This allows the impacts of plastic packaging to be incorporated into the previously developed version of the model. Hence, this new version includes the dynamics of actions related to food items in household purchasing patterns, storage and unpacking behaviours, consumption and disposal of plastic packaging incorporating the economic and environmental cost of waste. Waste reduction interventions analysed with the model includes both product innovation and behaviour change, such as offering consumers different pack sizes, recycled content, at home recycling method, or various packaging size/type/shape/reusability/durability.

Description of the expanded model

The extended household simulation model (HHSM) presented in this paper was built and run using ARENA Simulation Software version 16.1. The model consists of four main modules. These modules are market, purchase, storage and consumption. Figure 1 shows the screenshot of the model built in Arena Simulation Software. Each module can be customised for household size and the likely behaviour of various household archetype decisions with regards to activities relevant to food and packaging such as shopping, storing, unpacking, consuming and disposing. These archetypes are explained in detail in Kandemir et al (2020) and were produced by WRAP for consumer segmentation with regards to waste habits, attitudes, and practice. The behaviours of these various household archetypes' related to packaging interactions and food waste practices are further explored with a combination of qualitative semi-structured interviews and diary research during this study.

The extended HHSM simulates one household archetype for a single product type at a time. However, note that the input parameters for purchasing, storage and consumption for the single product represents a household that purchases, stores and consumes many products. For instance, it is not allowed to stack the entire fridge or freezer with a single product type, with a realistic limit set on the amount of fridge or freezer space that can be taken up by a product. Brief descriptions of the main dynamics of the modules are as follows:

Market Module

This module represents a typical grocery/top-up store shelf that consists of a single product type of various pack sizes. The type of the plastic packaging considered in this model is the original product packaging.

This shelf is replenished regularly. The replenishment rate, and the shelf life can be changed based on the scenario being considered. New products with longer remaining shelf lives are put at the back end of the shelf. Older products are kept at the front as in a typical grocery store. Expired products are discarded immediately. As a result, the products on the shelf can have various remaining shelf lives. Shelf life, open shelf life, shelf life based on where the item is stored (ambient temperatures, fridge, freezer), thawed shelf life and cooked shelf life are assigned to the packs in this module based on the input data that is set by the user. The cost and price of each package can be altered by the user. This option is especially important for exploring the effect of pricing on the purchase amounts, food and plastic waste accordingly.

Purchase Module

The shopping patterns depend on the behaviours of household archetypes. To better articulate these patterns, three different shopping forms are defined. A *main shopping* trip represents the approximately weekly shopping trip in which households purchase most of their weekly needs. In this form of shopping, there is always a 10% chance that the household forgets to purchase the product. Some households may prefer to check their storage and make a shopping list before the main shopping trip. The likelihood of making a shopping list depends on the behaviour of the household archetype in consideration. *Top-up shopping* trips represent the visits where the household purchases the products that they run out or about to run out. Lastly, *top-up shopping for special occasions* represents the visits where the household purchases a large amount of the product for a special occasion such as a family get together or an event at home.

Storage Module

Food items can be stored either in ambient temperatures (such as on a counter or in a cupboard), or in the fridge or freezer. After the shopping, the products can be put in the fridge, freezer or left in ambient temperatures either in their original packaging or transferred to other containers such as plastic or glass food storage containers (tubs) with snap close lids. The model has the feature of simulating the portioning of the packages using extra food storage containers before storing. This feature is especially important as it enables representation of households that portion and freeze fresh chicken/meat products to avoid defrosting the entire quantity of product at once. Another dynamic in this module is that previously opened packages can change storage location. For example, an opened pack from the fridge can be left on the counter or can be put in the freezer. Note that once a pack is opened for consumption or portioning, the minimum shelf life or open shelf life is applied to the product unless it is frozen. Once the products are frozen, the frozen shelf life is considered.

For the products that can be cooked, the leftovers can also be stored at ambient temperature, in the fridge or freezer. In that case, the cooked shelf life is applied. The cooked shelf life and the household's preference on consuming leftovers can be defined by the user based on the household behaviour.

Consumption Module

The frequency and the amount of desired consumption per person in the household is considered in this module and can be defined by the user. Once a person in the household decides to consume the product, he/she first checks the ambient temperature storage, second the fridge and lastly the freezer to consume the product. Previously opened packages are always consumed first. If the person can find the sufficient amount at home, he/she consumes it. Otherwise, it is recorded as an unfulfilled requirement. Further, the household may decide to visit a top-up shop in order to purchase this product the next day.

At the end of each day, all the storages are checked for the items that are expired for disposal. Note that some households may prefer to keep the expired items longer than necessary either because they forget about them, or they think it is still safe to consume (WRAP, 2011). They may place the plastic packages in the recycling bin or household waste bin if the product hasn't been portioned and placed in reusable containers. These actions may change from one household to another. The variables on these options can be set by the user. Re-used containers are washed after the disposal of the expired product to be reused. The food's original package size (i.e., small, large) and the various remaining shelf lives are set at the beginning of the model run.

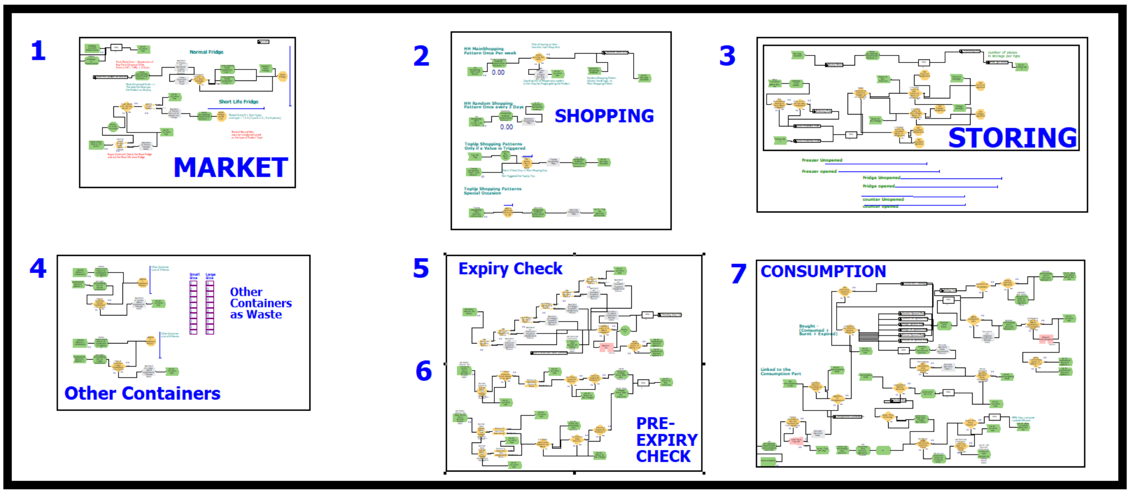

Figure 1. HHSM Arena Model

The primary simulation model logic is depicted in Figure 1. Entities representing packs of various sizes flow through the household modules. As stated in the description of the modules, the model requires a large range of user input parameters. These main input variables include but are not limited to the following:

- Household size includes the number of adults, children, and teenagers.
- Consumption rate and amount for each person in the household
- Plastic packaging types and package size variations in the market
- Shopping patterns and forms, purchase amounts including the variability of preferred pack sizes, probability of shopping list making and adjusting the amount being purchased accordingly, trigger levels for top-up shops, the likelihood of visiting the top-up shop on the day that the top-up shop visit is triggered.
- Shelf life, open shelf life, shelf life based on where the item is stored (ambient temperatures, fridge, freezer), thawed shelf life and cooked shelf life

Output parameters of primary interest are as follows:

- Total number of shopping trips
- Total amount purchased
- Total consumption and unfulfilled needs due to shortage of products in the household storage

- Total food waste
- Total plastic packaging waste

The model is built to simulate various food products such as chicken, milk, grapes, cheese, yoghurt, bread, potatoes, among other foods. As more input data becomes available, the existing model can be easily adapted to mimic additional items.

Preliminary findings on food and plastic packaging waste for chicken pieces

Insights from the interviews and diary research revealed various behaviour patterns on different household demographics about their interactions with food packaging and waste disposal actions.

This section provides a sample of findings from the advanced HHSM that focuses on single adult households on its chicken pieces waste and plastic packaging waste levels. In this case, two pack size options are available at the market. The single adult household can purchase small plastic packs of two chicken pieces and large plastic packs of six chicken pieces. The shelf at the market is replenished every 3 days with chicken pieces packs of 10 days shelf life. The opened shelf life of chicken pieces is set to 3 days.

In order to see a range of both food and plastic packaging waste, best and worst-case scenarios on the shelf life are considered. In the best-case scenario, households always buy the longest remaining shelf-life product from the market. In the worst-case scenario, households always buy the shortest remaining shelf-life products.

In general, as the households face a dilemma between opting for small size packs to reduce food waste that could happen due to open shelf life which leads to more plastic waste and large size packs to reduce plastic packaging waste which leads to more food waste, four scenarios are analysed. These are:

- Scenario 1: Purchasing small size packs with the shortest remaining shelf life
- Scenario 2: Purchasing small size packs with the longest remaining shelf life
- Scenario 3: Purchasing large size packs with the shortest remaining shelf life
- Scenario 4: Purchasing large size packs with the longest remaining shelf life

These 4 scenarios are run for two different single adult households. One of them prefers to purchase plastic packs of two chicken pieces whenever it is available at the market shelf and the other household prefers to purchase plastic packs of six chicken pieces whenever it is available at the market shelf.

The HHSM considers 4 modules from market, purchase, storage to consumption, in addition to end-of-life recycling. This is to highlight that recycling alone is not enough to integrate circular-to-resilient supply networks into the HHSM. For the optimal use of packaging and reduction of food waste there must be interventions in the purchase process such as package size and expiry dates; these types of interventions are represented in the four listed scenarios.

Results: Pack size variations among considered household

The HHSM presented in this work has a lengthy run time, [a minimum of 150 days], with a sufficient warm-up period to attain a steady-state behaviour of the performance measure. All point estimations are based on 30-replications averages. The initial findings presented in this section are strictly only applicable to households that act as those described. As a result, the quantitative results in this section should be seen as indicative rather than exact.

Figure 2 reveals that for single adult households purchasing large packs lead to significantly higher food waste rates. As expected, purchasing large packs that have a longer remaining shelf life leads to less food waste compared to purchasing shorter remaining shelf-life packs. When we compare the waste levels between purchasing large packs and small packs, purchasing small packs with longer shelf life is beneficial in terms of the food waste. However, when we compare the plastic packaging waste in these scenarios as seen in Figure 3, purchasing small packs and large packs with longer shelf life leads to very similar plastic packaging waste levels.

Note that purchasing only large packs of chicken pieces for a single household leads to less unfulfilled requirements as seen in Figure 5 as the household tends to have chicken pieces available most of the time at their house due to gathering larger quantities of pieces every time they go to the main shop or top up shop as seen in Figure 3. As expected, the large packs with the longer shelf life minimises the unfulfilled requirements.

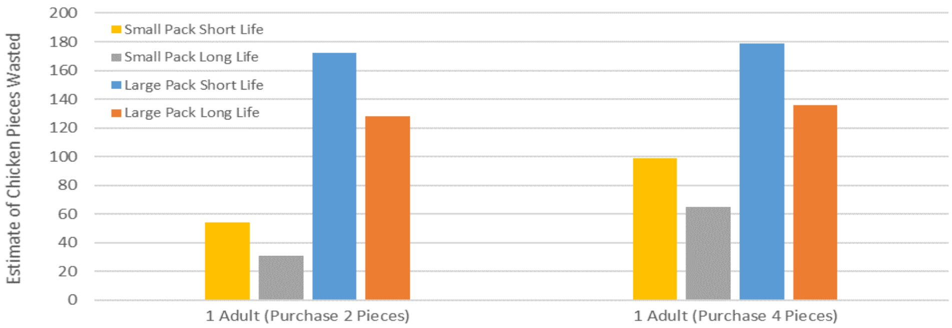

Figure 2 – Estimations on chicken pieces waste, comparing the 4 scenarios; purchase of either 2 or 4 pieces per shopping trip.

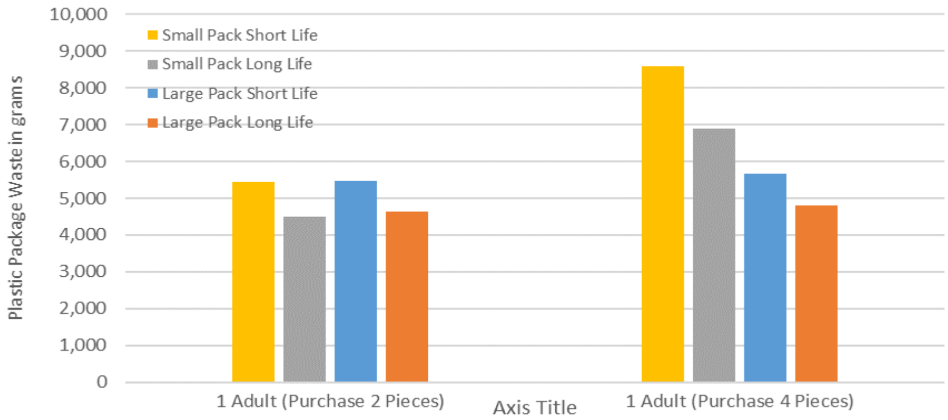

Figure 3 – Estimations on plastic packaging waste, comparing the 4 scenarios; purchase of either 2 or 4 pieces per shopping trip.

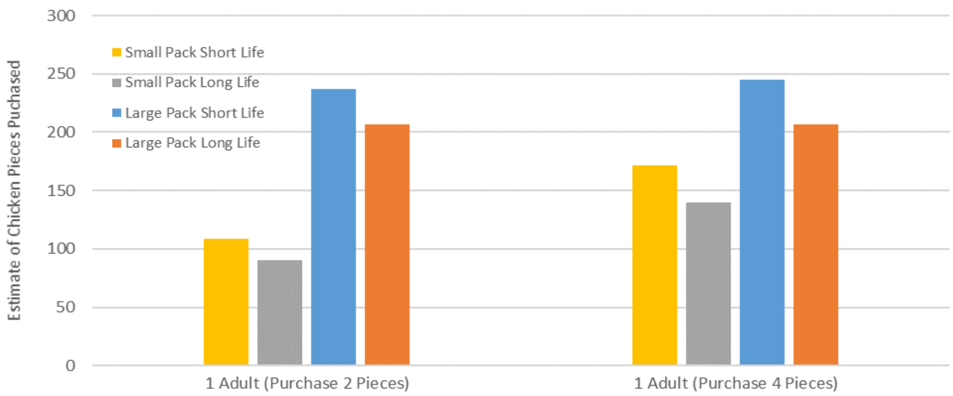

Figure 4 – Estimations on total chicken pieces purchased, comparing the 4 scenarios; purchase of either 2 or 4 pieces per shopping trip.

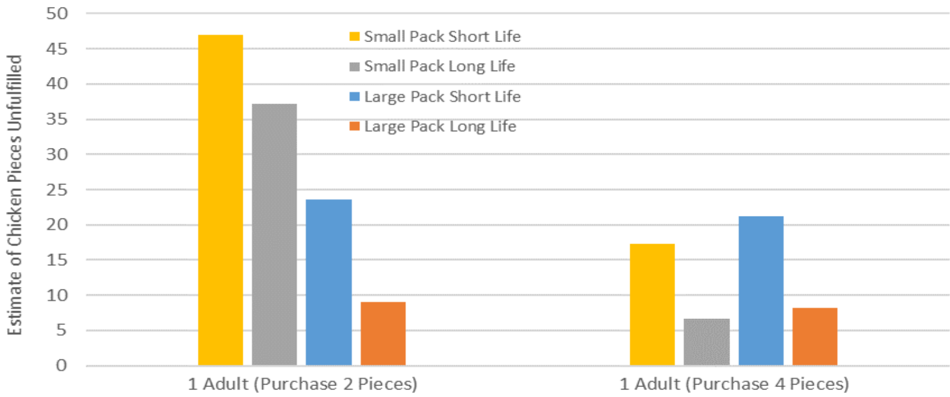

Figure 5 – Estimation of number of pieces of chicken "unfulfilled", comparing the 4 scenarios; purchase of either 2 or 4 pieces per shopping trip.

Table 1. Food and Plastic waste obtained applying the four considered scenarios; purchase of 2 pieces per shopping trip.

Buying 2 Pieces	Purchased (Pieces)	Consumed (Pieces)	Food Waste (Pieces)	Plastic Waste (Grams)
Scenario 1	109	49.25	54	5450
Scenario 2	90	54.6	31	4500
Scenario 3	237	62.4	172	5460
Scenario 4	207	69	128	4648

Table 2. Food and Plastic waste obtained applying the four considered scenarios; purchase of 4 pieces per shopping trip.

Buying 4 Pieces	Purchased (Pieces)	Consumed (Pieces)	Food Waste (Pieces)	Plastic Waste (Grams)
Scenario 1	172	72.8	99	8575
Scenario 2	140	71.8	65	6900
Scenario 3	245	64.3	179	5670
Scenario 4	207	67	136	4795

Tables 1 and 2 show clearly that scenario 2 (purchasing small size packs with longer remaining shelf life) leads to least food waste and plastic packaging waste compared to the other scenarios considered in this paper. However, this option increases the unfulfilled requirement of the household. Note that the unfulfilled requirement leads to more shopping trips as the household tends to do more top-up shopping trips (Figure 5).

Even though it increases the unfulfilled requirement, adopting purchasing small size packs with longer shelf life could achieve the lowest possible level of food and plastic packaging waste for single adult households. During the purchase process, single adult household must pick up small sized packs that have longer shelf-lives should be considered as one intervention strategy towards circular-to-resilient supply networks.

Figure 7 depicts the ratio of the chicken pieces wasted to the purchased amount over the 4 different considered scenarios.

To summarise, (Recoup, 2018) stated that consumers expect retailers to cut plastic packaging waste through applying upstream (market) intervention to reduce plastic waste. Nonetheless, this might drive up the food waste due to decreased shelf life. The household food and plastic waste model reflects the probabilistic nature of the dynamics of food related activities within a household. Consequently, it has proven that considering small packs would result in the lowest level of waste among all modelled scenarios, however this could increase the unfulfilled requirement for the single adult households that are considered in these scenarios.

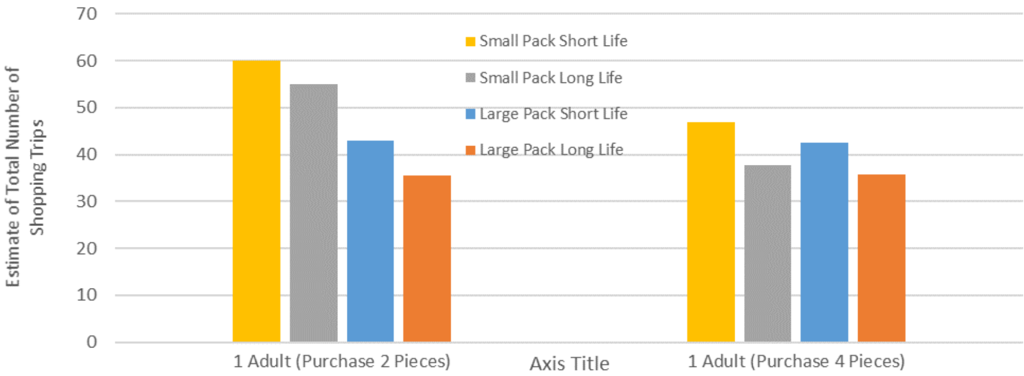

Figure 6 – Estimate of the Number of the Shopping Trips, comparing the 4 scenarios; purchase of either 2 or 4 pieces per shopping trip.

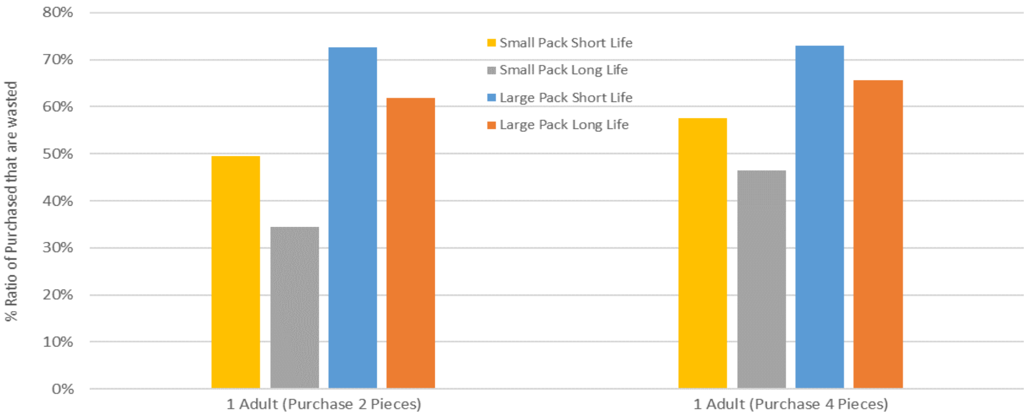

Figure 7 – Estimates of chicken pieces waste, comparing the default scenario; purchase of either 2 or 4 pieces per shopping trip.

Conclusions and Future Work

This study helps in reducing plastic packaging and food waste by providing a decision support tool to trigger action in the food industry and by consumers

It is based on interdisciplinary research and is an innovative application of DES which is able to rapidly test many food and plastic packaging waste reduction interventions and will be able to provide an evidence base with which policy makers, industry and governments can act upon concerning plastic and food waste reductions and trade-offs with cost, and environmental impacts taken into account. The findings from this new version of the HHSM will contribute to changes in food packaging and design in industry to achieve more sustainable and resilient plastic and food supply networks. This study is the first discrete event simulation combining behavioural insights and the most important factors of sustainability such as economic cost and greenhouse gas generation to explore trade-offs between plastic packaging waste and food waste, to support signatories of the UK's Courtauld Commitment 2030, The UK Plastic Pact communities, and international equivalents.

This study is the first step towards creating an evidence base that shows that changes to household purchases through upstream (market) intervention can reduce food and plastic waste much more than downstream (household) interventions aimed at increasing recycling rates. Our future research trajectory will build this evidence base further, including simulation of different behavioural interventions: portioning and leftover use, stock management, freezing, pre checking expiry dates; as well as technical solutions including portioning, extending shelf and open life (best before and used by dates), and changing packaging types (such as reusable and refillable containers).

Other possible future research includes integrating into the HHSM life cycle assessment data, including bill of materials, type of plastic packaging materials, energy input, cost, transport, manufacturing processes and packaging of goods. Likewise, the impacts of transportation (shopping trips) and reusable containers can also be integrated into the model to provide a more robust understanding of trade-offs.

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