Household food waste simulation model: Investigation of interventions for staple food items waste

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Abstract

Decreasing food and drink waste in the home can have a significant positive environmental and economic impact. However, few empirical studies have been performed on this issue, largely due to the cost and resources involved. This study describes a modelling method that can incorporate complex household dynamics and allow challenging questions regarding household food waste levels to be answered. The results can help governments and businesses to prioritise the actions that will be the most effective and efficient in reducing the amount of food being waste in the home.

Keywords: Discrete Event Simulation, Household Food Waste, Food Waste Intervention

Introduction

Globally, food production accounts for 70% of water use, 90% of land use and 30% of greenhouse gas emissions. By only eliminating food waste, up to a third of these resources could be saved (Global Food Waste Not, Want Not, 2013). In high-income countries, the largest contribution to food waste is generated from households (Parfitt et al., 2010). As a result, decreasing food and drink waste in the home can have a significant positive environmental impact. Various factors can affect the amount of food wasted in households. These factors include but are not limited to how food is sold, how often it is purchased, its shelf life, how it is stored in the home, and activities relating to the preparation, serving and consumption of food (Quested et al. 2013).

Given this, the amount of food waste in the home can be influenced by businesses supplying food to the home (e.g. food retailers and food processors / manufacturers) as well as the decisions and action of people in the home.

Changes that could be made by businesses in the supply chain with the potential to decrease the food waste in households include increasing the shelf life and open shelf life of the food items, selling the items in smaller packages, introducing smart labels etc. (Schanes et al., 2018). The behaviours and practices that householders can adopt to decrease the amount of food being wasted are often grouped into planning, shopping, storing, preparing and consumption (Wunder et al., 2019). Specific actions include planning meals, making a shopping list, avoiding impulse purchases, storing certain fruit and vegetables in the fridge, preparing an appropriate amounts for meals, and storing and using leftovers (van Geffen et al., 2017).

However, the impacts of these changes and actions on household food waste levels are not certain. Ideally, pilot studies would be conducted and empirical data obtained to investigate the effects on household food waste levels. Though, few empirical studies have been performed, largely due to the cost and resources involved (Reynolds et al., 2019 and Stöckli, 2018). This makes it difficult for governments and businesses to prioritise the actions that will be the most effective and efficient in reducing the amount of food being waste in the home.

In order to overcome these challenges, a preliminary discrete event simulation (DES) model has been tested and is currently being developed further using empirical data as input. This household food waste simulation model (HHSM) can incorporate complex household dynamics and allow challenging questions regarding household food waste levels to be answered. It simulates the purchase, storage, consumption and waste of a specific food item (e.g. milk) within a household over time.

In the remainder of this paper, the structure of the HHSM is explained, followed by a sample of findings on how changes in package sizes, shelf life, open shelf life and date labels affects the waste levels for staple dairy items namely milk, hard cheese and yoghurt in UK households. Implications for policy makers and other decision makers relating to household food waste are also discussed.

Methodology

The amount of food items consumed in a household each day is not constant but varies from day to day (Evans, 2012). Moreover, many cases of food waste in households are associated with random events such as buying a product with a shorter shelf life than usual, changes in plans (e.g. a work-related commitment). These random events can lead to ingredients for a meal being bought but not prepared and consumed, and so are, often wasted at a later date (WRAP, 2007). Methods that only include an average level of consumption (e.g. system dynamics) that do not include variation over time would fail to incorporate an important dynamic within the system and, accordingly, the modelling results would be less realistic (Quested, 2013).

For this study, a DES model that embraces the complexity of household dynamics related to the purchasing, storage, consumption and wastage of staple food items has been developed. DES is a system-based approach that can incorporate stochasticity of a real-life system and models a system as a sequence of events over time (Delaney and Vaccari, 1989).

The interdependencies created in the modules (purchasing, storage, demand, consumption) of the model reflects many of the features that are important to household food and drink waste. Different variants of the model can be adjusted for different staple food items, household sizes and other household characteristics. Both quantitative and qualitative research was used to inform the model. In addition, data from national surveys relating to food items such as purchasing levels and available shelf life has been used as input to the model. Verification and validation of the model is achieved through the investigations on milk waste.

Household Simulation Model (HHSM) Set-Up

The model consists of four modules. These modules are shopping, storage, demand and consumption. Each module can be customized for household size and the behaviour of various household archetypes decisions on shopping, storing and consuming numerous staple food items.

Note that HHSM models a single food product and single household in any given simulation. To model the effects of changes (e.g. to products) across a population, a range of household types are required – these have been developed to help model the impact in the United Kingdom (UK), the country of interest for this project. The user also needs to customize the model for specific products.

The model also focuses on food that is wasted because it has not been used in time: thrown away because it has gone past the date on its label, gone mouldy or become rotten. This may be because too much was purchased, pack sizes were too large for a household's needs, date labels were misinterpreted, items were not stored correctly in the home, or the shelf life of the product was relatively short. The model does not include food that is wasted because too much was prepared or served, rejected (e.g. due to a fussy household member), accidentally dropped on the floor, or due to appliance failure. It only focuses on food waste in the home; it does not model food waste in the supply chain.

Next, the description of each HHSM module is given briefly.

Shopping Module: Households can purchase food items from main shops and top-up shops. Main shop visits occur mid-week on either a Tuesday, Wednesday or Thursday, as randomly determined at the beginning of the week as the most households in the UK do a main shop approximately weekly. The amount of food item purchased at a main shop is fixed for every visit since people tend to have set habits when they shop for staple foods. The size and number of packages that will be purchased from the main shop can be set by the user regarding the household archetype and food item. If the household checks the fridge before shopping, the amount bought is adjusted accordingly by the model. For instance, if a household buys 4 pints of milk regularly on a main shop, but if they already have 2 pints in their fridge, they only buy 2 pints at this main shop visit. The probability of checking the fridge before shopping is another variable that can be set by the user for the household archetype under observation. A top-up shop is triggered if the household runs out of or is about to run out of the food item. This trigger level can be defined by the user. If the amount of food item in the home falls below the trigger level, there is a chance that the top-up occurs on that day or on the following day, provided no main shop occurs. The size and number of packages that will be purchased from the top-up shop is also fixed and can be varied by the model user.

Once the packages purchased from the main shop and top-up shop are set, the shelf life and open shelf life of the item is assigned to each package. Available shelf life and open shelf life is set by the user for the product. Available shelf life is the difference between the date the product is purchased and its use-by date. The shelf life of a product is defined as a probabilistic distribution to represent the case in real life. Open shelf life is the advice on the packs that is usually stated as 'once opened use within x days'. Open shelf life can be defined as a deterministic value by following the guidance on the packages. Moreover, these values can be altered for different household archetypes to reflect the degree to which the household adheres to these date labels; previous research has shown that many households are prepared to eat food after the dates on the packaging (WRAP, 2011).

Storage Module: Food items can be stored either in the fridge or freezer. After the shopping, packages are put in fridge or pantry depending on the staple food item. It is not common to purchase the staple food items frozen. However, depending on the household behaviour, staple food items can be frozen after purchase. The user can define the likelihood that the household will freeze the items that are about to expire. In that case, both unopened and previously opened packages can be put in the freezer. Once a package is put in the freezer, the frozen shelf life and thawed shelf life is assigned to that package. Frozen shelf life is the guided storage time of the food item in the freezer. Thawed shelf life is the recommended timeframe that the item needs to be consumed within once it is defrosted.

At the beginning of each day the fridge and freezer are checked for items that are expired and about to expire. The expired items become waste and the total waste is reported. In the case that the household choose to freeze the items that are about to expire, these items are put in the freezer. The likelihood that the household choose to freeze the items can be defined by the user.

Demand Module: Demand for the food item under consideration is created in this module. In this context, demand is how much of the food item in question the household would like to consume. If the household has a sufficient amount of that food item, then the amount consumed will equal the demand. If there is insufficient, then consumption will be less than the demand, and the demand that was not fulfilled is recorded as an output of the model.

There are options to enter the daily consumption distributions for adults and children between ages 0-6 and 7-17. Once daily demand is generated, it is sent to consumption module.

Consumption Module: Once a demand signal is received from the demand module, the amount in the current open package is checked. If the amount in current open package is enough, the demand is satisfied and the amount in current open package is updated. In case that there isn’t enough in current open package, a signal is sent to storage module to open a new package. First, the fridge is checked for available packages. In case there are no packages in the fridge, the freezer is checked for available packages. Once a new package is opened, a signal is sent to consumption module that informs the new package is ready for consumption. The demand will not be satisfied if no packages are available both in fridge and freezer.

Input Parameters: The model requires a large range of input data to function. These include:

- Household size including number of adults and number of children between ages 0-6 and 7-17
- Probability of consuming the item daily for adults and children
- Daily consumption amount (as a probabilistic distribution) for adults and children
- Regularly purchased package size of the item, number of packages purchased at each main shop visit, number of packages purchased at each top-up shop visit

- Probability of shopping list making and adjusting the amount being bought accordingly
- Average shelf life of item (deterministic or random), open shelf life of item
- Trigger level for top-up shop, likelihood of visiting the top-up shop on the day that the top-up shop visit triggered (if not visited on the same, it is visited on the next day)
- If the product can be frozen: Turn on/off freezing, Frozen shelf and thawed shelf life of the item, Likelihood of freezing the item that is about to expire (either open or unopened package), Probability of consuming a frozen item

Output Parameters: The model records various information from each run of the model. Of primary interest are the headline indicators:

- Total amount purchased
- Total amount consumed
- Total requirement/demand
- Total requirement not fulfilled due to no product in fridge or freezer
- Total amount wasted and the details on cause of the waste: Total waste caused by available shelf life, Total waste caused by open shelf life, Total waste caused by frozen shelf life ,Total waste caused by thawed shelf life

Each of these variables are recorded for the whole of the model run (usually set to 10 years).

Application of HHSM on UK population

The challenge is that the HHSM models a single household in any given simulation. However, it is useful to use the model to understand how an intervention affects the food waste generated from a range of households across a given population. Therefore, the changes relating to an intervention need to be modelled for several different household types. The use of household archetypes is being investigated as the most promising route to bridging the gap between individual simulations and creating inference for a whole population. In order to use the HHSM to obtain insight on waste levels for UK population, first, different household archetypes and their weights were defined so that the UK population is reflected by the archetypes. Based on WRAP's consumer segmentation research, 7 household archetypes were created to provide a range of households encompassing different numbers of occupants, and a range of practices relating to food and food waste (WRAP, unpublished). Weighting factors were determined to ensure that the average number of occupants in the households reflects the UK average. Description of these archetypes and their weighting factors can be found in Table 1.

For the baseline models of each product, the simulation model was set up with the inputs determined based on characteristics of these archetypes such as the number of people in the household, shopping patterns, consumption patterns, the attitude to food safety and date labels, and the management of food in the household. These inputs were gathered from the subject matter experts and following sources:

1. WRAP's retailer surveys (WRAP, 2012; WRAP, 2017), which is a survey across UK retailers of a range of factors believed to influence household food waste for a selection of products,
2. The National Diet & Nutrition Surveys (Gov.uk, 2019) which assesses the diet, nutrient intake and nutritional status of the general population of the UK,

3. Customer segmentation survey conducted by WRAP, which includes shopping and consumption patterns, the approach to food safety and date labels, freezing behaviour, and handling of food in the household

Table 1- Household Archetypes in UK population based on consumer segmentation research conducted by WRAP

Household Archetype	**Brief Description**	**Weighting factor**
Aspirational Discoverers (AD), Family	4-person HH, younger children, willing to take more risks, confident, good planning, moderately likely to throw away leftovers, moderate portioners.	7.8%
Functional Fuellers (FF), Single	1-person household, less willing to take risks,, low confidence in the kitchen, poor planning, likely to throw leftovers, moderate portioning.	14.3%
Functional Fuellers, Couple	2-person household, no children, less risk averse, low confidence in the kitchen, poor planning, likely to throw leftovers, moderate portioning.	10.7%
Spontaneous Creatives (SC), Single	1-person household, less risk averse, moderately low confidence in the kitchen, poor planning, leftovers likely to be thrown away, poor portioning.	13.7%
Spontaneous Creatives, Couple with one child	3-person household, one child, more risk averse, moderately low confidence in the kitchen, poor planning, leftovers likely to be thrown away, poor portioning.	16.0%
Ideal Advocates (IA), Couple	2-person household, no children, less risk averse, high confidence in the kitchen, good planning, leftovers will be used, good portioning.	24.3%
Pressured Providers (PP), Family	4-person household with (generally older) children, medium confidence in the kitchen, good planning, leftovers will be used, good portioning.	13.2%

Once the baseline models were set and validated for each product under investigation, the necessary scenarios were defined to understand first the magnitude of the effect of the input parameters and second the possible interventions to decrease food waste. These interventions include, but are not limited to, changes in package sizes, changes in food labelling terms (i.e. use by date vs. best before date), changes in freezing guidance, extensions on shelf life and open shelf life with new technological developments on smart date labels etc.

The next section summarizes a sample of possible findings that can be acquired by employing HHSM for the UK population.

Findings

The results of this tool can be explored to help inform public engagement on the issue of food waste in the home, and discussions with the food industry on changes to products, packaging and labeling that could help reduce food waste at home. This section provides a sample of findings from the HHSM for dairy products' waste levels. The waste level is defined as the percent of purchases wasted due to not being consumed in time (i.e. during open shelf life that is guided on the package, before expiration date). The quantitative results presented in this section are strictly only applicable to households that act as those described. Real households will differ from this simplified behaviour. As a result, the quantitative results in this section should be seen as indicative rather than exact.

Hard Cheese: Hard cheese, such as cheddar and parmesan is one of the dairy products that are subject to substantial variation in how people store it once opened. Development of smart packaging for hard cheese products and giving the right storage guidance is highly valuable. As a result, the waste level caused by open shelf life for hard cheese is of high interest. The HHSM is employed to understand the effect of open shelf life on waste level for hard cheese across the various household types and whole population. For instance, open shelf life guidance for hard cheese in the UK is 7 days. Figure 1 summarizes the changes in the waste level as the open shelf life varies from 7 to 14 days. According to the modelling results, single-occupancy households have the highest waste level per person which is expected and in accordance with previous research. The results suggest that open shelf life impacts strongly on waste. Note that the magnitude of the effect of the open shelf life on waste level decreases as the open shelf life period increases. Innovations that increase the open shelf life of hard cheese by one week can decrease the waste level by approximately up to 15 percentage points, from 17% to 2.3%.

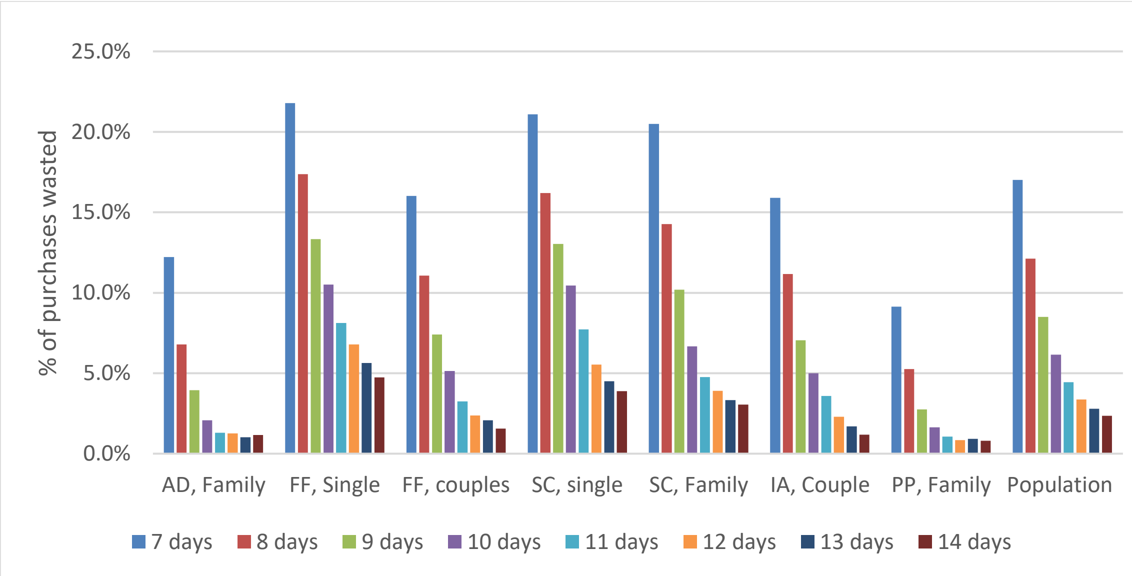

Figure 1 - Waste level outputs of hard cheese across the household archetypes and whole population as the open shelf life varies from 7 to 14 days

Milk: People's use of dates is linked to their understanding of what is meant by those dates and also factors in their perceived needs according to particular products (WRAP, 2008). Currently, milk can be found carrying a "best-before" date in UK. HHSM is used to measure the change of waste level in milk hypothetically if all milk bottles displayed with best-before date label. The experiments took into consideration the understanding of the households what is meant by those dates. Across the population, changing from "use-by" to "best-before" date label, on average, leads to extending the consumption period in the home by one day which is calculated based on the findings of Thompson et al., 2018 and the discussions with subject matter experts. This leads to decreasing the waste level for each household archetypes as seen in Figure 2.

According to the results in Figure 2, switching the date label from "use-by" to "best-before" can decrease the percentage of milk purchases that are wasted from 4.4% to 1.8% for the population– which is about 8 tonnes of milk yearly. Note that this is a hypothetical example and the safety of consuming milk one day beyond the use by date and extending open shelf life by one day needs to be confirmed with competent authorities.

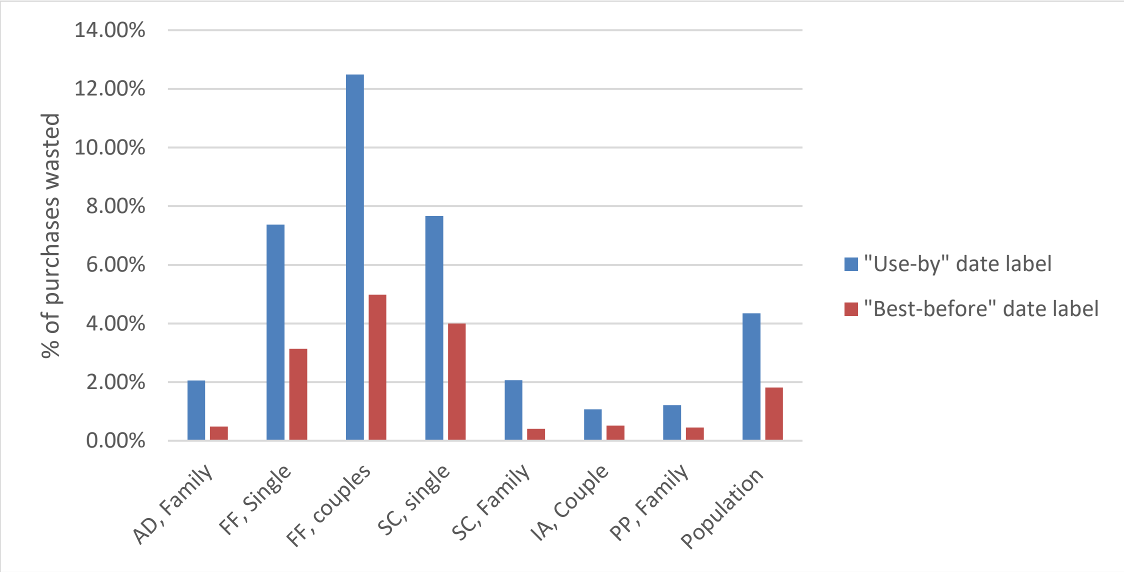

Figure 2 - The change in waste level of milk by switching the date label from "use-by" date to "best-before"

Yoghurt: Yoghurt is considered a staple food for several cultures. In the UK, it is one of the dairy items that is purchased regularly. In general, 6-7% of the yoghurt purchased by UK households is wasted because it is not used in time (i.e. before it is thrown away because it went mouldy / off or it deteriorated in quality) (Quested and Liam, 2014).

The size of packs available to consumers can influence whether or not they are left with surplus food. One of the main interests for yoghurt was to see the effect of purchasing smaller multi-packs versus single big pots on the different household archetypes and the whole population. The waste levels for these two extreme scenarios where household only buy multi-packs or big pots are summarized in Figure 3.

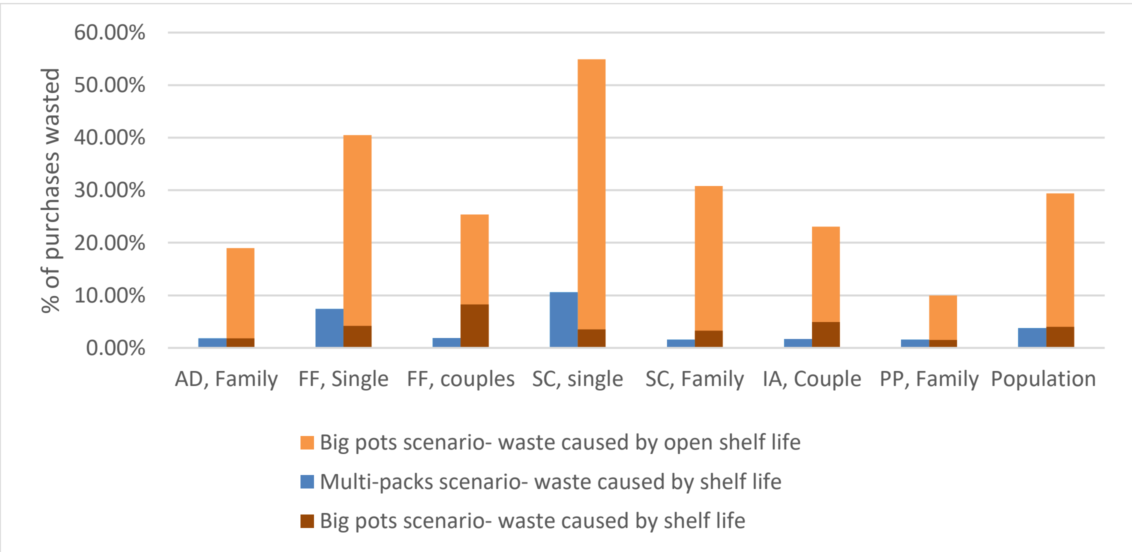

Figure 3 - Waste levels from purchasing "small multi-packs" vs. "single big pots"

As it can be seen, one-person households have the highest waste percentage per person and four-person households have the lowest waste percentage per person for both scenarios. Buying yogurt in smaller multi-packs eliminates the waste caused by open shelf life since the small pots are usually consumed immediately once opened. For single big pots, the main generation of waste is caused because the item is not consumed in time once the pack is opened. Overall, consuming only smaller multi-pack yogurt can decrease waste level by 25%, compared to only consuming single big pots.

To summarize, the household food waste model reflects the probabilistic nature of the dynamics of food related activities within a household. Consequently, it gives results on the effects of waste prevention actions that are sufficiently accurate to base many decisions. The magnitudes of the effects of waste prevention actions can be estimated by setting and employing this tool.

Conclusion

The generation of waste in the home requires an understanding of both the flow of food through the home and social factors (i.e. how people interact with the food). This work suggests that system-based approaches to considering waste prevention in the home can increase understanding of the issues and determine the approximate impact of potential interventions. This research delivers a quality assured method for rapidly testing many food waste reduction interventions and provides an evidence base with which policy makers, industry and governments can act upon. The modelling technique (DES) is not new, but its application to food waste in the home is novel and provides many useful insights. The developed model can incorporate a wide range of products and household dynamics critical to food waste. Moreover, this model can act as a tool for explaining how waste generation can be conceptualised. The results from this ongoing study will provide guidance on the most effective actions to reduce household food waste.

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References

Delaney, W., and Vaccari, E. (1989). “*Dynamic models and discrete event simulation*” Marcel Dekker, Inc., New York

Evans, D. (2012). “Beyond the Throwaway Society: Ordinary Domestic Practice and a Sociological Approach to Household Food Waste”. *Sociology*, Vol. 46, No. 1, pp.41–56.

Geffen, L., Herpen, E. and Trijp, H. (2017). *Quantified consumer insights on food waste. Pan-European research for quantified consumer food waste understanding*. [online] Available at: https://eu-refresh.org/sites/default/files/REFRESH%202017%20Quantified%20consumer%20insights%20on%20food%20waste%20D1.4_0.pdf [Accessed 7 Apr. 2019].

GLOBAL FOOD WASTE NOT, WANT NOT. (2013). [online] London: Institution of Mechanical Engineers. Available at: https://www.imeche.org/docs/default-source/default-document-library/global-food---waste-not-want-not.pdf?sfvrsn=0 [Accessed 1 Apr. 2019].

GOV.UK. (2019). *National Diet and Nutrition Survey*. [online] Available at: https://www.gov.uk/government/collections/national-diet-and-nutrition-survey#archive-of-ndns-reports [Accessed 1 Apr. 2019].

Parfitt, J., Barthel, M., and Macnaughton, S. (2010). “Food waste within food supply chains: quantification and potential for change to 2050”. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences,* Vol 365, No 1554, pp. 3065–3081.

Reynolds, C., Goucher, L., Quested, T., Bromley, S., Gillick, S., Wells, V., Evans, D., Koh, L., Carlsson Kanyama, A., Katzeff, C., Svenfelt, Å. and Jackson, P. (2019). Review: Consumption-stage food waste reduction interventions – What works and how to design better interventions. *Food Policy*, 83, pp.7-27.

Schanes, K., Dobernig, K. and Gözet, B. (2018). Food waste matters - A systematic review of household food waste practices and their policy implications. *Journal of Cleaner Production*, 182, pp.978-991.
Stöckli, S., Niklaus, E. and Dorn, M. (2018). Call for testing interventions to prevent consumer food waste. *Resources, Conservation and Recycling*, 136, pp.445-462.
Thompson, B., Toma, L., Barnes, A. and Revoredo-Giha, C. (2018). The effect of date labels on willingness to consume dairy products: Implications for food waste reduction. Waste Management, 78, pp.124-134.
Quested, T.E., Marsh, E., Stunell, D., Parry, A.D. (2013), "Spaghetti soup: The complex world of food waste behaviours". *Resources, Conservation and Recycling*, Vol 79, pp. 43-51.
Quested, T. (2013). "The Milk Model: Simulating Food Waste in the Home". Retrieved from http://www.wrap.org.uk/sites/files/wrap/Milk%20Model%20report.pdf, date of access: 20/01/2019
Quested, T. and Liam, M. (2014). *Household food and drink waste: A product focus*. [online] Banbury, Oxon. Available at: http://www.wrap.org.uk/content/household-food-drink-waste-%E2%80%93-product-focus [Accessed 7 Apr. 2019].
WRAP. (2007). "We Don't Waste Food! A Householder Survey". Retrieved from http://www.wrap.org.uk/sites/files/wrap/We_don_t_waste_food_-_A_household_survey_mar_07.db6802f9.6397.pdf, date of access: 20/01/2019
WRAP (2008). *Research into consumer behaviour in relation to food dates and portion sizes*. [online] Available at: http://www.wrap.org.uk/sites/files/wrap/Consumer%20behaviour%20food%20dates%2C%20portion%20sizes%20report%20july%202008.pdf [Accessed 1 Apr. 2019].
WRAP (2010). *Helping consumers reduce food waste – a retail survey*. [online] Available at: http://www.wrap.org.uk/sites/files/wrap/A%20Retail%20Survey.pdf [Accessed 1 Mar. 2019].
WRAP (2011). *Consumer insight: date labels and storage guidance*. [online] Available at: http://www.wrap.org.uk/sites/files/wrap/Technical%20report%20dates.pdf [Accessed 7 Apr. 2019].
WRAP (2012). *Helping Consumers Reduce Food Waste – A Retail Survey 2011*. [online] Available at: http://www.wrap.org.uk/sites/files/wrap/240412%20Retailer%20review%202011%20ES.pdf [Accessed 7 Apr. 2019].
WRAP (2017). *Helping Consumers Reduce Food Waste – Retail Survey 2015*. [online] Available at: http://www.wrap.org.uk/sites/files/wrap/Retail_Survey_2015_Summary_Report_0.pdf [Accessed 7 Apr. 2019].
WRAP (unpublished.). *Consumer Segmentation Research*.
Wunder, S., Herpen, E., McFarland, K., Ritter, A., Geffen, L., Stenmarck, Å. and Hulten, J. (2019). *Policies against consumer food waste: Policy options for behaviour change including public campaigns*. [online] Available at: https://eu-refresh.org/sites/default/files/REFRESH_Consumers%20and%20food%20waste_background%20to%20policy%20brief_190304.pdf [Accessed 4 Apr. 2019].