MASTER'S THESIS

Development of the EIFC-tool to explore environmental impacts of household food consumption

In cooperation with WRAP

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Abstract

Food consumption contributes to one-third of total household impacts, therefore this master's thesis assesses the environmental impacts of various food consumption behaviours within UK households and provides recommendations on how to reduce these impacts. This is done through the development of the 'Environmental Impacts of Food Consumption tool' (EIFC-tool) which uses outputs from the Household Simulation Model (HHSM) developed by the Waste and Resources Action Programme (WRAP) and researchers from the University of Sheffield.

The investigated areas of household food consumption are called 'consumption areas' and include: product, packaging, food waste, transportation, storage, and preparation. Five food products are modelled in the EIFC-tool, of which four are investigated further in the study: bacon, bread, chicken breast, and milk.

Life cycle assessment (LCA) is the key method, and the LCA results form background data in the EIFC-tool. LCA is used to find 'impact factors', which are the environmental impacts per one unit, such as 1 kilogram of bacon or 1 kWh of electricity. The EIFC-tool combines the impact factors with HHSM outputs to assess total environmental impacts of household food consumption of a certain product for one year. This is done for two household sizes: a single household and a four person household.

Behaviours changed in the HHSM are purchasing in different package sizes and using the freezer. Changing these behaviours results in different HHSM outputs of amount of product bought, consumed, and wasted. These differences subsequently cause a change in all other consumption areas. Modelling these changes in the EIFC-tool quantifies the differences in environmental impacts given different behaviours.

Further analyses in the EIFC-tool investigate how the environmental impacts of individual consumption areas may change with different behaviour such as preparing in bigger servings, buying a different packaging type, using various methods of transportation, or using different types of waste treatment.

The results show that freezing food reduces environmental impacts of food waste and other consumption areas such as transportation. Buying in smaller packages reduces the environmental impacts of food waste but increases packaging impacts; and buying in larger packages decreases the impacts of both packaging and transportation.

The main recommendation for consumers is to reduce their food waste. This can be done through buying in package sizes appropriate to household demand, and to use the freezer more often. These behavioural changes are more likely to occur through face-to-face interventions and having a change agent within the household.

Dansk resumé

Dette speciale undersøger de miljømæssige påvirkningerne af forskellige madsforbrugsmønstre af forbrugere i britiske husholdninger og giver anbefalinger til hvordan disse påvirkninger kan reduceres. Dette er gjort ved udvikling af 'Environmental Impacts of Food Consumption'-værktøjet (EIFC-tool) (miljømæssige påvirkninger af madforbrug) til vurdering af miljømæssige påvirkninger af seks områder relateret til madforbrug. Værktøjet bruger output fra Household Simulation Model (HHSM, husholdningssimularingsmodellen) udviklet af WRAP og Sheffield Universitet.

De seks områder forbundet til madforbrug kaldes comsumption areas (forbrugsområder) og relatere sig til produktion af det forbrugte produkt (produkt), produktion og affaldshåndtering af emballage (emballage), produktion og affaldshåndtering af madaffald (madaffald), transport til og fra butikken (transport), energiforbrug til opbevaring af produktet i husholdningen (opbevaring), og energiforbrug til forberedelse af produktet (forberedelse). Fem fødevarer er modeleret i EIFC-værktøjet, hvoraf fire fødevarer er undersøgt i specialet; bacon, brød, kyllingbryst og mælk.

Livscyklusvurdering (LCA) er hovedmetoden brugt i værktøjet og er baggrundsdata i EIFC-værktøjet til at vurdere miljøpåvirkningerne af forbruget af disse fødevarer. LCA metoden er brugt til at finde impact factors (påvirkningsfaktorer) beskrevet ved de miljømæssige påvirkninger af en skalérbar enhed brugt i EIFC-værktøjet (f.eks. de miljømæssige påvirkninger af 1 kilogram bacon eller 1 kWh af el). EIFC-værktøjet kombinerer påvirkningsfaktorer med output fra HHSM til at vurdere miljøpåvirkningerne af husholdningers madforbrug af en særlig fødevare over et år. Dette er gjort for to husholdningstyper: en enlig husholdning og en fire-personshusholdning.

HHSM modelerer forskellige forbrugsmønstre for hver undersøgt fødevare, hvor variable er køb af forskellige emballagetyper og fryserbrug. Disse variable resultere i mønsterforandring i andre forbrugsområder. Ydereligere analyser undersøger ved hjælp af EIFC-værktøjet hvordan miljøpåvirkninger af de forskellige forbrugsområder forandrer sig som resultat af forandrede mønstre såsom forberede større portionsanretninger, købe forskellige emballagetyper, brug af andre transportmuligheder og brug af anden affaldshåndtering.

Resultater viser at fryserbrug reducerer påpvirkninger i *madaffald* og andre forbrugsområder såsom *transport*. Køb af mindre emballagestørrelser reducerer *madaffald*, mens påvirkninger i andre forbrugsområder enten reduceres eller øges - herunder øges særligt påvirkninger fra emballage. De fleste anbefalinger fundet igennem resultaterne for forbrugerene er at reducere madaffald, fryse mad, køb i størrelser der tilsvarer husholdningens forbrug og at besøge lokale supermarkeder, helst uden bil. Yderligere anbefaliner til diverse interessenter er at producere emballage med lav miljøpåvirkninger, ingen mængderabat, og gør det mulig for forbruger at kompostere madaffald.

Preface

In cooperation with WRAP and the University of Sheffield

This master's thesis is written by students from Aalborg University studying 'Environmental Management & Sustainability Science', and is done in cooperation with the Waste and Resources Action Program (WRAP) in the UK. WRAP is considered to be one of the leading organisations when it comes to resource efficiency and waste management (WRAP, 2018a) and works within food waste and resource management, among other areas, with a goal to move society towards a more sustainable, resource-efficient economy. They work with government, producers, and communities to find solutions that are practical on all levels of the supply chain (WRAP, 2018b). Currently WRAP, along with the University of Sheffield, is working on the 'Household Simulation Model' (HHSM), which estimates household food waste due to items not consumed in time. The HHSM is used as a starting point for this study.
WRAP uses results from models such as the HHSM as the basis for recommendations to consumers, businesses, and governments. These models are run by WRAP themselves, and once analysed are used to inform their campaign teams on which issues to prioritise. This study expands on the HHSM, adding an environmental perspective by coupling the outputs of the HHSM to environmental impacts to see the impacts of changing behaviours. WRAP's objective is to work with the public and give insights to help others take the necessary steps to help reduce food waste. Since WRAP is based in the United Kingdom, this study will focus primarily on the UK.

Thank you

We would like to thank the people that helped us in the process of this master's thesis. Firstly, a huge thank you to the people at WRAP and the University of Sheffield for providing us with the HHSM and data needed to do this study. Likewise, they have helped shape the direction of the study, so that both parties could benefit the most from the final results. A special thanks to Tom Quested, Christian Reynolds, and Cansu Kandemir for regular meetings, useful feedback, and interesting discussions.
Secondly, a thank you to Teri Anderson, for using her free time to read our grammatical challenges and having a critical eye. Thank you to Sascha Eckstein for reading through and having suggestions to improve the study, with good tips on structure and critical questions.
Lastly, thank you to our supervisors Massimo Pizzol and Michele De Rosa from Aalborg University for supervising us in the writing of this master's thesis. They were always available for help (both spontaneously and planned!), and came with helpful, motivating, and constructive suggestions for improvement. They helped us become critical towards some challenges, and through that, we were able to improve the results of the study in the most effective way.

Abbreviations

AD family	Aspirational Discovers family
EIO	Economic input-output
FF single	Functional Fuellers single
FU	Functional unit
GB	Great Britiain
GHG	Greenhouse gas
HH	Household
HHSM	Household simulation model
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LDPE	Low-density polyethylene
nec	Not elsewhere classified
N/A	Not applicable
WRAP	Waste and Resources Action Programme

Contents

1 The environmental impacts of household food consumption

Household food consumption is associated with significant environmental impacts. A European Environment Agency (2005) report found that one third of households' total environmental impacts can be related to food and drink consumption. Various other studies showed that household food consumption has great environmental impacts (Tukker et al., 2010; European Environment Agency, 2005; Erjavec et al., 2018), and Erjavec et al. (2018) found that across various income groups, food consumption was always the top contributor to household impacts. However, studies such as these investigate only production and processing of the food itself and do not go into further detail about behaviours related to household food consumption. Since there are environmental impacts connected to all activities and behaviours surrounding household food consumption, it is important to look into these (and their impacts) in depth. To see the full picture of food consumption, the impacts of the food consumed should be investigated along with the impacts from packaging, transport, storage, preparation, and food wasted. These six areas are called consumption areas in this study.

Changing behaviours within the consumption areas may help reduce the environmental impacts of food consumption. A description of the consumption areas explored in this study and how they affect the environmental impacts of food consumption is presented below.

1.1 Production of food

The food sector contributes up to one-third of anthropogenic greenhouse gas (GHG) emissions, the livestock sector accounts for 14.5%, and cattle alone accounts for about 10% (Danish Council on Ethics, 2016). There are a large range of differences in environmental impacts between foods, so various products consumed within a household can affect the environmental impacts of the household (Danish Council on Ethics, 2016). The Danish Council on Ethics (2016) report shows that beef has the highest GHG emissions, followed by poultry and pork, dairy and eggs; and arable crops and vegetables have the lowest GHG emissions. Food-related GHG emissions and resource use rises with expenditure, primarily because as income rises people buy more meat, dairy, and processed foods (Ivanova et al., 2016).

1.2 Packaging

Food packaging consists of approximately half of the total weight of all packaging sales, and two-thirds of total packaging waste by volume (Marsh and Bugusu, 2007). Within food packaging itself, the production stage is the main cause of environmental impacts (Roy et al., 2009).

If the environmental impacts of packaging are assessed, the correlated reduction of food waste through the use of the packaging must also be implemented in the assessment. To achieve the primary functions of packaging while reducing food losses, packaging should ideally (Williams and Wikström, 2011; Heller et al., 2018):

- Protect food from physical damage
- Protect food from chemical and biological deterioration (by resealing easily)
- Be easily emptied
- Be easy to open
- Come in a variety of sizes, to avoid having food left over
- Provide information about the food in order to convey to customers about when to throw it away (best before date, use-by date) so that good, still durable food is not thrown away

A study by Williams et al. (2012) found that 20-25% of household food waste could be caused by packaging limitations. If food packaging were designed properly, it has the potential of reducing environmental impacts through the system by reducing food waste both directly and indirectly (Williams et al., 2012; Heller et al., 2018). Direct examples include having variations of packaging sizes or adding a lid or other resealable features; while indirect examples include information to the consumer on how to store the food properly, or how the best-before date should be interpreted (Williams et al., 2012).

1.3 Transport

According to the UN IPCC's fifth climate change assessment (Pachauri et al., 2014), 14% of total global GHG emissions come from transport. While this does not all come from consumers' trips to the store, transportation still accounts for environmental impacts within the food production and consumption system. The most common means of transport to supermarkets in the UK is by car, even though the distance to the shop may be short (WRAP, 2007b). In a study about Danish household consumption, the environmental impacts of twelve different consumption areas were analysed. Depending on the impact category, household transport was often within the top five consumption areas with the highest impacts (Erjavec et al., 2018).

1.4 Energy use: storage and preparation

25% of total annual global GHG emissions come from electricity and heat (Pachauri et al., 2014). In 2003, UK households accounted for 28% of the total UK energy consumption, where cooking made up 5.9% of household energy use and 62.9% was used for lighting and appliances (including refrigerators and freezers that are used for food storage (University of Cambridge, 2005)). As such, energy use for storage and preparation of food within the

household contributes to a substantial share of total energy consumption.
The environmental impacts of energy consumption come from energy production sources. While the UK is still increasing its share of renewable energy (3% as of 2016), most of the energy is still generated from non-renewable sources such as fossil fuels and gas which result in significant GHG emissions (Digest of United Kingdom Energy Statistics , 2016) .

1.5 Food waste

In the UK 8.3 million tonnes of food are wasted at the consumer stage annually, which costs £12 billion and contributes to 3% of the total greenhouse gas emissions of the UK (Quested et al., 2011). Food waste creates economic losses, uses significant resources like land and water, and creates almost 8% of global anthropogenic GHG per year (FAO, 2015).
In the UK, 60% of consumers do not see food waste as a problem because it is "natural" and can biodegrade (Williams et al., 2012). The environmental impacts connected to food waste come from the production, processing, transporting, and storing before food ends as waste (WRAP, 2017), where emissions are also released from decomposition. A focus on reducing food waste is more effective than focusing on the method of waste treatment, and reducing food waste is a key element in developing a sustainable food system (Quested et al., 2011).
Food waste is a problem that is increasingly discussed and is included in both the UN Sustainable Development Goals and the European Commission's Circular Economy package, where a goal was set in 2015 to halve food waste in retail and consumer stages by 2030 (European Commission, 2015; United Nations, 2015). Food waste is created throughout the value chain which makes it difficult to quantify, especially with no universal measuring method. Addressing the measurement problem is important in understanding the food waste issue in order to create solutions for this problem (European Commission, 2015). With the growing global population, reducing food waste is a much more resource-efficient solution than increasing food production (Tucker and Farrelly, 2016).
Influencing people's actions within the household is one of two main ways to reduce household food waste (Quested et al., 2013). Wasting food is not seen as one single behaviour, but as a combination of different behaviours that can increase the probability of food being wasted (Quested et al., 2013).

1.6 WRAP and their work with household food waste

The Waste and Resources Action Programme (WRAP) in the UK is a non-profit organisation working with waste and resource management with a goal to move society towards a more sustainable, resource-efficient economy. Within the food sector, WRAP campaigns to decrease the amount of food wasted in households by trying to influence food consumption as well as consumer behaviour. To investigate the effects of consumer behaviour, WRAP developed the *Milk Model*: a simulation that estimates the amount of milk wasted from a household over a period of time, given a certain set of criteria including shelf life dates and consumption patterns. The output of the model is a percentage of milk wasted in a household over one week (Quested, 2013).
Currently WRAP, along with the University of Sheffield, is developing a simulation model inspired by the Milk Model that models household food waste for a variety of

food items: the *Household Simulation Model* (HHSM). The HHSM is a discrete event simulation programmed in Arena software, and takes additional household factors into account compared to the Milk Model. The HHSM models consumption of one specific product at a time.

Through interviews with representatives from WRAP and the University of Sheffield, information is gathered on how the HHSM runs[1]. There are three main input categories in the HHSM:

1) 'Data related to shopping decisions'
2) 'Data related to household type and consumption patterns'
3) 'Data related to freezing'

1) 'Data related to shopping decisions' is how often the main shop is visited, if and when a top-up shop occurs (and the probability of occurrence), packaging size, number of packages purchased, if a shopping list is made, average and open shelf lives, and the probability of buying the item.

2)'Data related to household type' implements number of people in the household, demand interval (how often the consumer would like to consume the product during the day), and number of household consumption opportunities per demand interval. It implements the probability to actually consume or cook the item, the amount of consumption, the amount of consumption for special occasions (and the chances that the special occasion is cancelled, and if so, the probability that the item is frozen). From the inputs in this category, an average daily and weekly consumption is calculated.

3) The category 'Data related to freezing' can be turned on or off. If freezing is turned on the following parameters are implemented: the probability of freezing right after shopping, and both the frozen and thawed shelf lives. This category additionally implements if items in the home are checked and then eventually frozen, in what intervals, the minimum amount that can be frozen, and the probability of not checking the freezer when the fridge is empty.

The outputs from the HHSM provide the total amount of waste, total amount purchased, total consumption, total household requirement of the food, the requirement not fulfilled, and how much is left to be consumed at the end of the simulation. The waste outputs can be more detailed to give information on the reasons for wasting such as expiration date, open shelf life, amount wasted from the fridge/pantry, amount wasted from thawed and frozen shelf life, and amount wasted from the freezer. The outputs also show how often the main shop was visited, how often the top-up shop was visited, and how much was bought at each type of shop. Currently, the initial products to be run through the HHSM are:

- Milk
- Bread
- Yogurt
- Soft cheese
- Hard cheese
- Cream
- Chicken (breast)
- Chicken
- Bacon
- Sausage
- Sliced ham
- Beef (minced)
- Beef burgers (fresh)
- Beef (cuts/steaks)

[1] Cansu Kandemir, PhD research associate, the University of Sheffield, in discussion with the authors 13 February and 15 March 2019

Once finalised, the HHSM will be used by WRAP to explore different input parameters and see which behaviours can reduce food waste of different products. The goal is to simulate food consumption and waste within households given certain sets of consumer behaviour. The results will then be used to give recommendations to food manufacturers, consumers, and others on how they can produce, sell, and consume food without wasting (Quested, 2013). However, the HHSM does not account for environmental impacts of the food wasted, or how other consumption behaviours affect the environmental impacts of food consumption and waste.
This is a problem, because less food waste does not necessarily mean less environmental impacts. If a household changes consumption behaviours to decrease food waste, the environmental impacts in another consumption area may increase. Therefore, it is important to look at the whole picture of household food consumption, to see trends in environmental impacts between the various consumption areas.

1.7 Environmental trade-offs between consumption areas

To get an overview of the environmental impacts of household food consumption and how the consumption areas affect each other, various behaviours and consumption areas must be explored. Lowering the environmental impacts of one consumption area does not necessarily mean that the rest remain the same. In some cases, a change may lower the environmental impacts in one consumption area while the impacts remain the same or increase in a different consumption area: throughout this study, these are called *trade-offs*. It is interesting to investigate the trade-offs in environmental impacts across all consumption areas as a result of changes in one consumption area. The trade-offs could help answer questions such as 'Which is preferable: smaller or bigger package sizes, considering that smaller packaging has more packaging per kilogram of food product but may cause less food waste?'. Exploring these trade-offs and the related environmental impacts can help provide recommendations that help consumers move towards more sustainable household food consumption. Trade-offs can occur between any consumption area, and all of the consumption areas can be explored both interconnected and individually in order to create solutions to reduce environmental impacts of household food consumption.
Analysing trade-offs between the different consumption areas is not found to have been done before, but a calculation where all consumption areas are explored in relation to each other makes it possible to analyse trade-offs. Recommendations can then be suggested to reduce environmental impacts of household food consumption while accounting for the interconnected behaviours.

1.7.1 The EIFC-tool

As discussed above, a calculation of the effect behaviour can have on the various areas of household food consumption makes it possible to see where and how to reduce environmental impacts. This can help explore how different consumption areas affect each other, and how a behavioural change in one area interacts and affects the impacts of another.
The objective of this study is to develop a tool to quantify and analyse these trade-offs. This is done using LCA results to form background data in the tool, and having outputs

from the HHSM as manual inputs. This tool is called 'The Environmental Impacts of Food Consumption tool' (EIFC-tool), and assesses the environmental impacts of household food consumption of a certain product over one year, given certain behaviours associated with the household and the product. The products modelled in the tool are bacon, beef mince, bread, chicken breast, and milk. The EIFC-tool implements, and connects, the following consumption areas:

Consumption area	Included in the consumption area
Products	Production of products consumed
Food packaging	Production and waste treatment of packaging
Food waste	Production and waste treatment of products wasted
Transport	Transport to the main and top-up shops
Storage	Energy use for storage
Preparation	Energy use for preparation

Table 1.1: Household food consumption areas focused on in this study, and what is implemented in each consumption area.

1.8 Research question

How can changes in food consumption behaviour be modelled to analyse changes in household environmental impacts?

1.8.1 Sub-research questions

1. How can the environmental impacts between households with different food consumption behaviours be quantified and compared?
2. What effective recommendations can be made to actors in the food system to reduce environmental impacts of household food consumption?

Theories on consumer behaviour 2

In the current chapter, consumer behaviour theories are investigated to help answer the second sub-research question, 'What effective recommendations can be made to actors in the food system to reduce environmental impacts of household food consumption?'. The next sections describe how consumer behaviours influence food waste, how consumer behaviours affect shopping habits, and theories about changing consumer behaviour that can help shape recommendations.

2.1 How consumer behaviour influences food waste

Consumer behaviour is a key factor in generating food waste, but also in food waste prevention. This does not result from one behaviour, but rather of the interactions of many behaviours (Quested et al., 2013). One of the key findings in Quested et al. (2013) was that wasting food has little visibility to others and therefore is not highly important for the consumer, because there are not many social norms related to behaviours with less visibility. Food can be wasted for simple reasons such as spillage, inedible parts of food items, or cooking too much food. On average, older households tend to waste less than households containing younger members, with people between 18-34 wasting the most (Quested and Luzecka, 2014). Quested and Luzecka (2014) found that younger people waste more through poor planning (such as preparing too much food), and older people waste more due to 'food not used in time'. Larger households waste more food in absolute terms than a single household, but relatively less compared to a single household (WRAP, 2007a).

There are many consumer habits that influence food waste: meal planning, checking the fridge before shopping, making a shopping list, storing food properly, using up leftovers, and portioning properly, among many others (Quested et al., 2013). Habit plays a key role in food wasting behaviours which means the behaviours are being performed with little consciousness; this is a challenge when trying to change these behaviours (Quested et al., 2013; Aschemann-Witzel et al., 2015).

2.2 Hedonic and utilitarian shopping habits

In consumption theory it is believed that consumers shop based on two conditions, namely hedonic and utilitarian (Vieira et al., 2018). Hedonic describes a shopping practice related to gratification and based on values, whereas utilitarian refers to consumers who shop based on necessity or as a way of completing a chore (Batra and Ahtola, 1991). While

consumers may not exclusively fall into one category, they may shop with a mix of the two, with a preference for one or the other based on the purchase.
Understanding the two modes of shopping can aid in understanding why consumers shop for products the way they do, and also help producers and retailers to highlight certain characteristics of a product to improve sales. This is why highlighting discounts can improve sales with utilitarian shoppers, but premium characteristics (such as organic produce) may improve standing among hedonic shoppers (Vieira et al., 2018).
Using hedonic and utilitarian shopping theory in promoting food items may result in wiser or more conscious shopping, which in turn may reduce the environmental impacts of food consumption. This can be used in the recommendations by, for example, designing packaging that easily reseals and keeps food fresher for longer (hedonic). When the theories are used consciously, they can be used to directly or indirectly influence consumers to make certain choices (Vieira et al., 2018). However, the theory only works to a certain extent, as shopping is also largely based on habit and limited by economy. This is where other social theories can come into play to deconstruct and reconstruct habits to become more sustainable.

2.3 Social practice theory

Within sustainable food consumption, a 'practice' involves the relationship between the material aspects of eating (the physical food, appliances used to cook, how waste is treated) with socio-cultural norms (like meal expectations) (Devaney and Davies, 2017). Food consumption is not directed by one practice, but practices in combination with each other: consumption requires buying, preparing, and cooking food. Within social practice theories, environmentally damaging consumption is not viewed as a problem of the individual consumer but rather a problem embedded within practice because eventually these practices develop into norms (Jüttner, 2017). These practices are habits, and are places where behavioural change can take effect (Devaney and Davies, 2017). Over time, unsustainable habits can be changed through various interventions to challenge, disassemble, and reconfigure eating practices to become more sustainable (Devaney and Davies, 2017) through influencing and manipulating the various elements of the practice.
Devaney and Davies (2017) state that consumer engagement is key in a social practice approach to deconstruct and reconstruct food consumption habits, especially face-to-face interaction with people providing knowledge. Knowledge providers can act as change agents within the household. Sustainable eating practices can be more easily managed if one person takes on the responsibility for change within the household. If one person is willing to be the change agent and take on responsibility, other household members do not have to put in much effort to change (Devaney and Davies, 2017). It is important to implement one behavioural change at a time so consumers are not overwhelmed and can slowly ease into breaking habits and changing to more sustainable practices (Devaney and Davies, 2017). However, it is also important to connect the multiple practices of eating (buying food, preparing, and wasting) rather than focusing on just one practice, to enable consumers to see how everything is connected. Social practice theory can be used to shape recommendations because, as discussed above, food consumption is made of many interconnected practices that can be changed through various interventions. The current study views many different practices within food consumption (such as preparing

food, consuming food, and wasting food); and therefore creating recommendations based on assumptions in social practice theory could be useful for this study.

2.4 Social influence theories

Interventions could be more influential if social influence theories were more involved (Abrahamse and Steg, 2013). Various social influence approaches can be taken to change behaviour, and are used when constructing recommendations in this study.

Social norms are used to give information and provide feedback. There are two types of social norms: descriptive (the belief about what is most common in social situations) and injunctive (belief about which should be done in a certain situation). When using this in an environmental sense, information can be given to people about what other people are doing, or what other people should and should not do (Abrahamse and Steg, 2013).

People are more likely to act if information comes from someone in their social network (Young et al., 2017). A **block leader** informs people about social issues, based on assumptions that information is more effective if given by someone in their social network. Block leaders can be effective because they already occur in existing social networks so the chances are higher that information will reach a certain group. There are increased chances that people within the social network will actually act on the information, because the block leader spreading the information is someone they know personally, like, and have similarities with (Abrahamse and Steg, 2013).

Public commitment making publicly binds a person to a behaviour or opinion (Abrahamse and Steg, 2013; Young et al., 2017). This is effective because public commitments can influence behavioural change due to the social pressure individuals will feel to stick to the commitment (Abrahamse and Steg, 2013).

Modelling assumes that people are more likely to commit to a behaviour if they see someone (a 'model') doing the recommended behaviour (Abrahamse and Steg, 2013; Young et al., 2017).

A main point of social influences, and a component of all of the above-mentioned interventions, is that face-to-face interactions are a crucial element to changing behaviour (Young et al., 2017). This contrasts to behaviour change approaches for environmental sustainability that normally focus on government initiatives, such as providing infrastructure, legal structures, or information campaigns (Young et al., 2017). It is also thought that social media interventions can be as effective as traditional interventions, because they have the potential to replicate face-to-face interactions (Young et al., 2017). Social influence theories can be used to shape recommendations as they give an idea on the most effective ways to change behaviour. In this case, it would mean shaping the recommendations around a face-to-face interactions and possibly even involving social media, which is argued to be very effective due to the potential to replace face-to-face interactions with a fraction of the time and resources needed.

2.5 Connecting consumer theories to recommendations

The purpose of the consumer behaviour theories are to support the findings from the analysis in order to give recommendations to feasibly implement change in food consumption, and move it to a more sustainable practice.
Shopping theories suggest that it is worthwhile looking into how the characteristics of a food product are presented, as consumers shop in different ways. By shaping recommendations with the purpose to challenge, disassemble, and reconfigure the various practices within food consumption, it could be possible to change food consumption as a whole in order to make it more sustainable. Interventions include face-to-face interaction with people to support the transition to a more sustainable lifestyle or having one main change agent within the household to promote more sustainable food consumption.

Research design and key methods 3

3.1 Research design

The purpose of this study is investigating how changes in household food consumption behaviour can be modelled to analyse changes in household environmental impacts. This is done by creating a tool that connects consumption areas with environmental impacts, and performs a trade-off analysis between the different consumption areas. The research design in Figure 3.1 shows how the theories and methods are used in this study to answer the research question.

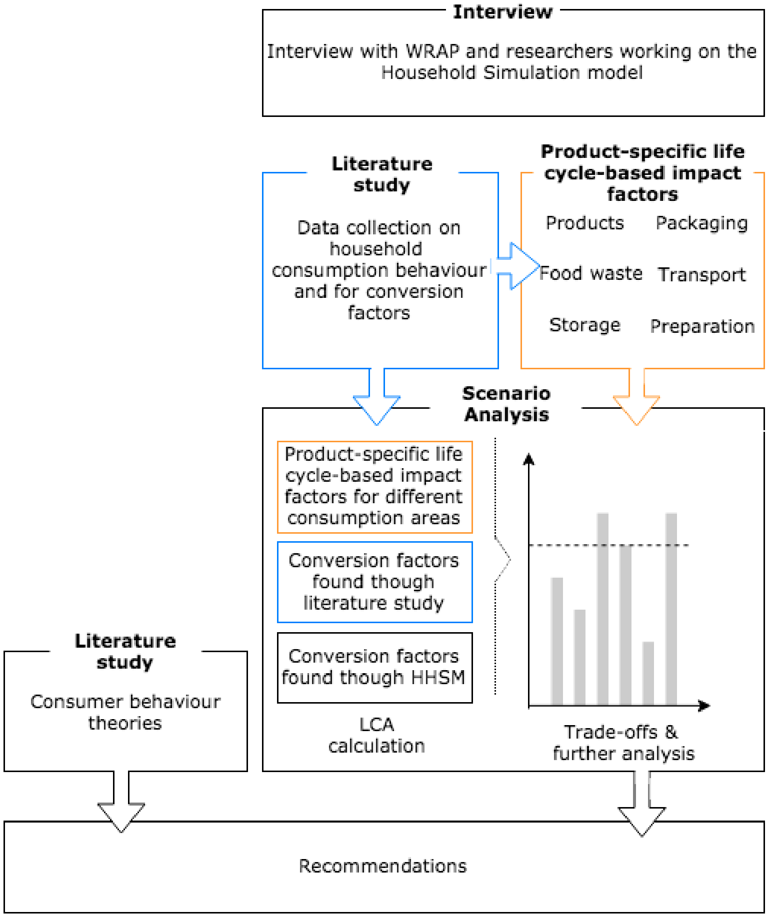


Figure 3.1: Research design for the current study, showing how the various methods are connected to answer the research question.

The following sections describe the methods (both qualitative and quantitative) used to answer the research question. The methods used in this study include interviews, literature study, and life cycle assessment.

3.2 Interviews

3.2.1 WRAP interview

The purpose of the interview with WRAP is to set the goal, expectations, and structure of the study. It is a semi-structured interview with questions sent in advance so the interviewees can prepare. This initial interview is split into four parts, starting with an introduction of the people in the HHSM project to gain an overview of the contacts in the project. Secondly, the interviewees provide a background on WRAP's current work on the Household Simulation Model. Thirdly, the delimitation of the EIFC-tool is discussed as to set a clear direction for the study and to discuss what parameters are most essential to look into. Finally, the more technical aspects are discussed in terms of the EIFC-tool, LCA database, and other considerations.

3.2.2 Expert interview about HHSM

The purpose of the expert interview is to gain knowledge on the HHSM, how it works, and what kind of data it produces, because the HHSM influences the way the EIFC-tool can be programmed. Cansu Kandemir from the University of Sheffield is the sole programmer of the Household Simulation Model, and the main objective of this expert interview is to gain knowledge about her field of expertise. As a regular attendee of the update meetings with representatives from WRAP, Kandemir is able to give valuable feedback and comments regarding connecting the HHSM to the EIFC-tool.

In the interview, Kandemir thoroughly describes the Household Simulation Model; the assumptions used within the model and on what basis these assumptions are made; how the model works; and what kind of outputs can be drawn from the HHSM to be used in the EIFC-tool. The interview includes a series of questions about the HHSM and the connection to the EIFC-tool that are not answered in the walk-through of HHSM.

3.3 Literature study

Literature study is used as a method for two different stages of the study, as seen in the research design. One area of literature study focuses on consumer behaviour theories as they, combined with the analysis of results from the EIFC-tool, shape the recommendations made at the end of the study. The literature study focuses on suitable theories that can be combined with the results. For this reason, books and peer-reviewed articles are preferred. Literature study is also used to find data on consumer behaviours of UK households to use as conversion factors in the EIFC-tool. Literature sources for conversion factors include technical data, where data sheets are used and verified by comparing several. In the next section, the conversion factors used to transform the data are shown.

3.3.1 Conversion factors needed as EIFC-tool inputs

Full descriptions, literature studies, and calculations for this is found in Appendix 1.
The HHSM provides the amount of product bought and wasted over one year and from this, the amount of product consumed per year is found. This is used to calculate the impacts of producing and processing the consumed portion of the product.
A list of packaging components, sizes, and weights for each of the five food products is provided by Valpak (see full packaging list in Appendix 2). A WRAP retailer survey (see Appendix 3C) provides data about how often each packaging type is bought. This information combined is seen in Table 3.1.

Food item	Packaging type	W [g]	How often bought
Bacon plastic tray, 240-250g	Plastic	17.73	84.7%
Bacon vacuum pack, 200-250g	Paper Plastic	0.5 7.53	15.3%
Bacon plastic tray, 300g	Plastic	21.59	84.7%
Bacon vacuum pack, 300g	Paper Plastic	0.78 4.97	15.3%
Beef mince plastic tray, 500g	Plastic	20.09	No data
Bread plastic bag, 400g	Plastic	9.45	86%
Bread paper bag, 400g	Paper	11.1	14%
Bread plastic bag, 800g	Plastic	10.16	43%
Bread plastic film, 800g	Plastic	6.21	43%
Bread paper bag, 800g	Paper	14.29	14%
Chicken breast plastic tray, 300g	Paper Plastic	0.79 18.60	100%
Chicken breast plastic bag, 500g	Plastic	15.67	29.5%
Chicken plastic tray, 500g	Paper Plastic	2.05 26.14	70.5%
Chicken breast plastic bag, 1000g	Plastic	26.31	29.5%
Chicken plastic tray, 1000g	Paper Plastic	2.27 30.64	70.5%
Milk plastic bottle, 1 pint	Plastic	19.03	90.5%
Milk in tetrapak, 0.5L	Paper Plastic Aluminium	16.74 1.1 0.5	9.5%
Milk plastic bottle, 2 pints	Plastic	29.98	90.5%
Milk in tetrapak, 1L	Paper Plastic Aluminium	29.5 2.6 0.5	9.5%

Table 3.1: Overview of packaging data used in the EIFC-tool. Column W shows the weight [g] of the different components used to model the packaging type. "How often bought" shows how often the product is bought in this packaging type, compared to the other packaging types in the same size.

In addition to production of the packaging, these components (paper, plastic, and aluminium) are connected to packaging waste treatment. The packaging waste treatment mix sends 42.33% to landfill, 42.33% to recycling, and 15.33% to incineration.

The amount of product wasted comes from HHSM outputs, which must go through waste treatment in order to view a full life cycle perspective. Although users can manually input how food is treated, a default waste treatment in the EIFC-tool setting calculates food waste treated by a food waste treatment mix. The waste treatment mix is 54.6% to landfill, 19.8% to incineration, and 25.6% to compost.The majority of milk is poured down the drain, and therefore all milk waste is treated by waste water treatment and not the food waste treatment mix.

The HHSM provides the number of shopping trips per year to buy each product. The average distance to the store is 5.2 km and can be manually changed in the EIFC-tool. 73.9% of consumers travel to the shop by car, 9% by public transport, and 17.1% by walk or cycle. The impact of transport for one specific product is calculated based on the number of products bought per shopping trip, which is a manual input in the EIFC-tool.

The amount of the product stored in the refrigerator or freezer is supplied by the HHSM. The electricity required for cooling and freezing the products (the heat capacity) is shown in Table 3.2. The energy required for opening the refrigerator or freezer is found in Table 3.3.

	Electricity use
Opening refrigerator door	0.023 kWh
Opening freezer door	0.058 kWh

Table 3.2: Electricity use for opening the refrigerator or freezer door once.

Amount	**Product**	**Cooling 10°C to 5°C**	**Freezing 10°C to -18°C**
1 kg	Bacon	0.002 kWh	0.048 kWh
1 kg	Beef mince	0.004 kWh	0.073 kWh
1 kg	Bread	-	0.024 kWh
1 kg	Chicken breast	0.004 kWh	0.075 kWh
1 kg	Milk	0.005 kWh	0.102 kWh

Table 3.3: Electricity use for cooling and freezing of 1 kg of each product. (-) indicates that the product is not cooled or frozen.

The HHSM provides outputs on how often a product is prepared, and literature study provides information on electricity requirements to prepare each product. The average preparation methods are seen in Table 3.4 and used in the EIFC-tool.
Electricity use per preparation changes per product and household size. This is used as background data in the tool and can be found in Appendix 1.

Food item	Toaster	Oven	Stove-top	Raw
Bacon	-	70.1%	29.9%	-
Beef mince	-	66.7%	33.3%	-
Bread	54.1 %	-	-	45.9%
Chicken breast	-	65.3%	34.7%	-
Milk	-	-	-	100%

Table 3.4: Occurrence of preparation methods for different products used in the EIFC-tool. This is found through a University of Sheffield survey (see Appendix 4C)).

3.4 Life cycle assessment to find impact factors

The quantitative method used in this study is Life Cycle Assessment (LCA). LCA assesses the environmental impacts throughout a product or service's life to give the potential environmental impacts from cradle to grave (International Organisation for Standardisation, 2008a). The environmental impacts found through LCA form the background data in the EIFC-tool; so the LCA is not used as a final result but as a data collection method for the EIFC-tool.
Multiple LCAs performed within each consumption area become pre-calculated LCA results used as scalable background data in the EIFC-tool. For the remainder of the study, these LCA results are called product-specific life cycle-based impact factors, or impact factors. The impact factors have a basis in the ISO standards 14040 and 14044 (International Organisation for Standardisation, 2008a,b) and are calculated in LCA software SimaPro. Two impact categories (Global warming and Non-renewable energy) are used to present the results of the EIFC-tool throughout this study. It is possible to analyse other impact categories, which are available in the background data sheets of the EIFC-tool.
The two impact categories are briefly explained below to understand what the impact category measures. Descriptions are from Schmidt and Watson (2013):
Global warming measures the global warming potential of CO_2 equivalents over a 100 year time period, measured in kg CO_2-eq.
Non-renewable energy is the total use of primary non-renewable energy resources, measured in MJ primary.

Life cycle inventory analysis (LCI) involves data collection and calculation, in order to quantify relevant foreground data external to the LCA database used. This is an iterative phase, where as the study proceeds it may be necessary to change data collection (International Organisation for Standardisation, 2008a). The foreground data is found using the HHSM from WRAP and literature study, and the background data comes from the database Exiobase.
Sections 4.2 - 4.7 in the Chapter 4 describe the life cycle inventory for each household consumption area, the corresponding LCA(s) done within each consumption area, and the results of the LCAs within each consumption area.

3.5 Household simulation model

The HHSM is a discrete event simulation which represents the random occurrences in real life. The simulation runs for 10 years where each day the household behave differently.
The simulations are based on multiple inputs (variables), such as how often a household goes shopping, how they follow shelf life information on the package, the opportunity to consume the product, which size the package is bought in, if they shop with a shopping list, and many others.
The main purpose of the HHSM is using these variables to simulate the purchase, storage, consumption, and waste of a certain product which provides the following outputs, among others:

- Total amount purchased
- Total number of shop visits (both top-up and main)
- Total consumption
- Total requirement
- Requirement not fulfilled
- Total waste
- Waste caused for various reasons
- Total amount frozen
- Number of packages goes into freezer
- Number of days fridge is active
- Number of days freezer is active

The 'Total consumption' is 'Total amount purchased' minus 'Total waste'. The outputs for freezing are added specifically for this study, as they are needed to model the consumption area 'storage' in the EIFC-tool.
The output 'Total requirement' shows the total amount consumed if a household were to consume the product at every consumption opportunity. 'Requirement not fulfilled' shows the total amount not consumed because the product was not available (a household ran out of the product, it was expired, or other reasons). When the requirement is not fulfilled, the household should substitute with another product though this is not implemented in the HHSM.
Between different runs of the model (where a variable like packaging size is changed), the total amount consumed, purchased, wasted, total requirement, and requirement not fulfilled are different- this limits the HHSM, because it is then difficult to compare run with each other.
When these different HHSM outputs are used in the EIFC-tool, the results from the EIFC-tool are not comparable for the same reason. Therefore, the results are not compared directly, but rather used in a way where trends of environmental impacts between consumption areas are explored. In order to have a baseline between the results, are they normalised.

3.5.1 Normalisation

To effectively compare consumption areas between different scenarios, the results are normalised. The normalised results are not an indication of which scenario is the best as the results do not implement 'requirement not fulfilled'. However, normalisation makes it easier see trends between scenarios.
To normalise is 'the amount of product eaten' scaled by using 'average amount eaten' (within a household and product), the unit of the normalised results is then 'environmental

impacts from average consumption of the product for one year'.

$$N_I = A_c/T_c \cdot I \tag{3.1}$$

N_I is the normalised impact, A_c is the 'Average amount consumed', T_c is the 'Total amount consumed', and I is the corresponding environmental impact.

When presenting results, the unit is impacts per average kilograms of product consumed within one year, where the average amount of product consumed depends on the household type and product eaten.

3.5.2 Household types

The households and their connected behaviours modelled in the tool come from the HHSM modelling (Kandemir et al., 2019):

Four person household - Aspirational Discoverers family
This first household size is the Aspirational Discoverers family (AD family). This is a four-person family with younger children, who are more risk averse because they have kids; confident; good kitchen planning; moderately likely to throw away leftovers; moderate portioners; and shopping is relatively regular.

One person household - Functional Fuellers single
The second household size is a single person household, called the Functional Fuellers single (FF single). This household is less likely to take risks; low confidence; poor kitchen planning; likely to throw away leftovers; and is a moderate portioner.

3.6 Connecting the methods to create the EIFC-tool

The LCAs form background data in the EIFC-tool which, when combined with conversion factors, result in environmental impacts of household food consumption. The connection between LCAs and the conversion factors are further explained, and Figure 3.2 on the following page shows the connection.

The LCAs for the consumption areas are made with a simple functional unit to result in product-specific life cycle-based impact factors.The blue and yellow boxes are found through the HHSM and literature study, respectively, and are the conversion factors. Conversion factors are multiplied with the impact factors in order to calculate environmental impacts within each consumption area. To find the total environmental impacts of a household consuming a certain product over one year, the environmental impacts from all consumption areas are added together.
Although in reality household consumption implements more areas, in this study it is chosen to limit these to the ones connected to the HHSM in order to work with data which is readily available and from the same source. Finding inputs from a variety of sources limits the accuracy of results as each source is based on different methods and uncertainties.

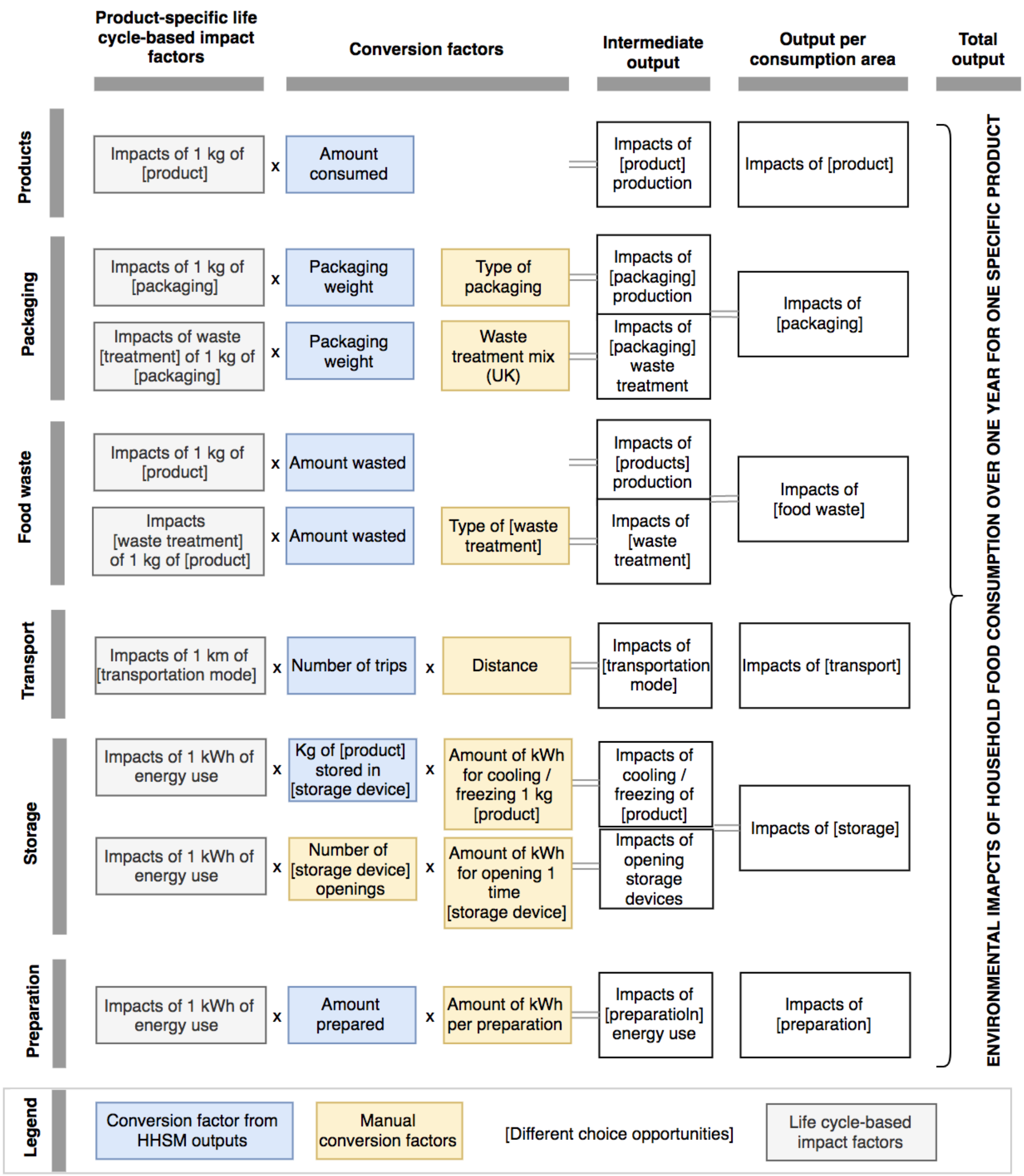


Figure 3.2: Overview of how the EIFC-tool is modelled. Here, the life cycle based impact factors (grey boxes), inputs from the HHSM (blue boxes), inputs from literature study or manual settings (yellow boxes) are seen, and how they are combined in order to show the full picture of household food consumption.

Life-cycle assessment to calculate impact factors 4

The LCA method is explained in the previous chapter (Section 3.4). This Chapter presents LCAs done specifically for this study including the goal and scope, inventory analysis, and results.

4.1 Goal and Scope

The LCAs are an intermediate step in creating the EIFC-tool, and result in impact factors which are scalable background data in the EIFC-tool. Impact factors are found within the consumption areas. The functional units for the LCAs are:

- **Product:** 1 kg of wet matter mass of [food item]
- **Packaging:** 1 kg of wet matter mass of [packaging type]
- **Packaging:** 1 kg of wet matter mass of [packaging type] treated by [waste treatment]
- **Food waste:** 1 kg of wet matter mass of [food item]
- **Food waste:** 1 kg of wet matter mass of food treated by [waste treatment]
- **Transport:** 1 km of transport by [mode of transport]
- **Storage/Preparation:** 1 kWh of electricity

It is chosen to use wet matter mass in this study because users of the EIFC-tool are not expected to know the dry matter ratio of the food products. It is for user convenience and ease that the results are in wet matter mass. For packaging, the wet matter is used because the function of packaging occurs at the wet matter weight, and the packaging weights for each food item have the function of holding and protecting the product.

4.1.1 Exiobase database

The Exiobase database is chosen for various reasons, including researchers' experience with the database and data in Exiobase corresponds well with this study. Exiobase is a free database, and thus can be used for public information and for further use by WRAP. Exiobase contains data for 43 countries, 5 rest of the world regions, and 164 activities. There are product markets for all 43 countries and for each country the 164 activities are specified for the corresponding market (Stadler et al., 2017). By-products are implemented in Exiobase through substitution.
In this study the 164 activities are referred to as *classifications*. Exiobase classifications are presented by the number followed by the title of the process, for example: 36 Processing of meat pigs (GB) means Exiobase classification 36, and (GB) means that this classification corresponds to this sector in Great Britain.

Exiobase classifications used in this study are in monetary or metric units, but the weight for items such as food and paper products is in dry matter. All dry matter values can be seen in Appendix 5.

4.1.2 Product system

Figure 4.1 shows the product system for the LCAs used to calculate the impact factors for the consumption areas. The LCAs are primarily made using background data. Foreground data is used for various LCAs, for calculating various waste mixes, electricity mixes, and the mix of Exiobase classifications for bread and milk. The product system is shown on Figure 4.1 and how it is constructed is explained further.

The product system for products shows the cradle-to-gate production of each product. One kilogram of product is modelled in each LCA. Bacon, beef mince, and chicken breast are modelled with one corresponding Exiobase classification. For bread and milk, two Exiobase classifications are used for each and therefore literature is used to determine how to combine the classifications (see Appendix 6).

The LCA of packaging includes two types of calculations: the first is the calculation of 1 kg of packaging type: plastic, paper, or aluminium. The second is the calculation of 1 kg of plastic, paper, or aluminium going to a UK waste treatment mix, which is foreground data which is found through literature study (see Appendix 6).

The LCA of food waste includes two types of calculations. The first is modelling production of the food that is actually wasted, which is the same LCA for products. The second is modelling treatment of food waste, where 1 kg of food is modelled by three different types of food waste treatments (landfill, incineration and composting). This allows for an option to manually change how food waste is treated in the EIFC-tool.

The LCA for transport models driving 1 km by either car or bus. The unit in Exiobase is monetary, so it is necessary to find foreground data which converts monetary units to 1 km. Walking/cycling is assumed to have no impacts.

The LCA for consumption areas storage and preparation is the same, as it calculates electricity use. For these LCAs, 1 kWh of electricity use is calculated where the electricity mix is foreground data found through literature study (Appendix 6).

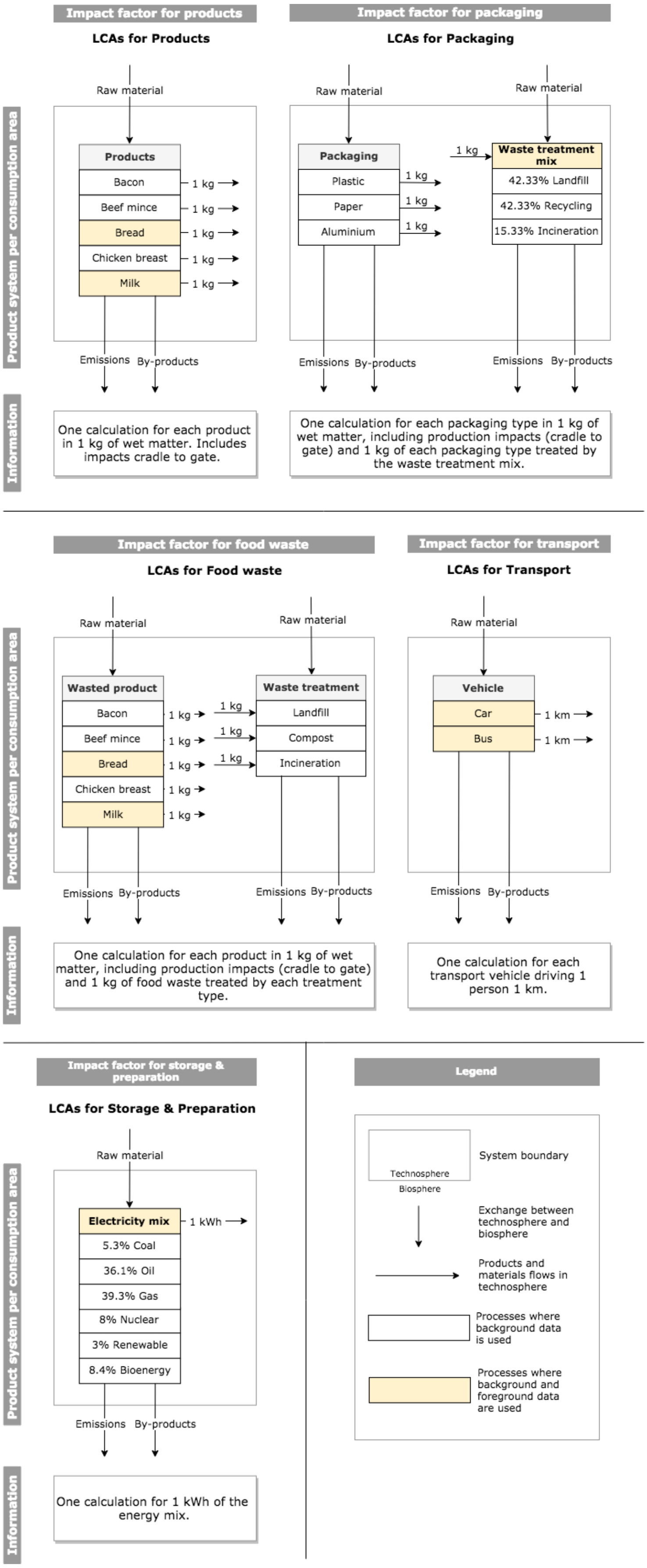


Figure 4.1: Product systems for each consumption area. This shows how the impact factors for all consumption areas are found through LCA.

4.2 LCA and results for products

The production of 1 kg of wet matter of each product is modelled in these LCAs, so five LCAs are calculated. Treatment of human waste from eating these products is deemed to be outside the scope of the study.
The following Exiobase classifications are used to model the production and processing of the products:

- **Bacon:** 36 Processing of meat pigs (GB)
- **Beef mince:** 35 Processing of meat cattle (GB)
- **Bread:** 2 Cultivation of wheat (GB) & 43 Processing of food products nec (GB)
- **Chicken breast:** 37 Processing of meat poultry (GB)
- **Milk:** 14 Raw milk (GB) & 40 Processing of dairy products (GB)

For bacon, beef mince, and chicken breast, the Exiobase classifications are fairly straightforward but for bread and milk some processing must be done. For bread, 2 Cultivation of wheat should make up 50% of bread production and 43 Processing of food products nec should make up the other 50%. 13% from 40 Processing of dairy products and 87% from 14 Raw milk gives an accurate ratio for milk production. For full analysis of bread and milk production classifications, see Appendix 6.
There are various limitations when modelling these five food products. For bacon, beef mince, and chicken breast, the uncertainty and limitation is that the Exiobase classifications are broad: pig meat, cattle meat, and poultry meat. The classifications may have higher or lower impacts than the specific products in this study. For bread and milk, there are additional limitations due to the additional use of literature study. If different literature was studied results may be different; but various literature is studied to minimise this uncertainty and get as accurate results as possible.
The results for the LCAs for each product is seen in Table 4.1.

	Global warming [kg CO_2-eq]	**Non-renewable energy [MJ primary]**
Bacon	4.65	737
Beef mince	18.7	676
Bread	1.12	371
Chicken breast	3.42	1410
Milk	1.41	76.8

Table 4.1: LCA results for 1 kg of wet matter of bacon, beef mince, bread, chicken breast, and milk for two chosen impact categories, Global warming, fossil and Non-renewable energy.

4.3 LCA and results for packaging

Data about common packaging types bought by consumers is provided from a WRAP retailer survey (2011 and 2015), and the full survey can be seen in Appendix 3C. Information about food packaging for the five food items is provided by the packaging company Valpak. The list includes material name, packaging components, weight, and recyclability. The full table can be seen in Appendix 2.
In total, there are seven different components in the packaging list, but it is chosen

to aggregate these into three types: plastic, paper, and aluminium. The analysis and validation of this decision, and what classifications to use, is found in Appendix 6.
In the LCA, the packaging Exiobase classifications are:

- **Paper:** 54 Paper (GB)
- **Plastic:** 64 Manufacture of rubber and plastic products (GB)
- **Aluminium:** 76 Aluminium (GB) production

As there are seven different packaging components, there is an uncertainty that the Exiobase classifications do not differ between various plastic types. However, this is accepted within the scope of this study as the EIFC-tool does not do trade-offs regarding different types of plastic but just between sizes of packaging (300g package versus 500g package) and broader packaging types (plastic versus Tetra Pak versus paper). In this way, differentiating packaging into just three categories falls within the scope of this study. The results for packaging production are as follows in Table 4.2.

	Global warming [kg CO_2-eq]	**Non-renewable energy [MJ primary]**
Paper	2.22	713
Plastic	6.91	2520
Aluminium	10.9	1340

Table 4.2: Results from the LCA calculation for 1 kg of wet matter of packaging materials: paper, plastic, and aluminium. Results are presented for the two chosen impact categories, Global warming, fossil and Non-renewable energy.

Packaging waste

In addition to resources used and emissions released during packaging production, the impacts of packaging waste must also be analysed. Paper, plastic, and aluminium have different waste scenarios, so different Exiobase classifications are used for each. The packaging waste scenarios consist of the classifications as seen in Table 4.3, along with the percentages of each classification that make up the UK waste mixes (Chartered Institution of Wastes Management, 2018).

There is uncertainty about packaging waste due to recyclability of the packaging types. Using data about how people recycle and how UK waste is treated gives an average of waste treatment, but it is difficult to find the percentage of packaging made from recycled material. Additionally, not all plastic types in the different packaging are recyclable - this too affects the results, but is not taken into consideration. In the end it is chosen to use the most common types of treatment for UK garbage, and use different Exiobase classifications based on whether the packaging is plastic, paper, or aluminium. It is assumed that this gives more accurate results than disaggregating into further detail and adding more assumptions.

Packaging type	Exiobase classifications	Share
Paper	53 Reprocessing of secondary paper into new pulp	42.33%
	155 Landfill of waste: Paper	42.33%
	141 Incineration of waste: Paper	15.33%
Plastic	60 Reprocessing of secondary plastic into new plastic	42.33%
	156 Landfill of waste: Plastic	42.33%
	142 Incineration of waste: Plastic	15.33%
Aluminium	77 Reprocessing of secondary aluminium into new alu.	42.33%
	157 Landfill of waste: Inert/metal/hazardous	42.33%
	143 Incineration of waste: Metals and inert metals	15.33%

Table 4.3: Packaging waste scenarios for paper, plastic and aluminium. Exiobase classifications 53, 60, and 77 represent the recycling process for each type. The distribution for amount of each material going to each waste treatment is shown in column 'Percent'.

The results of the packaging waste treatment LCAs are seen below in Table 4.4.

	Global warming [kg CO_2-eq]	Non-renewable energy [MJ primary]
Paper	0.461	-121
Plastic	-0.962	-192
Aluminium	-4.25	-1660

Table 4.4: Results from the LCA calculation for 1 kg of wet matter of packaging waste treatment for the two impact categories, Global warming, fossil and Non-renewable energy.

4.4 LCA and results for food waste

The LCA of food waste includes the production of the wasted food item as well as the waste treatment, to show the full impacts of the wasted food product. The LCA in this consumption area looks into the environmental impacts of 1 kilogram of food waste only, because the production of the food item is calculated in Section 4.2.
It is found through literature study that household food waste is primarily treated by landfill, incineration, and composting (See Appendix 1). The majority of milk is poured down the drain, so in this study milk is treated by waste water (WW) treatment. The Exiobase classifications used are:

- **Landfill:** 154 Landfill of waste: food (GB)
- **Incineration:** 140 Incineration of waste: food (GB)
- **Composting:** 150 Composting of food waste, incl. land application (GB)
- **WW treatment:** 152 Waste water treatment, food (GB)

An uncertainty is that not all of the mentioned waste treatment methods are available to all citizens in all regions of the UK. When manually putting waste treatment in the EIFC-tool this is not an issue, but for the default setting the assumption is that landfill, incineration, and composting are available to the modelled household.
The results for the LCAs are seen in Table 4.5.

	Global warming [kg CO_2-eq]	Non-renewable energy [MJ primary]
Landfill	1.49	41.7
Incineration	2.2	143
Compost	0.294	66.6
WW treatment	0.345	48.4

Table 4.5: The environmental impacts of 1 kg of wet matter of food being sent to various waste treatments, presented in the two impact categories, Global warming, fossil and Non-renewable energy.

4.5 LCA and results for transport

The LCAs within this consumption area calculate the environmental impacts associated with the mode of transportation taken to and from the shop. The following classifications are used to model transport:

- **Walk:** N/A
- **Cycle:** N/A
- **Car:** 122 Other land transport (GB)
- **Bus:** 122 Other land transport (GB)

122 Other land transport (GB) is chosen to model the impacts related to transport, where this classification includes "urban transport of passengers (...) carried out with motor bus, tramway, street vehicles (...)" (Eurostat, 1996). Passenger cars are not mentioned specifically, but it is the only classification which covers passenger land transport in vehicles.
This classification is in monetary units, which makes it difficult to model 1 km. 1 km by car emits 0.217 kg CO_2 per km, and 1 km of inner city public bus transport per person emits the equivalent of 0.19 kg CO_2 per passenger km (Carbonfund.org, 2019). Using this data, input in Exiobase for car are 1.01 USD and 0.9 USD for the bus.
Transforming the unit from monetary into kilometres results in uncertainty, because it is found through literature study with kg CO_2 as a baseline and not taking other impacts into account. However, this calculation is considered to be the best available option within the constraints of this study.
Another uncertainty is that it is chosen not to implement the production of the vehicles (car, bus, and bicycle). This would require allocating the production impacts to one kilometre per product, which would limit the accuracy of the final results. It is also assumed that a car is already owned by the household and is not used just for grocery shopping trips. The results from classification 122 Other land transport are found in Table 4.6.

	Global warming [kg $PM_{2.5}$-eq]	Non-renewable energy [MJ primary]
Car	0.218	53.9
Bus	0.193	48.1

Table 4.6: The results of the LCAs for transport by car and by bus for 1 km, calculated by Exiobase classification 122 Other land transport. Two impact categories are presented, Global warming, fossil and Non-renewable energy.

4.6 LCA and results for storage

It is assumed there are three ways the products can be stored: at room temperature, in the refrigerator, or in the freezer. The production of the storage device is not accessed, as it is assumed that everyone has a refrigerator and freezer at home and that calculation would implement many assumptions which limits the accuracy of the results.
As this consumption area is modelled by electricity use, 1 kWh of electricity is calculated in the LCA. Electricity connected to refrigerator and freezer use is defined by the electricity market mix for the UK, and can be seen in Appendix 6. The Exiobase classifications used in the electricity market mix are seen in Table 4.7.

Electricity source	[%]	Exiobase classification
Coal	5.3%	96 Production of electricity by coal (GB)
Oil	36.1%	101 Production of electricity by petroleum and other oil derivatives (GB)
Gas	39.3%	97 Production of electricity by gas (GB)
Nuclear	8.0%	98 Production of electricity by Nuclear (GB)
Renewable	3.0%	99 Production of electricity by hydro (GB) 100 Production of electricity by wind (GB) 103 Production of electricity by solar photovoltaic (GB)
Bioenergy	8.4%	102 Production of electricity by biomass and waste (GB)

Table 4.7: Electricity market mix for the UK and the Exiobase classifications used. The reports Digest of United Kingdom Energy Statistics (2016) and Carbon Brief (2018) do not specify the share of each renewable energy, so it is assumed that it is split equally among them.

The electricity market mix is based on data on the UK energy market, which includes both electricity and heat production. As the mix is given in percentage, and not in MJ, it is assumed that the UK energy production represents the electricity market mix used in this consumption area, although differences may occur.
Additionally, the Carbon Brief (2018) report used for the electricity market mix measured energy production by primary energy. This overestimates the use of fossil fuels in the conversion to useful energy, which may overestimate the environmental impacts of electricity.

The environmental impacts of 1 kWh of electricity from the electricity market mix are shown in Table 4.8.

	Global warming [kg CO_2-eq]	**Non-renewable energy [MJ primary]**
Electricity mix	0.625	25.8

Table 4.8: The two impact category results for Global warming and Non-renewable energy of the LCA of 1kWh of the electricity mix, as seen in Table 4.7.

4.7 LCA and results for preparation

The final LCA looks into preparation of the food items. In this study it is chosen to work with the options of toasting, baking, or frying/boiling the five food items. These are referred to as toaster, oven, and stove-top, respectively. Milk is only consumed raw. The electricity market for food preparation is the same as described in Table 4.7 in Section 4.6. The LCA results of 1 kWh of electricity for preparation of food is the same as the LCA from storage, so results are seen in Table 4.8 in Section 4.6.

Scenario analyses with the EIFC-tool 5

This chapter presents the results of the different scenarios modelled in the EIFC-tool. First, the definition and information about the scenarios are explained, then various hypotheses are presented. The hypotheses are tested, and normalised results are presented along with the assumptions on which the scenarios are modelled. Within each product, the results from the AD family are presented followed by the FF single.
Results are presented in terms of both Global warming and Non-renewable energy impacts. For each product and household type, it is chosen to show results of one or both of these impact categories depending on similarity of trends. Both impact categories are shown only if trends differ between them. This chapter analyses the four food products bacon, bread, chicken breast, and milk; as the HHSM outputs for beef mince are not available at current time. The EIFC-tool is found as additional material in Section 8.1, alongside the EIFC-tool documentation (Section 8.2).

5.1 Scenarios

Different consumption behaviours within a household are modelled: these are called scenarios. The different scenarios are defined by the HHSM inputs and are associated with different behaviours.

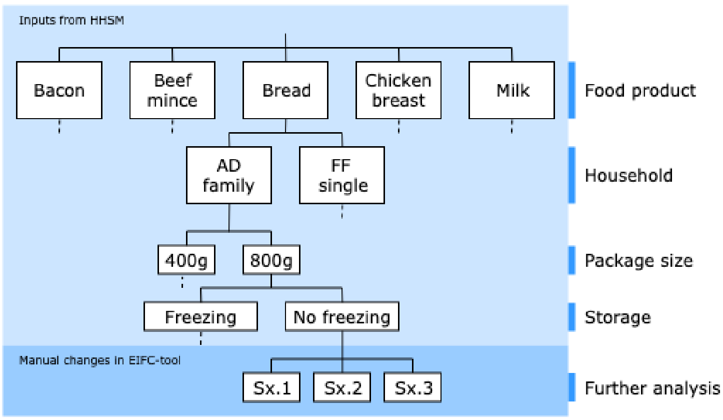


Figure 5.1: The scenarios start with the individual food product and become more specific in investigating various consumer behaviours. The variables are within package size and storage. Further analysis also allows changes within other consumption areas.

For each food item, two household types are analysed with 4-6 different scenarios each. The difference between the scenarios for each product is either package size purchased, or if the household freezes this product. These two behaviours can affect environmental impacts in all other consumption areas (the trade-offs). Figure 5.1 illustrates all scenarios made from HHSM inputs used for the trade-off analysis. In addition to the scenarios made within the HHSM, the behaviour of one consumption area can be changed within the EIFC-tool. The changes are made in the EIFC-tool to investigate how changes in package type, transportation mode, waste treatment, and preparation can affect the environmental impacts within a specific consumption area. This is used for further analysis, to reduce the impacts within one consumption area specifically.

5.1.1 Assumptions within the scenarios

For each scenario the following assumptions are used:

- Average food waste treatment
- 20 items bought per main shop (AD family)
- 10 items bought per main shop (FF single)
- 2 items bought per top-up shop
- Average mode of transport

More specific assumptions for each product type are explained in the scenario analysis.

5.2 Hypotheses for scenario analyses

A number of hypotheses are created as a foundation from which to start the analysis.

a) Decreasing the package size decreases the environmental impacts of food waste.
b) Storing food in the freezer decreases the environmental impacts of food waste.
c) Reducing the amount of plastic in packaging (by choosing a different package type) decreases environmental impacts.
d) Treating food waste as 100% composting decreases environmental impacts.
e) Using public transport and/or walking or biking decreases environmental impacts.
f) Larger serving sizes reduce the environmental impacts.

Hypotheses a) and b) are tested for each food product and family type, by exploring the trends in environmental impacts between different consumer behaviours.
Hypotheses c) to f) are tested for some of the products where specific consumption areas are shown to be significant. These are tested by using one of the scenarios as a baseline and changing one variable within the EIFC-tool:

- For hypothesis c): Changing the packaging type
- For hypothesis d): Changing the food waste treatment
- For hypothesis e): Changing the method of transport
- For hypothesis f): Changing the preparation sizes

5.3 Scenario analysis of Bacon

For each household type, six scenarios are analysed. The full HHSM output is found in Appendix 7.

5.3.1 Bacon scenarios: Aspirational Discoverers Family

Scenario 1: 200g package, no freezing
Scenario 2: 200g package, freezing
Scenario 3: 250g package, no freezing
Scenario 4: 250g package, freezing
Scenario 5: 300g package, no freezing
Scenario 6: 300g package, freezing

Table 5.1 shows the inputs used in the EIFC-tool, calculated from HHSM outputs.

	Unit	S1	S2	S3	S4	S5	S6
Total amount bought	kg	19.7	19.3	22.7	21.9	26.0	24.5
Packages bought	No.	99	98	91	88	87	82
Waste	%	4.6	2.2	9.7	4.6	17.3	8.7
Trips to main shop	No.	48	48	48	48	48	48
Trips to top-up shop	No.	44	44	41	38	38	33
Stored in freezer	%	0	2.4	0	5.8	0	12.1
Refrigerator opened	No.	74	73	91	88	108	102
Freezer opened	No.	0	14	0	32	0	60
Preparation (slices)	No.	564	573	660	674	716	745
Average amount consumed	kg	20.49					

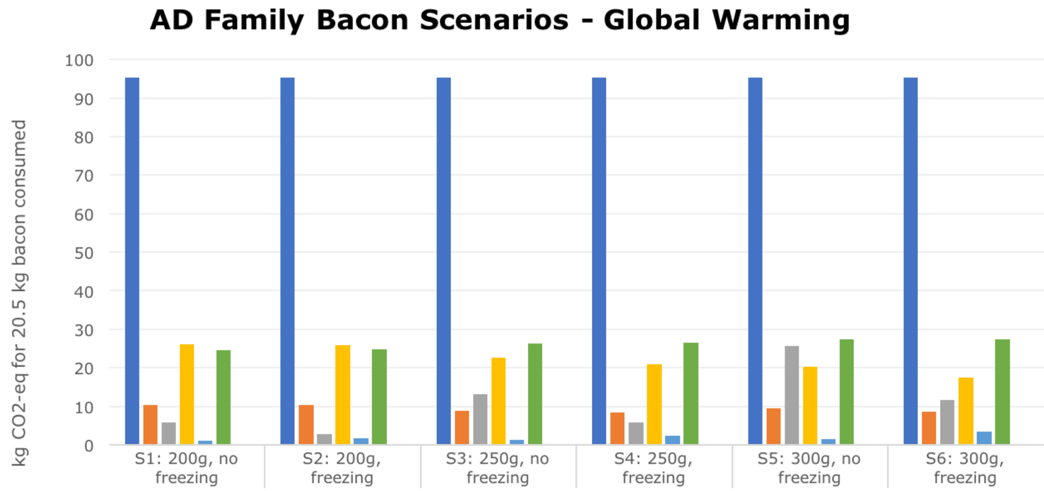
Table 5.1: Overview of data from the HHSM used for the analysis for the six bacon scenarios in the Aspirational Discoverers family. This data is input for the EIFC-tool, from which the results are normalised and presented below.

Assumptions for AD Family Bacon scenarios

- 84.7% plastic tray with film lid, 15.3% vacuum pack
- 8 slices prepared at a time
- 70.1% prepared in oven, 29.9% prepared on stove
- Refrigerator opened twice per 8 slices bought, and freezer opened twice per package frozen

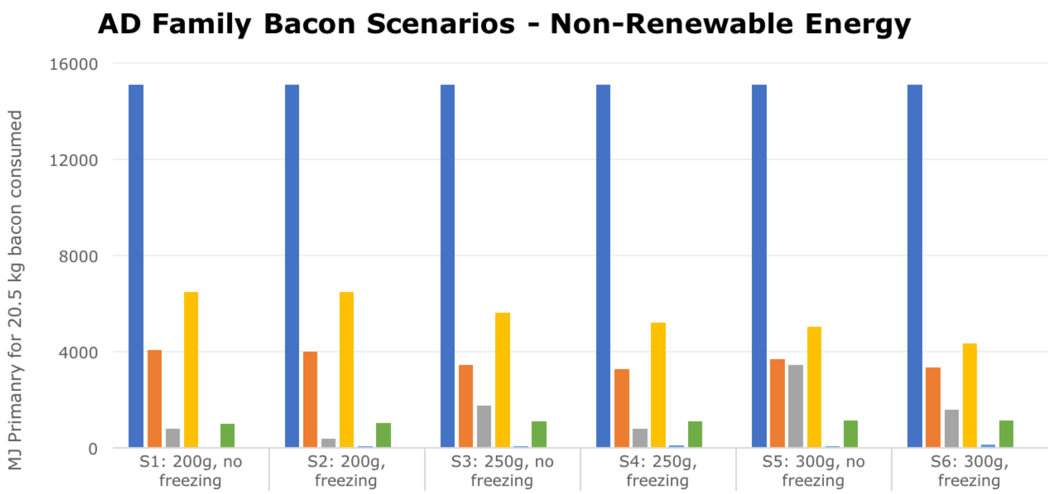
Results of AD Family Bacon scenarios

Figures 5.2 and 5.3 show the results for the six bacon scenarios within Global warming and Non-renewable energy. For the AD family, product is by far the most dominant consumption area within both impact categories. Transport is relatively high within both impact categories, and storage has the smallest impacts.



	S1: 200g, no freezing	S2: 200g, freezing	S3: 250g, no freezing	S4: 250g, freezing	S5: 300g, no freezing	S6: 300g, freezing
Product	95.3	95.3	95.3	95.3	95.3	95.3
Packaging	10.4	10.3	8.8	8.3	9.4	8.5
Food waste	5.9	2.8	13.2	5.9	25.6	11.7
Transportation	26.0	25.9	22.6	20.8	20.2	17.4
Storage	1.2	1.7	1.3	2.4	1.5	3.4
Preparation	24.6	24.9	26.4	26.4	27.3	27.3
Total	163.4	160.8	167.5	159.2	179.4	163.7

Figure 5.2: Normalised results for Global warming in the Aspirational Discoverers family bacon scenarios, who consume an average of 20.5 kg of bacon per year but have different consumption behaviour.



	S1: 200g, no freezing	S2: 200g, freezing	S3: 250g, no freezing	S4: 250g, freezing	S5: 300g, no freezing	S6: 300g, freezing
Product	15099	15099	15099	15099	15099	15099
Packaging	4076	4018	3435	3259	3690	3343
Food waste	795	371	1772	795	3450	1572
Transportation	6501	6473	5629	5198	5051	4349
Storage	49	71	55	100	62	142
Preparation	1016	1028	1091	1093	1128	1128
Total	27537	27060	27081	25545	28480	25633

Figure 5.3: Normalised results for Non-renewable energy in the Aspirational Discoverers family bacon scenarios, who consume an average of 20.5 kg of bacon per year but have different consumption behaviour.

5.3.2 Bacon scenarios: Functional Fuellers Single

Scenario 7: 200g packages, no freezing
Scenario 8: 200g packages, freezing
Scenario 9: 250g packages, no freezing
Scenario 10: 250g packages, freezing
Scenario 11: 300g packages, no freezing
Scenario 12: 300g packages, freezing

Table 5.2 shows the inputs for the EIFC-tool.

	Unit	S7	S8	S9	S10	S11	S12
Total amount bought	kg	7.2	7.2	8.4	8.1	9.6	9.1
Packages bought	No.	36	36	34	32	32	30
Waste	%	8.0	4.2	11.9	7.2	18.9	11.8
Trips to main shop	No.	24	24	24	23	23	23
Trips to top-up shop	No.	10	10	9	8	8	7
Stored in freezer	%	0	4.7	0	7.4	0	12.8
Refrigerator opened	No.	109	109	135	130	161	151
Freezer opened	No.	0	8	0	12	0	22
Preparation (slices)	No.	200	208	238	241	260	266
Average amount consumed	kg	7.38					

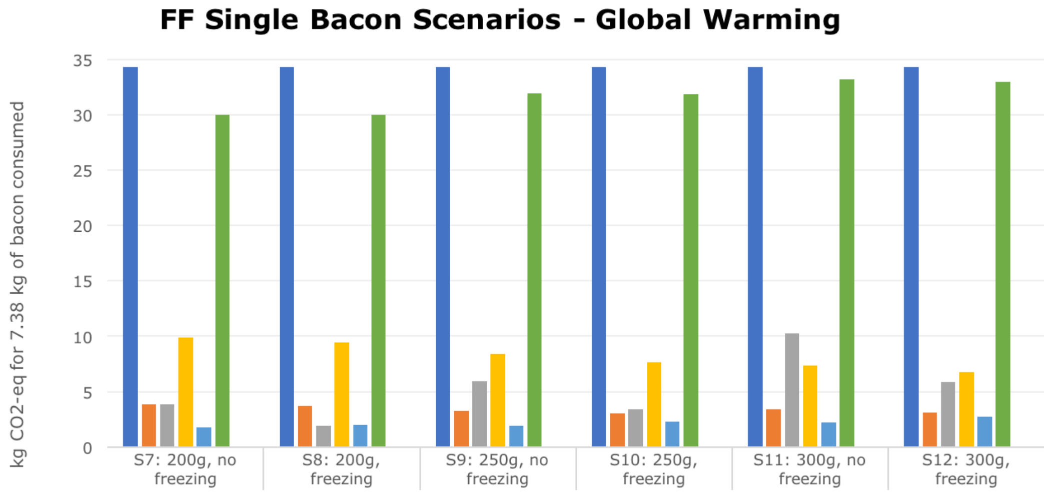
Table 5.2: Overview of data from the HHSM used for the analysis for the six bacon scenarios in the Functional Fuellers. This data is input for the EIFC-tool, from which the results are normalised and presented below.

Assumptions for FF Single Bacon scenarios

- 84.7% plastic tray with film lid, 15.3% vacuum pack
- 2 slices prepared at a time
- 70.1% prepared in oven, 29.9% prepared in stove
- Refrigerator opened twice per two slices bought, and freezer opened twice per package frozen

Results of FF Single Bacon scenarios

Production of bacon is the largest contributor to Global warming among the consumption areas, followed closely by preparation (Figure 5.4). For the most part, storage is the lowest contributor, though is a more significant consumption area when compared to the AD family.



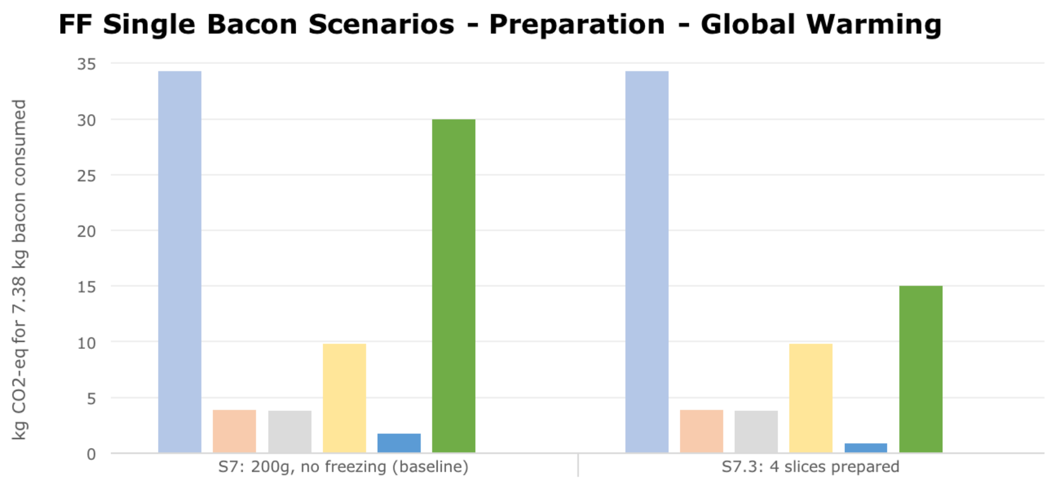
	S7: 200g, no freezing	S8: 200g, freezing	S9: 250g, no freezing	S10: 250g, freezing	S11: 300g, no freezing	S12: 300g, freezing
Product	34.3	34.3	34.3	34.3	34.3	34.3
Packaging	3.9	3.7	3.3	3.0	3.4	3.1
Food waste	3.8	1.9	6.0	3.4	10.3	5.9
Transportation	9.8	9.5	8.4	7.6	7.4	6.7
Storage	1.7	2.0	1.9	2.3	2.2	2.8
Preparation	30.0	30.0	32.0	31.9	33.2	32.9
Total	83.6	81.3	85.8	82.5	90.8	85.8

Figure 5.4: Normalised results for Global warming in the Functional Fuellers single bacon scenarios, who consume an average of 7.38 kg of bacon per year but have different consumption behaviour.

5.3.3 Hypotheses testing: Bacon

Hypothesis a) *'Decreasing the package size decreases the environmental impacts of food waste'* is proven true for both household types. However, impacts within packaging and transport increase in scenarios where 200g are bought compared to 250g or 300g packages. Hypothesis b) *'Storing food in the freezer decreases the environmental impacts of food waste'* is found to be true for both household types. Transport impacts decrease in the freezing scenarios, but impacts from both storage and preparation increase. The reduction from food waste outweighs the increase from storage and preparation.

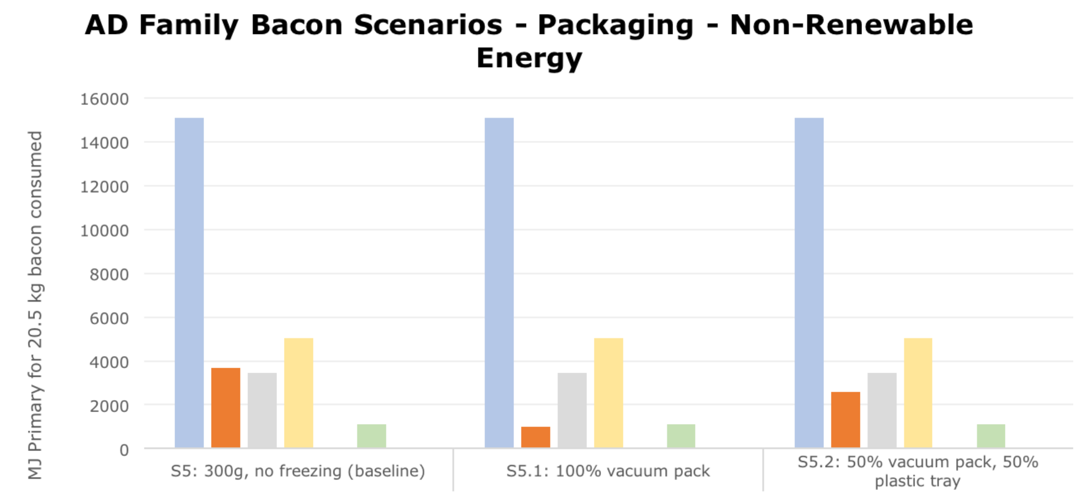
Preparation is a significant contributor to the total Global warming impacts, especially for the FF single who, on average consume more bacon per person per year than the AD family, and prepare fewer slices at a time. Hypothesis f) *'Larger serving sizes reduces the environmental impacts'* is tested in the FF single household by assuming that a FF single cooks four slices of bacon at a time, instead of two, which also effects storage because the refrigerator door is opened fewer times. Scenario 7 (FF single, 200g no freezing) is used as baseline, with Scenario 7.1 implementing the following changes: preparation size is four slices at a time which results in 100 preparations (instead of 200) and the refrigerator is opened 54 times (instead of 109). Figure 5.5 shows a reduction of 50% in Global warming impacts within the consumption areas storage and preparation. Although preparation and storage impacts decrease, this does not take into account that food waste may occur after preparation or, if eaten as leftovers, the refrigerator is still used for storing the leftovers.



	S7: 200g, no freezing (baseline)	S7.3: 4 slices prepared
Product	34.3	34.3
Packaging	3.9	3.9
Food Waste	3.8	3.8
Transportation	9.8	9.8
Storage	1.7	0.9
Preparation	30.0	15.0
Total	83.6	67.7

Figure 5.5: Normalised results for Global warming, for further scenario analysis in the FF single consuming bacon. The change is between Scenario 7 (preparing 2 slices at a time) and 7.1 (preparing 4 slices at a time).

Different bacon packaging types are explored to see how impacts can change by choosing a different packaging type, see Figure 5.6. This tests hypothesis c) *'Reducing the amount of plastic in packaging (by choosing a different package type) decreases environmental impacts'*. Here, Scenario 5 (where 84.7% is bought in plastic tray with film lid and 15.3% in vacuum pack) is the baseline, and Scenario 5.1 is buying 100% of bacon in vacuum pack, which results in reduced packaging impacts. Buying only in vacuum pack decreases Non-renewable energy impacts of packaging by 73% (see Figure 5.6). Scenario 5.2 models buying bacon in plastic tray half of the time and vacuum pack half of the time, where Non-renewable energy impacts reduce by 30% compared to baseline. By this further analysis, hypothesis c) is proven true.



	S5: 300g, no freezing (baseline)	S5.1: 100% vacuum pack	S5.2: 50% vacuum pack, 50% plastic tray
Product	15099	15099	15099
Packaging	3690	1000	2588
Food Waste	3450	3450	3450
Transportation	5051	5051	5051
Storage	62	62	62
Preparation	1128	1128	1128
Total	28480	25791	27378

Figure 5.6: Normalised results for Non-Renewable Energy, for further scenario analysis in the AD family consuming bacon. The change is within the packaging type bought, between Scenario 5 (84.7% plastic tray with film lid and 15.3% in vacuum pack), Scenario 5.1. (100% in vacuum pack), and Scenario 5.2. (50% plastic tray and 50% vacuum pack).

In conclusion for both AD family and FF single consuming bacon, a reduction in environmental impacts of packaging and food waste are seen in scenarios where bacon is frozen. Food waste decreases through buying smaller packaging, but this either positively or negatively affects other consumption areas. Environmental impacts of bacon consumption can be lowered by preparing bacon less often (and in larger servings), and buying in vacuum pack instead of a plastic tray.

5.4 Scenario analysis of Bread

For each household type, four scenarios are analysed. The HHSM outputs from different household scenarios of bread consumption are found in Appendix 8.

5.4.1 Bread scenarios: Aspirational Discoverers Family 5

Scenario 1: 400g packages, no freezing
Scenario 2: 400g packages, freezing
Scenario 3: 800g packages, no freezing
Scenario 4: 800g packages, freezing

Table 5.4 shows HHSM data used in the EIFC-tool.

	Unit	S1	S2	S3	S4
Total amount bought	kg	96.4	96.4	107	105.5
Packages bought	No.	241	241	134	132
Waste	%	0.048	0.011	1.9	0.48
Trips to main shop	No.	39	39	36	36
Trips to top-up shop	No.	202	202	98	96
Stored in freezer	%	0	0.03	0	1.3
Freezer opened	No.	0	1	0	2
Preparation (slices)	No.	2407	2409	2624	2624
Average amount consumed	kg	100.68			

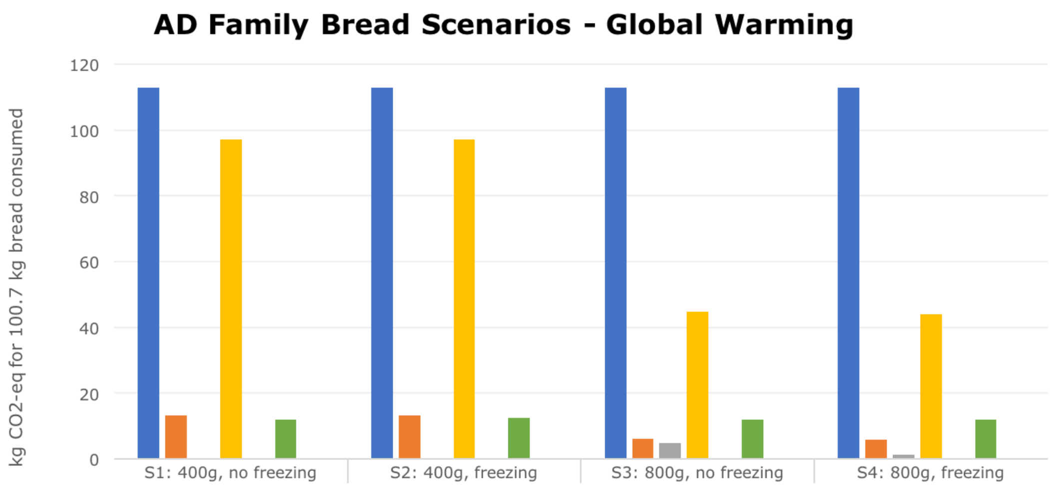
Table 5.3: Overview of data from the HHSM used for the analysis of the four bread scenarios in the Aspirational Discoverers family. This data is input for the EIFC-tool, from which the results are normalised and presented below.

Assumptions for AD family bread scenarios

- 400g package: 86% plastic bag, 14% paper packaging
- 800g package: 43% plastic bag, 43% plastic film, 14% paper packaging
- 45.9% eaten raw, 54.1% prepared in toaster
- No refrigerator use, freezer opened 2 times per 10 slices frozen

Results of AD Family bread scenarios

Figure 5.7 shows the results for the four bread scenarios for Global warming impacts.



	S1: 400g, no freezing	S2: 400g, freezing	S3: 800g, no freezing	S4: 800g, freezing
Product	112.9	112.9	113.0	113.0
Packaging	13.2	13.2	6.1	6.0
Food waste	0.1	0.03	4.8	1.2
Transportation	97.2	97.1	44.8	43.9
Storage	0.0	0.04	0.0	0.1
Preparation	12.1	12.5	12.1	12.1
Total	235.5	235.9	180.7	176.2

Figure 5.7: Normalised results for Global warming in the Aspirational Discoverers family bread scenarios, who consume an average of 100.7 kg of bread per year but have different consumption behaviour.

The biggest contributor is products, followed by transport. Packaging and preparation have a similar contribution in Scenarios 1 and 2, but packaging impacts drop to half in Scenarios 3 and 4. For the most part, food waste has a negligible contribution to the total environmental impacts of bread consumption.

5.4.2 Bread scenarios: Functional Fuellers Single

Scenario 5: 400g packages, no freezing
Scenario 6: 400g packages, freezing
Scenario 7: 800g packages, no freezing
Scenario 8: 800g packages, freezing

The numbers in Table 5.4 present the inputs for the EIFC-tool for the consumption of bread for the FF single.

	Unit	S5	S6	S7	S8
Total amount bought	kg	35.5	26.3	61.7	25.7
Packages bought	No.	88	66	77	32
Waste	%	24	5	55	13
Trips to main shop	No.	39	39	33	31
Trips to top-up shop	No.	50	27	44	2
Stored in freezer	%	0	17.3	0	36.3
Freezer opened	No.	0	57	0	117
Preparation (slices)	No.	669	621	699	557
Average amount consumed	kg	25.52			

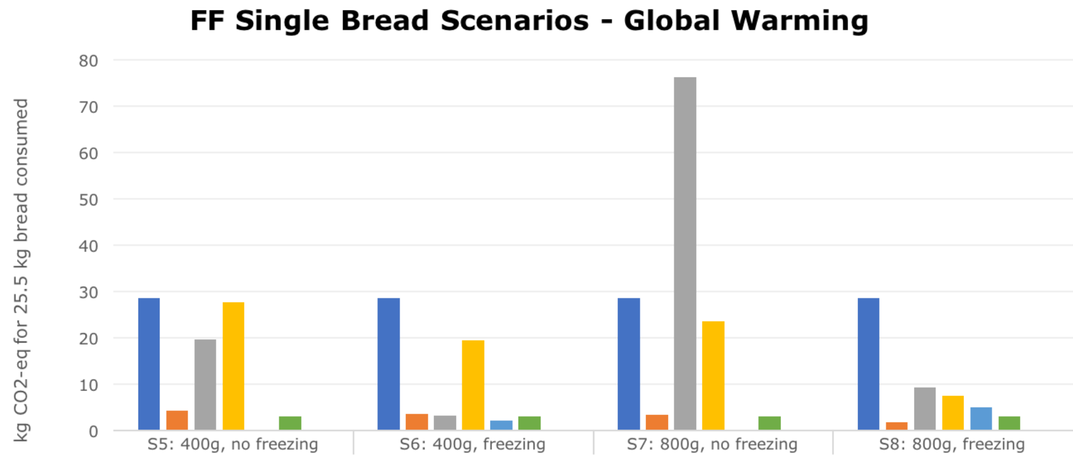
Table 5.4: Overview of data from the HHSM used for the analysis for the four bread scenarios in the Functional Fueller single. This data is input for the EIFC-tool, from which the results are normalised and presented below.

Assumptions for FF Single bread scenarios

- 400g packages: 86% plastic bag, 14% paper packaging
- 800g packages: 43% plastic bag, 43% plastic film, 14% paper packaging
- 45.9% eaten raw, 54.1% prepared in toaster.
- No refrigerator use, freezer opened 2 times per 4 slices frozen

Results of FF Single bread scenarios

Figure 5.8 shows the results for the four bread scenarios in Global warming impacts. Either transport or food waste is consistently the second largest contributor to total impacts. Food waste is much more significant for the FF single than for the AD family.



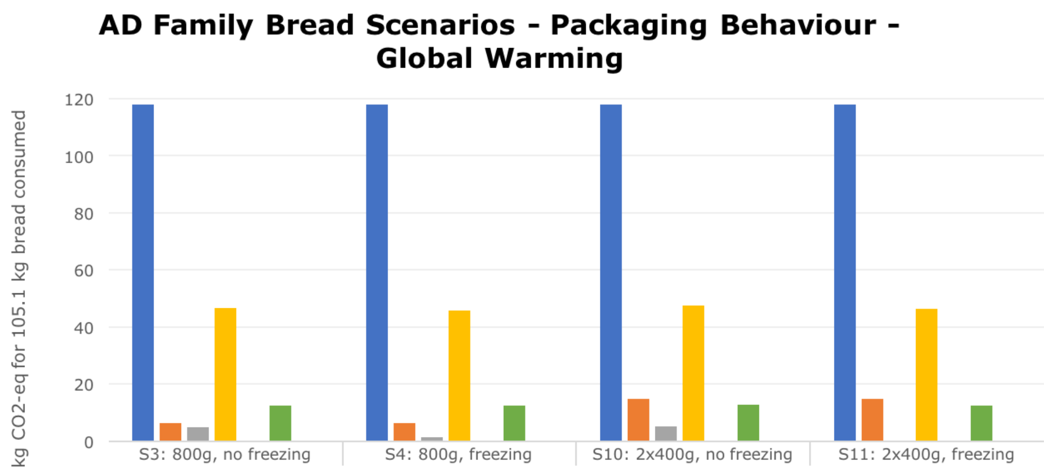
	S5: 400g, no freezing	S6: 400g, freezing	S7: 800g, no freezing	S8: 800g, freezing
Product	28.6	28.6	28.6	28.6
Packaging	4.4	3.5	3.3	1.7
Food waste	19.7	3.3	76.3	9.3
Transport	27.7	19.5	23.5	7.5
Storage	0.0	2.2	0.0	5.0
Preparation	3.0	3.0	3.1	3.0
Total	83.5	60.2	134.9	55.3

Figure 5.8: Normalised results for Global warming in the Functional Fuellers single bread scenarios, who consume an average of 25.5 kg of bread per year but have different consumption behaviour.

5.4.3 Hypotheses testing: Bread

For both household types, hypothesis a) '*decreasing the package size decreases the environmental impacts of food waste*' is found to be true. Although food waste decreases with smaller packages, transport and packaging impacts both increase. In the AD family, the difference in food waste between freezing and not freezing scenarios is small compared to the total impacts. This is because just a very small percentage of bread is frozen, where additional impacts in storage are extremely small compared to the total. For the FF single, the reduction in food waste impacts from freezing is clearly seen along with a reduction in transport and packaging impacts. Hypothesis b) '*storing food in the freezer decreases the environmental impacts of food waste* is true for both AD and FF households.

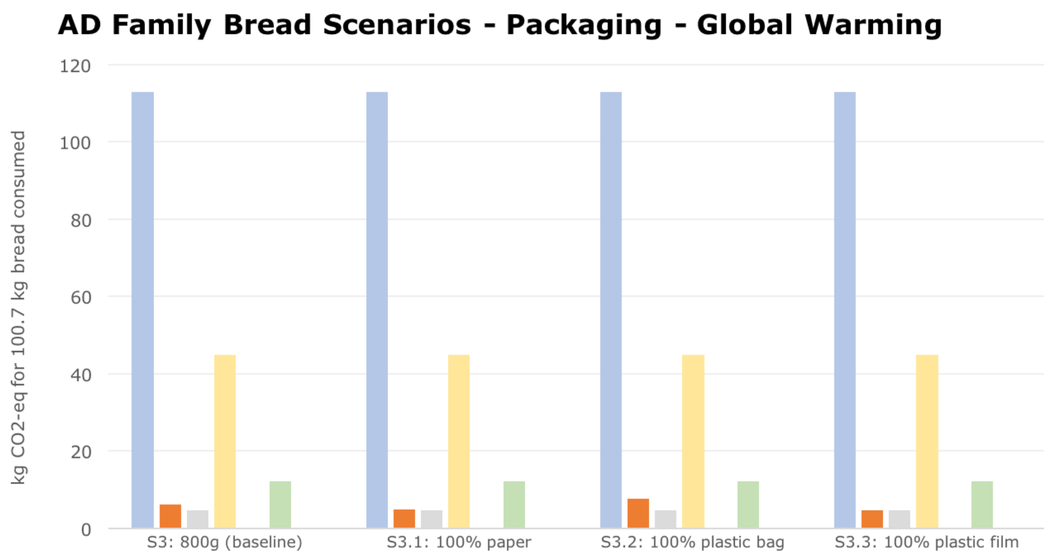
A limitation in the comparison of the given scenarios for bread is that the total amount purchased per shopping trip is either 400g or 800g, so in the AD family transport impacts are over twice as high in Scenarios 1 and 2 when 400g loaves are purchased. This is because families in Scenarios 1 and 2 must go to the top-up shop more often, so additional scenarios are assessed to see how impacts are affected when the same amount of bread is bought per trip but in different packaging sizes. Scenarios 3 and 4 (AD family buying in one 800g package) are compared with additional Scenarios 10 and 11 (AD family buying in two 400g packages), and HHSM outputs can be seen in Appendix 9. The Global warming impacts are seen on Figure 5.9. The same analysis is done for the FF single but the results are not shown, as the conclusions are the same for both family types. The significant difference is in packaging impacts, where the scenarios buying two 400g packages have over double the packaging impacts than the scenarios buying one 800g package. In this case, it is recommended for an AD family to buy one larger package instead of two smaller packages.



	S3: 800g, no freezing	S4: 800g, freezing	S10: 2x400g, no freezing	S11: 2x400g, freezing
Product	117.9	117.9	117.9	117.9
Packaging	6.3	6.3	14.9	14.7
Food waste	5.0	1.2	5.2	0.0
Transportation	46.7	45.8	47.5	46.4
Storage	0.0	0.1	0.0	0.2
Preparation	12.6	12.6	12.6	12.5
Total	188.6	183.9	198.2	191.7

Figure 5.9: Normalised results for Global warming, for further scenario analysis in the AD family consuming bread. This compares buying bread in one 800g package versus two 400g packages each shopping trip. Scenarios 3 and 4 are 'original' AD family scenarios, and Scenarios 10 and 11 are the further analyses.

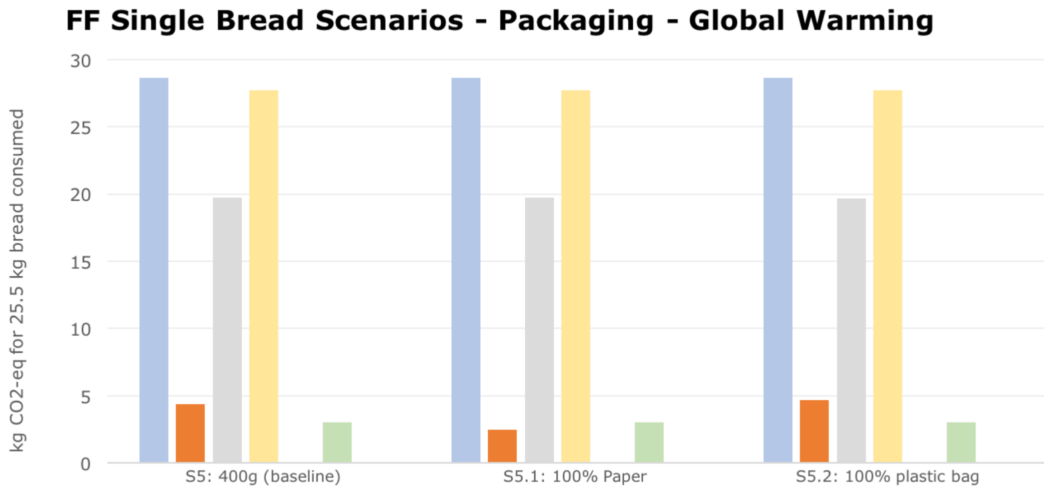
Hypothesis c) '*Reducing the amount of plastic in packaging (by choosing a different package type) decreases environmental impacts*' is tested to see how impacts change when investigating different packaging types. Scenario 3 (800g) is used as a baseline (43% bought in plastic bag, 43% plastic film and 14% in paper) where the only variable changed in the other scenarios is the packaging type.



	S3: 800g (baseline)	S3.1: 100% paper	S3.2: 100% plastic bag	S3.3: 100% plastic film
Product	113.0	113.0	113.0	113.0
Packaging	6.1	5.0	7.8	4.7
Food Waste	4.8	4.8	4.8	4.8
Transportation	44.8	44.8	44.8	44.8
Storage	0.0	0.0	0.0	0.0
Preparation	12.1	12.1	12.1	12.1
Total	180.7	179.6	182.4	179.3

Figure 5.10: Normalised results for Global warming, for further scenario analysis in the AD family consuming bread. The change is within the packaging type bought between Scenarios 3, 3.1, 3.2, and 3.3.

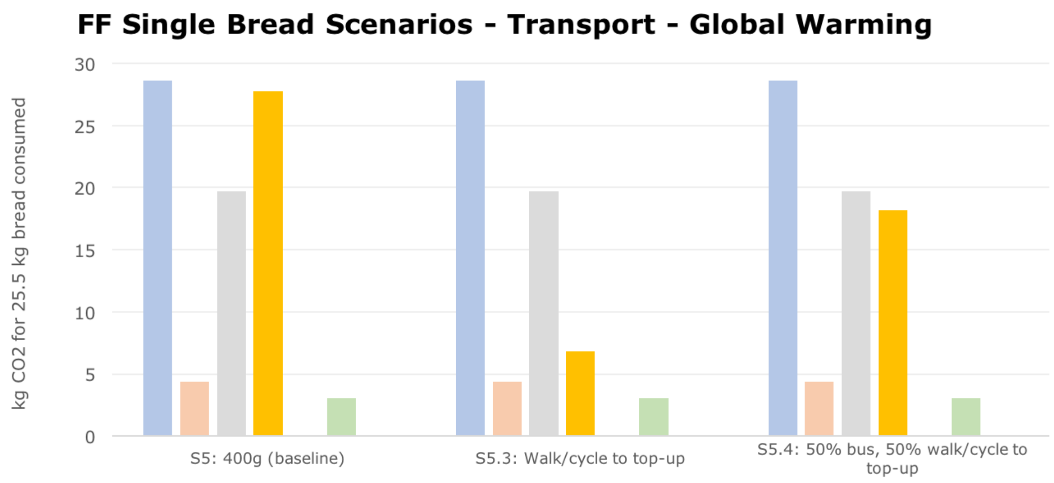
Figure 5.10 shows the changes in Global warming impacts, where all consumption areas are the same except packaging. When 100% is bought in paper bag, packaging Global warming impacts decrease by 18% (Scenario 3.1). Buying 100% in plastic bag (Scenario 3.2) increases the packaging impacts; and buying 100% in plastic film (Scenario 3.3) decreases the packaging impacts by 23% (which is a larger reduction than paper packaging). The effects of changing packaging type is also analysed for the FF single, where Scenario 5 (500g, no freezing) is used as a baseline.



	S5: 400g (baseline)	S5.1: 100% Paper	S5.2: 100% plastic bag
Product	28.6	28.6	28.6
Packaging	4.4	2.5	4.7
Food Waste	19.7	19.7	19.7
Transportation	27.7	27.7	27.7
Storage	0.0	0.0	0.0
Preparation	3.0	3.0	3.0
Total	83.5	81.6	83.7

Figure 5.11: Normalised results Global warming, for further scenario analysis in the FF single consuming bread. The change is in packaging type.

The difference between the AD family and FF single household is that a 400g package is only available in plastic bag or paper, so only these two types are explored in the FF single. The total Global warming impacts seen in Figure 5.11 vary depending on the packaging type chosen, with 100% paper having the least impacts within packaging. Hypothesis c) is true if buying in 400g packages, but not for buying in 800g packages because plastic film actually has lower impacts than paper. However, plastic film does have lower impacts than plastic bag (due to a decrease in plastic used).

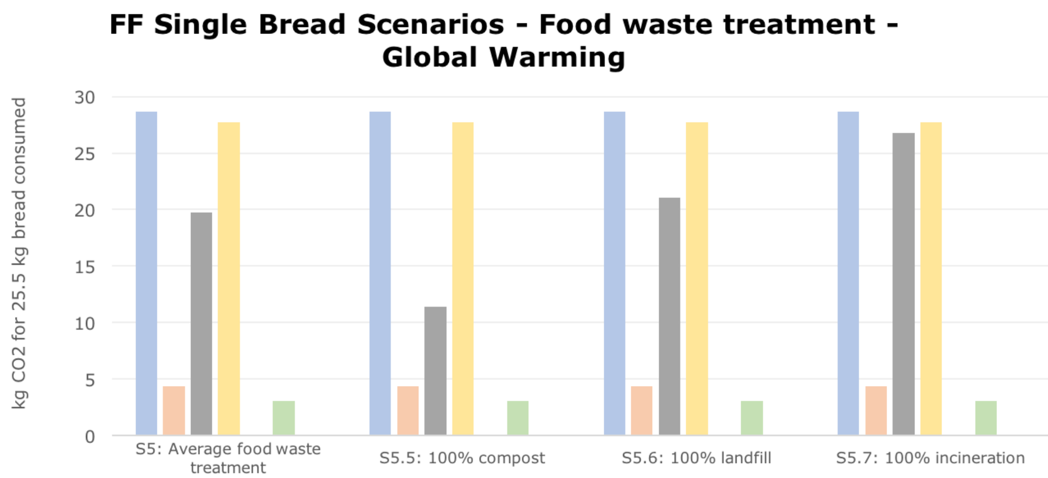


	S5: 400g (baseline)	S5.3: Walk/cycle to top-up	S5.4: 50% bus, 50% walk/cycle to top-up
Product	28.6	28.6	28.6
Packaging	4.4	4.4	4.4
Food Waste	19.7	19.7	19.7
Transportation	27.7	6.8	18.2
Storage	0.0	0.0	0.0
Preparation	3.0	3.0	3.0
Total	83.5	62.6	73.9

Figure 5.12: Normalised results for Global warming, for further scenario analysis in the FF single consuming bread, the change is within the transportation type.

Transport is a significant contributor to the total impacts of bread consumption in all scenarios. As more trips are taken to the top-up shop than to the main shop and fewer items are bought per trip, Figure 5.12 shows the difference between Scenario 5 (where the average transport method is used), Scenario 5.3 (where all top-up shopping is done by walking or cycling), and Scenario 5.4 (where half of top-up shopping is done by public transport, and half is done by walking or cycling).

Global warming impacts within transport decrease by approximately 75% if all top-up shops are done by walking. This confirms the hypothesis that '*using public transport and/or walking or biking decreases environmental impacts*'.



	S5: Average food waste treatment	S5.5: 100% compost	S5.6: 100% landfill	S5.7: 100% incineration
Product	28.6	28.6	28.6	28.6
Packaging	4.4	4.4	4.4	4.4
Food Waste	19.7	11.4	21.0	26.8
Transportation	27.7	27.7	27.7	27.7
Storage	0.0	0.0	0.0	0.0
Preparation	3.0	3.0	3.0	3.0
Total	83.5	75.2	84.8	90.6

Figure 5.13: Normalised results for Global warming, for further scenario analysis in the FF single consuming bread. The change is within food waste treatment.

Another scenario to explore reducing environmental impacts is treating food waste differently (see Figure 5.13). FF families have more bread waste than AD families, so changes in waste treatment is compared to the baseline FF single (Scenario 5). Assuming waste treatment is 100% compost (instead of the UK waste treatment mix including landfill, composting, and incineration), Global warming impacts decrease by 42% within the consumption area of food waste. If food waste is all sent to landfill, Global warming impacts of food waste increase by 6% and if food waste is all incinerated, Global warming impacts of food waste increase by 27%. This shows that the hypothesis d) '*treating food waste as 100% composting decreases environmental impacts*' is true within the impact category Global warming.

It is concluded that freezing bread decreases the environmental impacts of food waste, packaging, and transport for both family types. For the AD family, buying in smaller packages has minimal effect on food waste, and impacts in other consumption areas increase by buying in smaller packages. It is not recommended to buy in 400g packages, for the AD family. Buying bread in plastic film has the least packaging impacts, followed by bread bought in a paper bag. Walking or cycling to the top-up shop decreases transport impacts, so it is recommended to do that as often as possible. Composting bread decreases the Global warming impacts.

5.5 Scenario analysis of Chicken breast

Chicken breast is analysed for both household types, each with six scenarios. The HHSM outputs show that the AD family does not buy in single 300g packages but two at a time, which is reflected in the scenario descriptions below. The full HHSM outputs are found in Appendix 10.

5.5.1 Chicken breast scenarios: Aspirational Discoverers Family

Scenario 1: 2 x 300g package, no freezing
Scenario 2: 2 x 300g package, freezing
Scenario 3: 500g package, no freezing
Scenario 4: 500g package, freezing
Scenario 5: 1000g package, no freezing
Scenario 6: 1000g package, freezing

Table 5.5 shows the inputs for the tool, found from HHSM outputs. HHSM output is in number of breasts purchased and it is assumed that 2 breasts = 300g package, 4 breasts = 500g package, and 6 breasts = 1000g package (this assumption is further discussed in Section 6.3.2).

	Unit	S1	S2	S3	S4	S5	S6
Total amount bought	kg	50.7	48.5	44.1	41.3	87.3	63.2
Packages bought	No.	169	162	88	83	87	63
Waste	%	6.3	2.9	5.8	2.0	24.9	6.2
Trips to main shop	No.	52	52	48	46	47	42
Trips to top-up shop	No.	27	25	20	18	25	14
Stored in freezer	%	0	4.5	0	4.3	0	17.5
Refrigerator opened	No.	169	162	176	165	261	189
Freezer opened	No.	0	14	0	6	0	22
Preparation (breasts)	No.	316	317	333	324	393	355
Average amount consumed	kg	50.24					

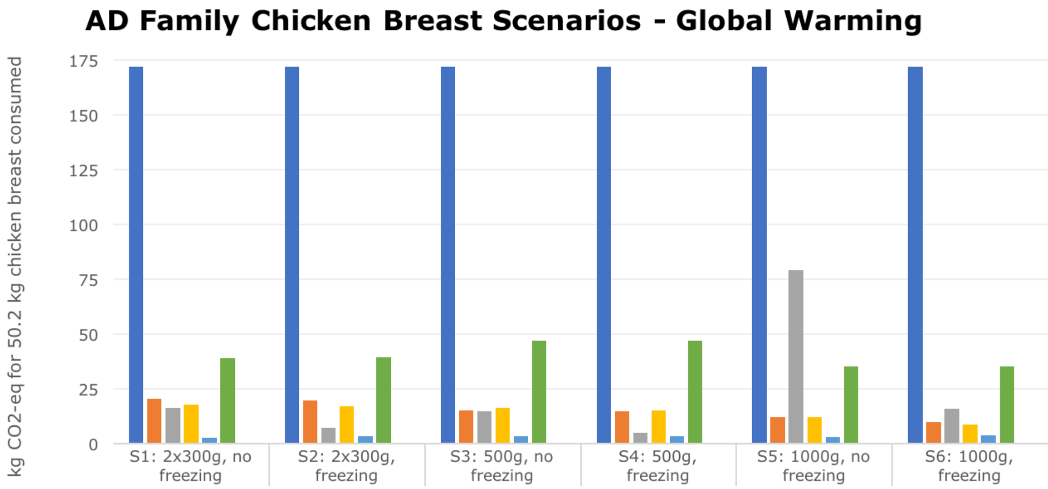
Table 5.5: Overview of data from the HHSM used for the analysis for the six chicken scenarios in the Aspirational Discoverers family. This data is input for the EIFC-tool, from which the results are normalised and presented below.

Assumptions for AD Family Chicken breast scenarios

- 300g package: 100% plastic tray
- 500 and 1000g packages: 70.5% plastic tray, 29.5% plastic bag
- 4 breasts prepared at a time
- 65.3% prepared in oven, 34.7% prepared on stove
- Refrigerator opened twice per 4 breasts bought, and freezer opened twice per package frozen

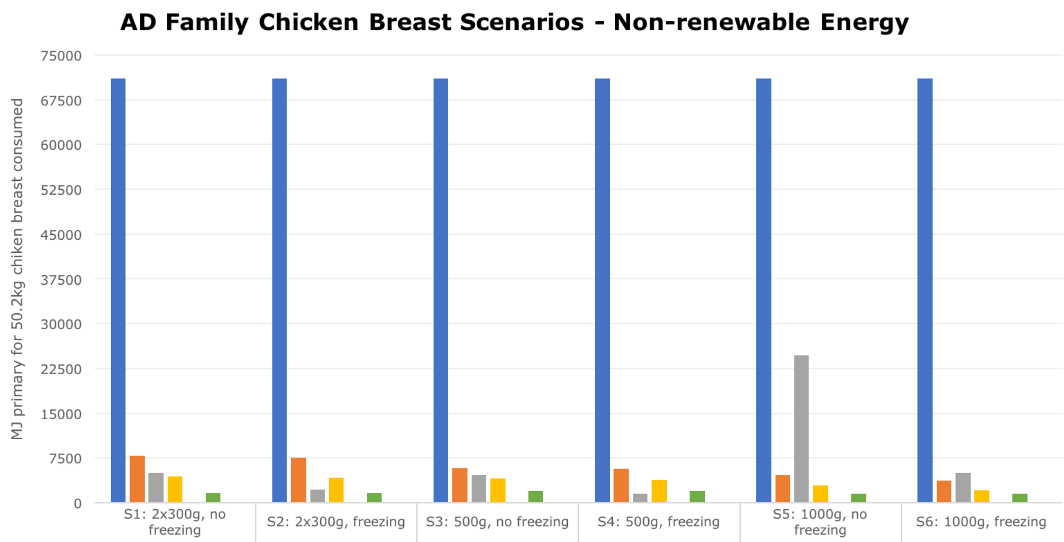
Results of AD Family Chicken breast scenarios

Figures 5.14 and 5.15 shows the Global warming and Non-renewable energy impacts for the AD family chicken breast scenarios.



	S1: 2x300g, no freezing	S2: 2x300g, freezing	S3: 500g, no freezing	S4: 500g, freezing	S5: 1000g, no freezing	S6: 1000g, freezing
Product	172.0	172.0	172.0	172.0	172.0	172.0
Packaging	20.2	19.5	15.0	14.5	11.9	9.6
Food waste	16.0	7.1	14.7	4.9	79.1	15.8
Transportation	17.7	16.9	16.1	15.1	11.8	8.5
Storage	2.6	3.2	3.1	3.4	3.0	3.5
Preparation	38.8	39.2	46.7	46.7	34.9	34.9
Total	267.3	258.0	267.6	256.6	312.7	244.2

Figure 5.14: Normalised results for Global warming in the Aspirational Discoverers family chicken breast scenarios, who consume an average of 50.2 kg of chicken breast per year but have different consumption behaviour.



	S1: 2x300g, no freezing	S2: 2x300g, freezing	S3: 500g, no freezing	S4: 500g, freezing	S5: 1000g, no freezing	S6: 1000g, freezing
Product	71081	71081	71081	71081	71081	71081
Packaging	7841	7582	5817	5631	4632	3709
Food waste	5009	2225	4587	1520	24701	4924
Transportation	4418	4221	4006	3780	2944	2129
Storage	109	132	129	140	122	143
Preparation	1604	1623	1932	1930	1445	1444
Total	90062	86864	87552	84082	104925	83430

Figure 5.15: Normalised results for Non-renewable energy in the Aspirational Discoverers family chicken breast scenarios, who consume an average of 50.2 kg of chicken breast per year but have different consumption behaviour.

Chicken breast production is by far the largest contributor to Global warming and Non-renewable energy impacts. Preparation is noticeably high in Global warming, and within Scenario 5 food waste is also significant. In Non-renewable energy, packaging usually has the highest impacts after product except for two scenarios with a higher amount of food waste (Scenarios 5 and 6).

5.5.2 Chicken breast scenarios: Functional Fuellers Single

Scenario 7: 300g packages, no freezing
Scenario 8: 300g packages, freezing
Scenario 9: 500g package, no freezing
Scenario 10: 500g package, freezing
Scenario 11: 1000g package, no freezing
Scenario 12: 1000g package, freezing

Table 5.6 shows the inputs for the tool, found from HHSM outputs.

	Unit	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**
Total amount bought	kg	23.7	17.4	33.2	14.5	65.3	26.1
Packages bought	No.	79	58	66	29	65	26
Waste	%	29.2	7.1	61.9	20.9	74.8	42.2
Trips to main shop	No.	48	45	49	29	48	26
Trips to top-up shop	No.	15	7	17	0	17	0
Stored in freezer	%	0	20.1	0	45.9	0	55.3
Refrigerator opened	No.	316	234	531	232	782	313
Freezer opened	No.	0	24	0	27	0	29
Preparation (breasts)	No.	112	109	101	91	98	89
Average amount consumed	No.	14.8					

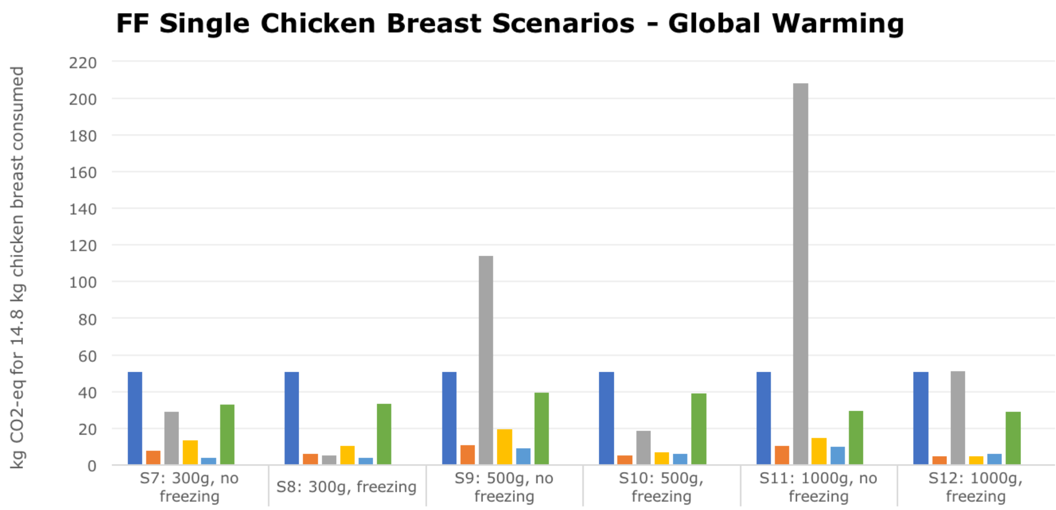
Table 5.6: Overview of data from the HHSM used for the analysis for the six chicken scenarios in the Functional Fuellers single. This data is input for the EIFC-tool, from which the results are normalised and presented below.

Assumptions for FF Single Chicken breast scenarios

- 300g package: 100% plastic tray
- 500 and 1000g packages: 70.5% plastic tray, 29.5% plastic bag
- 1 breast prepared at a time
- 65.3% prepared in oven, 34.7% prepared on stove
- Refrigerator opened twice per 1 breast bought, and freezer opened twice per package frozen

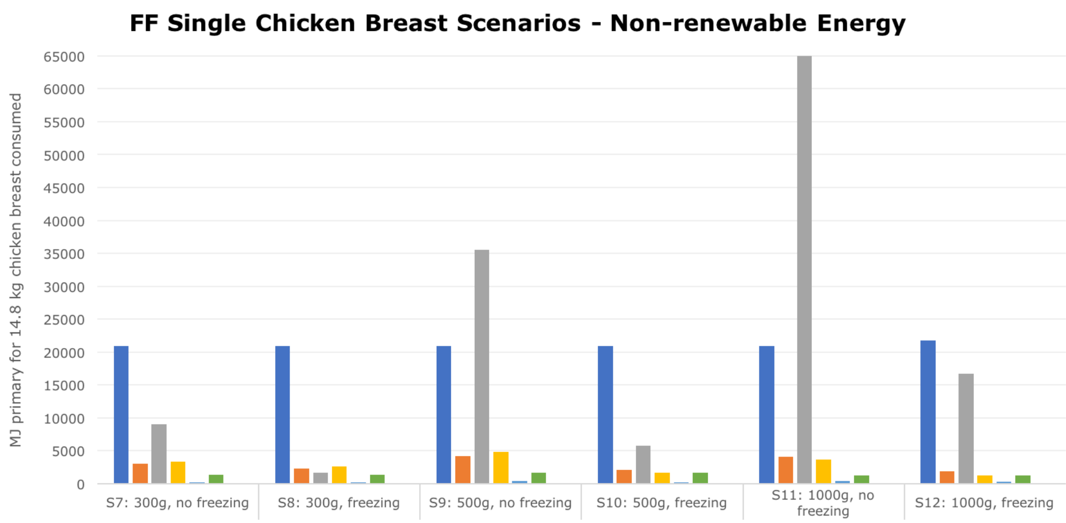
Results of FF Single Chicken breast scenarios

Figures 5.16 and 5.17 show the Global warming and Non-renewable energy impact results for the FF single scenarios for chicken breast. In both Global warming and Non-renewable energy, food waste is a significant consumption area especially for Scenario 11 (1000g, no freezing). Preparation is significant in Global warming, and transport and preparation impacts stay fairly stable throughout scenarios in Non-renewable energy.



	S7: 300g, no freezing	S8: 300g, freezing	S9: 500g, no freezing	S10: 500g, freezing	S11: 1000g, no freezing	S12: 1000g, freezing
Product	50.6	50.6	50.6	50.6	50.6	50.6
Packaging	7.8	6.0	10.9	5.3	10.4	4.6
Food waste	28.9	5.4	113.9	18.5	208.1	51.2
Transportation	13.6	10.4	19.3	6.9	14.7	4.7
Storage	4.0	4.0	9.0	6.0	10.2	6.1
Preparation	32.9	33.3	39.4	39.1	29.4	29.1
Total	137.9	109.6	243.0	126.3	323.3	146.2

Figure 5.16: Normalised results for Global warming in the Functional Fuellers Single chicken breast scenarios, who consume an average of 14.7 kg of chicken breast per year but have different consumption behaviour.



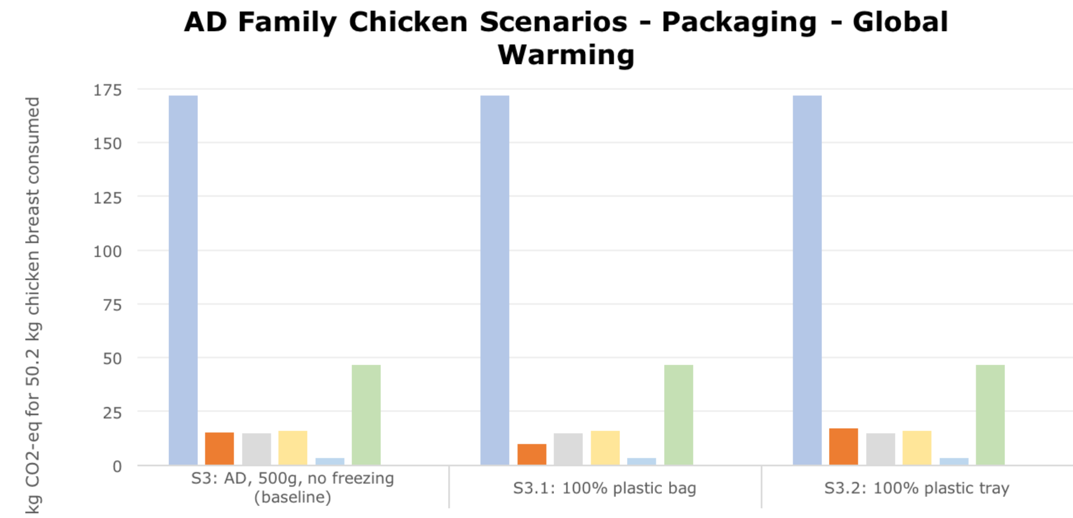
	S7: 300g, no freezing	S8: 300g, freezing	S9: 500g, no freezing	S10: 500g, freezing	S11: 1000g, no freezing	S12: 1000g, freezing
Product	20892	20892	20892	20892	20892	21803
Packaging	3050	2325	4211	2041	4052	1845
Food waste	9031	1673	35575	5786	64995	16684
Transportation	3400	2596	4821	1716	3665	1221
Storage	166	167	370	247	420	264
Preparation	1362	1375	1629	1618	1215	1256
Total	37900	29028	67498	32299	95239	43072

Figure 5.17: Normalised results for Non-renewable energy in the Functional Fuellers Single chicken breast scenarios, who consume an average of 14.7 kg of chicken breast per year but have different consumption behaviour.

5.5.3 Hypotheses testing: Chicken breast

Hypothesis a) '*decreasing the package size decreases the environmental impacts of food waste*' is true in the FF single. For the AD family it cannot be proven true or false because the impacts in food waste for Scenario 3 (500g package) are lower than for Scenario 1 (2 x 300g packages) and Scenario 5 (1000g package). Buying in a 500g package reduces the food waste compared to buying two 300g packages, which are smaller packages but the total amount bought is higher. A decrease in food waste impacts is seen when buying in 500g packages versus 1000g packages. As smaller package sizes are bought, the packaging impacts increase. This is due to more packaging per product but additionally, only plastic tray is available for the 300g packages. Both plastic tray and plastic bag are available for the 500g and 1000g packages, and plastic bag has less plastic per packaging.

Hypothesis b) states '*storing food in the freezer decreases the environmental impacts of food waste*'. This is evident in Figures 5.14 and 5.16 where freezing scenarios always have lower food waste impacts compared to the corresponding scenario without freezing. Using the freezer to keep chicken breasts good for longer can reduce the food waste impacts in the impact categories investigated by 56-80% for the AD Family, and 75-84% for the FF single depending on the package size bought. When chicken breast is frozen, the impacts within packaging are reduced especially for the FF single household. Within the FF single household, storage impacts decrease when the freezer is used because in most of the freezing scenarios, less than half the amount of packages are bought and wasted. There is less refrigerator use and amount of refrigerator or freezer openings, because less is bought.



	S3: AD, 500g, no freezing (baseline)	S3.1: 100% plastic bag	S3.2: 100% plastic tray
Product	172.0	172.0	172.0
Packaging	15.0	9.9	17.1
Food waste	14.7	14.7	14.7
Transportation	16.0	16.1	16.0
Storage	3.1	3.1	3.1
Preparation	46.7	46.7	46.7
Total	267.6	262.5	269.7

Figure 5.18: Normalised results for Global warming in the Aspirational Discoverers family chicken breast scenarios, for two packaging trade-off scenarios in the AD family buying 100% plastic bag or 100% plastic tray packaging for 500g.

Figure 5.18 investigates the changes in Global warming impacts for Scenario 3 (70.5% plastic tray and 29.5% plastic bag) when changing to 100% plastic tray and 100% plastic bag. Buying just in plastic bag shows a reduction in impacts in Global warming of 34% within packaging, and for plastic tray the impacts increase by 12.3%.
This tests hypothesis c) '*Reducing the amount of plastic in packaging (by choosing a different package type) decreases environmental impacts*' and proves it to be true, as plastic bag contains a lesser weight of plastic than a plastic tray does.

It is concluded that freezing reduces food waste and packaging impacts within the AD family and FF single. For the AD family it is most ideal to buy in 500g packages, through looking at the trends within the different consumption areas. For the FF single, buying in 300g packages most accurately represents the requirement. Buying chicken breast more frequently in plastic bags reduces Global warming impacts.

5.6 Scenario analysis of Milk

For each household type, four scenarios are analysed. Outputs from the HHSM are found in Appendix 11.

5.6.1 Milk scenarios: Aspirational Discoverers Family

Scenario 1: 8 bottles of 1 pint, no freezing
Scenario 2: 8 bottles of 1 pint, freezing
Scenario 3: 4 bottles of 2 pints, no freezing
Scenario 4: 4 bottles of 2 pints, freezing

The number of bottles indicates the amount purchased per shopping trip but the total amount purchased per trip is the same for each of the scenarios. Table 5.7 shows the inputs for the tool, found from HHSM outputs.

	Unit	**S1**	**S2**	**S3**	**S4**
Total amount bought	kg	450.9	446.5	449.4	446.5
Total amount packages bought	No.	771	763	384	382
Waste	%	1.55	1	1.2	0.64
Trips to main shop	No.	52	45	52	52
Trips to top-up shop	No.	52	59	56	56
Stored in freezer	%	0	1.5	0	0.9
Refrigerator opened	No.	1542	1526	1536	1528
Freezer opened	No.	0	32	0	12
Average amount consumed	kg	443.40			

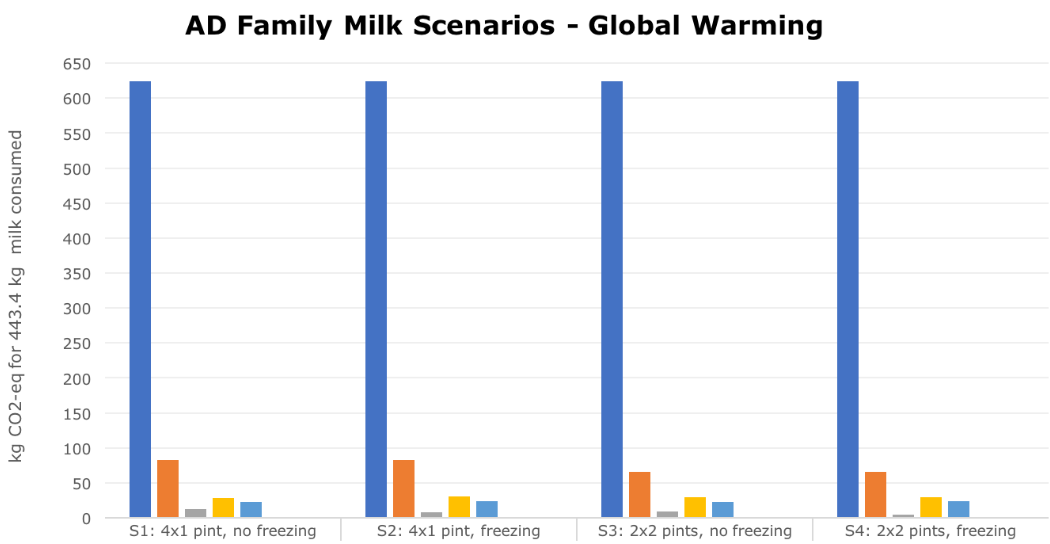
Table 5.7: Overview of data from the HHSM used for the analysis for the four milk scenarios in the Aspirational Discoverers family. This data is input for the EIFC-tool, from which the results are normalised and presented below.

Assumptions for AD Family milk scenarios

- Waste treatment by 100% waste water treatment
- 90.5% plastic bottle, 9.5% Tetra Pak
- 100% consumed raw
- Refrigerator opened twice per pint bought, and freezer opened twice per bottle frozen

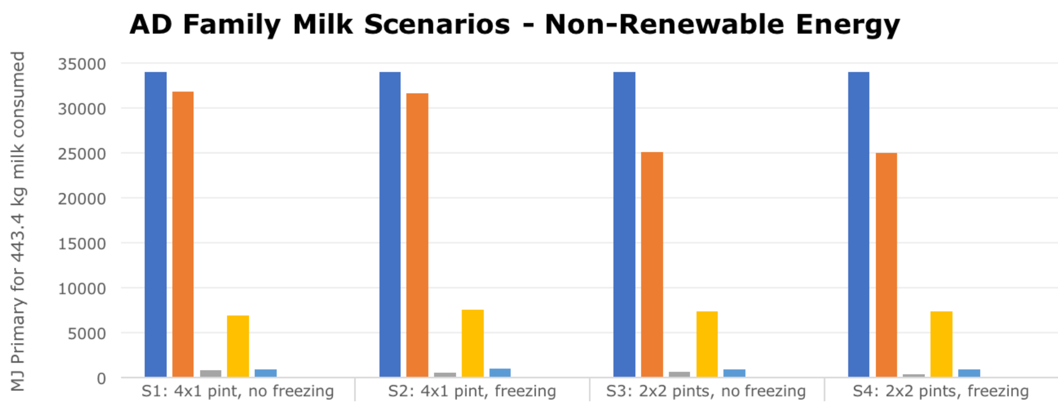
Milk scenarios: Aspirational Discoverers family

Figures 5.19 and 5.20 show the results for the four milk scenarios, for Global warming and Non-renewable energy. Product is by far the largest contributor to Global warming impacts, and products and packaging are the two most significant consumption areas within Non-renewable energy. Transport is the third highest contributing consumption area for both impact categories. Food waste is a small contributor, as the percentage of milk wasted is small in the HHSM outputs.



	S1: 4x1 pint, no freezing	S2: 4x1 pint, freezing	S3: 2x2 pints, no freezing	S4: 2x2 pints, freezing
Product	624.2	624.2	624.2	624.2
Packaging	82.9	82.4	65.5	65.2
Food Waste	12.2	7.8	9.4	5.0
Transportation	27.8	30.4	29.5	29.6
Storage	22.9	24.3	22.8	23.4
Preparation	0.0	0.0	0.0	0.0
Total	770.0	769.1	751.4	747.3

Figure 5.19: Normalised results for Global warming in the Aspirational Discoverers family milk scenarios, who consume an average of 443.3 kg milk per year but have different consumption behaviour.



	S1: 4x1 pint, no freezing	S2: 4x1 pint, freezing	S3: 2x2 pints, no freezing	S4: 2x2 pints, freezing
Product	34035	34035	34035	34035
Packaging	31853	31657	25136	25026
Food Waste	874	561	674	357
Transportation	6931	7575	7371	7377
Storage	946	1005	942	966
Preparation	0	0	0	0
Total	74639	74832	68158	67761

Figure 5.20: Normalised results for Non-renewable energy in the Aspirational Discoverers family milk scenarios, who consume an average of 443.3 kg milk per year but have different consumption behaviour.

5.6.2 Milk scenarios: Functional Fuellers single

Scenario 5: 2 bottles of 1 pint, no freezing
Scenario 6: 2 bottles of 1 pint, freezing
Scenario 7: 1 bottle of 2 pints, no freezing
Scenario 8: 1 bottle of 2 pints, freezing

Table 5.8 shows the inputs for the tool.

	Unit	S5	S6	S7	S8
Total amount bought	kg	78.1	77	81	78
Total amount packages bought	No.	133	132	69	67
Waste	%	1.87	1.18	7.3	4.7
Trips to main shop	No.	46	45	40	40
Trips to top-up shop	No.	27	26	29	27
Stored in freezer	%	0	1.4	0	4.8
Refrigerator opened	No.	532	528	552	536
Freezer opened	No.	0	10	0	32
Average amount consumed	kg	75.54			

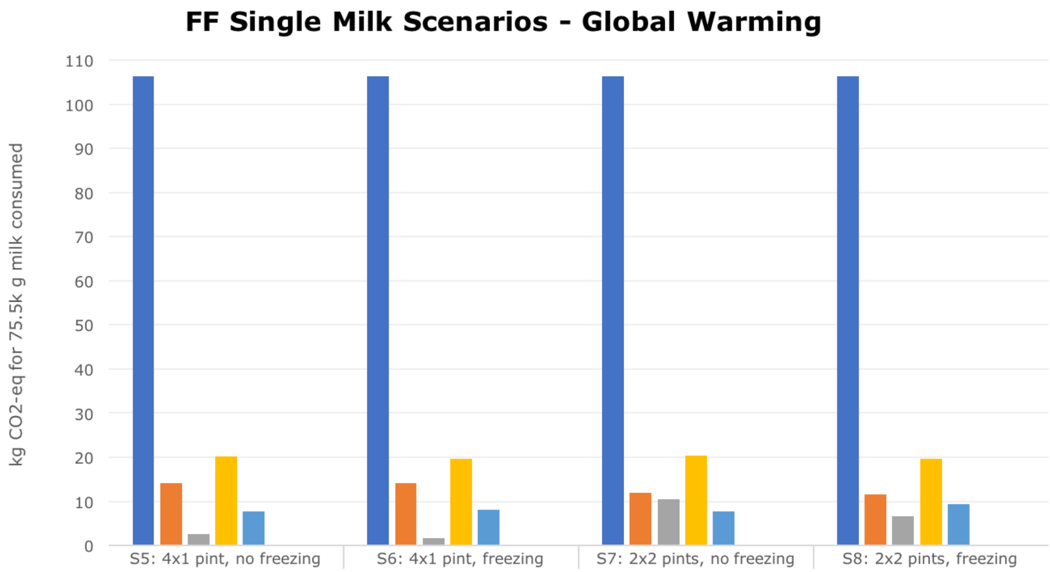
Table 5.8: Overview of data from the HHSM used for the analysis for the four milk scenarios in the Functional Fuellers single. This data is input for the EIFC-tool, from which the results are normalised and presented below.

Assumptions for FF single milk scenarios

- Waste treatment by 100% waste water treatment
- 90.5% plastic bottle, 9.5% Tetra Pak
- 100% consumed raw
- Refrigerator opened twice per half pint bought, and freezer opened twice per package frozen

Results of FF single milk scenarios

Figure 5.21 shows the results for the four FF single milk scenarios in the impact category Global warming. Product is the most prominent consumption area, followed by transport and packaging.



	S5: 4x1 pint, no freezing	S6: 4x1 pint, freezing	S7: 2x2 pints, no freezing	S8: 2x2 pints, freezing
Product	106.3	106.3	106.3	106.3
Packaging	14.1	14.1	11.8	11.6
Food Waste	2.5	1.6	10.4	6.5
Transportation	20.1	19.7	20.3	19.6
Storage	7.7	8.1	7.8	9.4
Preparation	0.0	0.0	0.0	0.0
Total	150.8	149.8	156.7	153.5

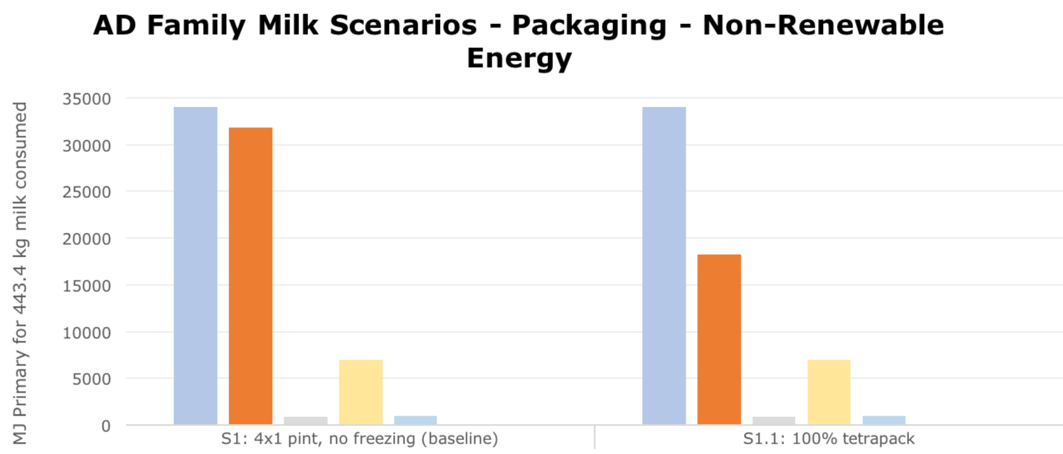
Figure 5.21: Normalised results for Global warming in the Functional Fueller single milk scenarios, who consume an average of 75.5 kg milk per year but have different consumption behaviour.

5.6.3 Hypotheses testing: Milk

Hypothesis a) '*decreasing the package size decreases the environmental impacts of food waste*' can not be confirmed true for the AD family milk scenarios, as the environmental impacts of food waste for the AD family are lower when buying in 2 pint packages. However, the hypothesis is true for FF single milk scenarios where the impacts of food waste are lower with the smaller package size. Even though the packaging impacts from buying in smaller packages are higher, the decrease in food waste is of a larger magnitude.
Hypothesis b) '*storing food in the freezer decreases the environmental impacts of food waste*' is tested for the FF single, and it is found that storing in the freezer decreases the food

waste impacts by approximately 36%. Transport impacts decrease in the scenarios where milk is frozen, and so the increase in storage impacts from freezing scenarios (6 and 8) are less than the reduction in both food waste and transport impacts. The same is seen for the AD family.

Hypothesis c) '*reducing the amount of plastic in packaging (by choosing a different package type) decreases environmental impacts*' is tested by analysing how impacts change if milk is bought in 100% Tetra Pak (Scenario 1.1) compared to the average packaging type (90.5% in plastic bottle and 9.5% in Tetra Pak). Figure 5.22 shows the difference between Scenario 1 and Scenario 1.1 for the impact category Non-renewable energy, where the reduction in impacts within packaging from Scenario 1 to Scenario 1.1 is 43%. The hypothesis is therefore tested true.



	S1: 4x1 pint, no freezing (baseline)	S1.1: 100% tetrapack
Product	34040	34040
Packaging	31858	18253
Food Waste	874	874
Transportation	6932	6932
Storage	946	946
Preparation	0	0
Total	74650	61045

Figure 5.22: Normalised results for Non-renewable energy in the AD family Scenario 1, where the packaging type is changed to 100% Tetra Pak (Scenario 1.1).

> It is concluded that using the freezer results in less environmental impacts within the consumption areas, even though storage impacts increase. Buying milk in Tetra Pak lowers Non-renewable energy impacts, so a shift towards buying milk from Tetra Pak is recommended. In the FF single, buying smaller packages decreases food waste so buying Tetra Pak in smaller sizes is recommended.

Discussion 6

This chapter discusses scenarios analysed in the EIFC-tool, general trends seen throughout the results, uncertainties and limitations within the study, and how consumer theories can support the results to reduce environmental impacts within household food consumption.

6.1 Discussion of scenario analyses

This section provides further analysis of certain scenario- or product-specific results from Chapter 5.

Products
Bacon, chicken breast, and milk show more significant impacts from the consumption area products than bread. As meat and dairy products inherently have higher impacts (than plant-based products), consuming low-impact food products would reduce the overall impacts of household food consumption. However, this is not explored further, as this study is not focused on providing dietary recommendations.

Packaging
Most results show that when the amount of plastic is reduced, the impacts reduce as well. However, it is not taken into account that shelf life may be affected by packaging type, which could affect the level of food waste. In the scope of this study, it is assumed that shelf life is not affected by a change in package type.

Transport to top-up shop
For bread, the transport impacts contribute more significantly to the total impacts than for the other products. This is because bread is a frequently-consumed product which often requires a top-up shop; so changing the transportation method is explored only within the top-up shop for bread consumption. Transport impacts decrease by 75% by walking or cycling to the top-up shop. The size of the decrease is surprising- this can be used for recommendations to clearly illustrate to the consumer how effective changing the transportation method can be.

Preparation
Preparation contributes more significantly to impacts for bacon and chicken breast than for bread or milk. As milk is only consumed raw and bread is consumed raw almost half of the time, this is not surprising; but as investigated in the bacon scenarios, it is possible to lower the impacts of preparation by cooking in larger servings.

Composting

In some scenarios, impacts from food waste are a significant contributor to total impacts. Even though these impacts occur primarily from the production and processing of wasted food, various waste treatment methods are analysed to see how the impacts change. If all food waste is composted, rather than treated by the UK waste treatment mix for food, the Global warming impacts related to food waste decrease. This is because in composting, food is broken down aerobically (which does not release methane) whereas in landfill, food is broken down anaerobically and releases both CO_2 and methane into the atmosphere. Although composting is explored only for bread, this applies to all products in this study because food waste treatment in Exiobase is not modelled for specific products but for food waste in general.

6.2 Trends across results

When analysing the results it is found that generally there is no 'one solution fits all' to reduce environmental impacts, and behaviours that reduce environmental impacts vary depending on the product and the family type. However, some overall trends are seen and discussed below.
Several broad trends regarding package size and freezing are seen for both household types. For all food products, both packaging and transport impacts decrease when buying in larger package sizes, and food waste decreases when buying in smaller packages. Freezer use significantly decreases the food waste (which becomes more evident when larger package sizes are bought) and decreases transport impacts. When food products are frozen, the reduction in food waste and transport impacts exceed the increase in storage impacts, resulting in a net decrease of environmental impacts.

There are also consistent differences between the two household types. For all products, transport contributes more significantly to the total environmental impacts in the FF single household than the AD family household. Food waste impacts also contribute more significantly in FF single than the AD family. These differences are expected as single households have more food waste per person. This is especially evident in this analysis where the same package sizes are bought for a single household and for a four-person family, which may not accurately represent the household demand. The high transport impacts result from the assumption that the FF single buys only 10 products at the main shop, which means the impacts related to the investigated product are higher than an AD family, who buy 20 products at the main shop.

6.3 Uncertainties and limitations

6.3.1 Methodological limitations

When using LCA as a method, it must be kept in mind that LCA indicates only potential environmental impacts related to the functional unit and not the actual impacts of a product or service. The potential environmental impacts found through LCA come from assumptions made during modelling, data collection, and data processing. All assumptions made are backed up through research and made as accurately as possible, however, the LCAs would generate different results if different assumptions had been made.

When using LCA to calculate background data for the EIFC-tool, several mixes are made. These include the electricity and waste treatment mixes which are both based on literature study (detailed in Appendix 1). The electricity mix is based on numbers from the UK government (Digest of United Kingdom Energy Statistics) so are assumed to be accurate. The waste treatment mix is based on a mixture of two literature studies, which introduces an uncertainty into the calculations. The mix is based on a WRAP (2007b) survey on how households dispose food which is combined with another study investigating what happens beyond the household in the UK municipal waste management system (Chartered Institution of Wastes Management, 2018). The first survey relates only to food waste and the second source relates to overall household waste, so the two are not completely comparable. To limit the uncertainty, only parts of the two studies are combined. Because none of these sources alone give a complete picture of the UK food waste treatment mix, food waste treated as 'regular waste' in the WRAP (2007b) survey is combined with the municipal waste management data.

Another assumption is that packaging waste treatment is simplified compared to reality. In the LCA done in this study, it is assumed that packaging is separated into its components (plastic, paper, and aluminium), deposited in the correct bins, and 42.3% is recycled. In reality, it is likely that many packages end up in the general trash or are not deposited in the correct bin, which would result in different impacts. The LCAs do not include the impact of certain processes, such as separating the packages into the different components (for example separating Tetra Pak into aluminium, plastic, and paper). Therefore, the impacts from packaging waste treatment is likely an underestimation of the actual impacts.

A benefit of an input-output database like Exiobase is that the classifications are country-specific. A disadvantage is that the classifications contain aggregated data for the group of products and services within each classification. Because the classifications are not product- or service-specific, there is an uncertainty in how specific they are modelled. For example, Exiobase classifications model the pig processing sector as a whole, but may not model bacon processing as accurately. In this study it is chosen to use Exiobase because of the country-specific classifications and researcher familiarity with the database.

6.3.2 The Household Simulation Model

The HHSM simulates 'requirement', which is the amount of product a household wants to consume in a year. The instances where they do not have the opportunity to consume the product (they run out of it or it has gone bad, and the trigger for top-up shop does not occur) is defined as 'requirement not fulfilled' in the HHSM outputs. For each scenario, the 'requirement not fulfilled' is different. This in itself makes it difficult to compare two different scenarios as one may have less food waste than the other, but in addition there are different 'requirements not fulfilled'.
To reduce this uncertainty, the results from the EIFC-tool are normalised in order to compare scenarios. It is not possible to recommend certain scenarios as 'better' within this study, because the 'requirement not fulfilled' is not taken into consideration. For this reason, this study focuses on trends rather than specific absolute values.

In this study, the HHSM provides inputs to the EIFC-tool. The development of the HHSM is done by WRAP and the University of Sheffield and is built for their purposes. Therefore,

to use HHSM outputs as inputs in the EIFC-tool, various assumptions are made.
For package size bought, there are two data sources that must be combined in the EIFC-tool: packaging components, size, and weights come from Valpak; and number of pieces bought come from the HHSM outputs. In the HHSM, bacon and chicken breasts are modelled in slices or breasts (pieces), but number and weight of the pieces across simulations in the HHSM do not align precisely with the package sizes given by Valpak. There is a disconnect between the number of pieces and the package size, so two options are available: either assume the weight of a piece is the same through all package sizes, or use the package size from Valpak and assume the weight of a piece changes between sizes. If the weight of a piece is assumed to be the same between package sizes, this does not fit with package sizes provided by Valpak. If the Valpak sizes are assumed to be correct, the pieces have varying weights depending on the package size. Either option introduces uncertainty into the calculations and affects the results.
In this study it is chosen to use the package size provided by Valpak, which means the mass of each slice of bacon and chicken breast is assumed to be different in each each package size. Depending on package size, a slice of bacon weighs between 30-33g and a chicken breast weighs between 125-167g. When results are normalised, all consumption areas are normalised in accordance the weight difference. This overestimates the impacts of the consumption areas in the lower-weight products, and underestimates the impacts of the higher-weight products. To assess the influence of this assumption, a sensitivity analysis is done for the FF single where all chicken breasts weigh 150g (see Appendix 12). In the sensitivity analysis, the weight of breasts in the package does not truly represent the package size provided by Valpak. The results show that although impacts within the consumption area vary between the sensitivity analysis and the original, the trends between the two are the same. Accordingly, the assumption made in the study is not seen to affect the results significantly.

As the HHSM is still in development, it is expected that some outputs may contain errors. The waste percentage of bread in the HHSM is lower than the average in the UK, and for chicken breast is higher, but WRAP has indicated that no modelling errors in these products have been found. The potential modelling errors of the HHSM would result in inaccurate results from the EIFC-tool. This means that single consumption areas could have higher or lower impacts than seen in this study, and the consumption areas focused on within recommendations could be affected. The numbers for beef mince have not been provided because the waste numbers are too high, as the HHSM is still in process of modelling behaviours around using and or freezing leftovers. Once these behaviours are modelled, the waste is expected to reduce to more accurate numbers.

6.3.3 The EIFC-tool

The HHSM does not cover all consumption areas that are modelled in the EIFC-tool, so creating the EIFC-tool requires literature study as well as assumptions about food consumption behaviour. Assumptions include allocating products to main shop and top-up shop and the cooking times for food. Any assumptions made within the study affect the results: if less products are bought at a main shop the product impacts would be higher; if cooking time is longer the preparation impacts would be higher. With this in mind, the assumptions are chosen to represent average households as accurately as possible.

Two options are considered to allocate transport to the top-up shop: allocating the transport impacts to each of the products bought per trip; or allocating all impacts of transport to the product which triggers the shopping. This is done only for a top-up shop and not the main shop since it is assumed that a trip to the main shop is not triggered by any certain product, but rather that it is done every week. The difference between the two options is that the former requires an assumption about how many products are bought per top-up shop and the latter allocates all emissions to one product bought. The number of products bought is used for this study but if the other method were chosen, the transport-related impacts would be higher. The effect of this is investigated in a sensitivity analysis of the EIFC-tool, where all top-up shop impacts are allocated to the product which triggers the top-up shop (see Appendix 12). The analysis shows that transport impacts increase when allocating all impacts from the top-up shop to the certain product, and if this had been done throughout the study, the impacts from transport would be more significant for both family types.

An assumption made is that most households have a car, a refrigerator, and a freezer. Accordingly, the production of the vehicle and the appliances is not accounted for in the impacts of consuming a certain food product. The impacts of producing the vehicle or appliances would not be influenced by consumer behaviour, and are not deemed relevant for the purpose of the EIFC-tool. If production were implemented this would increase the impacts, but this addition is assumed to be negligible and adding additional assumptions would create further uncertainties in the results.

6.4 The study in hindsight

It is clear from analysing the results that some scenarios do not represent the most common behaviours. HHSM outputs are provided on the assumption that the AD family and FF single buy the same package sizes. In hindsight, this seems unrealistic as the different household sizes do not have the same demand. This means that in the some scenarios either the AD family purchases too little or the FF single purchases too much. In hindsight, package sizes more representative of the household demand would have been requested to be modelled in the HHSM. These include AD families buying 2 x 800g loaves of bread at each shop, or the FF single buying chicken breast in 150g or 200g packages. This would have resulted in different analyses and potentially in different recommendations.

Instead, the presented results show extreme scenarios which are used to demonstrate how '*wrong*' behaviours within one consumption area affect other consumption areas, and are used to recommend how important it is to buy package sizes which represent the household demand.

6.5 Future work

In this study, results are normalised for comparison. To analyse more specific values, it would require further work in the HHSM to limit the discrepancies in total requirement between the HHSM and the EIFC-tool. This could provide a version of the HHSM and the EIFC-tool where household food consumption as a whole is modelled, so that substitutions could be made when the requirement is not fulfilled.

It would also be interesting to look into packaging design in the future (instead of only

packaging sizes and types) to evaluate which designs have the most beneficial effect on food waste and environmental impacts. Implementing the effect of packaging design on other consumption areas in the EIFC-tool would be extremely beneficial in designing new and improved food packaging.
Further refinement of the EIFC-tool includes adding information on the electricity use of specific types of appliances, and the impacts of using different types of vehicles. This would allow the user to tailor the impact assessment more specifically to a certain family.

Because the EIFC-tool creates a holistic picture of environmental impacts of household food consumption, it has implications on future research. For example, an argument for buying in smaller package sizes is that it decreases food waste, but it is not taken into account that smaller package sizes have more packaging per kilogram of food and may require more transport.
The EIFC-tool is unique in this way, because it shows how all six consumption areas are interconnected. This is useful for future research, because human consumption behaviour is so complex. Each piece of the puzzle cannot be analysed effectively in isolation: the holistic picture must be examined.

6.6 Connecting consumer behaviour theories with trends

This section discusses how consumer theories can help shift consumer behaviours to result in a more sustainable food practice. Results from the EIFC-tool are used in combination with social theories about changing behaviours in order to create the recommendations presented in Chapter 7.
The results of the HHSM and the EIFC-tool show that changing behaviours within one consumption area leads to changes in environmental impacts in other consumption areas. These results support social practice theory, which states that there are many interconnected practices involved in food consumption. These practices are habits where behavioural change can occur - but how can habits be changed? Effective interventions can disassemble and reconstruct unsustainable eating habits, in order to shift towards more sustainable consumption patterns.
As presented in Chapter 1, many people do not consider food waste as an issue because it is 'natural'; but a take-away from the EIFC-tool results and analysis is that there should be a focus on behaviours that reduce food waste. Interactions between behaviours is a key variable in generating food waste, but consumer behaviour can also be a key factor in preventing food waste (as mentioned in Section 2.1). The importance of reducing avoidable food waste should be highlighted so consumers can recognise how their behaviour affects environmental impacts of food consumption. Since wasting food has little visibility to others it may not be highly important to consumers, but awareness of reducing food waste can be raised. Once people are aware, habits can start breaking and re-forming. Social norms guide behaviour, so if the norm changes so that people *should* reduce food waste (an injunctive social norm), a shift towards food-reducing behaviours is expected.

Change agents or block leaders are effective social influence approaches when changing behaviour, as face-to-face interaction is key (explained through social practice theory and social influence theory, in Sections 2.4 and 2.3). Trends between consumption areas shows that a change in one consumption area affects impacts of other consumption areas: for example, a decrease in food waste impacts has a corresponding decrease in transportation and packaging impacts. If a change agent or block leader focuses on behaviours to reduce food wastage, it is assumed that impacts in transport and packaging consumption areas will naturally decrease. Change agents in this regard could include a parent keeping a shopping list and meal-planning, or single households committing with friends to reduce food waste and keeping each other responsible (which is also public commitment-making, another behaviour change intervention). Both block leaders and change agents act as models and if they exhibit certain behaviours, people in their social networks may also try to commit to these behaviours. While information campaigns are a good start to raise awareness, it is crucial to have face-to-face interaction to change behaviours.

Influencing consumers to buy in package sizes representative of their household demand is an effective method to reduce environmental impacts of household food consumption. Information can be given to consumers to create awareness at the point of purchase. As discussed in Section 2.2, awareness of consumers' shopping habits can help guide consumers towards certain practices. Hedonic shoppers purchase based on values, and if the environmental benefits of a product can be highlighted these consumers may be more inclined to buy. Highlighting the environmental benefit of buying in appropriate package sizes to appeal to hedonic shoppers could come through signage in the store, or labelling on food products with information about appropriate package sizes which decrease environmental impacts. Minimising the cost of food per kilogram could influence an utilitarian shopper to skip bulk discounts, and instead buy only what they need. For single households in particular, it is effective to have various package sizes available at stores so that appropriate sizes can be bought; but it is also important that prices reflect this, and that different package sizes have the same price per kilogram.

Getting consumers to more actively use their freezer is another trend to reduce impacts that is highlighted in Section 6.2. For this, they need to know when, how, and which products can be frozen. Freezing information should be clearly marked on products to encourage consumers to use the freezer more often, and consumers should be made aware of how food waste can be reduced by using the freezer. If a change agent within the household freezes food, there is the potential that other members of the household will adopt the behaviours due to modelling. This may be especially effective when highlighting the monetary benefits of freezing food. Committing to freezing food may prove to be easier when there is a reward (saving money) for doing so. Finally, changing mindset in regard to food planning and shopping is a crucial step towards more freezer use.

Conclusion 7

The purpose of this study is investigating how changes in household food consumption behaviour can be modelled to analyse changes in household environmental impacts. This is achieved by developing the 'Environmental Impacts of Food Consumption tool' (EIFC-tool) which creates a holistic picture of the environmental impacts from a household consuming a specific product over one year.
The EIFC-tool is created by combining LCA and literature study within six comsumption areas: product, packaging, food waste, transport, storage and preparation. To model behaviour about how households buy, consume, and waste food products, outputs from the Household Simulation Model (HHSM) are used. Each simulation in the HHSM has different variables such as household size, if the household freezes food, and what package size is bought. These simulations are called 'scenarios' and are modelled in the EIFC-tool to quantify environmental impacts for different household behaviours. In order to compare the scenarios, the results are normalised and trends are found across scenarios. The main trends are:

- Freezing food reduces environmental impacts within food waste and transport, with a small increase in storage
- Buying in smaller package sizes decreases the environmental impacts of food waste
- Buying in bigger package sizes decreases the environmental impacts of packaging and transport

Further analyses within the EIFC-tool show that environmental impacts are reduced by buying packaging containing less plastic; walking or cycling to the top-up shop; preparing bigger portions of food at a time; and composting food waste.

The trends found from looking at scenario results are combined with consumer behaviour theories in order to make effective recommendations to reduce household environmental impacts. The consumer theories focus on face-to-face interaction as key in behavioural change, as well as having a change agent within the household. Recommendations are given to consumers, producers, government, and supermarkets.
On a consumer level, the recommendations include:

1. **Reduce food waste**
   With a growing population, the smartest solution is to reduce food waste rather than producing more food. Tactics to reduce food waste include buying in the appropriate package size for the household, using the freezer for food, and making shopping lists (planning). Over time, if it is emphasised that food waste should *not* occur, this can become an injunctive social norm. Reducing food waste is not only an environmental benefit, but also an economic benefit.

2. **Use the freezer more often**
   If a family utilises the freezer to its full potential, it is effective to buy larger packages less frequently. This decreases the household's environmental impacts related to packaging, transport, and food waste. A change agent can be responsible for freezing food directly after shopping or before expiry.
3. **Buy food according to household demand**
   The results show that households must buy in appropriate package sizes according to how much they eat. If too much is bought, there is increased food waste; if too little is bought, there are increased packaging and transport impacts.
4. **Walk and cycle to the top-up shop**
   Since top-up shops are generally closer than main shops and fewer items are bought, it is realistic that the top-up shop could be visited by foot or bicycle. Public commitment making is a way to implement this recommendation, where a goal could be to walk or cycle more often than drive. If people are bound to a commitment, their behaviour may change.
5. **Prepare food in larger portions**
   It is recommended to prepare larger portions at a time. Storage of leftovers and meal planning must align with preparing larger portions, so that more food is not wasted. Again, having a change agent in the household is beneficial for this recommendation to plan and prepare the food to ensure enough is cooked but with minimal wasted leftovers.

The recommendations are created for individual consumer behaviours, but often affect household consumption as a whole.
However, it is not only consumer behaviour that must change. The European Environment Agency (2005) writes that achieving sustainable consumption and production is a complex issue that all actors (governments, businesses, and consumers) must work together to solve the problem. Therefore, recommendations are made to other actors in the food supply chain. The first recommendation is that producers and supermarkets should offer multiple package sizes and minimise price difference per kilogram, in order to discourage bulk discounts and allow consumers to choose appropriate package sizes for their needs. The second recommendation, also for producers, is to focus on packaging with the least environmental impacts. The last is for governments and municipalities, to create more composting infrastructure. This could be done by creating green bins and a system where food waste can be composted.

8 Additional material and appendices

The additional material and appendices mentioned throughout the report are listed below. Appendices are found directly within this chapter or are available online [click here].

Appendix title		Section
Additional material 1	EIFC-tool	8.1
Additional material 2	EIFC-tool documentation	8.2
Appendix 1	Data collection for conversion factors	8.3
Appendix 2	Valpak packaging list	8.4
Appendix 3C	WRAP retailer survey	8.5
Appendix 4C	Food Understanding Comparison	8.6
Appendix 5	Dry matter overview	8.7
Appendix 6	Impact factors	8.8
Appendix 7	Bacon HHSM output	8.9
Appendix 8	Bread HHSM output	8.10
Appendix 9	Bread HHSM output 2x400	8.11
Appendix 10	Chicken breast HHSM output	8.12
Appendix 11	Milk HHSM output	8.13
Appendix 12	Sensitivity analysis	8.14

Table 8.1: Overview of additional material and the appendices. Includes appendix number, name, and where they are found within this chapter. C indicates that the appendix is confidential.

8.1 Additional material 1: EIFC-tool

This additional material is available online: [Click here]

8.2 Additional material 2: EIFC-tool documentation

This section explains the EIFC-tool in detail and acts as a guide to use the EIFC-tool correctly. It is recommended to use this documentation while performing simulations in the tool to ensure that the right inputs are chosen.
The tool is developed by Annika Erjavec, Daniel Benner, and Luzie Rück, in co-operation with WRAP (Spring 2019).

8.2.1 Sheet:'Information'

This sheet gives an overview of the tool.

- Background knowledge of the tool
- What can be found in the tool
- User guide of the tool
- Explanation of buttons in the tool
- Theory behind the EIFC-tool (figure)

8.2.2 Sheet:'Inputs'

This is the sheet where the main actions are taken. All inputs are put into the tool here. On the bottom left, a legend is presented which guides through how to find the inputs, where manual inputs are needed, and which fields fill out automatically. The inputs are separated into *Model*, *Product*, *Packaging*, *Food waste*, *Transportation (Main shop)*, *Transportation (Top-up shop)*, *Storage*, and *Preparation*. For some fields it is necessary that other fields are filled out; therefore it is recommended to fill out the tool from top to bottom. Small red flags in the corner of cells indicate further information that can be seen by hovering the mouse over it.

Model

- Name of model (C5): If multiple runs are modelled, it can be helpful to give the model a name
- Household type (C6): Through a drop down menu either FF single or AD family can be chosen. Household type affects the preparation results
- Household size (C7): Automatically fills out depending on the household type (B6)
- Functional unit (C8): Gives information about the functional unit the EIFC-tool is based on

Product

- Product (C10): Through a drop down menu Bacon, Beef (minced), Bread, Chicken breast, or Milk can be chosen. The product chosen affects the possible choices and inputs in other fields.
- Total amount bought in a year (kg) (C11): Amount of product purchased within a year(found through HHSM outputs)
- Total amount eaten (C12): This field self-fills after (C21) has an input. This occurs through a calculation in the background where C11 and C21 are multiplied together

Packaging

- Total number of packages bought (C13): Found from HHSM data, using amount bought divided by package size
- Package size (C14): For each food product a different drop down menu appears with options for various packaging sizes. Depending on the food product, there are 1-3 options
- Type of packaging (C15-C17) and (D15-D17): When a package size is chosen, the cells C15-C17 automatically fill out with the available types of packaging. Cells D15-17 are manually filled out with the percentage each of package type bought. This should always add up to 100%, as seen in D18.

Food waste

- Waste in % (C21): Percentage of amount wasted, found through the HHSM output
- Total amount wasted in kg (C22): Fills out automatically and calculates the amount wasted in kilograms, by using fields C11 and C21
- Food waste treatment (C23): Through a drop down menu two mixes can be chosen: i) Average food waste treatment (then no further fields within *Food waste* have to be filled out) or ii) Custom input (then the further inputs within *Food waste* have to be filled out). It is recommended to chose i) if the waste treatment is not known as it uses the average UK waste treatment (see sheet: 'Food waste'). If the waste treatment mix is known choose ii)
- (C24-C27): The percentage of the different waste treatments has to be put in. Waste water treatment is just for milk. The fields C24-27 must sum up to 100%, as seen in C28.

Transportation
Transportation is separated into main and top-up shops, to make it possible for the user to be more specific in regards to the differences between the two shops.

Main shop:

- Amount of shopping trips per year to purchase this product at main shop (C30): An output from the HHSM says how often the main shop is visited
- Distance to main shop (one way in km) (C31): Recommended is the average 5.2 km, but can be manually input
- Type of vehicle (C32-C34): Can be chosen through a drop down menu between Car, Public transport or Walk/Cycle. Not all three fields have to be chosen, but the sum needs to be 100% in field D35.
  The yellow information box to the right shows the average transportation methods in the UK, which can be used for inputs if the transportation mode is unknown
- Average amount of products purchased per trip (C36): Used to allocate the impacts from the transport to the certain product. For the AD family 1-25 items are recommended, and for the FF single 1-15.

Top-up shop:
Same functions as for the Main shop, though the average amount of products per trip is recommended to be between 1-5 for the AD family and 1-2 for the FF single.

Storage

- Stored at ambient temperature (C46): How much of the time the product is stored at ambient temperature (in percentage)
- Stored in refrigerator (C47): How much of the time the product is stored at the refrigerator (in percentage). This is an HHSM output
- Stored in freezer (C48): How much of the time the product is stored in the freezer (in percentage). This is an HHSM output
- C49: The sum of C46-C48, and should result in 100%
- Total number of times refrigerator opened (C50): Recommendations about possible inputs are found in the yellow information box to the right

- Total number of times freezer opened (C51): Recommendations about possible inputs are found in the yellow information box to the right

Preparation

- (Changes in regards to product chosen in C10) C53:
  - Bacon: Number of slices prepared in a year
  - Beef mince: Kilogram of beef mince prepared in a year
  - Bread: Slices of bread prepared in a year
  - Chicken breast: Number of chicken breasts prepared in a year
  - Milk: Kilogram of milk prepared in a year

- 54-57C: Percentage of how much of the product is prepared raw, in the toaster, in the oven, or on the stove top. Fills out automatically in regards to product chosen in 10C - must add up to 100%

Buttons

- G60 Save results button: The calculation is saved in the sheet 'Modelling' - Macros need to be enabled for that when opening the EIFC-tool
- G61 Clear inputs button: All input fields within the 'Inputs' sheet are cleared

8.2.3 Sheet: Products

This sheet shows the background data behind calculating impacts from the production of the different products, Bacon, Beef mince, Bread, Chicken breast and Milk. This sheet contains a drop-down menu for products.

The background data covers for each food product the impacts connected for 1kg of product, found through Exiobase. These impacts are connected to the amount of product eaten 12C, to calculate the impacts of 'products', but are also used for the production impacts from the product wasted 22C, and are part of the impacts of 'food waste'. The sheet also gives an overview over which Exiobase classifications are used for which product.

8.2.4 Sheet: Packaging

This sheet shows the background data behind calculating impacts from production of packaging and waste treatment of packaging. The sheet contains a drop-down menu, which is different for each product chosen (10C). The drop-down menu implements different package types which are available for the product.

Background data 1 gives data about amount in kg of components in each package type.

Background data 2.1-2.3 covers for each component, paper, plastic and aluminium, the impacts connected to 1kg of component. These are connected with **background data 1** to calculate the impacts per packaging and then multiplied with 14C number of packages bought.

Background data 3 cover impacts of average waste treatment for 1kg of paper through recycling 42.33%, Landfill 42.33% and Incineration 15.33%.
Background data 4 cover impacts of average waste treatment for 1kg of plastic through

recycling 42.33%, Landfill 42.33% and Incineration 15.33%.
Background data 5 cover impacts of average waste treatment for 1kg of aluminium through recycling 42.33%, Landfill 42.33% and Incineration 15.33%.

8.2.5 Sheet: Food waste

This sheet shows the background data behind calculating impacts from the production of wasted food, and waste treatment of the wasted food. This sheet contains a drop-down menu for product being analysed, as well as three forms of background data.

Background data 1 gives data about waste treatment types and each connected Exiobase classification.
Background data 2.1-2.4 are the LCA results from 1kg of food waste treated by each of the various treatment types: landfill, incineration, composting, and waste water treatment.
Background data 3 is the composition of the average food waste treatment from the UK. Background data 3.1 is the mix for the solid foods (bacon, beef mince, bread, and chicken breast) and 3.2 is for milk, where waste is treated 100% by waste water treatment.

Each kilogram of food wasted is multiplied by the environmental impacts of the waste treatment mix.

8.2.6 Sheet: Transport

This sheet shows the background data behind calculating impacts from going to the main and top-up shop. This sheet contains three drop-down menus, to provide the option of three methods of transport taken to the supermarket. Options are: car, public transport, walk/cycle, and no second/third type of vehicle.

Background data 1 gives data about the Exiobase classifications connected to each transportation method.
Background data 2.1-2.3 are the LCA results for 1 km of transport.

8.2.7 Sheet: Storage

This sheet shows the background data behind calculating impacts of storing products in the refrigerator or freezer. This sheet does not contain a drop down menu.

Background data 1 gives data about the Exiobase classification connected to refrigerator and freezer electricity use - in both of these cases, a mix is made in Exiobase to represent the UK electricity mix.
Background data 2 is the LCA results from 1 kWh of the UK electricity mix.

There is **information** on the side about the liquid and solid heat capacities for each product as well as the water content. This is used to calculate the energy needed to cool and freeze the products. Information is also written on the energy use used when opening the refrigerator and freezer doors, which is connected to number of times the doors are opened per year.

8.2.8 Sheet: Preparation

This sheet shows the background data behind calculating impacts of preparing the food products. This sheet does not contain a drop down menu; but energy used for preparation depends on the household size (4 person AD family or one person FF single).

Background data 1.1 gives data about the Exiobase classification connected to preparation - in all preparation methods, a mix is made in Exiobase to represent the UK electricity mix.
Background data 1.2 shows the various preparation types (raw, toaster, oven, and stove-top) and the food products (bacon, beef mince, bread, chicken breast, and milk). This table shows the amount of energy used to prepare one 'meal' for the household size.
Information on the side provides information about how often each product is prepared by each preparation method.

8.2.9 Sheet: Calculations

This sheet contains all the intermediate calculations going from inputs to outputs. This includes all calculations related to each consumption area, as well as all options within the tool. This is connected to three impact categories: Global warming, fossil; Respiratory inorganics; and Non-renewable energy. For instance, within the consumption area packaging, there are impacts related to all the available packaging types in the EIFC-tool, and the waste treatment of those packaging types. These are all connected to the input sheet, and scale in accordance with the data within that sheet. This also means, that if bacon is investigated, the environmental impacts related to the remaining food products in the sheet shows zero.

8.2.10 Sheet: Outputs

This sheet, much like 'Calculations', shows the environmental impacts related to each consumption area, with 'Transportation' split into *main shop* and *top-up shop*. Again, the results are shown for the three impact categories Global warming, fossil; Respiratory inorganics; and Non-renewable energy.
These results are aggregated data from the 'Calculations' sheet, divided into the consumption areas, where graphs at the top show how each consumption area percentage-wise contribute to the total environmental impacts within the three impact categories.

8.2.11 Sheet: Modelling

This sheet is connected to the button '*Save results*' in the Inputs sheet. All data from the input and output sheets are saved in a single row, and each runs adds another row of saved data. This allows for comparison between the different runs.
All saved results can be clear by clicking the '*clear content*' button in A2-B2.

8.3 Appendix 1: Data collection for conversion factors

8.3.1 Conversion factors for packaging

Conversion factors are used to find the total environmental impacts of packaging in the EIFC-tool, and connect impact factors with packaging data. The conversion factors are found through the HHSM outputs (size and amount bought), a retailer survey done by WRAP, and data on the make-up of packaging types given by Valpak. The weights and components of packaging for each product, and the connected Exiobase classifications, are shown in Table 8.2.

Food item	Exiobase classification	W [g]
Bacon plastic tray, 240-250g	64 Manufacture of rubber and plastic products	17.73
Bacon plastic tray, 300g	64 Manufacture of rubber and plastic products	21.59
Bacon vacuum pack, 200-250g	54 Paper	0.5
	64 Manufacture of rubber and plastic products	7.53
Bacon vacuum pack, 300g	54 Paper	0.78
	64 Manufacture of rubber and plastic products	4.97
Beef mince in plastic tray, 500g	64 Manufacture of rubber and plastic products	20.09
Bread plastic bag, 400g	64 Manufacture of rubber and plastic products	9.45
Bread plastic bag, 800g	64 Manufacture of rubber and plastic products	10.16
Bread plastic film, 800g	64 Manufacture of rubber and plastic products	6.21
Bread in paper, 400g	54 Paper	11.1
Bread in paper, 800g	54 Paper	14.29
Chicken breast in bag, 500g	64 Manufacture of rubber and plastic products	15.67
Chicken breast in bag, 1000g	64 Manufacture of rubber and plastic products	26.31
Chicken in tray, 300g	54 Paper	0.79
	64 Manufacture of rubber and plastic products	18.60
Chicken in tray, 500g	54 Paper	2.05
	64 Manufacture of rubber and plastic products	26.14
Chicken in tray, 1000g	54 Paper	2.27
	64 Manufacture of rubber and plastic products	30.64
Milk plastic bottle, 1 pint	64 Manufacture of rubber and plastic products	19.03
Milk plastic bottle, 2 pints	64 Manufacture of rubber and plastic products	29.98
Milk in tetrapak, 0.5L	54 Paper	16.74
	64 Manufacture of rubber and plastic products	1.1
	76 Aluminium production	0.5
Milk in tetrapak, 1L	54 Paper	29.5
	64 Manufacture of rubber and plastic products	2.6
	76 Aluminium production	0.5

Table 8.2: Exiobase classifications used to model packaging types. The column W refers to weight in grams of the packaging type used.

The WRAP retailer survey (see Appendix 3C) found what types and sizes of packaging consumers buy, and the percentage of packaging types bought for each product is found and presented in Table 8.3.

Product	Percentages	Packaging type
Bacon	80%	Plastic tray with film lid
	10.6%	Vacuum pack
	9.4%	Other
Beef mince	N/A	No data available
Bread	86%	Plastic film/bag
	12.8%	Paper
	1.2%	Other
Chicken breast	70.4%	Plastic tray with film lid
	29.4%	Plastic film/bag
	0.2%	Other
Milk	90%	Plastic bottle with screw lid
	9%	Tetrapak
	1%	Other

Table 8.3: Data from the WRAP retailer survey on which packaging types of each product are bought by consumers.

8.3.2 Conversion factors for food waste

Waste treatment at end of life influences the environmental impacts of food waste. Through a survey, WRAP (2007b) investigated how uneaten food waste was treated in households. Uneaten food waste refers to cooked food not eaten, such as leftovers which could have been avoided. The survey allowed multiple options, but when scaled to a 100%, it found that 74.4% went to *regular waste* and 25.6% to *compost*. The WRAP (2007b) survey had more options regarding waste disposal, but for the purpose of simplifying the tool for the benefit of the user interface, it was chosen to group them together.
For this purpose 'Feed to animals', 'macerator', 'burn it', and 'pour down sink' from the WRAP (2007b) survey are removed from the calculations, while 'council food collection', 'home composting', 'council green waste collection', and 'in garden/field' were combined into a single category called 'Composting'. This leaves two categories: Regular waste and Composting.

The waste treatment for 'regular waste' varies depending on the municipality, so an average for the UK is set up. Chartered Institution of Wastes Management (2018) found that of household waste (including food waste) in the UK, 42% is sent to landfill, 42% is sent to recycling/compost, and 15% is sent to incineration. The final 1% is categorised as "other". The difference in percentages between the CIWM and WRAP reports most likely comes from different perspectives on waste: WRAP focused on food waste only, but CIWM focused on household waste in general. With this in mind, it makes sense that the share of composted waste is higher in the WRAP survey. Combining data from the WRAP (2007b) survey and Chartered Institution of Wastes Management (2018) is assumed to be a close estimate of food waste treatment methods in the UK.

Scaling Chartered Institution of Wastes Management (2018) numbers on landfill and incineration into 'regular waste' from the WRAP survey results in 54.6% of food waste going to landfill, 19.8% to incineration, and 25.6% to composting in the final waste mix. The default setting for the average waste treatment of uneaten food represents the mix shown on Figure 8.1.

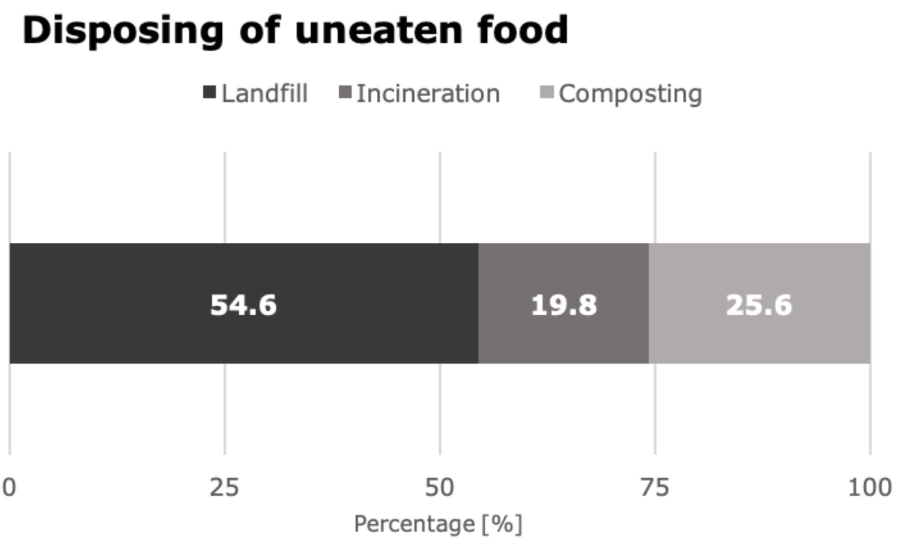


Figure 8.1: Percentage of uneaten food going to landfill, incineration, and compost in the UK, representing the average waste treatment through two studies (WRAP, 2007b) and (Chartered Institution of Wastes Management, 2018) which are used for the EIFC-tool.

WRAP (2007b) found that in 90.3% of cases milk is poured down the sink, which is not an option in the mix shown in Figure 8.1. For the purposes of this study, it is assumed that milk is only poured down the sink so all milk wasted is assumed to be treated by waste water treatment.

8.3.3 Conversion factors for transport

Conversion factors for transport include the method of transportation taken to and from the shop and the average distance to the shop. This is done through literature study.
Mode of transport
In a WRAP (2007b) report, 2844 respondents were asked for their mode of transport to a main shop. The results were as follows:

- 94.9% by car
- 21.5% walk
- 11.9% by bus
- 3.9% by taxi
- 1.6% by bicycle
- 1.1% use delivery service
- 0.3% by train
- 0.2% by motorcycle

As the EIFC-tool only has three options for transport, the data is processed to sum up to 100%.
Car, taxi, motorcycle, and delivery service are combined under the category Car; bus and train are combined under the category Public transport; walking and cycling are combined under Walk/Bicycle (results seen on Figure 8.2).

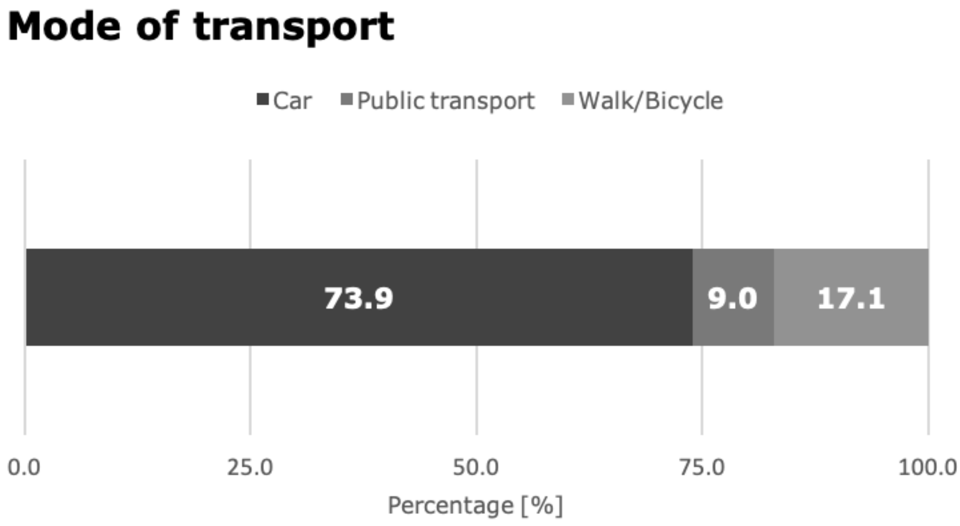


Figure 8.2: The data from (WRAP, 2007b) are scaled so that the sum of responses adds up to 100%, and presents the three categories of transport which the EIFC-tool implements.

Modelling transport in the EIFC-tool also requires assumptions about the average distance to the store. The average distance is seen in Figure 8.3:

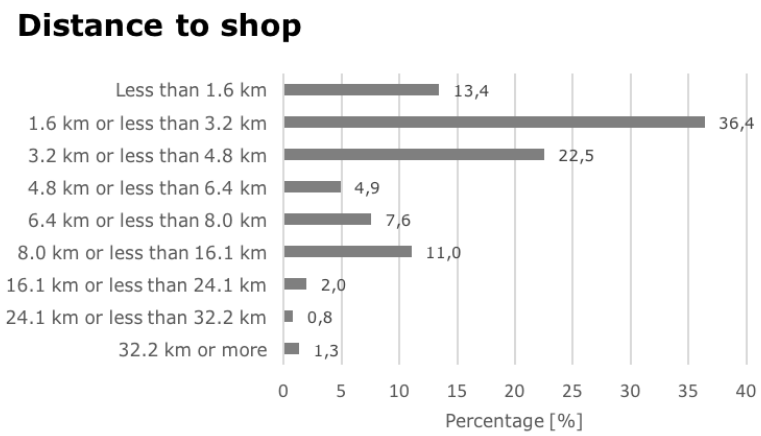


Figure 8.3: In the survey, 2747 respondents had the possibility of multiple responses. The data from (WRAP, 2007b) is scaled so that the sum of responses adds up to 100%. The average distance is 5.2 km to the store.

WRAP (2007b) only refers to distance and method of transport to main shop but in the HHSM and the EIFC-tool there is the possibility of a top-up shop. Top-up shops occur more frequently, but the survey does not specify the average to the top-shop or the method of transportation.
In this study, it is assumed that the distance to the shop is shorter than the 5.2 km for the main shop, because it is assumed that during a top-up shop the closest shop is visited. When modelling the scenarios in the report 2.5 km is chosen for top-up shop distance, but can be manually changed within the EIFC-tool.

8.3.4 Conversion factors for storage

This section looks into the product-specific electricity use for cooling or freezing a product in the refrigerator or freezer. In the EIFC-tool, 1 kWh of electricity use is transformed using outputs from the HHSM and literature review. Literature review is used to find the heat capacity for each food product, and it is assumed that the food product is moved to the refrigerator or freezer when arriving home from shopping, where the product has a temperature of 10 degrees centigrade.
The energy requirements for cooling the product is determined by Equation 8.1.

$$\phi_c = m \cdot c_p \cdot \Delta t \tag{8.1}$$

φ_c is the energy required to cool the product, m is the mass of the product, c_p is the heat capacity of the product, and Δt is the difference in temperature.

The energy requirements for freezing the product is determined by Equation 8.2.

$$\phi_f = m \cdot (c_{pl} \cdot \Delta t_l + c_{p_s} \cdot \Delta t_s) \tag{8.2}$$

φ_f is the energy required to freeze the product, m is the mass of the product, $c_{p\ l}$ is the heat capacity of the product in liquid form, $c_{p\ s}$ is the heat capacity of the product in solid form, and Δt_l is the difference in temperature above freezing and Δt_l is the difference in temperature below freezing.

Table 8.4 shows the heat capacities for each food product. As the heat capacity differs above and below the freezing point, each product has two heat capacities: referred to as *liquid* for above freezing, and *solid* for below freezing temperature.

Food item	Unit	Liquid	Solid
Bacon	J/kgC	1510	1050
Beef mince	J/kgC	3100	1590
Bread	J/kgC	1590	1170
Chicken breast	J/kgC	2720	1840
Milk	J/kgC	3779	1970

Table 8.4: Heat capacity for each product in liquid and solid state (Engineering Toolbox, 2018). The unit is Joules per kilogram Celcius.

In addition to cooling and freezing the products, energy is required to move the product from liquid to solid: 333550 Joules are required to freeze 1 kg of water at 0 degrees centigrade (Hansen et al., 1987). This energy is not used to further cool the product, but for the phase shift from liquid to solid. For this, only water is assumed to shift phase. As seen in Equation 8.3

$$\phi_s = m \cdot (1 - DR) \cdot 333550[J] \tag{8.3}$$

Where $\varphi$is the energy required, m is the mass, and DR is the dry matter of the product.

The heat capacities in Table 8.4 are in Joules but must be converted into kWh in order to be in the same units as the impact factor. This conversion can be found in Equation 8.4.

$$1[J] = 0.0000002778[kWh] \tag{8.4}$$

Combining equations 8.1 or 8.2 with 8.3 and 8.4 gives the energy (in kWh) required to cool and/or freeze the product in the refrigerator or the freezer. However energy is also required to open the door to the refrigerator and/or freezer. WRAP (2013) found that 0.058 kWh is required for each opening of the freezer. As no number such number for the refrigerator is found in literature study, this number is scaled in accordance to the Δt between both the freezer and ambient temperature, and refrigerator and ambient temperature; which gives 0.023 kWh.

Finally, when the energy required for the cooling is found, it has to be transformed from cooling to electricity. As electricity is of a higher energy quality, less kWh are needed to cool. In this case, it is assumed that 1 kWh of electricity produces 2 kWh of cooling for the refrigerator (College Physics, 2018) and 1 kWh of electricity to produce 1 kWh of cooling for the freezer.

8.3.5 Conversion factors for preparation

Conversion factors for preparation are needed to transform 1 kWh of electricity use into electricity used to cook the products. Table 8.5 shows the electricity use required per preparation for the products and household types. The numbers are found through literature study and are implemented in the background data of the EIFC-tool.
Amount of product prepared between oven and stove-top may differ within a product and household type, so at a time it is assumed that preparation sizes are:

- Bacon: 8 slices in the oven and 4 slices on the stove-top in the AD family, and 2 slices for both oven and stove-top for the FF single.
- Beef mince: 500g in the AD Family for both oven and stove-top, and 250g for the FF single.
- Bread: 2 slices in the toaster for both the AD family and for the FF single.
- Chicken breast: 4 breasts in the oven and 2 on the stove-top in the AD family, and 1 breast for both oven and stove-top for the FF single.

Food item	Household type	Unit	Toaster	Oven	Stove-top
Bacon	AD	kWh	-	0.06	0.07
	FF	kWh	-	0.25	0.14
Bread	AD/FF	kWh	0.01	-	-
Beef mince	AD	kWh	-	1.2	0.53
	FF	kWh	-	0.6	0.27
Chicken breast	AD	kWh	-	0.13	0.3
	FF	kWh	-	0.5	0.6
Milk	AD/FF	kWh	-	-	-

Table 8.5: Energy use for the various preparation methods of the different products. Preparation sizes between 'Oven' and 'Stove-top' may differ within a product and household type, and are presented above the table.

A survey by the University of Sheffield, the 'Default report' (March 2019) provided data about common preparation methods for each product (see Appendix 4C). The following numbers are calculated from that report and can be seen below in Table 8.6.

Food item	Toaster	Oven	Stove-top	Eat as is
Bread	54.1 %	-	-	45.9%
Bacon	-	70.1%	29.9%	-
Beef mince	-	66.7%	33.3%	-
Chicken	-	65.3%	34.7%	-
Milk	-	-	-	100%

Table 8.6: Numbers found through a University of Sheffield survey (see Appendix 4C). Milk is assumed always to be consumed raw. The table shows how often the products are prepared by oven or stove-top. For bread, toasting is also an option.

8.4 Appendix 2: Valpak packaging list

Tables 8.7 and 8.8 show packaging weights and components for different packaging types and sizes, given by Valpak. Table 8.7 shows packaging for bacon, beef mince, bread, and chicken breast. Table 8.8 shows packaging for milk.

Item	Material	Type	W [g]	Recycled?
Bacon plastic tray & lid, 240-250g	PE Plastic	Tray	15.73	Maybe
	LDPE plastic	Wrap	2	No
Bacon plastic tray & lid, 300g	PE Plastic	Tray	19.59	Maybe
	LDPE plastic	Wrap	2	No
Bacon vacuum pack, 200-250g	Paper	Label	0.5	Yes
	LDPE plastic	Film	7.53	No
Bacon vacuum pack, 300g	Paper	Label	0.78	Maybe
	PE plastic	Film	4.97	No
Beef mince, 500g	PET Plastic	Tray	17.4	Maybe
	LDPE Plastic	Film	1.9	No
	PE Plastic	Absorbant p.	0.79	Maybe
Bread in plastic film/bag, 400g	LDPE	Bag	9.35	No
	LDPE plastic	Tie	0.1	No
Bread in plastic film/bag, 800g	LDPE	Bag	10.6	No
	LDPE plastic	Tie	0.1	No
Bread plastic film, 800g	LDPE plastic	Bag	6.21	No
Bread in paper, 400g	Paper	Bag	11.1	Yes
Bread in paper, 800g	Paper	Bag	14.29	Yes
Chicken breast film/bag, 500g	PP Plastic	Bag	15.67	No
Chicken breast film/bag, 1000g	PP Plastic	Bag	26.31	No
Chicken in tray, 300g	Paper	Label	0.79	Yes
	Plastic	Film	2	No
	Plastic	Tray	16.60	Maybe
Chicken in tray, 500g	Paper	Label	2.05	Yes
	LDPE Plastic	Wrap	1.54	No
	PP Plastic	Tray	24.6	Maybe
Chicken in tray, 1000g	Paper	Label	2.27	Yes
	LDPE Plastic	Wrap	1.76	No
	PP Plastic	Tray	28.88	Maybe

Table 8.7: Specific types of packaging, weights, and recyclability of various packaging types given by Valpak for bacon, beef mince, bread, and chicken breast. The column W presents weight in grams.

Item	Material	Type	W [g]	Recycled?
Milk plastic bottle, 1 pint	Plastic	Seal	0.27	No
	HDPE plastic	Bottle	16.55	Yes
	HDPE plastic	Cap	1.66	Yes
	PP plastic	Label	0.55	Maybe
Milk plastic bottle, 2 pints	Plastic	Seal	0.26	No
	HDPE plastic	Bottle	26.94	Yes
	HDPE plastic	Cap	1.84	Yes
	PP plastic	Label	0.94	Maybe
Milk plastic bottle, 4 pints	Plastic	Seal	0.29	No
	HDPE plastic	Bottle	38.98	Yes
	HDPE plastic	Cap	1.56	Yes
	PP plastic	Label	0.74	Maybe
Milk in Tetrapak, 0.5L	Paper	Carton	16.74	Yes
	PP plastic	Cap	1.1	Yes
	Aluminium	Seal	0.5	No
Milk in Tetrapak, 1L	Paper	Carton	29.5	Yes
	PP plastic	Cap	2.6	Yes

Table 8.8: Specific types of packaging, weights, and recyclability of various packaging types given by Valpak for milk. The column W indicates the weight in grams.

8.5 Appendix 3C: WRAP retailer survey

This appendix is confidential. Contact researchers for access: aerjav17@student.aau.dk

8.6 Appendix 4C: Food Understanding Comparison

This appendix is confidential. Contact researchers for access: aerjav17@student.aau.dk

8.7 Appendix 5: Dry matter overview

This Appendix gives an overview of the dry matter ratio of each product. The ratios for bacon, beef mince, and chicken breast come directly from the Exiobase classifications. Bread is created using 50% classification 35 and 50% classification 2, which gives a total dry matter of 0.622. Milk is created using 13% from classification 40 and 87% from classification 14, which gives a total dry matter ratio of 0.162.

Product	Exiobase classification	DM ratio
Bacon	36 Processing of meat pigs	0.589
Beef mince	35 Processing of meat cattle	0.394
Bread	2 Cultivation of wheat	0.85
	43 Processing of food products nec	0.67
Chicken breast	37 Processing of poultry	0.37
Milk	14 Raw milk	0.12
	40 Processing of dairy products	0.443

Table 8.9: Dry matter ratio of each product used in the study. Dry matter ratios come from Exiobase.

8.8 Appendix 6: Impact Factors

This Appendix provides background knowledge on how the LCAs are modelled.

8.8.1 Products

For bacon, beef mince, and chicken breast, the Exiobase classifications are fairly straightforward. For bread and milk, some processing must be done.

There is no classification specifically for bread; the most accurate are 2 Cultivation of wheat and 43 Processing of food products nec. It is assumed that 2 Cultivation of wheat impacts is too low (as processing is not included) and 43 Processing of food products nec is too high (as it includes products with higher impacts than bread), so a combination of the two is needed. Literature study is done to see which mix of the two to use.

Espinoza-Orias et al. (2011) states that in UK bread production, cultivation of wheat contributes to 35% of the impacts, processing of raw materials contributes to 19% of the impacts, manufacturing to 16%, and the remainder (transport, packaging, consumption) contributes the remaining 30% of the impacts. Since the remainder of bread production is calculated more specifically in the other consumption areas and incorporated into the EIFC-tool, the focus in the current LCA is just on the wheat cultivation, processing, and manufacturing. Since cultivation makes up 35%, and processing (19%) and manufacturing (16%) together make up 35%, it is assumed that half of bread production comes from 2 Cultivation of wheat and half comes from 43 Processing of food products nec. The Espinoza-Orias et al. (2011) study found that each 800g bread loaf in the UK results in between 1.1 - 1.2 kg CO_2 which means, on the high end, 1.5 kg CO_2 per 1 kg of bread. A bread category in Exiobase consisting of half 2 Cultivation of wheat and half 43 Processing of food products nec leads to 1 kg of wet matter of bread having 1.12 kg CO_2 which seems reasonable.

There are some uncertainties about this calculation. 43 Processing of food products nec takes into account a variety of other food products aside from bread (Eurostat, 1996) so it is uncertain if the impacts are higher or lower than a loaf of bread. When validated against other studies, the bread mix in this study falls within the range of results, so it is assumed to be as correct as possible within the scope of this study. The mix is more accurate than taking either 2 Cultivation of wheat or 43 Processing of food products nec, so is felt to be the most valid combination to use moving forward in this study.

Milk is one of the least processed dairy products, so the mix to be used in this study is primarily 14 Raw milk with some contribution by 40 Processing of dairy products. As Daneshi et al. (2014) state in their paper, 13% of energy in milk production results from the processing stage, which is not implemented in the 14 Raw milk classification. The Exiobase milk mix therefore includes 13% from 40 Processing of dairy products and 87% from 14 Raw milk. There are uncertainties in this mix just as in the bread mix. Again it is seen that this mix is the most accurate to use, instead of either of the Exiobase classifications.

8.8.2 Packaging

A list of packaging components for each packaging types and size was given by Valpak (see Appendix 2). In total, there are seven different components in the packaging: paper, aluminium, plastic, PE (polyethylene) plastic, LDPE (low-density polyethylene) plastic, HDPE (high-density polyethylene) plastic, and PP (polypropylene) plastic. Since Exiobase does not separate plastics to this extent, plastics are researched further to see if it is necessary to disaggregate the Exiobase data.
Harding et al. (2007) stated that the global warming potential for various plastic polymers (HDPE, LDPE, and PP) was between 2.5 and 3.5kg CO_2-eq. The three polymers had similar impacts in other impact categories, except for a couple where PP was different from the others; but since PP is used in such small amounts in the packaging in the current study (especially compared to the rest of the packaging) it is assumed that for the purposes of this study, plastics can be combined to fall under one classification. The Exiobase classification 64 Manufacture of rubber and plastic products is chosen to encompass all of the plastic used in packaging, because it takes into account production of plastic packaging products (Eurostat, 1996). Another Exiobase classification 59 Plastics, basic is also looked into but that is responsible for production of the various polymers whereas 64 Manufacture of rubber and plastic products also includes production into the various forms, like packaging (Eurostat, 1996). The classification 64 Manufacture of rubber and plastic products uses more resources and energy in order to create the usable packaging, so the impacts are higher than if 59 Plastics, basic is used.

Packaging waste

The UK waste treatment mix is used as the packaging waste treatment mix. Chartered Institution of Wastes Management (2018) states that 42% of municipal waste is sent to landfill, 42% sent to recycling/compost, 15% to incineration, and 1% to "other". In this project, "other" is equally divided among the three categories.

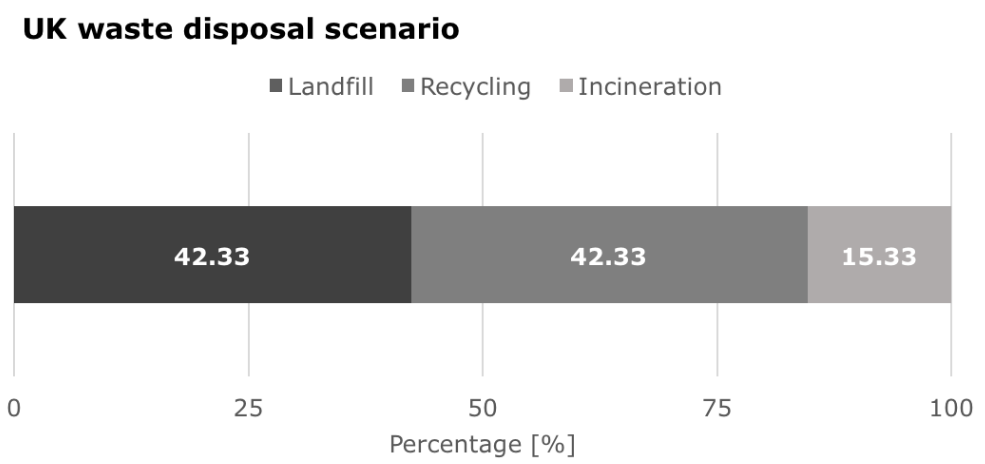


Figure 8.4: UK waste disposal scenario for packaging (Chartered Institution of Wastes Management, 2018).

8.8.3 Storage and Preparation

The UK electricity mix is seen on Figure 8.5. Import is part of the market mix but is taken out in this study; the percentage of imports is quite small and the electricity comes from various global sources. The percentage is so small that it likely would not make a significant change in the final results; so the remaining electricity sources are scaled taking import out of the mix. Wind, solar, and hydro energy are categorised under 'renewable energy'.

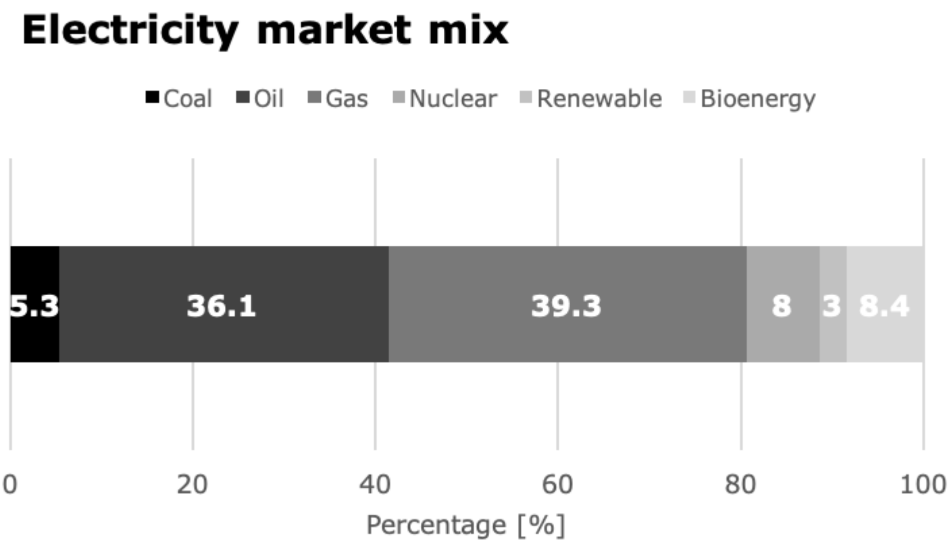


Figure 8.5: The UK electricity market mix used in the calculations (Digest of United Kingdom Energy Statistics , 2016; Carbon Brief, 2018).

8.9 Appendix 7: Bacon HHSM output

This appendix is available online: [Click here]

8.10 Appendix 8: Bread HHSM output

This appendix is available online: [Click here]

8.11 Appendix 9: Bread HHSM output 2x400

This appendix is available online: [Click here]

8.12 Appendix 10: Chicken breast HHSM output

This appendix is available online: [Click here]

8.13 Appendix 11: Milk HHSM output

This appendix is available online: [Click here]

8.14 Appendix 13: Sensitivity Analyses

8.14.1 Chicken breast sensitivity analysis

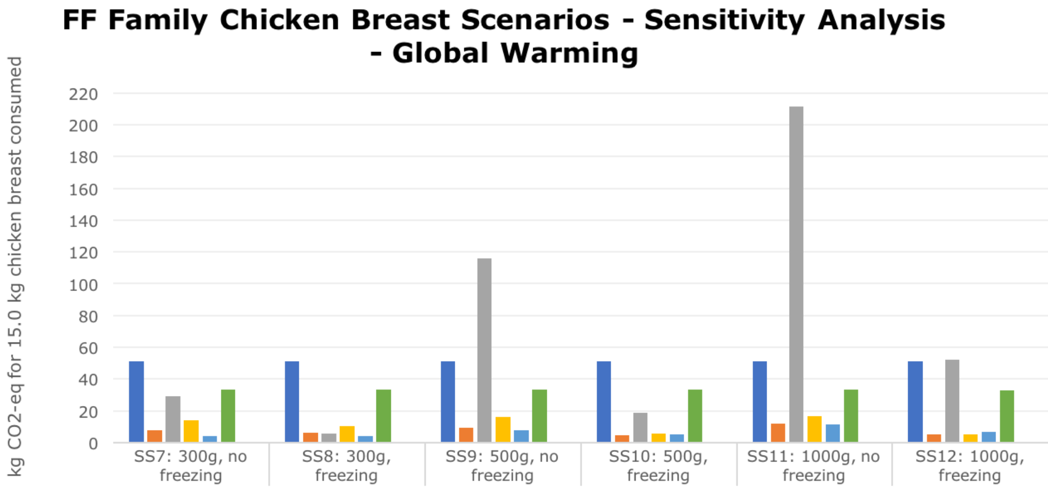
An assumption is made in the results that the chicken breasts in a 300g package weigh 150g, in a 500g package weigh 125g, and in a 1000g package weigh 167g. This sensitivity analysis looks into the assumption that each chicken breasts weigh 150g (for each package size) to see how this affects the results. This means that the package sizes from Valpak do not completely fit the number of chicken breasts, but the effect of that choice is analysed.

SS7 and SS8 are 2 breasts (300g) in a 300g pack, SS9 and SS10 are 4 breasts (600g) in a 500g pack, and 6 breasts (900g) in a 1000g pack.

	Unit	SS7	SS8	SS9	SS10	SS11	SS12
Total amount bought	kg	23.7	17.5	39.9	17.4	58.6	23.5
Packages bought	No.	79	58	66	29	65	26
Waste	%	29.2	7.1	61.9	20.9	74.8	42.2
Trips to main shop	No.	48	45	49	29	48	26
Trips to top-up shop	No.	15	7	17	0	17	0
Stored in freezer	%	0	20.1	0	45.9	0	55.3
Refrigerator opened	No.	316	234	531	232	782	313
Freezer opened	No.	0	24	0	27	0	29
Preparation (breasts)	No.	112	109	101	91	98	89
Average amount consumed	No.	30.1					

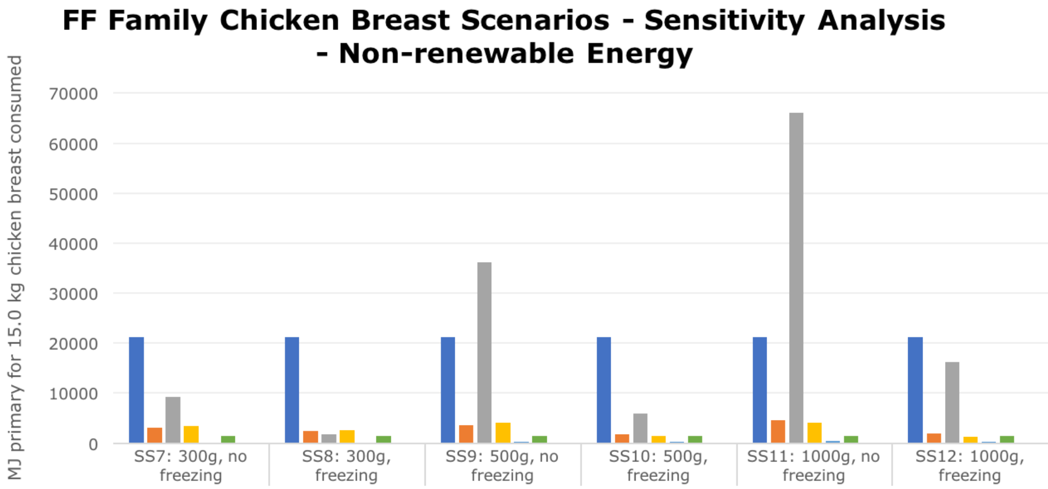
Table 8.10: Overview of data from the HHSM used for the sensitivity analysis for the six chicken scenarios for the Functional Fuellers single. This data is input into the EIFC-tool, from which the results are normalised and presented below.

The results for Global warming and Non-renewable energy for the sensitivity scenarios are shown in Figures 8.6 and 8.7.



	SS7: 300g, no freezing	SS8: 300g, freezing	SS9: 500g, no freezing	SS10: 500g, freezing	SS11: 1000g, no freezing	SS12: 1000g, freezing
Product	51.4	51.4	51.4	51.4	51.4	51.4
Packaging	8.0	6.0	9.2	4.5	11.8	5.1
Food Waste	29.4	5.4	115.7	18.8	211.4	52.0
Transportation	13.8	10.5	16.3	5.8	16.6	5.3
Storage	4.1	4.1	7.6	5.1	11.5	6.8
Preparation	33.4	33.6	33.3	33.1	33.3	32.8
Total	140.0	111.0	233.4	118.7	335.9	153.4

Figure 8.6: Normalised results for the impact category Global warming for the sensitivity analysis of the Functional Fuellers Single chicken breast scenarios, who consume an average 15 kg of bacon and have different consumption patterns, over one year.



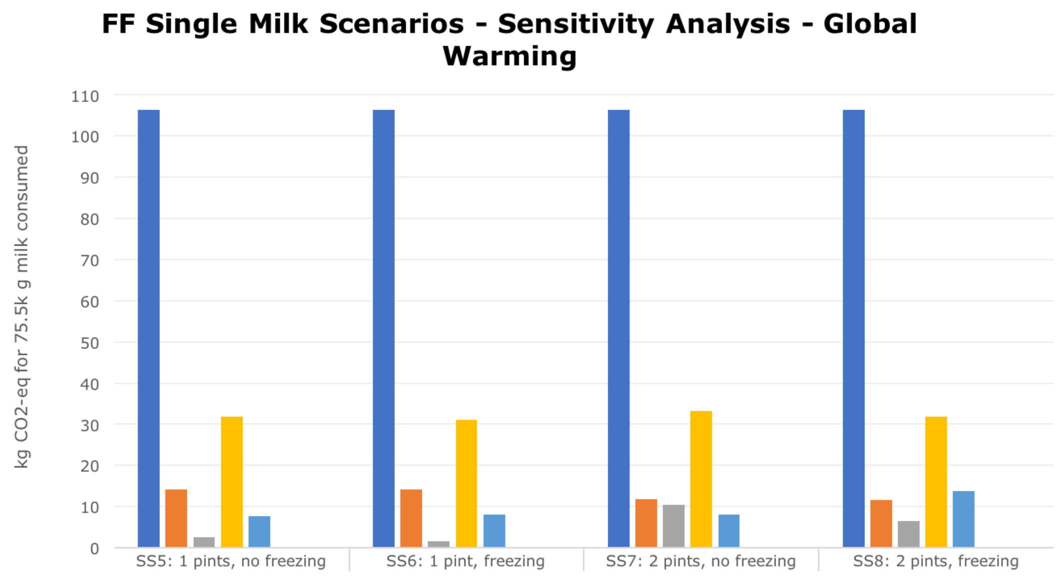
	SS7: 300g, no freezing	SS8: 300g, freezing	SS9: 500g, no freezing	SS10: 500g, freezing	SS11: 1000g, no freezing	SS12: 1000g, freezing
Product	21221	21221	21221	21221	21221	21221
Packaging	3098	2348	3559	1727	4587	1995
Food Waste	9173	1700	36135	5877	66019	16239
Transportation	3453	2621	4075	1452	4148	1319
Storage	169	168	313	212	475	282
Preparation	1383	1389	1377	1370	1375	1358
Total	38497	29448	66680	31859	97825	42413

Figure 8.7: Normalised results for the impact category Non-renewable energy for the sensitivity analysis of the Functional Fuellers Single chicken breast scenarios, who consume an average 15 kg of bacon and have different consumption patterns, over one year.

Overall, the impacts vary between the sensitivity analysis and the original. Comparing the contribution from the different consumption areas and looking at the relation between them, there is not a big difference between the results presented in Section 5.5 and the results presented in this section. The recognised trends are the same, and this assumption is not seen to affect the results significantly.

8.14.2 Transport sensitivity analysis

It is chosen for the presented scenarios in this study to allocate transport to however many products are bought at the main and top-up shop. This is assumed to be likely correct for the main shop (since households do not do a full main shop if they are out of one product but rather for several products reason), but for the top-up shop a consumer may just go because of the certain product but end up buying others. This asks the question, should the impacts connected to that trip be allocated equally, or just to the product which triggered the top-up shop? In this sensitivity analysis, scenarios are modelled where all top-up shop transportation impacts are allocated to the one product which triggers the top-up shop (see Figure 8.8). The FF single consuming milk is analysed.



	SS5: 1 pints, no freezing	SS6: 1 pint, freezing	SS7: 2 pints, no freezing	SS8: 2 pints, freezing
Product	106.3	106.3	106.3	106.3
Packaging	14.1	14.1	11.8	11.6
Food Waste	2.5	1.6	10.4	6.5
Transportation	31.9	31.1	33.2	31.8
Storage	7.7	8.1	8.1	13.8
Preparation	0.0	0.0	0.0	0.0
Total	162.5	161.2	170.0	170.1

Figure 8.8: Normalised results for the impact category Global warming for the sensitivity analysis of the Functional Fuellers Single milk scenarios, who consume an average 15 kg of milk and have different consumption patterns, over one year.

As expected, transport impacts increase when allocating impacts to just the specific product when going to the top-up shop. Although in the original scenarios transport was also the most dominant consumption area (after product), it is more clearly seen in this figure that transport is a significant contributor. If this assumption were used throughout the whole report, transport would show to be more significant.

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