Life cycle environmental and economic sustainability in the baby food sector

A thesis submitted to The University of Manchester for the degree of Doctor of Philosophy in the Faculty of Science and Engineering

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by

Natalia Sieti

School of Chemical Engineering and Analytical Science

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List of Abbreviations

ADPe	Abiotic Depletion Potential (elements)
ADPf	Abiotic Depletion Potential (fossil)
AP	Acidification Potential
BR	Brazil
CH	Switzerland
CML	Centrum voor Milieuwetenschappen (Institute of Environmental Sciences)
CO_2	Carbon Dioxide
DCB	Dichlorobenzene
DE	Germany
EoL	End of Life
EP	Eutrophication Potential
eq.	equivalent
ES	Spain
EU	European Union
f.u.	functional unit
FAETP	Freshwater Aquatic Ecotoxicity Potential
FMCG	Fast Moving Consumer Goods
g	grams
GaBi	Ganzheitliche Bilanz (Holistic Balance)
GB	Great Britain
GHG	Greenhouse Gases
GLO	Global
GWP	Global Warming Potential
HDPE	High Density Polyethylene
HTP	Human Toxicity Potential
HVAC	Heating, Ventilation and Air Conditioning
IFS	Infat Feeding Survey
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standardisation Organisation
IT	Italy
kg	kilograms
L	Littre
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LDPE	Low Density Polyethylene
MAETP	Marine Aquatic Ecotoxicity Potential
MJ	Megajoules
Mt	Megatonne
NL	Netherlands
NOx	Nitrogen Oxides
OCE	Oceanic

ODP	Ozone Depletion Potential
POCP	Photochemical Ozone Creation Potential
R11	Trichlorofluoromethane
RER	Europe
RoW	Rest of the World
RP	Retail Price
Sb	Antimony
SE	Sweden
SETAC	Society of Environmental Toxicology and Chemistry
SO_2	Sulphur Oxide
TETP	Terrestrial Ecotoxicity Potential
TJ	Terrajoule
UK	United Kingdom
US	United States
VA	Value Added

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Abstract

This research addresses life cycle environmental and economic sustainability in the baby food sector. In the UK, this sector has been growing rapidly, expanding by around 30% between 2009 and 2014, by which time it was worth an estimated £181 million per year. This growth sits within a context of high emissions from the food sector: in 2015, UK net GHG emissions were estimated to be 496 million tonnes (Mt) and the domestic food chain was responsible for 115 Mt CO_2 eq. emissions. However, within this overall food chain, very little is known about the sustainability of the baby food sector, with almost no prior literature in the area.

The research presented here begins with market research to identify the characteristics of products available in the ready-made food market, in which wet and dry products in jars and pouches dominate sales. Subsequently, 12 representative products are selected from those available on the market and each is assessed in detail to establish its environmental and economic impacts using life cycle assessment (LCA), life cycle costing (LCC) and value added (VA) assessment. The findings of these product-level assessments are then compared to home-made equivalents and finally scaled up according to sales volumes to provide an overall view of the baby food sector as a whole.

Wet and dry variants of ready-made porridge products are assessed first as the most commonly consumed breakfast option. The dry product is shown to have 5%-70% the impacts of the wet, on average, and the importance of product formulation is clear: for dry porridge, reformulation could reduce impacts by up to 67%. For the wet porridge, switching from glass jars to plastic pouches is also shown to decrease impacts by up to 89%. Assessment of 11 wet ready-made products demonstrates that the highest impacts are found in spaghetti Bolognese and salmon risotto, and that raw materials are the major hotspot of the life cycle, contributing 12-69%, followed by manufacturing at 2-49%. When combined into a range of weekly diets limited differences are observed between diets, except in cases where dairy-free diets result in compensatory increases in meat consumption. When the aforementioned selection of ready-made products is compared to its home-made equivalent, the home-made options are shown to have lower impacts by 50% to 17 times. This is due to the avoidance of manufacturing and extra packaging stages, as well as shorter supply chains resulting in less waste overall.

At the product level, the LCC of ready-made meals ranges from £0.08 to £0.26 per 125 g product, compared to £0.02-£0.20 for the home-made equivalents. Value added is, on average, approximately four times higher for ready-made meals than home-made, illustrating the potential profit of the sector. Annually, the ready-made baby food sector has an LCC of £40m and carbon footprint of 109 kt CO_2 eq. This carbon footprint represents only 0.1% of the UK food and drinks sector.

The results of this research show that considerable improvements can be made to the environmental and economic sustainability of baby foods, both ready- and home-made, while home-made options tend to have lower costs and environmental impacts. The outputs provide benchmarking and improvement opportunities for industry and government, as well as insight for consumers.

Keywords: baby food, life cycle assessment, life cycle costing, sustainability, ready-made meals, diet

Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Copyright Statement

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Chapter 1. Introduction

Although the concept of sustainability was developed during the 1980's, there is still much discussion over its definition. The most classic definition of sustainable development is the one according to the World Commission on Environment and Development (WCED) report entitled "Our Common Future" (otherwise known as the Brundtland Report) (United Nations 1987) "*Sustainable development is development that meets the needs of the present, without compromising the ability of future generations to meet their own needs*".

Sustainable development is commonly perceived to reflect environmental issues but in fact it is widely acknowledged to encompass three pillars: environment, society and economy (United Nations 2005). Since it is difficult to measure the "level of sustainability" of different sections of society, to determine change oriented actions (Azapagic and Perdan 2000) and to enable this assessment, the development of sustainable development indicators are necessary (United Nations 1992a). Sustainability indicators fall under the umbrella of standardising models, as scientific attempts to represent and capture sustainability vary (Todorov and Marinova 2009).

With a growing awareness in the sustainability area, and food production being highly dependent on natural resources, there is the need to improve sustainability of production and consumption, with minimisation of all the associated detrimental impacts. Life cycle thinking expands the focus along the supply chain downstream and upstream, including all phases from extraction of raw materials to waste management, aiming to integrate the needs of both upstream and downstream domains to calibrate towards a (more) sustainable system.

To meet the growing consumer demand in convenience and changing consumption patterns, ready-made baby foods have been introduced to the market with great economic success: a survey of infants (aged 6-12 months) in the US found that 81% consumed ready-made baby food (Nestle Nutrition Institute 2008). As a result, the highly processed, ready-made baby food market in the UK grew by around 30% between 2009 and 2014, by which time it it was worth an estimated £181 million per year (Mintel 2014).

The baby food sector has a variety of stakeholders, including manufacturers, retailers, inter-governmental and governmental bodies, private investors, NGOs and consumers. Between them, they are interested in a range of sustainability aspects. For example, manufacturers and retailers are interested in innovation (e.g. product development), profits, and legislation. Government is concerned about regulations such as the UK meeting the 2030 resource efficiency goals toward a sustainable food system (HM Government 2010) and reducing its greenhouse gas (GHG) emissions by 80% by 2050 (Parliament of the United Kingdom 2008). At the downstream end of the supply chain, civil society is concerned about economical and convenient products as well as the quality and healthiness of those products.

However, despite the sector's socio-economic importance, the only subsector to receive considerable attention from a sustainability perspective is that of formula feeding (BPNI and IBFAN Asia 2014; Tinling et al. 2011; Andrew and Baby Milk Action 1991). Studies of the sustainability impacts of products other than baby milk are rare: one study is found in literature focussing on the environmental impacts of baby food in Sweden 20 years ago (Mattsson 1999), and another focuses on alternative baby food packaging methods (Humbert et al. 2009). One further study provides a top-level estimate of sectoral impacts based on the annual sales of different baby-food products (Fisher et al. 2013), but this does not include any detailed LCA.

In addition to the general lack of published research into the environmental impacts of baby food, it is also true to say that not many environmentally-friendly baby food products exist in the market. In the French baby food sector, organic baby food start-up Yooji, adopted Marine Stewardship Council (MSC) certified baby food products in 2014, which was a global first at the time (Scott-Thomas 2014). As stated on Ella's kitchen website, the company uses Forest Stewardship Council-certified cardboard and recycled paper and upcycles its plastic packaging.

1.1 Aims and objectives

Given the above, there is an evident urgency to understand the impacts of this underexplored field. To provide further information and stimulate the debate about the sustainability of baby food, this study aims to evaluate the environmental and economic sustainability of this growing market, taking a life cycle approach and focusing on the UK situation.

The specific objectives of the project are to:

1. Select representative baby food products for each meal category, i.e. breakfast, lunch and dessert;
2. Conduct life cycle environmental and economic sustainability assessment of the selected products and provide a comparison to home-made equivalents;
3. Scale up the results at the sectoral level to investigate the environmental and economic sustainability in the UK baby food sector; and
4. Provide conclusions and recommendations for improvements to stakeholders from industry, government, independent bodies and consumers.

As outlined above, sustainability studies of baby food products are rare and mostly outside the UK; therefore, this research aims to fill this gap. The novelty of this research is also the approach, since there are no integrated studies considering the environmental and economic aspects of sustainability, either at the individual baby food product level or at the sectoral level.

As far as the author is aware, this is the first study of its kind, not only for the UK but also internationally. The main novelty of the project includes:

1. Identification of representative food products via a broad review of the baby food market including “product variations”;
2. Assessment of the environmental and economic impacts of individual baby foods and comparisons to home-made alternatives, in the UK, on a life cycle basis;
3. Evaluation of the environmental and economic sustainability of the UK baby food sector;
4. Identification of areas for improvement in the baby food life cycle.

1.2 Dissertation structure

The next section provides an overview of the baby food sector through a market research, which in turn leads to the selection of representative baby food products upon which the rest of the work is focused. This is followed by the methodology used in the research.

Following the market research and selection of candidate products, the project resulted in four research papers which are presented in Chapters 2-5 and are written with the intention to be submitted to academic journals. In Chapter 2, LCA is applied to a cereal-based product as a representative of the ready-made baby food breakfast category, in order to establish which stages or other aspects of the product life cycle generate the most impacts on the environment. Improvement opportunities are also analysed to identify the best variation of the product, and the highest potential for environmental impacts reduction. Chapter 3 explores and quantifies the environmental impacts of ready-made breakfasts, lunches and desserts in order to examine the environmental impacts of different product groups. Additionally, this study examines differences between diet types by assembling the ready-made baby foods into various weekly menus. Chapter 4 compares the life cycle environmental impacts of commercially prepared ready-made breakfast, lunch and dessert meals with their homemade alternatives. This provides insight to consumers regarding the effects of their choices, as well as to manufacturers regarding the benchmarking of their products and how best to minimise impacts. Chapter 5calculates life cycle costs for the ready-made products, to assess the economic pillar of sustainability. Additionally, individual product analyses are scaled up to estimate the costs and value added in the baby food sector. Finally, Chapter 6 contains conclusions and recommendations for future work.

1.3 Methodology

The overarching conceptual framework of the study is outlined in Figure 1.1 in which life cycle sustainability is highlighted as the major step following the market review and selection of representative products. This comprises environmental and economic assessment, the methodologies of which are outlined in the following sections.

Following the sustainability assessment, sectoral assessment is performed and conclusions and recommendations are made. These steps are discussed below in Section 5.1 and 5.2, respectively.

While this section provides an overview of the methodology, detailed information on assumptions and data sources are found in Chapters 2-5.

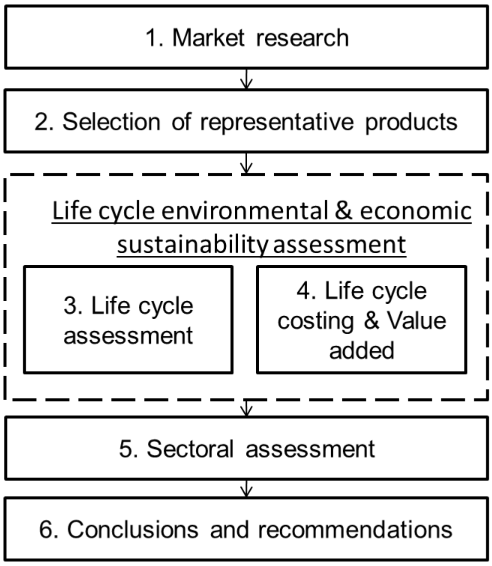

Figure 1.1 Methodological framework for the environmental and economic sustainability assessment in the baby food sector

1.3.1 Market Research

As the overall aim of this work is to understand the environmental and economic sustainability of the baby food sector, it is necessary to review the baby food products currently available on the market. To that end, this section presents the outcomes of the market research (step 1 in Figure 1.1) conducted by collecting information from manufacturers and retailers both in-store and online.

The baby food market is dominated by five main companies in the UK, as displayed in Figure 2 by their value shares in 2013 (Mintel 2013). These are Hipp Organic (24%), Heinz (23%), Ella's kitchen (20%), Cow & Gate (19%) and Organix (14%). Although Euromonitor International (2015) identifies more companies and brand names in the sector, this study focuses on ready-made meals as opposed to infant formula and, therefore, is based on the five major manufacturers of such products.

In total, the market research conducted here identifies 513 baby food products produced by the five companies shown in Figure 1.2.

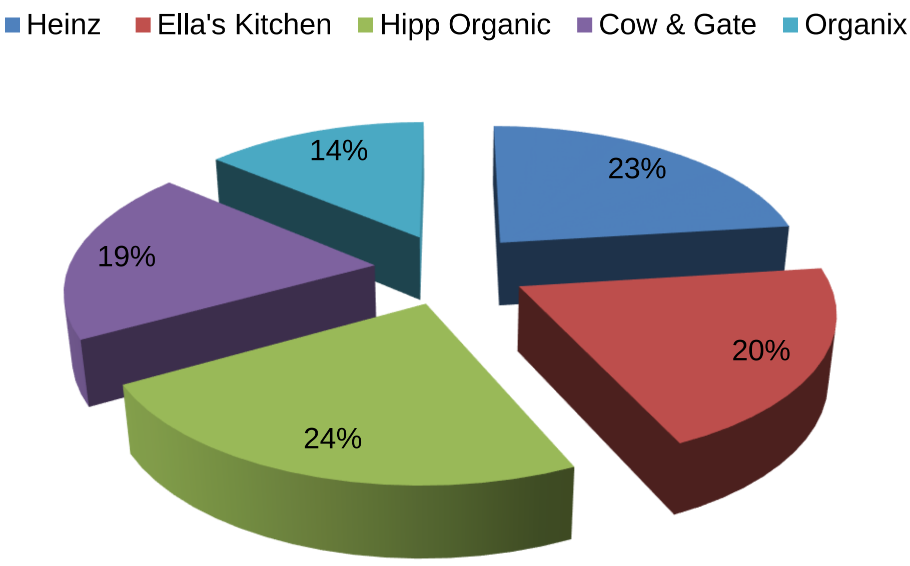

Figure 1.2 Leading brands' shares, by mass

Although the categorisation of products differs per market report, in this study, the products are divided into four segments: baby milk, baby food (wet and dry), baby finger food and baby drinks, based on Mintel (2015). Based on own market research, excluding baby milk, wet and dry baby food has the highest share of the market (83%), followed by baby finger food (15%) and baby drinks (2%) Figure 1.3).

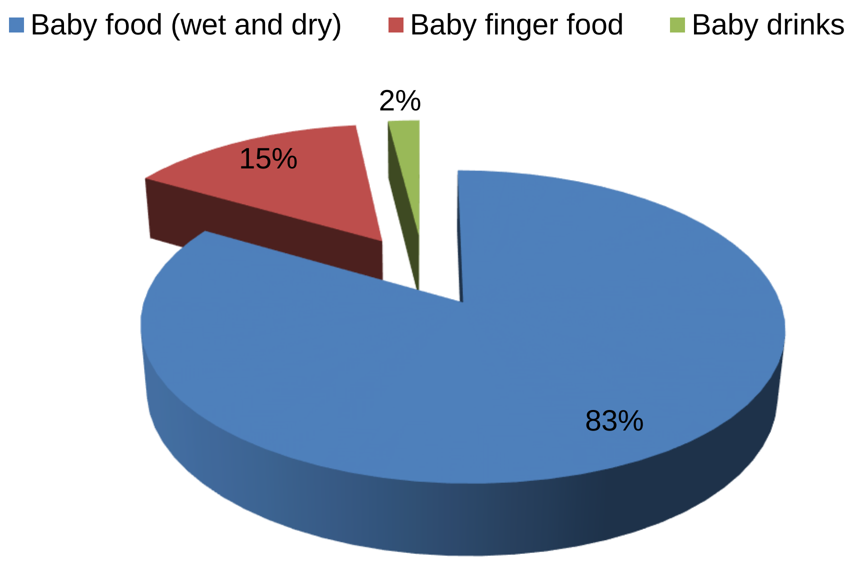

Figure 1.3 Baby food market segmentation, by mass

As indicated in Figure 1.4 **Error! Reference source not found.**, the distribution of baby food (wet and dry) is further defined based on the meal type, with meals divided between three categories: breakfast, lunch and dessert. According to The Caroline Walker Trust (2011), a baby might have an eating pattern something like 3 complementary meals per day, as breakfast lunch and tea. However, here lunch is considered the main meal of the day and tea is called dessert. Dessert is supposed to be eaten at the time of dinner, but dinner is not considered as the most significant meal of the day.

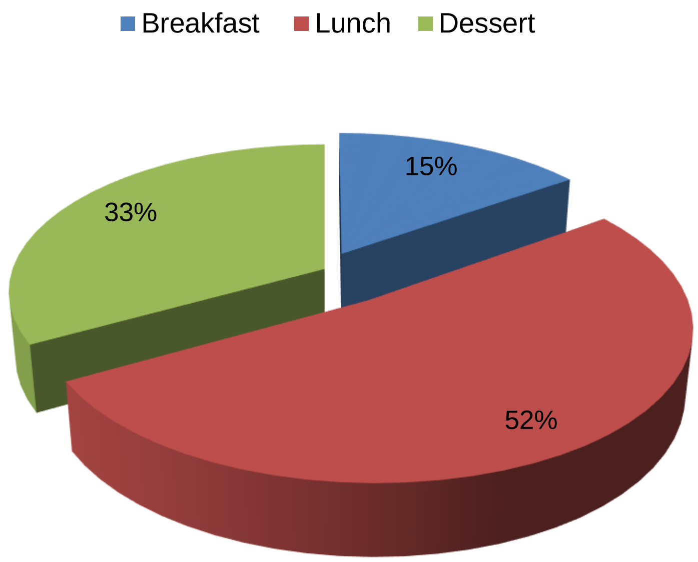

Figure 1.4 Distribution of products based on meal type

Given the complexity of different requirements at different ages, it is important to categorise baby food clearly. Infant meals can be divided into five groups, in much the same way as adult foods: breakfast, main meal, desserts, drinks and snacks. Babies slowly progress to three meals per day, after the sixth month of their development.

As indicated in **Error! Reference source not found.** the wet and dry baby foods are packaged in a variety of packaging, including pouches (34% by mass), jars (30%), cardboard boxes (14%), pots and tray meals (8% each), bottles (3%) and cans (2%).

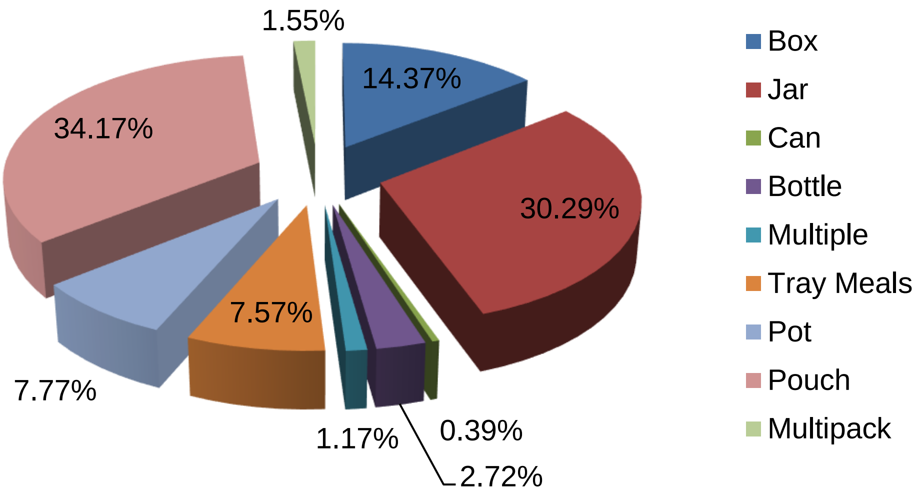

Figure 1.5 Segmentation of the baby food market by packaging. “Multiple” means that a product fits into more than one packaging category

Data collected from companies’ websites allow the categorisation of products based on their target age group and developmental stage (Figure 1.6), of which 46% are Stage 1 products for four plus months, 28% are Stage 2 products from seven plus months, 10% are Stage 3 products from 10+ months and 16% are products for one-year old children and older. Although the level of processing changes between the different age groups due to texture differences, the seventh month of developent was selected, in this study, due to ambiguity in legislation regarding the age of complementary food introduction: it is likely that babies around seven months of age are still quite reliant on the type of food products sold within the sector because complementary solid foods are only being introduced to their diets around this time. Moreover, since the most energy-intensive steps of manufacturing, such as sterilisation, are health and safety requirements across all age groups and therefore are simillar for all babies under one-year old, products in Stage 2 should be broadly representative of other baby-food products.

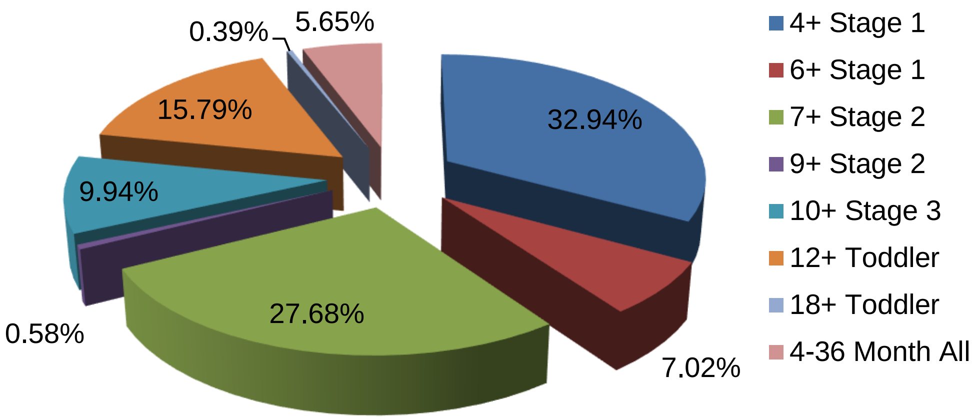

Figure 1.6 Distribution of products per developmental stage based on sample of 513 products identified

With regard to a healthy nutritional diet, it is common to group foods into five core food groups: cereals, meat/fish, fruits, vegetables and beans, and milk products. Aggregating similar ingredients into "building blocks" in this manner (e.g. milk products/dairy instead of milk, cheese, yoghurt etc.), is an approach commonly used in diet assessments (Milà I Canals et al. 2011). The breakdown of the market sample into these food groups is shown in Figure 1.7, demonstrating that the sector is dominated by cereals, meat/poultry/ fish and fruits.

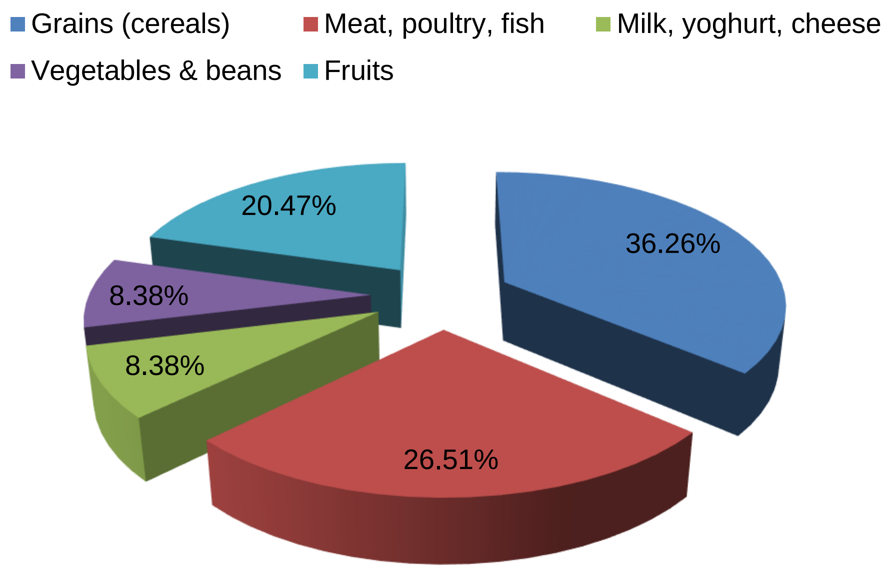

Figure 1.7 Products per core food group based on sample of 513 products identified

With respect to the core food groups identified (Figure 1.7), these are broken down further into ingredients as summarised in Figure 1.8

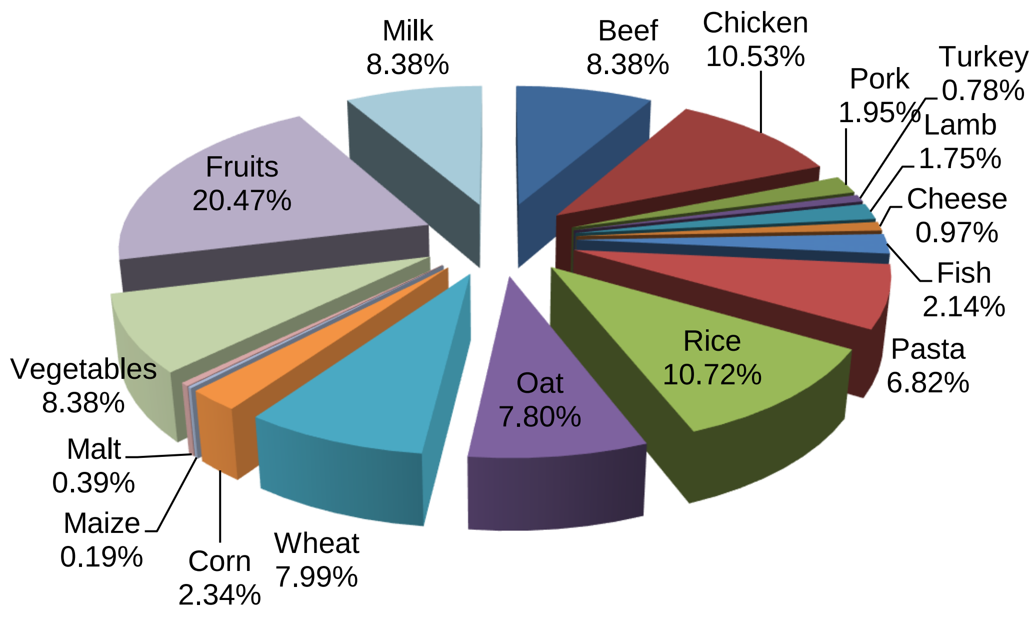

Figure 1.8 Ingredient based distribution of ready-made baby foods

Ready-made baby foods vary per portion sizes, from 70 g to 230 g, with the majority of jars for Stage 1 and Stage 2 being 125 g. As part of the market research, the portion sizes of the 513 products are identified as shown inFigure 1.9 The serving sizes in the market sample are: 17% of products 120 g, 30% of products 125 g, 20% of products 130 g, 14% of products 190 g and 20% other. The biggest contribution is by products between 100 g and 150 g.

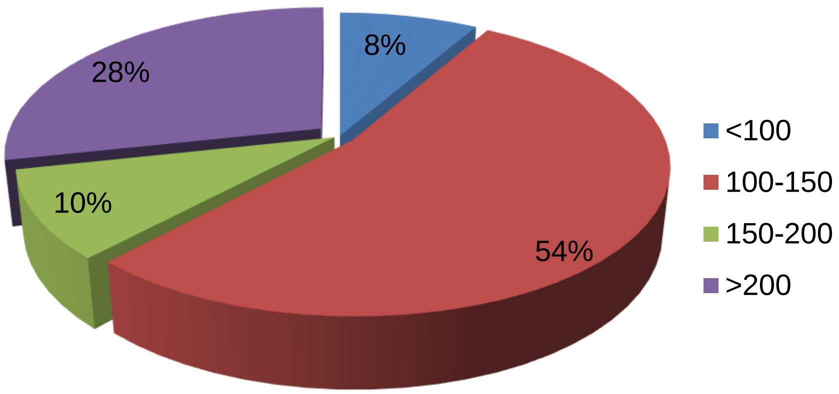

Figure 1.9 Percentage of different product sizes in the baby food market

The ready-made products on the market can also be categorised according to their farming and processing practices. **Error! Reference source not found.** shows the breakdown of all 513 products by farming category, demonstrating an almost equal split between conventional and organic produce. This has become a key marketing differentiator in recent years, with several brands such as Ella's Kitchen, HiPP and Organix focusing entirely on organic produce.

Regarding the processing of baby foods, the requirement for homogeneity of texture leads to little variance in processing between products, except for the case of dry products, sold to be heated and rehydrated in the home. As shown in Figure 1.11wet baby food is the largest category in mass terms, accounting for 76% of the share of ready-made baby foods (the implications of which are explored in Chapter 3).

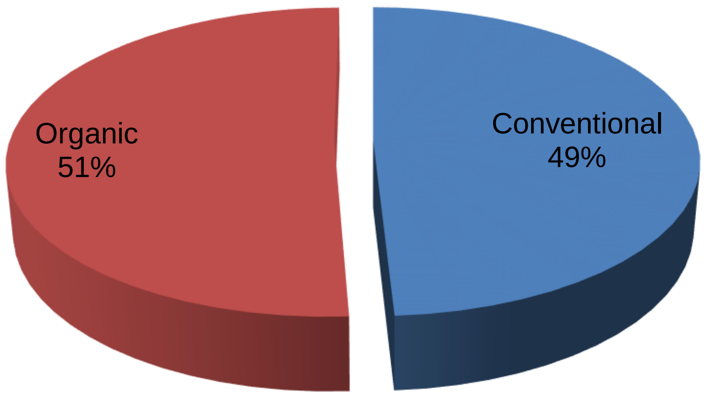

Figure 1.10 Breakdown of ready-made baby foods according to farming practices

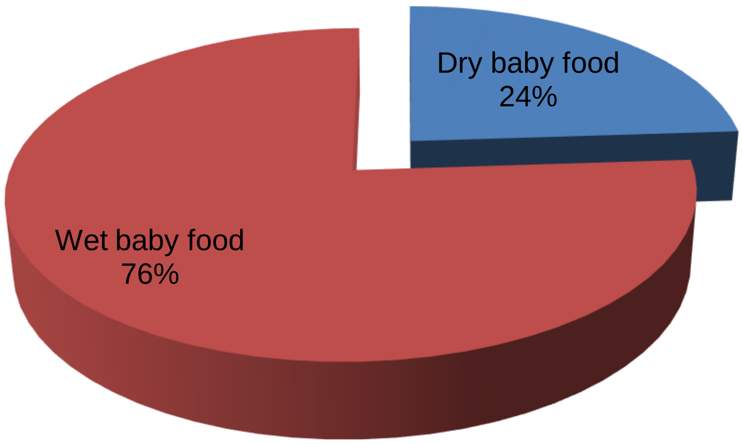

Figure 1.11 Breakdown of ready-made baby foods according to processing

In summary, the market research conducted here attempts to provide an overview of the ready-made baby foods available on the market, categorised by their meal type, ingredients, packaging, target developmental stage, portion sizes, farming practices and processing type. Of the 513 products identified in this study, 83% are wet and dry ready-made baby foods (per mass), and approximately half of those products are lunches. Jars and pouches are the most common packaging type, together accounting for 64% of the sample, while 33% of products are aimed at babies from 4 months and 27% of these are meat-based. The product portfolio in terms of share is similar between the main brands, with almost 20% share by mass per brand.

Based on the above findings, it is possible to ensure that the LCA and LCC work is representative of the sector by selecting a range of candidate products for detailed assessment. This selection process is detailed in the following section.

1.3.2 Selection of representative food products

As discussed above, 513 baby food products are sold in the UK, which are divided into four segments: baby milk, baby food wet and dry, baby finger food and baby drinks, (Mintel 2015). Excluding baby milk, wet and dry foods are the largest segment in monetary terms, and account for 83% of the marketplace by mass. Consequently, this segment is selected as the focus of this study in order to maximise its representativeness of the sector.

The following subsections outline this study’s assumptions regarding daily baby food consumption and the selection of specific products.

Figure 1.12 Example of commercial baby food products that helped defined model products

1.3.2.1 Daily consumption

A baby’s diet plays a significant role in its current and future health and development (BSNA 2013). The total diet may comprise a mixture of milk, ready-made and home-made foods. Ready-made foods can be characterised as highly processed foods that “have many ingredients and are mostly or fully prepared in the factory” (Utah State University 2016), whereas home-made foods involve some ingredients being brought to assembly at home and prepared from scratch, through a recipe (Bentley 2014).

Regardless of the type of meal consumed, the Infant Feeding Survey (IFS) shows that three solid meals a day are given to babies incrementally during their first year, in addition to milk feeds (McAndrew et al. 2012).

However, there are no formal recommendations for baby food portion sizes. The amount of solids suggested per meal, based on a weaning chart, is 50 to 75 g (10-15 teaspoons) up to seven months of age and from seven months 75 to 100 g (15-20 teaspoons) (Hipp UK Ltd 2016). According to a sample weekly menu for babies seven to nine months old by The Caroline Walker Trust (2011), the total solid food consumption is around 380 g per day for home-made meals. The same study for a 7 month old baby might have an eating pattern something like the 3 complementary meals per day, as breakfast lunch and tea. In this study lunch is considered the main meal of the day and tea is called dessert.

As outlined in the previous section and Figure 1.9the serving size of products on the market varies, with the majority sitting within the 100-150 g category. In particular, 125 g is the most common serving size for products targeted at Stages 1 and 2 of early development (ages 4 to 9+ months). Such products account for the majority of a baby's life prior to the introduction of adult foods, and consequently products of mass 125 g are likely to be the most commonly encountered during the period in which the baby is most reliant on ready-made products. Therefore, 125 g is selected as the most representative serving size.

Market research by Mintel (Mintel 2013) shows that the daily consumption of ready-made baby food varies widely: 32% of babies consume ready-made baby food once a day, 22% 2-3 times a day, 19% once a week or less, 19% 2-3 times a week, and 8% 4 times a day or more. Another study available identifies a consumption of 1.3 to 3.3 jars per day; the former in Eastern European Countries and the latter in the United States (Stallone and Jacobson 1995).

Based on the above, this study assumes a daily menu comprising three jars per day, each of 125 g, resulting in total daily consumption of 375 g per day, which is in line with the estimate of 380 g above (The Caroline Walker Trust 2011).

Nutritional requirements vary per month and between boys and girls, however an overview is shown in Table 1.1. The requirements for vitamins depend on the source of nutrition, maternal dietary factors, and daily intake. Healthy babies are expected to double their birth weight by 6 months of age and triple it by 12 months of age (Butte et al. 2000).

Table 1.1 Nutritional requirements per developmental stage, based on United States Department of Agriculture (2000)

Age (months)	Carbohydrate (g/day)	Fibre (g/day)	Protein (g/day)	Lipids (g/day)	Calcium (mg/day)	Iron (mg/day)	Energy Requirements (kcal/day)
0-6	60	5	9.1	31	210	0.27	542.75
7-12	95	5	11	30	270	11	727.83

Based on the above, by the 7th developmental month, the energy requirement for a baby are almost 728 kcal / day and for the total daily consumption of 375 g per day, there, that is almost 2 kcal/ g consumed considered in this study.

1.3.2.2 Selection of meals

Specific representative meals must be chosen to allow for both assessment and comparison of individual product types and the total sectoral evaluation. Product formulations are defined following the market research detailed above. However, since companies are only required to disclose a list of ingredients and not the exact contribution of those ingredients, assumptions must be made. Therefore a “model product” approach is considered whereby “product variations” which are representative[1] of the baby food sector portfolio are considered, similar to the “meta-product” approach carried by Milà I Canals et al. (2011). “Meta-product is an abstraction of product group that describes that product group. That is an average recipe that does not exist in the market, but is a good enough representation of the hundreds of variants of the products in the market” (Milà I Canals et al. 2011). A “model product” approach takes on a similar approach: an average recipe composition derived as an average of the market recipes for each brand and/or product variation. Up to 12 “model products” are assessed, which represent different meals (Figure 1.12).

The Eat Well Guide (Public Health England 2016) is the UK’s definition of a healthy balanced diet, wherein 33% of an adult’s energy intake should come from fruits and

[1] Representative product types are selected as those with the highest sales on an online retailer (Amazon) and representativeness of recipe and packaging. Research was performed on eMarket (websites). The searching criteria (i.e. “popularity”, specified in the text) changes base on sales (non-public data).

vegetables, 33% from starchy food, 15% from dairy based products, 12% from meat/fish and 7% from sweets/fat. One could argue that a similar approach of “clustering” ingredients to food groups could be taken for feeding babies, although the Eat Well Guide is designed specifically for children over the age of two, primarily due to its focus on solid, adult foods.

Such an approach is taken in the Chapter 3 of this study according to which environmental impacts of food groups are assessed following the clustering of the market sample products into six food groups based on their ingredients (cereals; vegetables and beans; fruits; milk, yoghurt, cheese; oils and sugar; and meat, poultry and fish) to cover all Eat Well Plate food groups. As mentioned above, aggregating similar ingredients into “building blocks” according to Milà I Canals et al. (2011) is a commonly used approach in diet assessments.

Based on the above information, the market analysis and the sectoral product portfolio, a menu is selected for consideration in this study, as detailed below.

Breakfast

One of the most-consumed types of baby food in the UK for breakfast, based on online retailers, is oat porridge, in addition to baby rice (McAndrew et al. 2012). For this reason, a porridge combining these two ingredients is selected for consideration in this study. A variation in the main ingredients is identified in the market with equivalent products having differing compositions. Baby foods can generally be divided into those preserved by a heat process and storage in a hermetically sealed container, and those preserved by low water activity. These two formats are considered separately in this study. For further details in the specification of this product, see Table 2.1.

Lunch

To identify representative baby food products in the lunch category, 313 ready-made products are considered out of the aforementioned sample of 513 products available in the UK market, taking into consideration only wet ready-made products. The results are summarised in Table 1.2based on the percentage frequency by which different food items appear on the front product label and in the recipe description.

There are two sections regarding labelling, one is the front of product label, called "Principal Display Panel" that shows the name and identifies the food. The other section of the label is the information panel labelling, entailing ingredients, nutritional facts and the company/location of manufacture (NYS Small Business Development Center 2015). Ingredients with less than 2% in the product label and less than 10% contribution to the recipe are not considered in this study.

It is possible to identify that the majority of foods consumed in the fruit group are apples and bananas, carrots, tomatoes and potatoes in the vegetable group and chicken and beef in the meat group.

Table 1.2 Breakdown of the food items in ready-made baby food formulations

On the front label		In the recipe description	
Apple	17%	Carrot	47%
Chicken	13%	Apple	39%
Beef	10%	Rice	38%
Pasta	7%	Onion	36%
Yoghurt	6%	Potato	33%
Fish	4%	Milk	31%
Carrot	4%	Tomato	28%
Banana	3%	Banana	21%
Pudding	3%	Peas	16%
Pear	3%	Parsnip	16%
		Chicken	14%
		Cheese	11%
		Broccoli	10%

Five meals are considered in total, based on their popularity, as judged by their best-selling status at an online retailer and their inclusion of the most-consumed ingredients in ready-made baby food formulations:

- **Chicken lunch**, composed of 20% water, 16% parsnip, 13% chicken, 12% carrot, 8% potatoes,8% peas, 8% swede 7% tomato 7% cornflour,1% sunflower oil;
- **Vegetable and chicken risotto**, composed of 28% water, 20% rice flour, 12% carrots, 12% tomatoes, 8% zucchini, 8% chicken, 6% maize ,5% onions,1% rapeseed oil;
- **Spaghetti Bolognese**, composed of 27%tomato, 18% dry pasta (durum wheat), 17% water, 13.5% onion, 13.5% carrot, 9% beef, 1% rapeseed oil, 1% corn flour;

- **Vegetable lasagne**, composed of 22% tomatoes, 20% carrot, 19% dry pasta (durum wheat) ,17% water, 6% zucchini, 5% onions, 5% full milk, 3% cheese, 2% rapeseed oil, 1% corn flour;
- **Salmon risotto** composed of 24% carrots, 23% rice, 22% water, 9% salmon, 8% cheese 5% onions) 5% peas, 2% full milk., 2% rapeseed oil

These recipes are based on the information from the major UK retailers, to ensure that they are representative of the recipes across the sector.

Dessert

For this category, based on the data in Table 1.2 and popularity criteria, the following five fruit-based products are considered:

- **Apple, pear and banana**, composed of 42% apple puree, 38% pear and 20% banana;
- **Strawberry, raspberry and banana**, composed of 79% apple puree, 8% strawberries, 8% banana and 5% raspberries;
- **Strawberry yoghurt**, composed of 37% yoghurt, 30% strawberries, 22% bananas, 10% apples and 1% rice flour;
- **Apples and rice**, composed of 96% apple, 3% milk powder, 1% rice flour;
- **Banana and chocolate pudding**, composed of 50% whole milk, 25% rice flour, 12% banana, 10% water, 2% sugar and 1% cocoa powder.

1.3.3 Environmental sustainability assessment

Since more than 80% of all product-related environmental impacts are determined by product design (German Federal Environment Agency 2000), with food being one of the most environmentally important product groups (European Commission 2006b; Weidema et al. 2005), Life Cycle Management helps put sustainable development into practice within the area of product oriented environmental management (Rebitzer and Hunkeler 2003). Life Cycle Assessment (LCA) serves as an environmental management and decision support tool which assesses the environmental impacts of products throughout their life cycle. Being an internationally standardised methodology, the requirements for conducting LCA studies are provided in ISO 14040 and ISO 14044 (ISO 2006a; ISO 2006b).

Although there are various environmental assessment tools, among which are the material flow analysis, resource accounting, environmental input-output analysis, ecological footprint and life cycle analysis, and despite their similarities in aim on informed decision making, differences exist. Dealing with trade-offs and avoiding sub-optimisation is an integral part of the life cycle analysis (LCA), which is the focus of this study, as opposed to other methodologies i.e. the environmental input output analysis (EIO).

These two methods complement themselves. More specifically, the EIO takes a top down approach, looking at a macro-scale, whereas life cycle analysis takes a bottom up approach looking at a different level of detail. More specifically, the EIO evaluates the environmental impacts embodied in goods and services that are traded between nations, hence does not include downstream impacts. Life cycle analysis is based on process data, adding up the environmental impacts of all the individual processes from extraction to disposal or End of Life, considering both upstream and downstream impacts.

This means that a continual improvement of a product’s environmental impacts during its life cycle is integral and requires supply chain cooperation which can be achieved when sufficient knowledge exists about the total environmental impacts during a product’s life cycle and about the possibility of reducing them.

Therefore, environmental sustainability assessment in this study is conducted via Life Cycle Assessment (LCA). LCA is used to assess environmental impacts of products or human activities throughout their life cycle. It is standardised by ISO 14040 and ISO 14044 (ISO 2006a; ISO 2006b) and comprises the following phases (Figure 1.13):

i. goal and scope definition;
ii. inventory analysis;
iii. impact assessment; and
iv. interpretation.

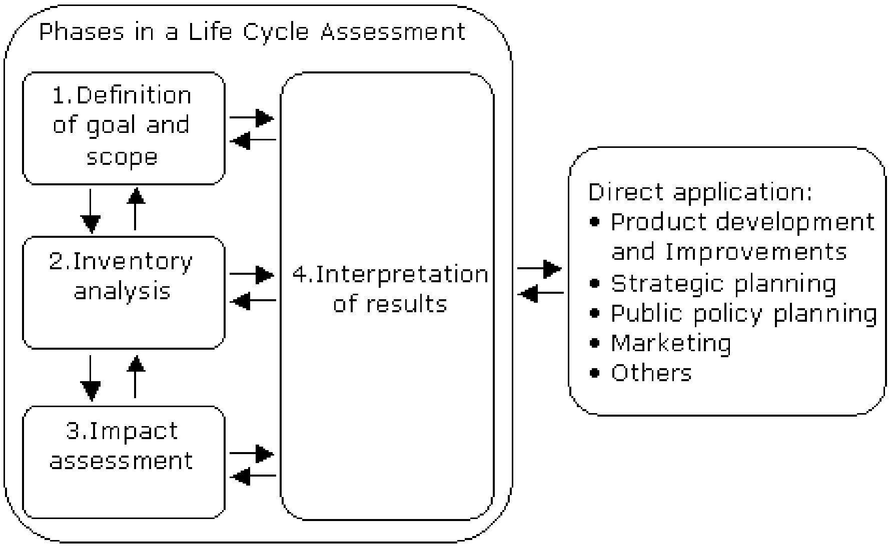

Figure 1.13 Phases in LCA (ISO 2006a)

LCA involves choices and assumptions at each of the stages outlined above. However, a decision must also be made regarding the overall conceptual approach by following the principles of either attributional or consequential LCA. Attributional LCA (aLCA) “aims to quantify the emissions attributable to a product at a given level of production” whereas consequential LCA (cLCA) “aims to quantify the change in emissions which result from a change in production” (Brander et al. 2008).

Key differences between aLCA and cLCA are discussed by Brander et al. (2008) and include the recommendation that aLCA is conducted at the product level and cLCA at a global or policy level. It is also of note that aLCA has lower uncertainty than cLCA (Brander et al. 2008).

As the primary aim of this work is to analyse and compare products and, secondly, to expand these analyses to the sectoral level based on the selection of representative products, an attributional approach to LCA is adopted here. To enable fair comparison between models this study has harmonised the methodological choices such as the definition of the functional unit, system boundaries, allocation methods and environmental impact categories across all products under investigation.

i. Definition of goal and scope

In this phase, the intended application, audience and reasons for carrying out the study are discussed. In addition, the functional unit is defined, along with the system boundaries.

In this work, the goal of the study is to assess the life cycle environmental and economic sustainability in the baby food sector. The scope of the study is from “cradle to grave”, comprising raw materials (agriculture), manufacturing (baby food processing), packaging, retail, use (consumption), End of Life (EoL) waste management and transportation. Two functional units are considered:

- at the level of individual products, the functional unit is defined as “production and consumption of one baby meal”, equivalent to a serving of 125 g and
- at the sectoral level, the functional unit is defined as “33 million kg of wet and dry ready-made baby food sold annually” based on UK sales in 2014 (Mintel 2015).

Correct definition of the functional unit depends on the purpose of the study. The selection of the first functional unit is based on the market research discussed above and is justified in the same section.

For the sectoral assessment, an aggregation of the results for the individual products based on the distribution of product meal types (Figure 1.4) with their sales volumes, helps identify whole sectoral impacts.

Component excluded from this study

The below components, are out of scope (excluded from this study) but briefly introduced here, as they could be explored as future work.

- Social sustainability assessment
- Organic farming practice
- Infant milk formula

More specifically, due to the fact that more data are available for conventional farming, organic farming is excluded from the analysis, although a comparative case study between organic and conventional food production was initially considered. However as organic products were identified in the market research, an overview of the literature is provided here.

Out of the 513 products identified in this research, 51% by mass is organic and 49% is conventional. In the UK, sales of organic products increased by 4% in 2014 (Collins Daniel et al. 2015) and in 2013 three in ten parents trusted organic baby food over conventional (Mintel 2013). There is also a trend for baby food companies tapping into economies in emerging markets (e.g. Brazil, Russia, and China). In 2012, a major

UK organic baby food company distributed to 14 countries and had an increase of 76% in overseas sales.

Most infant cereals include prebiotics, mineral or vitamin that claim to deliver additional to basic nutritional value benefits, such as supporting a baby's natural immune system. As for the organic market in the UK, it is the third largest in Europe, after Germany and France (Schaack et al. 2012). Although there is a wide debate on internet fora by parents who want answers on what is best for their baby's health, there is little comprehensive review of the organic versus non organic debate.

The debate emphasises on nutritional quality and studies provide variable and controversial results (Matt et al. 2011). The two driving market trends are organic/natural ingredients and fortified/ functional foods. The British Government encourages people to eat healthy sustainable diets (HM Government 2010; NHS 2013). The same applies for infant feeding with eight government support programmes (e.g. Start4Life) aimed at parents and health professionals (BSNA 2013). Baby foods are the second biggest category after breakfast cereals for which claims are made about intrinsic or added health value (Bradbury et al. 1996).

Research found a willingness to pay an organic price premium in the range of 16-27% to reduce pesticide exposure for babies in the US (Maguire et al. 2004). Another US study suggests that the organic premium ranged in 2004 from 12-49% and 30-52% in 2006 (Smith et al. 2009). Various studies asses the willingness of consumers to pay for fortified foods Consumers are looking for functional foods that provide benefits that can either reduce risks of disease or promote good health. In Europe calcium fortified is important by 23% towards purchasing decisions, vitamins fortified by 24%, minerals fortified by 21% and micronutrient fortified by 18% (The Nielsen Company 2015). Authors have also analysed willingness to pay for functional foods (Munene 2006; Arnoult et al. 2007; Masters and Sanogo 2002).

Commercial foods, excluding dried cereals needing reconstitution, are found to be 50% less nutrient dense than similar "spoonable" family foods (García et al. 2013). For this reason, a holistic approach is needed to compare different methods taking account apart from nutrition, other health related aspects such as pesticide residues, nitrates etc. (Matt et al. 2011). In the case of baby food the use of pesticides per tonne of baby food was four times higher for the conventional production system compared to the organic one. Organic addresses the parents concern for safety in the food supply (Mattsson 1999). Technology and production chain contribute to safety, since in the case of jarred apple based baby food, washing does not significantly remove pesticides, but steam boiling is identified as the most efficient step in terms of residue decrease (Stepán et al. 2005).

Summarising, there are various economic and policy aspects in the Baby Food sector which are interrelated with social and environmental aspects. However, this research only focuses on the assessment of the environmental and economic pillars of sustainability, thus leaving the social sustainability of the baby food sector outside the scope of this study. This is mainly due to the existence of various methodologies to approach the assessment of social sustainability and the difficulty in measuring social sustainability without reliable data. The environmental and economic findings of this research will enable a more comprehensive overview of social sustainability aspects in the baby food sector, which has been recommended as part of future work.

Baby Milk/Infant formula is also excluded from this study, firstly because there is plenty of research on dairy already and the dipole “formula feeding vs breastfeeding” impacts on the environment have already been discussed (BPNI and IBFAN Asia 2014; Tinling et al. 2011; Andrew and Baby Milk Action 1991). Therefore, it would not be novel to assess the baby milk segment. Additionally, the ready-made products have a greater variety of ingredients that due to the agriculture techniques as well as their country of origin might lead to much higher environmental impacts. However, since in many cases primary stakeholders are similar for baby food and baby milk, in this section, a brief summary of relevant literature is covered.

Although infant milk/formula is excluded from this study, it is part of the baby food and drink sector and is the growth engine of the sector. For every £1 spent on these products in 2013, 60 pence was captured by the baby milk segment (Mintel 2014). UNICEF UK has revealed potential savings to the NHS of about £40 million per year from a moderate increase in breastfeeding (Euromonitor International 2014). In an attempt to lead evidence-based advocacy for breastfeeding, two assessments were identified related to the environmental impacts of infant formula, in the US and in China. In the US study, life cycle assessment was carried out, focussing on greenhouse gas emissions; formula’s emissions were seven times higher than that of liquid reveals due to the fact that it is concentrated and dried (Tinling et al. 2011). The Chinese study revealed an environmental impact equal to 800 L of water used to make 1 L of milk and 4700 L of water for 1 kg of milk powder (BPNI and IBFAN Asia

2014) . Not to mention social exclusion due to inability of social segments to afford such a costly product and inequality along with health aspects due to sugar levels. Infant formula can be harmful if not used properly or if the water quality is compromised. This has particular implications in developing countries.

Another study assessed the ecological impact of bottle-feeding, regarding natural resource use, pollution and waste disposal among others (Andrew and Baby Milk Action 1991). Regarding waste, the report estimates that if every baby in the USA is bottle-fed almost 86,000 tons of tin plate is used up in the 550 million discarded baby milk tins and if these tins have paper, around 1,230 tons of paper is added to wastage. Regarding the dairy industry, cattle produce 20% of the total annual methane emissions and to produce 1 kg of baby milk in Mexico 12.5 m^2 of rainforest is destroyed (Andrew and Baby Milk Action 1991). The efficiency of land use depends on what food is produced. For example, more people will be fed if cereals are cultivated in a hectare rather than if cattle is raised in the case of milk production. However, nutritional intake has also to be considered when comparing different food products. In the case of food products, eutrophication is a very important environmental impact followed by energy use. In the case of milk production, the fertilisers used to grow feed for dairy cows are highly soluble; therefore leach into rivers and the ground water contaminating it. Nitrate fertilisers and sewage mostly cause eutrophication. Cleaning nitrate-polluted waters is costly; It is estimated that 80% of nitrogen pollution is from agricultural sources, putting annual external costs at £16.4 million per year in the UK (Pretty et al. 2000). Water issues are becoming more and more apparent with water scarcity already challenging the South East of England (Consumer Council for Water 2010).

Although research and policy on breastfeeding is often done separately from complementary food, there seems to be a connection between the two. From the perspective of mothers and households the two issues must be considered together towards integrated child feeding policies (Van Esterik 2002).

ii. Inventory analysis

This phase involves data collection, calculation procedures and validation of both to quantify inputs into, and outputs from, the system. Allocation of environmental burdens is also carried out in this phase.

Primary data involve the market research discussed in the 1.3.1 Market Research and secondary data are sourced from literature or Ecoinvent (2015) where available. Ecoinvent is a publicly available Life Cycle Inventory database which can be integrated to GaBi software. GaBi software is one of the most widely used and best supported tools in life cycle engineering, to conduct LCA studies (Cooper and Fava 2006). The software allows products or systems to be modelled as plans and processes, by mapping out energy and material flows.

This study draws a variety of publicly available data from various sources, constraining it to their relative accuracy. Therefore, an appropriate quality assessment method for life cycle inventory data is necessary for the robustness of the conclusions. The approach taken in this study is displayed in the below graph.

Due to the evolving nature of LCA and the lack of uniform standards in terms of allocation methods and databases (i.e. data formats vary between databases) it is difficult to regard consistency between databases a quality dimension. However, consistency is part of the data quality assessment method considered, as mentioned above, to enable fair comparison between models: this study has harmonised the methodological choices such as the definition of the functional unit, system boundaries, allocation methods and environmental impact categories across all products under investigation for uniformity of the method applied. In regards to allocation methods, when a market is already established, allocation is used whereas when this is not the case, system expansion is considered.

According to the ISO (2006b) standards, the allocation hierarchy first recommends avoidance of allocation or else system expansion. Where allocation cannot be avoided, it is recommended to allocate in a way that reflect physical relationships and finally, where physical relationship alone cannot be established, data might be allocated based on economic value. In terms of literature, economic allocation was most commonly employed in the food products studies revised by Schau & Fet 2008; de Vries & de Boer 2010, although in some cases mass allocation was used. However, system expansion users argued that the results are more reliable than using co-product allocation (Schau and Fet 2008).

As Figure 1.14 shows, data collection starts with the life cycle inventory (LCI) data. The reason why the life cycle inventory data were used as the first criterion is so that data could be adjusted to current time and geographical conditions. Additionally, when adjustments to the inventory were not feasible, this limitation is reported in the study. Therefore the second step was representativeness of data. When emissions data were used, they were judged based on completeness, where unreported emissions were recorded. As products are assumed to be sold and consumed in the UK, UK specific data are used wherever possible, and data from elsewhere are adapted to UK conditions as far as practicable. When UK data were not available, geographical differences were recorded. Followed by precisions, whether data were model derived, measured, or estimated, the source of data was recorded and no distinction was made. Same approach was the next step in the logical sequence of data collection, where processes and materials were recorded based on technological representativeness (Figure 1.14.) For dry products, the manufacturing stage is modelled based upon drum drying as the most available technology in the market (Andritz AG Separation 2016) the most commonly used technology (Baker Perkins 1991; Gantwerker and Leong 1984) and the one about which the most information exists. For wet baby food, data are acquired from the only available study of baby food manufacturing which provides plant data provided by industry (Mattsson 1999). In all cases the production of machinery and buildings is left out of scope, due to lack of high quality data on composition and lifetime throughput.

Part of quality control process was to compare the datasets with values from other scientific sources, both in terms of inventory data but most importantly for results of ingredients for example to make sure they fall within a reported set of values. For the agricultural stage data, comparisons with other data sources were made when possible. When validation from literature takes place, the year of publication is recorded for reference, as seen in Figure 1.14.

To combat uncertainty in the model, sensitivity analyses were conducted where possible, based on system hotspots. All results were recorded.

The method developed and employed across all different studies as depicted in Figure 1.14, provides a qualitative measure of data robustness. More specifically, data are robust enough to prove the validity of the methodology, further improvements however could be achieved in the future by including more up-to date data sources. It has to be noted that this study draws resources from various other studies of varying qualities and that the limitations of the study are stated in the text where appropriate.

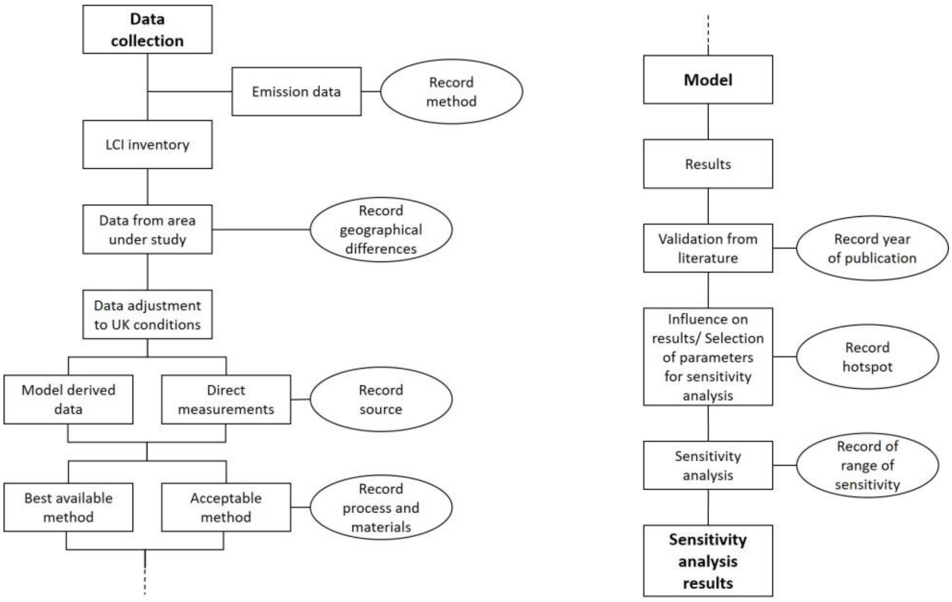

Figure 1.14 Data quality assessment methodology

iii. Impact assessment

This phase involves selection of impact categories to be considered and estimation of the impacts based on the environmental burdens estimated in inventory analysis. No method can show that one characterisation method is the “correct” one (Finnveden 2000) , but in this study 11 potential impacts are evaluated based on the CML 2001 impact assessment method developed by the Institute of Environmental Sciences at the University of Leiden in the Netherlands (Guinée et al. 2002).

This method considers the following 11 impacts: Abiotic depletion potential elements (ADP elements), Abiotic depletion potential of fossil fuels (ADP fossil), Acidification potential (AP), Eutrophication potential (EP), Freshwater aquatic ecotoxicity potential (FAETP),Global warming potential (GWP), Human toxicity potential (HTP), Marine aquatic ecotoxicity potential (MAETP), Ozone depletion potential (ODP), Photochemical oxidants creation potential (POCP) and Terrestrial ecotoxicity potential (TETP).

The environmental impacts are estimated using GaBi software (Thinkstep 2015). Biogenic carbon was not included in the GWP results as these emissions are part of the natural carbon cycle, therefore considered carbon neutral.

The reason why CML 2001 is selected is that, at the start of this study, this method was the most well established and the most widely used, while later impact assessment methodologies such as ReCiPe (Goedkoop et al. 2009) had been less widely deployed.

The estimation of environmental impacts is done by multiplying a unit mass of the emission to the environment with a characterisation factor, expressing a linear contribution (Glaumann et al. 2010): The characterisation factors are based on scientific quantitative analysis.

The estimation of environmental impacts can be followed by their normalisation to a certain region over a certain period and aggregation into a single environmental index using weights of importance for the impacts considered. According to the ISO standards, these steps are optional (ISO 2006a; ISO 2006b) and are not considered in this study due to the additional uncertainty they introduce.

iv. Interpretation of results

The last phase of LCA includes identification of hotspots, addressing any limitations (e.g. via sensitivity analysis) and finally drawing conclusions and providing recommendations. All of these steps are considered in this work.

1.3.4 Economic sustainability assessment

To assess the economic dimension of sustainability, life cycle costing is carried out following the methodology proposed by Swarr et al. (2011); in addition, value added is also considered (Hunkeler et al. 2008). This is the approach favoured by the Society of Environmental Toxicology and Chemistry (SETAC), the body which started the standardisation process of LCA (Klöpffer 2006), and consequently ensures greater consistency, accuracy and integration of the environmental and economic parameters.

Like LCA, the LCC follows the life cycle of a product or a system, but instead of environmental, considers monetary inputs and outputs throughout the system. Since LCA is conducted in steady state conditions (Swarr et al. 2011), the LCC in this study is also conducted in steady state.

Following the methodology suggested by Swarr et al. (2011), life cycle costs of baby food is calculated as follows:

$$LCC = C_{RM} + C_M + C_P + C_R + C_C + C_W + C_{trans} \qquad (1)$$

where:

LCC	Total life cycle cost of the ready-made baby food product
C_{RM}	Cost of raw materials (cultivation and processing of ingredients)
C_M	Cost of manufacturing the ready-made baby food product
C_P	Cost of packaging
C_R	Cost of retail
C_c	Cost of consumption (use) phase
C_W	Cost of disposal (including recycling, when the cost is subtracted as resale value)
C_{trans}	Cost of transportation

Value added is calculated following Schmidt Rivera & Azapagic (2016), as follows:

$$VA = RP - LCC_{\textit{cradle to retail}} \qquad (2)$$

where:

VA	Value added from "cradle to retail", as it represents the difference between the sale price and the production cost of a sold unit.
RP	Retail price of the ready-made baby food or the raw materials in the case of home-made food
$LCC_{\text{cradle to retail}}$	Life cycle cost from cradle to retail

Cost data are gathered from official statistics (retail prices index), EU statistics (European Food Prices Monitoring Tool), governmental databases and product prices from retailers. So far, no studies are found in literature considering the LCC in the baby food sector.

1.3.5 Sectoral assessment

A sustainability assessment of the current condition of the baby food sector serves to provide an understanding of how much the baby food companies and their product portfolios contribute as a whole to the UK emissions and economy. As already mentioned in Section1.3.3 Environmental sustainability assessment, the functional unit of "33 million kg of wet and dry ready-made baby food sold annually" (Mintel 2015) is considered. The calculation of impacts for the sectoral assessment follows an aggregation of the results as in distribution of products based on meal type (Figure 1.4) for the individual products with their sales volumes.

1.3.6 Conclusions and recommendations for improvement

Based on the results of the environmental and economic sustainability assessment and focusing on hotspots, recommendations for improvements are made for the baby food industry, policy and consumers (Chapter 6).

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Chapter 2. Environmental impacts of baby food: Ready-made porridge products

Natalia Sieti, Ximena C. Schmidt Rivera, Laurence Stamford* and Adisa Azapagic

Sustainable Industrial Systems, School of Chemical Engineering and Analytical Science, The University of Manchester, Manchester M13 9PL, UK

*Corresponding author: laurence.stamford@manchester.ac.uk

Abstract

Scant information is available on the environmental impacts of baby food. Therefore, the aim of this work is to evaluate the life cycle environmental sustainability of one of the most common baby foods consumed for breakfast – ready-made porridge – and to identify options for improvements. Two variants of the product are considered: dry and wet porridge. The latter has from 43% to 23 times higher impacts than the dry alternative, with the global warming potential (GWP) of wet porridge being 2.6 times higher. However, the results are sensitive to the assumption on energy consumption for the manufacture of wet porridge, showing that reducing the amount of energy by 30% would reduce this difference by 5%-70% across the impacts. The main hotspots for both products are the raw materials and manufacturing; packaging is also significant for the wet option. For the dry porridge, product reformulation would reduce the environmental impacts by 1%-67%, including a 34% reduction in GWP. Reducing water content of the cereal mixture in dry porridge from 80% to 50% would reduce GWP of the manufacturing process by 65% and by 9% in the whole life cycle. Using a plastic pouch instead of a glass jar would decrease most environmental impacts of wet porridge by 7%-89%. The findings of this study will be of interest to both baby food producers and consumers.

Keywords: baby food; environmental impacts; life cycle assessment; porridge; ready-made meals

2.1 Introduction

With the awareness of sustainability gaining momentum, consumers are increasingly demanding more sustainable food products. While information on the life cycle environmental impacts of food products is becoming more widely available, the data for processed food, particularly ready-made meals, are still lacking. This is especially the case for baby food products, despite the fact that in 2014 the sector was worth £28.5 billion globally (Euromonitor International 2010). To our knowledge, only one prior life cycle assessment (LCA) of baby food exists, carried out 20 years ago in Sweden (Mattsson 1999). That study considered a cereal-based product as the baby food used most commonly in Sweden. The same also applies in the UK, where cereal-based baby foods are normally used to transition infants from liquid to solid meals when they are approximately seven months old. While cereal baby foods are often available in both dry and wet form, Mattsson (1999) assessed only a dry product, composed of oatmeal, wheat flour, milk and whey powder, and oils. However, this composition differs from that typically found on the market in the present day. Additionally, the system boundary in that study was from cradle the gate, including preparation of the meal and end-of-life waste management. Furthermore, three impacts were considered: global warming potential, acidification and eutrophication. The hotspots were found to be agriculture and food processing, primarily due to the impacts of milk production, pesticides used for the feed production and the fossil fuel used in processing.

A more recent study, based in the UK, also looked at baby food products but it did not carry out a detailed LCA. Instead, it took a top-level approach based on the annual sales of different products (Fisher et al. 2013) to estimate their global warming potentials. However, given the nature of the study, little information is available on the composition, processing conditions and other parameters.

In light of the above, the aim of this work is to evaluate the life cycle environmental sustainability of baby porridge and identify opportunities for improvements. Both dry and wet alternatives are considered. The methodology is detailed in the next section, including the assumptions and data used in LCA modelling.

2.2 Methods

The study has been carried out following the ISO 14040/14044 methodology (ISO 2006a; ISO 2006b). The impacts have been estimated according to the CML 2011 method (Guinée et al. 2002), using Gabi LCA software V6.1 (Thinkstep 2015). The methodology, data and the assumptions are described in more detail in the following sections.

2.2.1 Goal and scope of the study

The goal of the study is to estimate the environmental impacts of dry and wet ready-made porridge for babies and to identify the hotspots across the supply chain, with the aim of identifying improvement opportunities. The study is based in the UK and the results are aimed at both food manufacturers and consumers.

The recipes for the dry and wet products are given in Table 2.1. These represent average composition obtained by own market research into the brands of porridge available on the market, produced by five main manufactures. As can be seen, the main ingredients for both alternatives are cereals (oat flakes and rice flour), milk and sugar. The main difference between them is that dry porridge is made using milk powder while the wet product contains fresh milk and water.

As outlined in Figure 2.1, the scope of the study is from "cradle to grave" and the functional unit is defined as "production and consumption of one porridge meal", equivalent to 125 g. The life stages considered for both types of porridge are detailed in Table 2.2. For the dry and wet porridge, they encompass the production and processing of raw materials (ingredients), the manufacturing of the ready-made product and packaging, product distribution, retail, consumption, end-of-life (EoL) waste management and transportation between these stages.

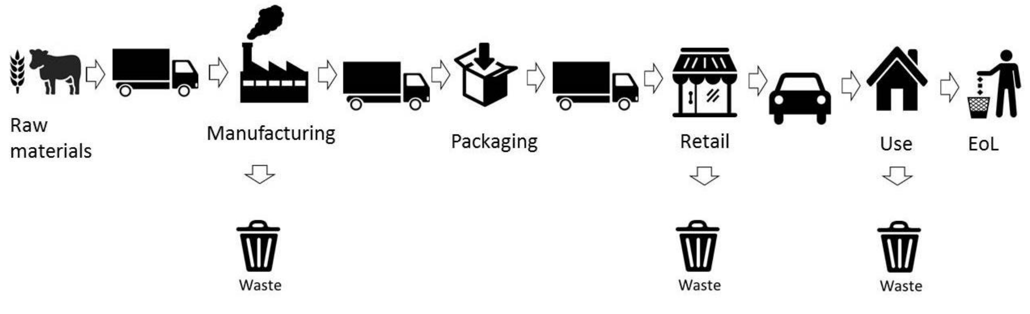


Figure 2.1 System boundaries for the ready-made porridge

Table 2.1 Composition of the dry and wet porridge

Ingredients	Dry [a] (g)	Wet (g)
Oat flakes	10.94 (35%)	6.25 (5%)
Rice flour	3.44 (11%)	13.75 (11%)
Milk powder	9.38 (30%)	-
Whole milk	-	67.5 (54%)
Sugar	6.25 (20%)	12.5 (10%)
Palm oil	0.94 (3%)	
Barley malt extract	0.31 (1%)	
Water	-	25 (20%)
Total	31.25 (100%)	125 (100%)

[a] As bought. During preparation, three parts of water are added to one part of the product.

Table 2.2 Stages considered in the life cycles of porridge

Stage	Dry porridge	Wet porridge
Raw materials (ingredients)	Cultivation of cereals (oats, rice, barley) and sugar cane	Cultivation of cereals (oats, rice, barley) and sugar cane
	Milling of cereals (oats, rice)	Milling of cereals (oats, rice)
	Dairy farming	Dairy farming
	Milk powder production	Milk production
	Sugar production and refining	Sugar production and refining
	Cultivation of oil palm	-
	Palm oil production and refining	-
	Barley malt extract production	-
Manufacturing	Dry porridge manufacturing	
	Cleaning in place	
Packaging	Manufacturing of packaging	Manufacturing of packaging
	Transport from packaging manufacturer to porridge manufacturer	Transport from packaging manufacturer to porridge manufacturer
	Transport from baby food manufacturing site to retailer	Transport from baby food manufacturing site to retailer
Retail	Lighting	Lighting
	Heating, ventilating and air conditioning (HVAC)	Heating, ventilating and air conditioning (HVAC)
	Waste management	Waste management
Use	Transport from retail to home	Transport from retail to home
	Home preparation (kettle water boiling)	Home preparation (gas hob heating)
	Food waste management	Food waste management
	Waste water management	Waste water management
End of life	Packaging waste management	Packaging waste management

2.2.2 Inventory data

As mentioned earlier, the data for the composition of the dry and wet porridge have been obtained through own market research. The manufacturing data have been sourced from the literature and own estimates. Background life cycle inventory data have been taken from the Ecoinvent database V3.1 (Ecoinvent 2015). An overview of the inventory data is given in

Table 2.3 and discussed in the next section.

2.2.2.1 Raw materials (ingredients)

Country specific data have been used for the ingredients where known and available. Further details are provided below.

Oat flakes: Life cycle inventory data for oat seeds do not exist in the Ecoinvent database; therefore, the data for barley seeds from Switzerland have been used instead (Ecoinvent 2015). Due to the fact that grain yield and grain quality differ regionally and between oat varieties, influenced by fertilisers among other factors, background data on oat grain cultivation in the Netherlands are used because the relationship was provided for seed, fertiliser, pesticides application rates and yield (Marinussen et al. 2012). For field operations (sowing, baling, combine harvesting, ploughing, tillage, harrowing and crop spraying) and grain drying (from 16% to 12% moisture content), data for porridge oats from the UK have been used (McDevitt and Milà i Canals 2011; Nemecek and Kagi 2007) in combination with data for field operations from Ecoinvent (2015). Emissions from fertilisers and pesticides (ammonia, nitrate, nitrous oxide and phosphate) during field operations are included based on the IPCC model (IPCC 2006). For oat flakes production, data from Nielsen et al. (2003) have been used and waste is assumed to be composted since land spreading is the main waste management route in the food and drink industry (Bartlett 2010; Carr and Downing 2014).

Table 2.3 Summary of life cycle inventory data

Life cycle stage	Process/material	Country of origin	Source of LCI data
Raw materials	Oats seeds at regional storehouse	NL	Barley seeds used as a proxy (Ecoinvent Centre 2015)
	Cultivation of oats	NL	Marinussen et al. (2012)
	Field operations for oats	UK	McDevitt and Milà i Canals (2011), Ecoinvent (2015)
	Oat grains drying	UK	Nemecek and Kagi (2007)
	Oat flakes milling	UK	Nielsen et al. (2003)
	Cultivation of rice	US	Ecoinvent Centre (2015)
	Barley grain production	DE	〃
	Barley malt extract dry production	UK	Own calculations
	Sugar from sugar cane, at refinery	BR	Ecoinvent Centre (2015)
	Milling of rice	UK	Van Zeist et al. (2012)
	Milk production	UK	Own modelling
	Feed for dairy cows		Williams et al. (2006)
	Milk powder production	UK	Nielsen et al. (2003)
	Palm oil production and refining	MY	Ecoinvent Centre (2015)
Manufacturing	Dry porridge manufacturing	UK	Almena et al. (2017)
	Wet porridge manufacturing	UK	Mattsson (1999)
Packaging	Manufacturing of packaging	RER[a]	Ecoinvent Centre (2015)
Retail	Supermarket storage	UK	Brunel University (2008)
Use	Energy consumption for meal preparation	UK	Own calculations
	Meal preparation techniques	UK	Manufacturers' instructions
Transport	Road transport, lorry	RER	Ecoinvent Centre (2015)
	Road transport, car	RER	〃
	Sea transport	OCE[b]	〃
Waste management	Treatment of biowaste, municipal incineration	CH	〃
	Treatment of bio-waste, composting	CH	〃
	Treatment of municipal solid waste, sanitary landfill	CH	〃
	Disposal, polyethylene, 0.4% water, to sanitary landfill	CH	〃
	Disposal, packaging cardboard, 19.6% water to sanitary landfill	CH	〃
	System credited for glass: packaging glass, white at regional storage	CH	〃
	Energy for glass recycling: glass cullets, sorted, at sorting plant	RER	〃
	System credited for cardboard recycling: packaging, corrugated board, mixed fibre, single wall, at plant	RER	〃
	Energy for cardboard recycling: paper, recycling no deinking, at plant	RER	〃
	Disposal, glass, 0% water, to inert material landfill	CH	〃
	Disposal, aluminium 0% water, to sanitary landfill	CH	〃
	Treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter	RER	〃
Waste water management	Treatment, sewage, wastewater treatment, class 3	CH	
Energy	Electricity	UK	Own modelling based on 2015 electricity mix DECC (2016)
	Natural gas, burned in boiler condensing modulating	RER	Ecoinvent Centre (2015)
Water	Tap water, at user	RER	〃

[a] Europe ,[b] Oceanic

Rice flour: Although Italy accounts for more than 50% of the EU rice production (Blengini and Busto 2009), US rice is considered here because the UK imports from the US are higher than from any other country (Defra 2014). There are no data for rice flour production and instead data for milling and processing are based on the corresponding stages for wheat flour production, using data from Nielsen et al. (2003).

Milk production: The life cycle environmental impacts of milk from "cradle to farm gate" have been estimated as part of this study. These data have then been used to estimate the impacts of milk powder. The animal feed is based on UK data (Williams et al. 2006), using an average of the autumn and spring feed, composed of 55% wheat grain, 25% barley grain and 20% protein (rape meal) for concentrates. Enteric methane emissions per cow are proportional to fodder intake (Williams et al. 2006), as is the excreted nitrogen in manure to the feed composition (Burgos et al. 2010)). An average of 2-2.5 kg manure per kg of milk is produced based on a typical diet (Weiss and St-pierre 2010). Water requirements for milk production have been sourced from DairyCo (2013). Electricity energy inputs and diesel fuel inputs are based on dairy farms in Ireland (Upton et al. 2013). For further details on both the liquid and milk powder, see Tables S1 and S2 in the Supplementary Information (SI).

For milk production beyond the farm gate, data are based on Eide (2002). For the milk powder, data have been sourced from literature (Nielsen et al. 2003), whereby the production plant specialises in milk powder production with no other co-products produced.

Sugar: The EU imports sugar mainly from Brazil (International Sugar Organization 2014) where sugar is produced from sugar cane. The life cycle inventory data for sugar from Brazilian sugar cane have been sourced from the Ecoinvent database.

Palm oil : Ecoinvent data for Malaysian palm oil are considered, since this is the main source of this ingredient in the UK (Defra 2012).

Barley malt extract: Data for barley grain production are not available for the UK; therefore, barley grains from Germany are used instead due to similarity to the UK weather conditions. The barley malting process is the same as for beer making (European Commission 2006a) and consists of soaking grains in water, boiling and evaporation, to produce the malt extract powder. Therefore, up until the boiling step, assumptions are based on the fact that 7 t of extract after boiling make 68 kl of beer

(Kløverpris et al. 2009). For the last step to get the dry malt extract (4.5% moisture), 3 MJ/kg has to be evaporated (European Commission 2006a). In this case, for the production of 1 kg of dry barley malt extract, 9.7 l of water is evaporated. The evaporation process is based on the Ecoinvent data for grain drying at high temperatures.

Spices, flavourings and preservatives: These are not considered due to their negligible contribution to the recipes and lack of LCA data.

2.2.2.2 Manufacturing

For the dry porridge, the process starts with receipt of ingredients. After cereals have been milled and resized, they are stored in silos. When needed, they are fed by gravity into a vessel through a "recipe formulation system" at a predefined rate and dose. The cereals are first dry-mixed in the vessel after which water is added to enable the steam cooking and gelatinisation in the next step. The cooked slurry is then dried in a drum drier by spreading it on the surface of the dryer. The dried powder, containing 6% of moisture, is removed as the drum is rotated. In parallel, the rest of the ingredients are milled to reduce size and are then mixed with the powder. Finally, the finished product is filled in plastic bags and then packed in cardboard boxes ('bag in box' packaging). The unit operations used in the manufacturing process are detailed in Table 2.4.

The data for the manufacturing process have been obtained from Almena et al. (2017) who modelled the process based on the patent by Gantwerker and Leong (1984). The two critical points are gelatinisation in cooking and product stability in drying. The process parameters (temperature and time) are influenced by the ratio of water to cereals during cooking (here assumed at 4:1) and moisture content in the drying process. A temperature of 80^{o}C is assumed for cooking (Gantwerker and Leong 1984). The water content in the cereals slurry can range from 30% to 80% (Tester and Morrison 1990; Altay and Gunasekaran 2006; Tester and Karkalas 1996; Wootton 1979). In this study, 80% is assumed in the baseline estimations and the lower water contents are considered in the sensitivity analysis.

In the case of wet porridge, the ingredients are milled, followed by wet mixing, further homogenisation and cooking. The cooked mixture is then filled into sterilised glass jars. Due to a lack of data for wet porridge production, the energy consumption is based on the production of a carrot purée (Mattsson, 1999) as the only data available for wet baby food manufacture (Table 2.5). Consequently, there is some uncertainty in these data which is explored as part of a sensitivity analysis.

The amount of food waste generated in manufacturing is assumed to be equal to 10% of the final product for the dry and 7% for the wet porridge. These assumptions are within the values for food products reported in literature (Bond et al. 2013; Tesco 2014; Holding et al. 2010).

Cleaning of the equipment and the treatment of the resulting wastewater are also considered (Table 2.4).

Table 2.4 Data for the manufacture of dry porridge

	Unit operation	Value	Unit (per f.u.)	References
Raw materials preparation				
Size reduction (raw ingredients)	Milling	7.16	kJ	NSI Equipments Pvt.Ltd (2016)
Mixing	Dry mixing	0.45	kJ	PM Industries and Process Equipment Pvt.Ltd (2016)
Slurry preparation	Wet mixing		kJ	IKA® (2010)
Gelatinisation	Steam cooking	47.1	kJ	Fulton (2014) Own calculations
Drying	Drum drying	396	kJ	Andritz AG Separation (2016))
Size reduction (post drying)	Milling	1.2	J	NSI Equipments (Pvt.Ltd 2016)
Mixing		0.18	kJ	PM Industries and Process Equipment Pvt.Ltd (2016)
Filling (into packaging)		1.39	kJ	Alibaba marketplace (2016)
Boxing		2.97	kJ	〃
Equipment cleaning				
Water		0.047	L	Eide et al. (2003)
Nitric acid (50% in H_2O)		0.028	mg	〃
Sodium hydroxide (50% in H_2O)		0.118	mg	〃
Electricity		18.6	J	〃

Table 2.5 Data for the manufacture of wet porridge (Mattsson 1999)

Resource	Amount (per f.u.)	Unit (per f.u.)
Natural gas	1395	kJ
Electricity	188	kJ
Diesel	1.75	kJ
Water	5.5	L
Chemicals	0.175	g

2.2.2.3 Packaging

The packaging used for the two types of porridge is summarised in Table 2.6. As mentioned earlier, dry porridge is packaged in a plastic bag in a cardboard box ('bag in box') while the wet variety is sold in glass jars. For the packaging materials, averages of packaging specifications available at retailers have been used, obtained through own market research. The life cycle inventory data have been sourced from Ecoinvent assuming the average mix of virgin and recycled materials in Europe and rest of the world (the UK specific data are not available in Ecoinvent). Secondary packaging, such as cardboard cases, shrink wrap, etc., has negligible impacts (Lilllywhite et al. 2013) and, hence, it is not considered. The ratio of aluminium and plastics (for the lid lining) in the jar cap is based on Amienyo (2012).

Table 2.6 Data for the primary packaging for dry and wet porridge (per functional unit)

Packaging specification	Dry	Wet
Dimensions (cm)		
Length	12	
Width	3.5	
Height	19	8
Diameter		5
Materials (g)		
Cardboard (box)	25	
White glass (jar)		88
Aluminium (lid)		5
Low density polyethylene	5[a]	3[b]

[a] Bag
[b] Lid

2.2.2.4 Retail

The major selling points for ready-made baby foods are hypermarkets and supermarkets that also represent 73% of the UK grocery market by value (Defra 2006). Energy data have been derived from Nielsen et al. (2003) and they refer to retailing of pasta as a representative fast-moving consumer goods stored at room temperature. These conditions are equivalent to both the dry and wet porridge. Electricity and heat consumption have been allocated to the products based on exposure area (1350 m^2) and average flow of the products in large retail stores (Nielsen et al. 2003). The data on energy use at retailer can be found in Table 2.7.

Food losses at retailer are considered to be equal to 2% of the product sold; this is equivalent to 3 g per functional unit, including packaging waste (Canals et al. 2007).

Table 2.7 Energy used at retailer for dry and wet porridge per functional unit (Nielsen et al. 2003)

Energy type	Amount (kWh)
Electricity for lighting	0.13
Heating	0.076

2.2.2.5 Use

The use stage for the dry ready-made porridge involves boiling water to prepare the meal using one part of cereals and three parts of water, as recommended by manufacturers. Therefore, to prepare 125 g of the meal (functional unit), 31.25 g of porridge and 93.75 ml of water are needed. A kettle is considered as a water heating appliance. It has been assumed that the consumer boils ½ litre of water and the electricity consumption has been determined using a smart meter (Table 2.8). This amount of water has been assumed for two reasons: there is a minimum requirement for the water content in a kettle for safety reason and the consumer will typically boil more water than actually required (Azapagic et al. 2016).

Wet ready-made porridge does not require preparation other than heating. Direct heating of the product on a gas hob, while constantly stirring, is assumed for this purpose. Gas hobs are considered as they are much more prevalent in the UK than the electric ones (Defra 2013). The energy consumption has been measured using a smart meter (Table 2.8). While the heating could be achieved using other appliances (e.g. microwave), hobs are used more frequently in households with children (Hulme et al. 2011) to avoid the creation of pockets of heat in the food, as per manufacturer's suggestions.

It is assumed that 1 L of cold tap water is used for manual washing up of plates and cutlery (Defra 2008); the use of hot water is considered in the sensitivity analysis. Life cycle inventory data for tap water and wastewater produced during dish washing have been sourced from Ecoinvent. Post-consumer food waste is also considered, assuming 14% of waste for both the dry and wet products (Holding et al. 2010).

Table 2.8 Energy consumption for meal preparation per functional unit

Product	Appliance	Amount (kWh)	Data source

Dry porridge	Kettle	0.050	Own measurements with smart meter
Wet porridge	Gas hob	0.063	〃

2.2.2.6 Waste management

Management of waste is based on current UK waste management practices (DEFRA 2015); for details, see

Table 2.9. Food waste from the manufacturing process is assumed to be composted. For packaging, closed loop recycling is considered. Therefore, the system is credited for the avoidance of virgin packaging material by subtracting the impacts from the production of the virgin material but adding the energy for recycling. Waste not recycled is landfilled (Defra 2015a).

Household wastes are split according to the waste management methods of the UK in year 2014/2015: 12% of food waste collected by local authorities is recycled, the remaining 80% is part landfilled (45%) and the rest incinerated (55%) with energy recovery (Defra 2015a).

2.2.2.7 Transportation

The transport modes and distances are summarised in

Table 2.10). The road transport within the UK is assumed to be by diesel lorry (Euro 3) distances are assumed at 100 km, one way. For the transportation of imported ingredients, the use of transoceanic freight is considered with distances calculated using Google maps. For consumer shopping, an average of around 8 km per week per household is assumed by passenger car, as opposed to bus, walking and cycling(Pretty et al. 2005).

2.2.3 Allocation and system expansion

Several ingredients are produced together with co-products, so the impacts had to be allocated between them. The following details the approach taken for the relevant ingredients.

Oat straw and bran: In the UK, the majority of straw is used for livestock feed and animal bedding (Kilpatrick 2008). Here, the former is assumed and the system has been credited for replacing barley grain based on their respective metabolisable energy[2] of 6.5 MJ/kg (Feedipedia 2017) and 13.2 MJ/kg dry matter (Macdonald et al. 2018).

Economic allocation has been used to allocate the impacts between oat flakes and bran based on their respective market prices of £1.19/kg (Buy Whole Foods Online 2016) and £2.25/kg (Healthy Supplies 2016).

Rice bran: The system has been credited for bran produced during rice milling, assuming its use as livestock feed. For consistency, it is assumed that it replaces barley grain, which is used in this study for milk production.

[2] The amount of energy a ruminant animal is able to use per unit of dry matter of foodstuff eaten.

Table 2.9 Material losses and waste treatment

Life cycle stage	Losses/waste (%)	Assumed waste treatment options in Ecoinvent	Reference
Dry porridge			
Ingredients in raw materials (oat flakes)	5%	Treatment of bio-waste, composting	Nielsen et al. (2003)
Ingredients in raw materials (rice flour)	1%	Treatment of bio-waste, composting	〃
Ingredients in manufacturing	10%	Treatment of bio-waste, composting	Assumption
Baby food at retailer	2%	Treatment of bio-waste, composting	Bond et al. (2013)
Post-consumer food waste	14%	Treatment of bio-waste, composting; treatment of bio-waste municipal incineration; treatment of municipal solid waste, sanitary landfill	Defra (2015a)
Post-consumer cardboard	60%	Credit for packaging, corrugated board, mixed fibre, single wall, at plant	Defra (2015b)
	40%	Disposal, packaging cardboard, 19.6% water, to sanitary landfill	〃
Post-consumer plastic film	100%	Disposal polyethylene, 0.4% water, to sanitary landfill	Information on packaging
Wet porridge			
Ingredients in raw materials (oat flakes)	5%	Treatment of bio-waste, composting	〃
Ingredients at baby food manufacturer	7%	Treatment of bio-waste, composting	Holding et al. (2010)
Ingredients at retailer	2%	Treatment of bio-waste, composting	Bond et al. (2013)
Post-consumer food waste	14%	Treatment of bio-waste, composting; treatment of bio-waste municipal incineration; treatment of municipal solid waste; sanitary landfill	Defra (2015a)
Postconsumer aluminium	25%	Disposal aluminium 0% water to sanitary landfill	〃
	75%	Treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter	〃
Post-consumer glass	30%	Disposal, glass 0% water, to inert material landfill	〃
	70%	Recycling and credits for which glass packaging, at regional storage	〃

Table 2.10 Transport data[a]

Life cycle stage	Country of origin	Assumed distances and mode of transport	Vehicle
Raw materials to manufacturer			
Rice	US	6826 km by sea	Transoceanic freight ship
Sugar	Brazil	8845 km by sea	〃
Palm oil	Malaysia	10,464 km by sea	〃
Other ingredients	UK	100 km by road	Lorry, 16-32 t
Packaging to porridge manufacturer	UK	100 km by road	Lorry, 7.5-16 t
Porridge to retailer	UK	100 km by road	Lorry, 16-32 t
Porridge to consumer's home	UK	8 km by road	Transport, passenger car

[a] Life cycle inventory data from Ecoinvent.

Malt sprouts: Barley sprouts are a by-product of barley malt and wort production. The system has been credited for their use as animal feed (Melorose et al. 2015), replacing barley grain. The credit is based on their gross energy (data on metabolisable energy were not available): 4140 kcal/kg for malt sprouts (Krishna 1985) and 4420 kcal/kg for barley grain (Heuzé et al. 2016).

Milk production: Economic allocation is considered for milk (90%) and beef (10%), based on the allocation factors in Cederberg and Stadig (2003). To apply this allocation ratio, it is necessary first to calculate the amount of beef produced per kg of milk, which has been carried out as follows. Friesian-Holstein cows, the predominant breed of dairy cow in the UK (Foster et al. 2007), are almost 60% carcass (Schaefer 2005) with the rest being edible meat (Oklahoma Department of Agriculture Food & Forestry 2013). Therefore, a cow weighing 600 kg (Williams et al. 2006) gives 240 kg of beef sold for consumption. On average, a cow produces 7500 kg milk per year (Williams et al. 2006) and thus it provides 0.032 kg of beef per kg of milk. Therefore, the former represents 10% of farmer's income and the latter 90%.

The average nitrogen content in cattle manure of 0.6% by weight (FAO 2005) is used to credit the system for displacing urea fertiliser. The latter has a nitrogen content of 46% (Defra 2010). Hence, given that production of 1 kg of milk generates on average approximately 3 kg cattle manure (Weiss and St-pierre 2010) and that stoichiometrically 1 kg nitrogen is equivalent to 2.16 kg of urea fertiliser, approximately 40 g of urea is substituted per kg of milk produced at farm.

Economic allocation has also been performed between milk (67%) and cream (33%), based on the milk price at farm gate equivalent of 16 pence per litre (p/L) and income to liquid processor from cream of 5.10 p/L in December 2015 (AHDB Dairy 2015).

2.3 Results and discussion

This section presents and analyses the environmental impacts of the dry and wet ready-made porridge products. The comparison of the results with the literature is presented in the subsequent section, followed by a sensitivity analysis and identification of improvement opportunities to examine the influence of environmental hotspots on the impacts of the two types of product.

2.3.1 Environmental impacts of ready-made porridge

The environmental impacts of the two variants of baby porridge are displayed in Figure 2.2. As can be seen, wet porridge has considerably higher impacts than the dry, largely due to the assumed higher use of energy in the manufacturing process. However, the impacts from the raw materials are higher for the dry product because of the milk powder. These results are discussed in more detail for each impact in turn in the following sections. For the impacts of liquid and powder milk production, which have been estimated as part of this study, see Figures A.1 and A.2 in Appendix A.

2.3.1.1 Global warming potential (GWP)

The GWP for dry porridge is estimated at 141 g CO_2 eq./f.u., with the hotspots being the raw materials with an almost 70% contribution, followed by manufacturing with around 15%. The impact from the raw materials is dominated by milk powder production, contributing 70% of the total. Milk itself has an estimated impact of 0.943 kg CO_2 eq./kg and milk powder 8.25 kg CO_2 eq./kg (see Figures A.1 and A.2 in Appendix A). The reason for a high value is that 7.8 kg of raw milk is required for the production of 1 kg of milk powder (Nielsen et al. 2003) and removal of water from milk to produce the powder is energy intensive (1.08 MJ/kg raw milk; see Table S2 in the SI). The next most important contributor in the raw materials stage is rice (8%) due to methane emissions from paddy rice cultivation. In the manufacturing stage, the main contribution is drum drying, causing almost 70% of the impact from this stage.

Wet porridge has 2.5 times higher GWP (363 g CO_2 eq./f.u) than the dry, with the hotspots being the manufacturing and packaging stages, with almost 30% contribution each. In contrast with the dry porridge, raw materials contribute only 20% to the total impact due mostly to the absence of milk powder. The 3.5 times higher energy consumption for the production of wet porridge than the dry variant (see Table 2.4 and

Table 2.5), as well as the use of a glass jar as packaging, result in its having a considerably higher impact. Within the packaging stage, the glass contributes approximately 88%, with the remainder related to the aluminium lid.

2.3.1.2 Abiotic depletion potential of elements (ADPe) and fossil resources (ADPf)

The results in Figure 2.2 show that the ADPe for the dry porridge is estimated at 130 μg Sb eq./f.u, most of which comes from the raw materials. This is largely related to the use of fertilisers and pesticides for production of cereals, both for the porridge and also as a feed to dairy cows.

The difference between the wet and dry product is much higher here than for GWP, with wet porridge having 23 times higher ADPe, estimated at 2960 μg Sb eq. This is mainly due to the glass jar and aluminium lid, with the former contributing 59% and the latter 41% to the ADPe from packaging.

For the dry porridge, the ADPf is 0.79 MJ/f.u. with the raw materials and manufacturing being major contributors. For the wet product, the ADPf is considerably higher at 3.85 MJ/f.u., with most of the impact related to energy use in manufacturing and packaging, with equal contributions.

2.3.1.3 Acidification (AP) and eutrophication potentials (EP)

The AP for the dry porridge is 1.5 g SO_2 eq./f.u, with 90% the impact attributed to the raw materials, mainly due to fertilisers used in cereals cultivation, feed production and animal manure. For the wet porridge, the impact is again higher (2.6 g SO_2 eq./f.u.), with the raw materials and packaging contributing 50% each. The raw materials contribution is due to pesticides and fertilisers used in cereals cultivation. In the case of packaging, the contribution is due to the use of electricity for production of glass packaging.

The EP for the dry product is 0.63 g PO_4 eq./f.u. and for the wet 0.91 g PO_4 eq./f.u. The raw materials are the main contributors (almost 90%) to the former, due to nitrates from fertilisers. For the wet porridge, the ingredients contribute 50% and packaging 30%. The latter is related to phosphate and nitrogen oxides emitted during packaging production.

2.3.1.4 Freshwater aquatic ecotoxicity potential (FAETP)

The results show that the dry porridge has a FAETP of 22 g dichlorobenzene (DCB) eq./f.u while that of the wet product has three times higher impact, estimated at 61 g DCB eq./f.u. For the dry formulation, the main hotspots are the raw materials (60%), particularly milk powder, related to the production of animal feed. Manufacturing causes 20% of the impact while the use stage and end-of-life waste management contribute the remaining 10% each.

The higher impact of the wet porridge is due to the packaging which contributes 66% to the total, followed by the raw materials and manufacturing with 16% each. The FAETP is mainly due to the electricity used in these stages.

2.3.1.5 Human toxicity potential (HTP)

The HTP for the dry meal is 37 g DCB eq./f.u., mainly dominated by the raw materials (65%), followed by manufacturing (15%). The raw materials' contribution is mainly due to pesticides production for cultivation of cereals and oil palms. Manufacturing adds to the HTP via combustion of fossil fuels from the electricity mix.

The HTP for the wet porridge is much higher at 288 g DCB eq./f.u., with packaging (45%) and raw materials (20%) being the major contributing stages. This is due to combustion of fossil fuels related to the use of electricity for packaging production. End-of-life also makes a contribution (17%), because of electricity used for packaging recycling. For the raw materials, sugar plays an important role, contributing 43% to the HTP in this stage. This is due to the emissions to agricultural soil of heavy metals and pesticides used in the cultivation of sugarcane.

2.3.1.6 Marine aquatic ecotoxicity potential (MAETP)

The marine aquatic ecotoxicity potentials of the dry and wet products are presented in Figure 2.2. The results show that the dry porridge has a total impact of 34 kg DCB eq./f.u, dominated by the raw materials stage (almost 55%). This is due to electricity used for milk powder and rice flour production. The MAETP of the wet ready-made porridge is much higher at 412 kg DCB eq./f.u. and is dominated by the packaging with an 80% contribution, mostly due to emissions and energy used for production of the glass jar and aluminium lid (approximately 85% and 15% of the packaging impact, respectively).

2.3.1.7 Terrestrial ecotoxicity potential (TETP)

In the case of the dry porridge, most of the impact of 3.1 g DCB eq./f.u. is from the raw materials (95%). Milk powder is the key contributor due to the upstream requirement for animal feed and the associated pesticide and fertiliser production, as well as nitrate emissions from manure.

The same trend is found the wet porridge, where the raw materials contribute 70% to the total TETP of 5.1 g DCB eq. Much of this impact is related to pesticides associated with the production of liquid milk (cultivation of feed for dairy cows, especially rape meal) and heavy metals in the soil related to sugarcane cultivation and liquid milk production. Packaging follows with a contribution of almost 20%.

2.3.1.8 Photochemical oxidants creation potential (POCP)

As shown in Figure 2.2, the POCP of the dry porridge is estimated at 92 mg C_2H_4 eq./f.u. Emissions associated with the life cycle of electricity dominate the raw materials stage, with the latter contributing almost 80% to the total.

For the wet product, the impact is equal to 299 mg C_2H_4 eq./f.u, more than three times higher than for the dry option. In this case, the majority of the POCP is due to the raw materials (70%), followed by packaging (20%). This is due to emissions of sulphur dioxide, carbon monoxide and volatile organic compounds during production of sugar and electricity used in the manufacture of the meal and glass packaging.

2.3.1.9 Ozone layer depletion potential (ODP)

The ODP of the dry porridge has a total value of 6.6 μg R11 eq./f.u. and is dominated by the raw materials stage (40%), followed by manufacturing (25%). The wet product variety again has a much higher impact, estimated at 32.9 μg R11 eq./f.u. The latter is largely due to manufacturing (50%) and packaging (40%). In both stages, most of the impact originates from halon emissions associated with electricity generation.

2.3.2 Comparison of results with literature

As mentioned in the introduction, there is only one other LCA study of cereal-based baby food (Mattsson 1999). Comparison with this study is difficult due to the differences in the assumptions and the lack of detail provided. The main difference between the two studies include product composition, system boundary and data. Nevertheless, the contribution trends match, with agriculture and food processing being the main hotspots in both studies. Specifically, the contribution of drum drying used for the dry porridge, accounting for almost 70% of the manufacturing impacts on average (Figure 2.4), is in agreement with Mattsson's findings that evaporation and drying processes contribute the most in the food processing stage.

The results for GWP and AP are also comparable. For dry porridge, the former was estimated by Mattsson at 2000 kg CO_2 eq./t produced, while in this study the impact ranged from 1128 kg CO_2 eq./t for the dry to 2904 kg CO_2 eq./t for the wet product. For the AP, the previous study reported 18 kg SO_2 eq./t, compared to 12 kg/t for dry porridge and 20.8 kg/t for the wet estimated in this work. The contribution of different stages is also similar to the wet porridge, where the former study found that agriculture contributed 55% and processing 37% vs 50% each here. For EP, again a similar breakdown was reported by Mattsson, with high contributions of the raw materials (68%). The total impact cannot be compared between the two studies due to the use of different methodologies and reference compounds.

While the study by (Fisher et al. 2013) mentioned in the introduction did not use conventional LCA, their estimates for GWP are in the range found in this study: 208 g CO_2 eq./meal vs 141 and 363 g CO_2 eq. for the dry and wet products, respectively.

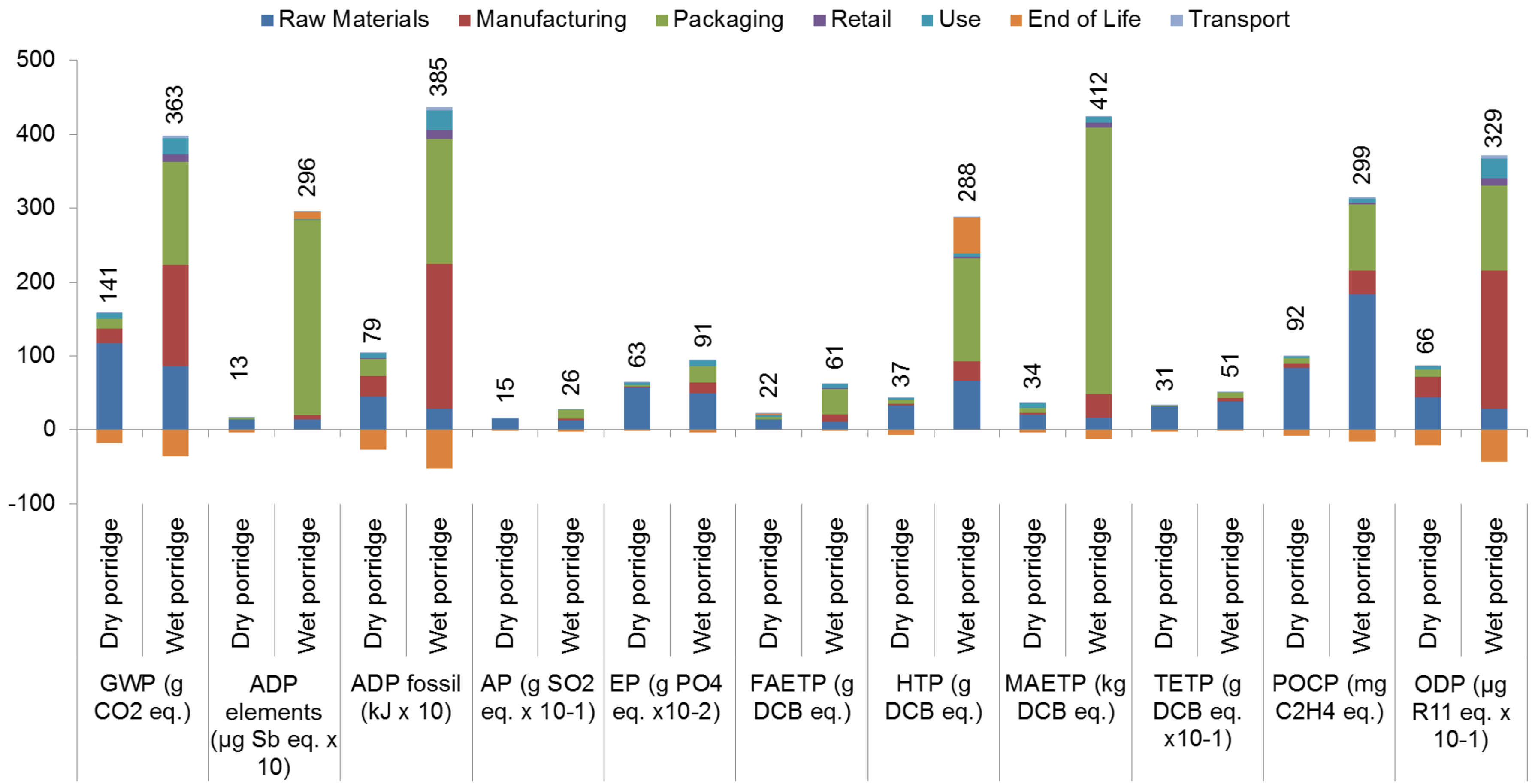


Figure 2.2 Comparison of the environmental impacts of the dry and wet ready-made porridge, showing contributions of different life cycle stages (Impacts expressed per functional unit: consumption of one meal (125 g of porridge). GWP: global warming potential; ADPe: Abiotic depletion potential elements, ADPf: Abiotic depletion potential fossil, AP: Acidification potential, EP: Eutrophication potential, FAETP: Freshwater aquatic ecotoxicity potential, HTP: Human toxicity potential, MAETP: Marine aquatic ecotoxicity potential, TETP: Terrestrial ecotoxicity potential, POCP: Photochemical oxidants creation potential, ODP: Ozone depletion potential, DCB: dichlorobenzene)

2.3.3 Sensitivity analysis

The sensitivity analysis explores the effect on the total impacts of the following assumptions and data:

i) energy consumption in the production of wet porridge;

ii) energy consumption for heating the wet porridge; and

iii) use of hot water for washing up of dishes.

These are discussed in turn below.

2.3.3.1 Energy consumption in wet porridge production

Given that the contribution to the impacts of natural gas by far outstrips the contribution of electricity due to a much higher demand (
Table 2.5), the focus here is on natural gas. Its consumption has been varied by ±30%, an uncertainty range typically found in LCA of food products (FAO 2010a).

When decreasing the usage of natural gas by 30%, the greatest decrease in impacts in the manufacturing stage is observed for ADPf (25%), GWP (24%) and ODP (27%); for further details, see Figure A.3 in Appendix A. However, these changes are much smaller across the whole life cycle of wet porridge (10% for ADPf, 8% for GWP and 12% for ODP). The remaining environmental impacts change by 0.1% to 2.2%. A similar trend is found for the increase of energy consumption by 30%.

Therefore, these results suggest that, within the ranges considered, the results are relatively robust and do not change the ranking of the meal option

2.3.3.2 Energy consumption for heating wet porridge

To explore the influence on the impacts of consumer behaviour related to heating the wet porridge meal, the amount of natural gas used by the gas hob is doubled on the consumption assumed in the baseline. This is to account for extended heating that may be practised by the consumer.

As indicated in Figure A.4 in Appendix A, the overall effect is modest, with the impacts increasing by 0.1-7.8%. The greatest increase is noticed for TETP (7.8%), followed by ADPf (6.5%) and GWP (4.5%).

2.3.3.3 Use of hot water for washing up

It has been assumed in the baseline that the dishes are washed up using cold tap water (10ºC). Here, water heated to 40ºC is assumed to gauge the influence on the overall results.

The results for dry porridge shown in Figure A.5a (Appendix A) suggest that using hot water for washing up would increase the total life cycle impacts by 5-97%. The greatest change is found for MAETP (97%), ADP fossil (59%) and ODP (41%); GWP would be 18.5% higher. In the case of wet porridge, the effect is somewhat less pronounced, with the impacts increasing by 1-42%, particularly ODP (42%), ADP fossil (35%) and GWP (25%); see Figure S5b. Thus, the results are sensitive to the assumption on the temperature of water used for washing up. These results also show that consumers can play an important role in reducing the impacts of porridge (and other food) by using cold rather than warm water for cleaning the dishes.

2.3.4 Improvement opportunities

Given that the main hotspots for dry porridge are the milk powder and energy consumption by the drum drier, the following improvement opportunities are considered for this product:

- changes to the product formulation with respect to the contribution of milk powder; and
- variations in the water content in the cereals slurry and the related energy consumption by the drum dryer in the manufacturing process.

For the wet product, the main hotspots for most impacts (seven out of 11) are energy consumption in the manufacturing process and the glass packaging. The former may be due to the data uncertainty which was discussed in the previous section. Thus, the focus here is on replacing the glass jar with a plastic pouch.

2.3.4.1 Changing the recipe of dry porridge

To explore the effect on the results of milk powder, its amount in the recipe is varied from the baseline with the contribution of the cereals changed proportionally to preserve the functional unit (125 g per meal). At first, two product formulations are considered with the amounts of milk powder lower than in the baseline (‘Prod 1’ and ‘Prod 2’ in Table 2.11). A further two recipes are also evaluated, in which the amount of milk powder is assumed to be higher than in the baseline (‘Prod 3’ and ‘Prod 4’), to contrast the results. The manufacturing parameters have been kept the same as in the baseline for all the product formulations, including the water content in the slurry (80%) before the drying process and the product moisture content after it (6%).

Table 2.11 Changing the recipe of dry porridge

		Less milk powder		More milk powder	
Recipe	Baseline	Prod 1	Prod 2	Prod 3	Prod 4
Oat flakes (%)	0.35	0.50	0.43	0.27	0.20
Rice flour (%)	0.11	0.16	0.13	0.09	0.06
Milk powder (%)	0.30	0.10	0.20	0.40	0.50
Sugar	0.20	0.20	0.20	0.20	0.20
Palm oil	0.03	0.03	0.03	0.03	0.03
Barley malt extract	0.01	0.01	0.01	0.01	0.01

The results in Figure 2.4 indicate that the best option for most impacts is Prod 1 which corresponds to the lowest amount of milk powder in the mixture. Across the impact categories, Prod 1 shows a reduction of 1%-67% compared to the baseline formulation. At the opposite end of the scale, Prod 4, with 40% more milk powder than in the baseline, has 2%-67% higher impacts.

As in the baseline, the raw materials and manufacturing are the main contributors to most impacts across the different product recipes. To illustrate the effects of the later in more detail, the influence of these two stages on the GWP is considered in Figure 2.5a&b. If the amount of milk powder decreases (Prod 1 and 2), energy used in manufacturing increases (Figure 2.5b). This is due to the higher amount of cereals used per functional unit which require higher energy in the drying and mixing processes. However, this increase in energy consumption due to a higher proportion of cereals does not result in a higher overall GWP: rather, the opposite is true due to the higher GWP of milk compared to the cereals (Figure 2.4a). Hence, there is a trade-off between increased manufacturing energy consumption and decreased GWP. Overall, reducing the proportion of milk powder in the product while increasing the share of cereals could help reduce the environmental impacts (Figure 2.5).

While beyond the scope of this study, product quality is affected by its formulation since different ingredients have different nutritional profiles. Therefore, when considering the environmental improvement opportunities, aspects such as nutrition, food quality and safety must be considered simultaneously, to make sure that one sustainability issue is not solved at the expense of another.

2.3.4.2 Changing water content in the production of dry porridge

As discussed earlier, drum drying contributes the most to the impacts from the manufacturing of dry porridge. As this process and wet mixing/cooking depend on one another, this section explores the influence of water content on the impacts from manufacturing. As mentioned in section 0, water content of cereals slurry can range from 30% to 80% depending on the technology. Here, a range of 50%-70% is assumed since no change in the technology is considered. These results are compared in Figure 2.7 to the 80% water content in the baseline. As can be seen, when the water content falls from 80% to 50%, the impacts of the manufacturing stage reduce by 38%-66%.

The effect on the overall impacts, however, is much smaller. This is exemplified by GWP: while this impact from the manufacturing stage reduces by 65%, the overall reduction across the life cycle is only 9% (Figure 2.7) for the water content reduction from the baseline 80% to 50%.

The energy consumption depends on the drying rate which is fixed for each water content and a consequent temperature increase with water content. However, other effects should be considered, which are beyond the scope of this work. For instance, product quality, especially nutrition, safety and texture are important; therefore, the influence of water content on biochemistry requires further consideration. Furthermore, the rheological properties of the mixture may be important depending on the capabilities of the equipment. Different types of technology could be used, but this depends on cost in addition to product quality factors, leading to a complex and case-specific range of possibilities which cannot be addressed here.

2.3.4.3 Changing the packaging for wet porridge

As seen in Figure 2.2, packaging is a major contributor to seven out of 11 impacts associated with the wet product, including ADPe and GWP. It also has a bearing on the impacts from end-of-life recycling, notably for GWP, ADPf and ODP. For these reasons, a plastic pouch with a cap is considered as an alternative. As shown in Table 2.12, the pouch has multiple layers, the weight of which has been calculated based on the ratio between a layer's typical thickness (Canadian Food Inspection Agency 2002) and the total package weight.

The results in Figure 2.8 indicate that swapping the glass jar for a pouch decreases the environmental impacts from 7% (GWP) to 89% (ADPe). However, the EP increases by 13% due to higher impacts from end-of-life recycling. The contribution of different components to the impact of the pouch and glass jar can be seen in Figure A.6 in Appendix A.

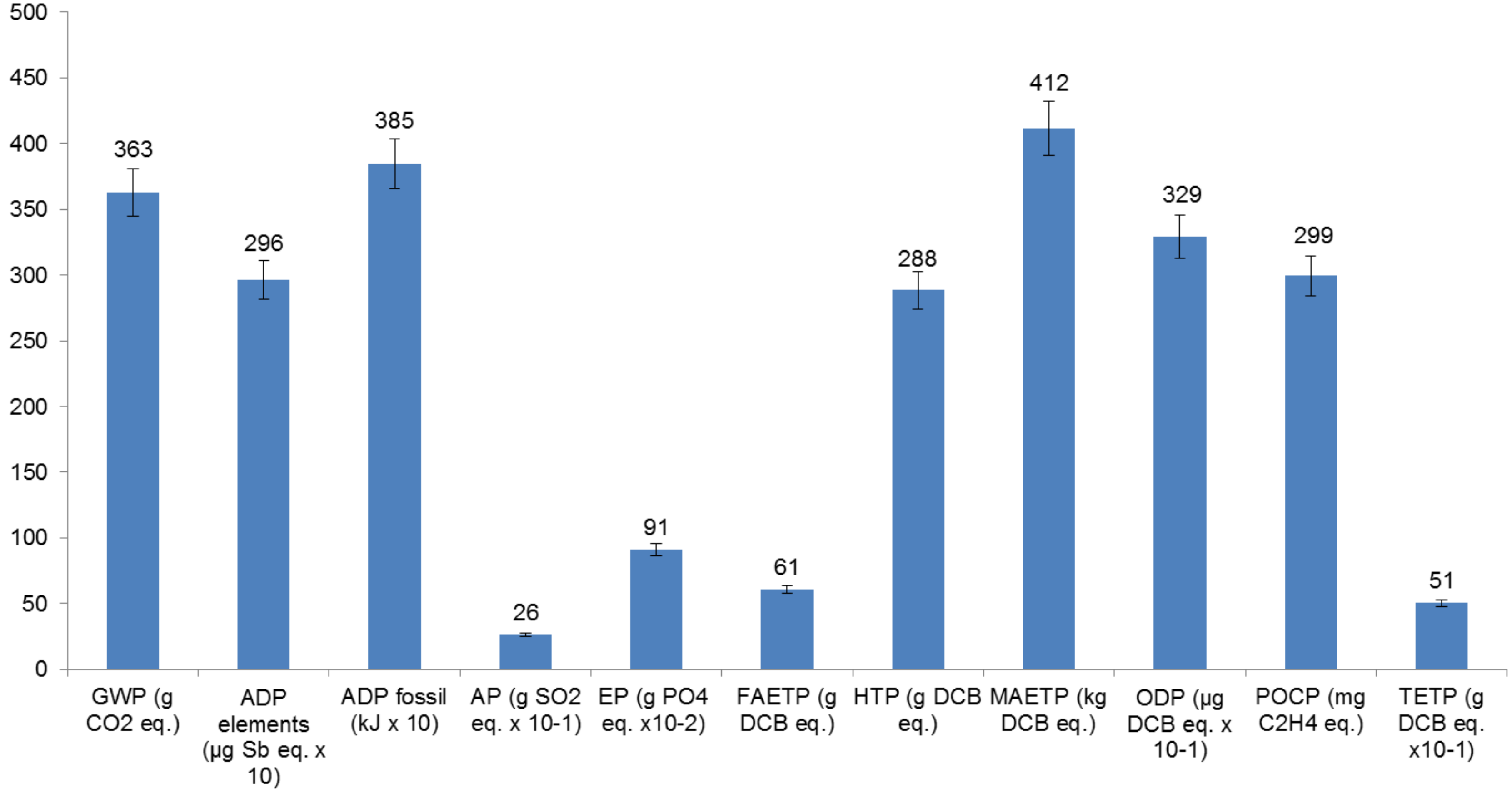


Figure 2.3 Sensitivity analysis for the use of natural gas in the manufacture of wet porridge
(Impacts expressed per functional unit: consumption of one meal (125 g of porridge). For the impacts nomenclature, see Figure 2.2. DCB: dichlorobenzene

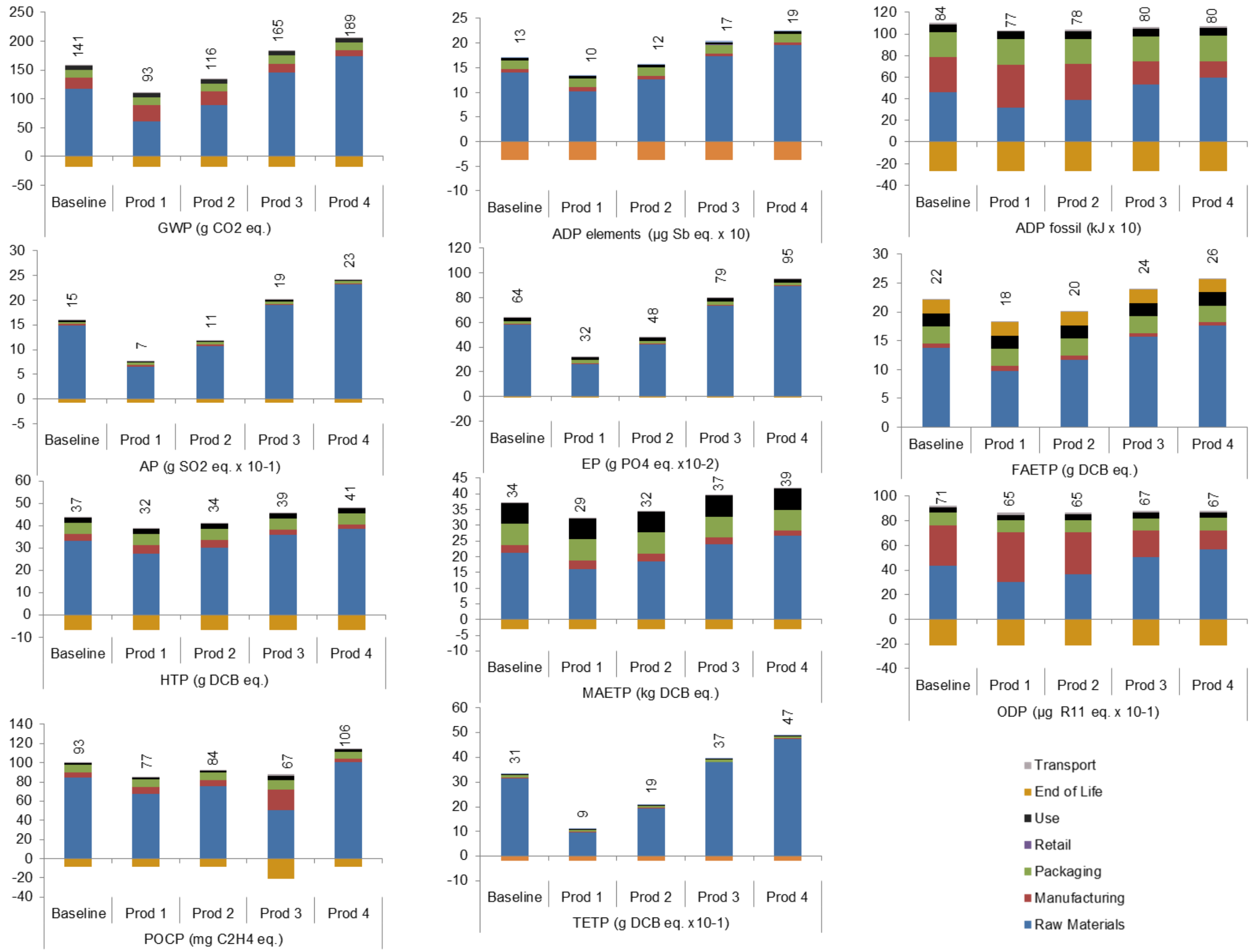
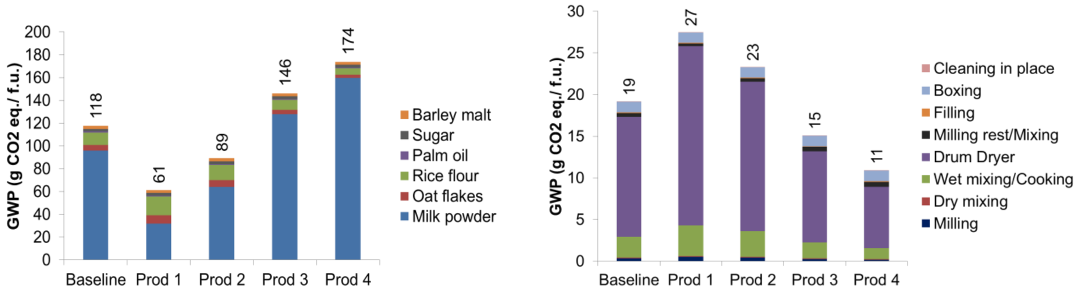


Figure 2.4 Effect on environmental impacts of product formulation for dry porridge.
(Impacts are expressed per functional unit (125 g per meal). For details on the product formulations (Prod 1-Prod 4), see Table 2.11. The negative values represent system credits. For the impacts nomenclature, see Figure 2.2. DCB: dichlorobenzene)



a) Raw materials b) Manufacturing

Figure 2.5 Effect of product formulation on the global warming potential (GWP) of the raw materials (a) and manufacturing (b) for dry porridge

Table 2.12 Data for the pouch used as a packaging for wet porridge

	Specification	Value
Dimensions	Width	3.5
	Height (cm)	13.5
	Length (m)	8
Pouch	Polypropylene, granulate (g)	7.3
	Aluminium foil (g)	0.66
	Nylon 6 production (g)	1.1
	Polyester resin (g)	0.94
Cap	High density polyethylene, granulate (g)	5
End of life	Landfilling	100%

2.4 Conclusions

This paper has compared the life cycle environmental impacts of dry and wet ready-made porridge meals for babies. The results suggest that the impacts of the latter are higher than of the dry equivalent by 43% to 23 times; GWP is 2.6 times higher. The main reasons for these differences are much higher impacts in the manufacturing of wet porridge due to the assumptions on energy consumption, as well as due to the glass packaging. However, for the dry product, the impacts from the raw materials are higher than for the wet alternative because of the powder milk which is not used in the latter. The main hotspots for both products are the raw materials and for the wet, manufacturing and packaging.

For the dry option, product reformulation provides opportunities to reduce environmental impacts by 1%-67% including a 34% reduction in GWP. These reductions can be achieved by reducing the amount of milk powder in the recipe while increasing proportionally the contribution of cereals. This example can help food companies to consider how baby food products could be re-designed to improve their environmental sustainability. However, other factors must also be considered, such as required changes in the production process and increased energy consumption in the manufacturing stage, as well as the nutritional aspects of the product. A further aspect is consumer behaviour – if the product contains less milk, they may wish to enrich its nutritional value by adding milk during preparation of the meal. Nevertheless, the increase in impacts would still be lower than using milk powder in the manufacturing as the consumer would probably use liquid milk for these purposes.

Further improvement opportunities for the dry porridge include reducing the water content of the cereal mixture from 80% to 50% during manufacturing. This results in a 65% reduction in the GWP of the manufacturing stage and in an overall decrease in the impact of 9%. However, again other factors must be considered, including any possible effects on the manufacturing process.

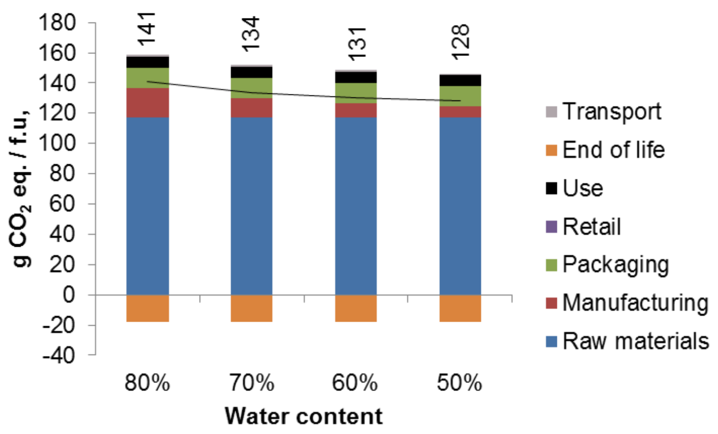


Figure 2.6 Effect on the total GWP of water content during production of dry porridge (The labels on top of the graph bars denote the total impacts after the end-of-life credits.)

For the wet alternative, swapping the commonly used glass jar for a laminated pouch decreases the environmental impacts by 7%-89%; GWP reduces by 7%. However, these pouches cannot be recycled at present. Furthermore, eutrophication also increases by 15% due to higher impact from recycling.

Finally, it must be borne in mind that baby food products do not exist in isolation, but as a wide range of options designed to provide a nutritionally sound basis for early development of infants. Therefore, it is necessary to consider a more holistic feeding approach, including menus or overall diets in order to gain a more complete understanding of the environmental impacts from baby food.

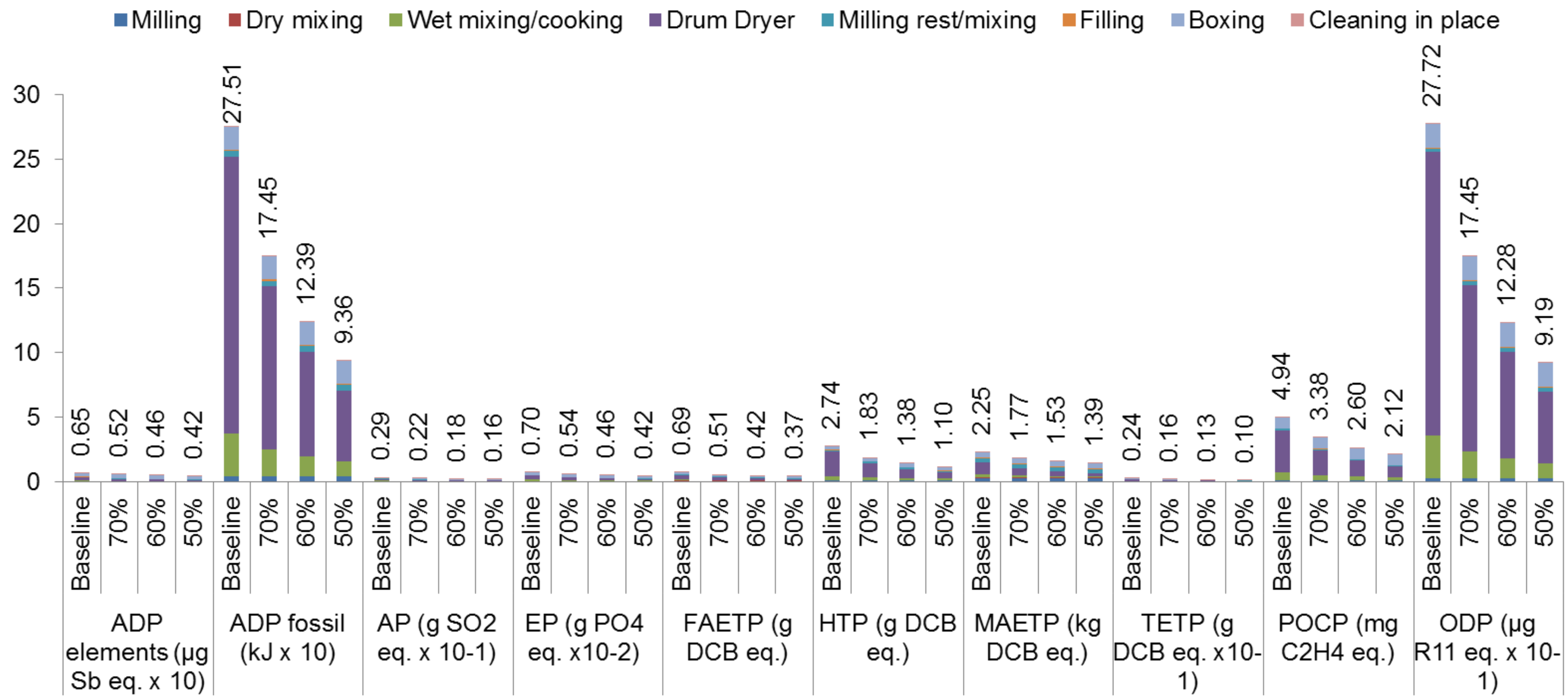


Figure 2.7 Effect of water content on the impacts from the drum drying process

(Impacts are expressed per functional unit (125 g per meal). For the impacts nomenclature, see Figure 2.2. DCB: dichlorobenzene

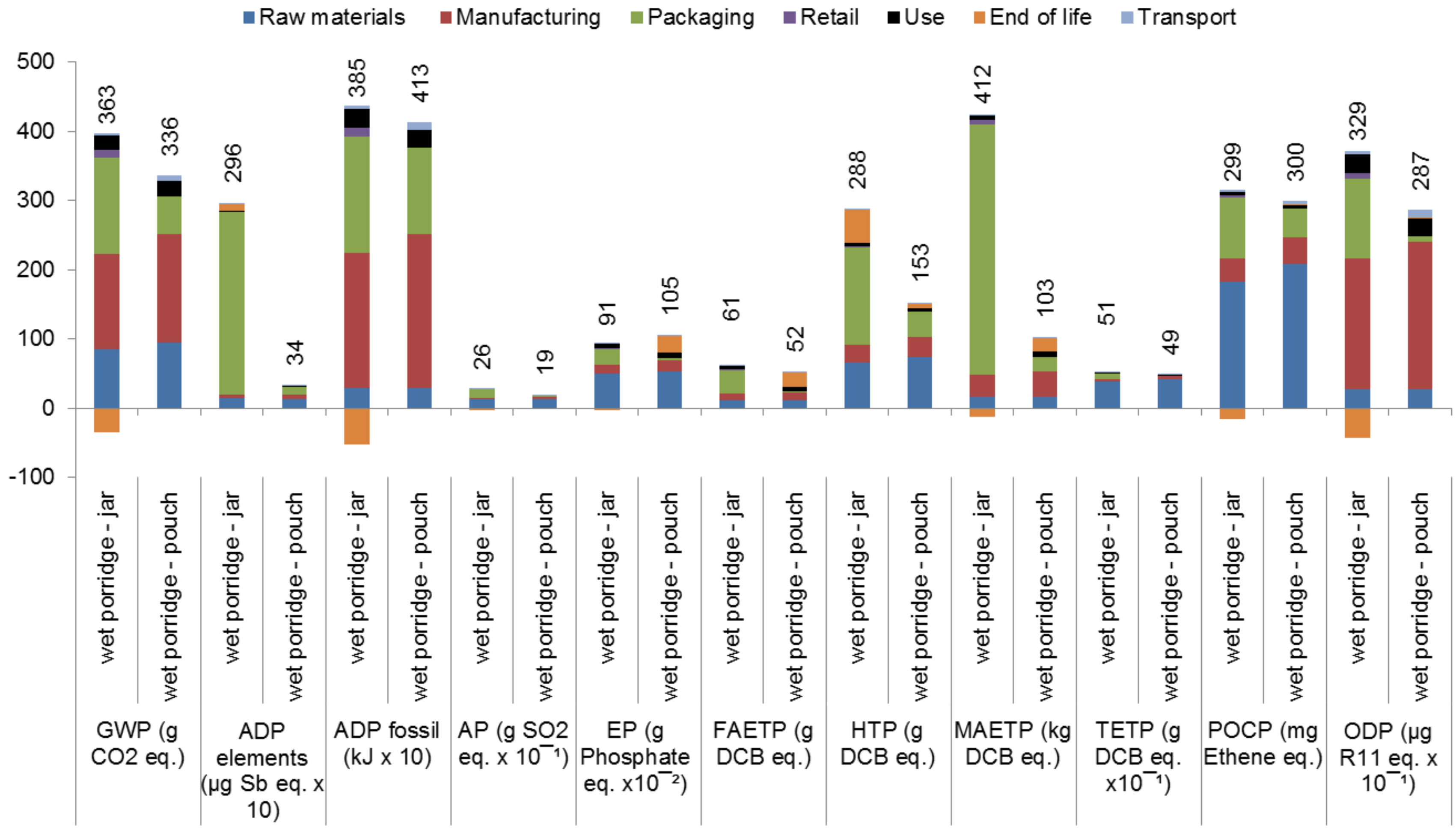


Figure 2.8 Comparison of impacts for different packaging used for wet porridge

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Chapter 3. Environmental sustainability assessment of ready-made baby foods: meals, menus and diets

Natalia Sieti, Ximena C. Schmidt Rivera, Laurence Stamford* and Adisa Azapagic

Sustainable Industrial Systems, School of Chemical Engineering and Analytical Science, The University of Manchester, Manchester M13 9PL, UK

*Corresponding author: laurence.stamford@manchester.ac.uk

Abstract

Diets have an important impact on human health and the environment. Dietary choices can support or inhibit development throughout childhood and most studies addressing baby food products consequently emphasise their nutritional aspects. However, there is a growing body of literature in quantifying environmental impacts of diets, but virtually none of this literature has addressed baby foods. Therefore, this study uses life cycle assessment (LCA) to quantify and explore the environmental impacts of different ready-made baby foods, both at the level of individual meals and their combinations with a weekly menu. A total of 11 individual baby food products are considered based on those available on the UK market, spanning breakfast, lunch and dessert. The menus following four different diets – omnivorous, vegetarian, pescaterian and dairy-free – are evaluated. Among the meals considered, fruit-based desserts have on average the lowest and spaghetti Bolognese the highest impacts. Across the 11 impacts assessed the main contributors for all the meals are the raw materials (12-69%) and the manufacturing process (2-49%). There is little difference in impacts between the omnivore, pescatarian and vegetarian diets, with the latter having slightly lower impacts. However, the dairy-free diet has significantly higher impacts than the other three because of the higher contribution of meat in the menu. More meaty and creamy recipes are found to have higher impacts so their reduction or substitution offers a potential for environmental improvements. It is expected that the results of this study will be of interest to baby food manufacturers as well as consumers.

Keywords: baby food; environmental impacts; life cycle assessment; diet

3.1 Introduction

Diet is very important for infants since what they eat in their early developmental stages determines, to a degree, their health later in life. However, it is also widely acknowledged that the global food system is a significant contributor to a range of environmental, social and economic sustainability issues, and consequently diet is closely linked to sustainability. The environmental impacts of diets have already been demonstrated to vary with the food group (Barilla Center 2010). For example, according to Notarnicola et al. (2017) meat and dairy products have the highest environmental impacts of food consumption in Europe. Hallström et al. (2015) also showed that the climate change impact of a reduced-meat diet depends on which foods substitute meat and that there is a research gap on consumption patterns of specific groups in the population. On the other hand, Tukker et al. (2011) suggest that "moderate diet changes are not enough to reduce impacts from food consumption drastically".

In the UK, one of the priorities of the 2030 Strategy for food is focused around enabling and encouraging sustainable diets. Although measuring the environmental footprint of food products tends to focus on single issues, such as carbon footprint, there is a need for broader environmental assessments of what we choose to eat (HM Government 2010), considering the full life cycle of food.

There are numerous life cycle assessment (LCA) studies of various food and drinks products (e.g. Schmidt Rivera et al. 2014; Amienyo et al. 2013; Canals et al. 2008; Peacock et al. 2011; Point et al. 2012). However, despite a rapid growth of the baby food sector, there is little information on the environmental sustainability of baby food. The only study available so far is an LCA study carried out in Sweden 20 years ago (Mattsson 1999) which considered a carrot puree and a cereal-based baby food product. As far as the authors are aware, no other LCA studies of baby food have been reported in the literature.

Therefore, this paper aims to fill this knowledge gap by quantifying the environmental impact of different ready-made baby foods. It also considers different product groups to estimate the extent to which food choices affect the environmental impacts. Finally, the paper estimates the impacts associated with different types of diet and identifies possible improvement opportunities through consumer choices.

3.2 Methods

3.2.1 Goal and scope of the study

The goal of the study is to assess the environmental impacts of selected ready-made baby foods both in comparison to each other and as part of an overall weekly diet. The following food products are chosen for assessment across the three daily meals:

1. Breakfast: wet porridge (dry porridge is not considered as the focus here is on 'wet' food products);
2. Lunch: chicken lunch; vegetable and chicken risotto; spaghetti Bolognese; vegetable lasagne; salmon risotto;
3. Dessert: apple, pear and banana; strawberry, raspberry and banana; strawberry yoghurt; apples and rice; banana and chocolate pudding.

The above products are selected based on own market analysis, covering all food groups in the "Eat Well Plate" (Public Health England 2016). Following the dietary guidelines in the latter, market sample products are clustered into six food groups based on their ingredients: cereals; vegetables and beans; fruits; milk, yoghurt and cheese; oils and sugar; and meat, poultry and fish. Instead of assessing the impacts of all ingredients, similar ingredients are aggregated into "building blocks, e.g. milk and dairy foods instead of milk, cheese, yoghurt etc. This is also commonly practised in diet assessments (Milà I Canals et al. 2011). Thus, the aim of this is to determine what food groups make the highest contribution to the environmental footprint of an omnivore diet.

Two functional units are considered:

1. Individual meals: "one ready-made meal consumed by a baby at home", equivalent to a serving of 125 g.
2. Weekly diet: "three ready-made meals - breakfast, lunch and dessert - consumed by a baby daily at home over a week", with each meal equivalent to a serving of 125 g. This functional unit is based on the findings of market research: 8% of babies consume ready-made baby food four times or more per day, 22% 2-3 times per day, 32% once per day, 19% 2-3 times per day, and 19% once per week or less (Mintel 2013). By comparison, an older study (Stallone and Jacobson 1995) determined consumption at 1.3 jars per day in eastern Europe and 3.3 jars in the United States.

The product formulations are based on the information from the major UK retailers, to ensure that they are representative of the recipes across the sector. A total of 513 commercially produced baby food products were sampled, produced by the five leading companies selling baby food in the UK.

The guiding principle for the choice of food groups and ready-made meals was the percentage frequency by which different food items appear on the front product label and in the recipe description. Based on this analysis, the most consumed foods are apples and bananas in the fruit group, carrots, tomatoes and potatoes in the vegetable group and chicken and beef in the meat group (Table 3.1). This information was combined with the identification of best-selling products on the UK market, as reported by Amazon. As a result of this analysis, 11 typical UK meals produced by all food brands have been selected for analysis (Table 3.1).

Since some recipes do not provide the exact contribution of the ingredients, assumptions have been made where necessary. The final product formulations can be seen in Figure 3.1. For further details on the product formulations, see Table B.1 in Appendix B.

Table 3.1 Breakdown of the components in ready-made baby food formulations for lunch and dessert meals (average values across the leading brands)

On the front label		In the recipe description	
Apple	17%	Carrot	47%
Chicken	13%	Apple	39%
Beef	10%	Rice	38%
Pasta	7%	Onion	36%
Yoghurt	6%	Potato	33%
Fish	4%	Milk	31%
Carrot	4%	Tomato	28%
Banana	3%	Banana	21%
Pudding	3%	Peas	16%
Pear	3%	Parsnip	16%
		Chicken	14%
		Cheese	11%
		Broccoli	10%

The system boundaries are from “cradle to grave”, as indicated in Figure 3.2. An overview of the life cycle stages considered for all products is given in

Table 3.2 with more detail on each stage provided. These encompass the production and processing of raw materials (ingredients), the manufacturing of the ready-made baby food, the production of packaging materials, product distribution, retail, consumption and end-of-life (EoL) waste management. The consumption stage involves heating up the food using a gas hob.

3.2.1 Inventory data

As mentioned above, the data for the composition of the meals have been obtained through own market research while the manufacturing data are from literature (Mattsson 1999). Background life cycle inventory data have been sourced from the Ecoinvent database version 3.1 (Ecoinvent 2015) where available and supplemented by data from literature or own estimates, as summarised in

Table 3.2 and detailed below. Where stated, the background data have been adjusted for UK conditions with respect to the electricity mix.

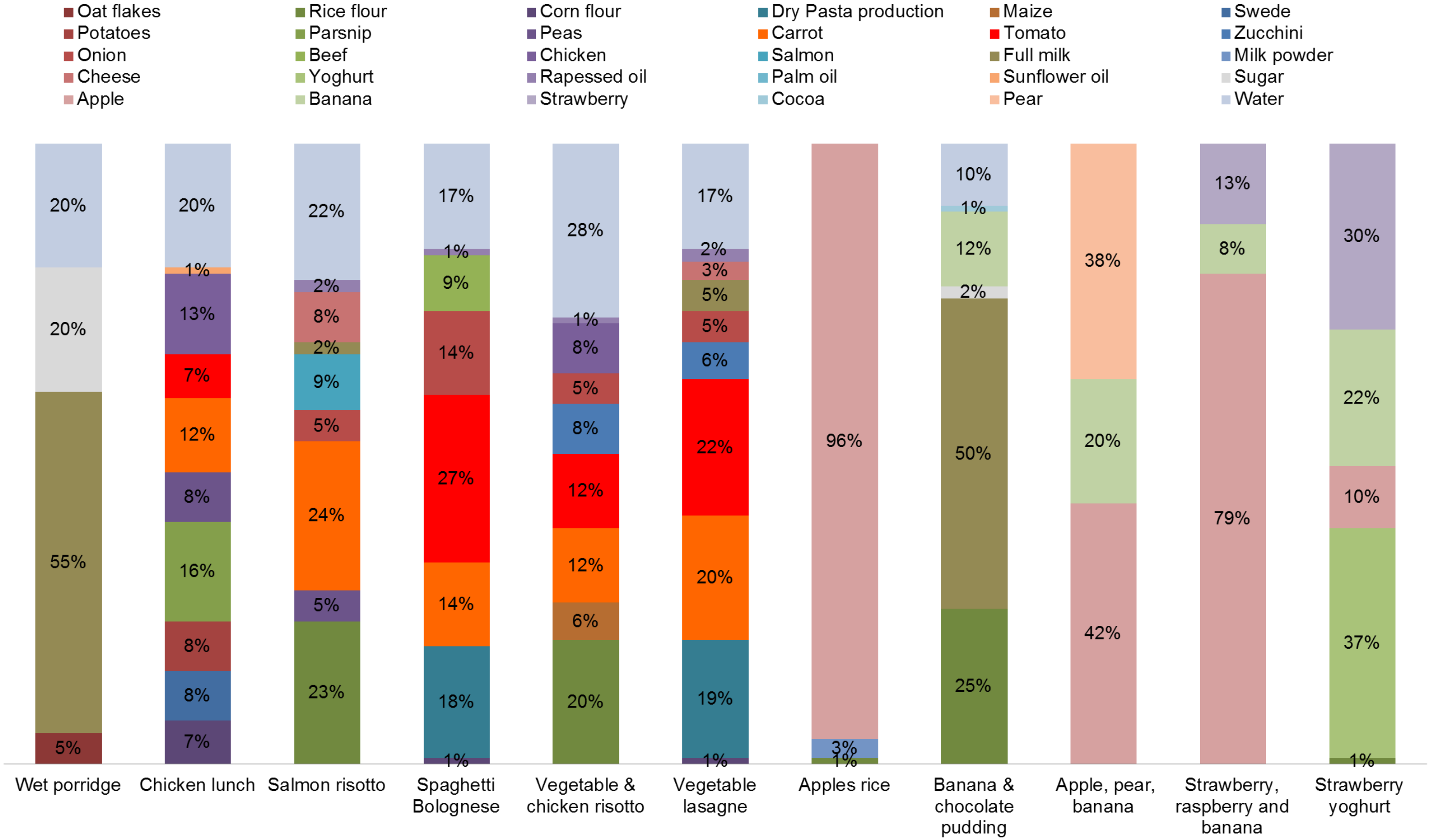


Figure 3.1 Breakfast, lunch and dessert products and the breakdown of their ingredients by mass contribution (all products have a total mass of 125 g)

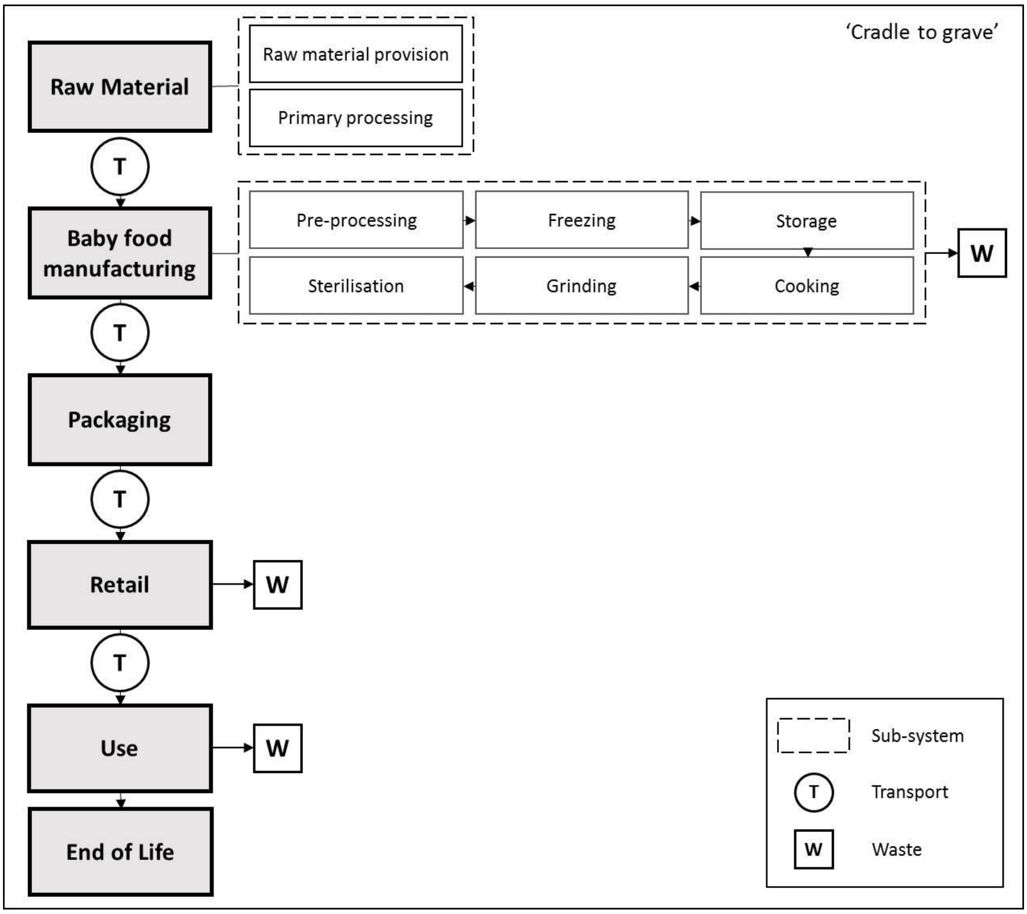


Figure 3.2 System boundary and the stages in the life cycle of the baby ready-made meals

3.2.1.1 Raw materials (Ingredients)

For the ingredients, where available and known, country specific data are used. A more detailed specification of the data sources for the raw materials can be found below, in the order that they are displayed on

Table 3.2.

Meat- and fish-based ingredients

Chicken: The UK is the largest chicken meat producer in the EU with 77% self-sufficiency, in 2014, mainly importing from Thailand (41% of imports) and Brazil (13%) (AHDB 2015a). In terms of tonnage, 53% of the imports are fresh/frozen poultry, 40% processed and 7% salted, with a similar trend in terms of value (AHDB 2015a). To represent the UK as closely as possible, this study assumes that 77% of chicken consumed is British and 23% Brazilian frozen, packed poultry (as no inventory data are available for Thai chicken imports). For British chicken, data from Williams et al. (2006b) and Foster et al. (2006) are used, to model the system both for UK broiler raising and broiler processing industry. For feed, input maize grain is used instead of sunflower meal and soya oil instead of soya meal (Ecoinvent 2015) due to availability of inventory data. Wheat straw is also used as bedding, as the type of bedding varies based on animal welfare standards. A British chicken at intensive farming is of 2.2 kg live weight. Plastic waste from packaging is disposed and sent to sanitary landfill and wastewater is sent to wastewater treatment (Ecoinvent 2015). For Brazilian chicken the LCA data are sourced from Prudêncio da Silva et al. (2014).

Table 3.2 Summary of life cycle inventory data

Stage	Ready-made	Country of origin	Source of LCI data
Raw materials (ingredients)	Chicken farming, slaughtering	GB, BR	Williams et al. (2006); Prudêncio da Silva et al. (2014); Nielsen et al. (2003)
	Beef farming, slaughtering, freezing	GB	Nielsen et al. (2003); Williams et al. (2006)
	Salmon farming & processing	GB	Nielsen et al. (2003); Winther et al. (2009)
	Dairy farming	GB	Williams et al. (2006); Upton et al. (2013)
	Milk production	GB	Nielsen et al. (2003)
	Milk powder production	GB	〃
	Cheese production	GB	〃
	Yoghurt production	GB	Nielsen et al. (2003); Williams et al. (2006); Ecoinvent (2016)
	Cultivation of oats	SE	Ecoinvent (2015)
	Cultivation of rice	US	〃
	Cultivation of sugar	BR	〃
	Cultivation of wheat	RoW[b]	〃
	Cultivation of corn	US	〃
	Milling of cereals (oats, rice, corn)	GB	Nielsen et al. (2003)
	Durum wheat semolina production & pasta production	IT	Lo Giudice et al. (2011)
	Cultivation of tomatoes	ES, NL, GB	Theurl et al. (2014); Williams et al. (2006); Antón et al. (2012)
	Cultivation of potatoes	CH	Ecoinvent (2015)
	Cultivation of carrots, zucchini, onion	GLO[a]	〃
	Cultivation of peas	ES	〃
	Cultivation of swede, parsnip	SE	Davis et al. (2011)
	Cultivation of fruits (apple, pear, banana, strawberries)	GLO	〃
	Cultivation of cocoa beans & cocoa production	Ghana	Ntiamoah & Afrane (2008)
	Cultivation sunflower	RoW	Ecoinvent (2015)
	Cultivation rapeseed	RoW	〃
	Palm oil, at oil mill	MY	〃
	Sunflower oil production	GB	〃
	Rapeseed oil production	GB	Nielsen et al. (2003)
	Tap water, at user	RER	Ecoinvent (2015)
Manufacturing	Baby food manufacturing	GB	Mattsson (1999)
	Waste management	RoW	
Packaging	Packaging manufacturing	RER	Ecoinvent (2015)
Retail	Supermarket details	GB	Nielsen et al. (2003)
Use	Energy consumption, for meal preparation	GB	Own calculations
	Meal preparation techniques	GB	On pack
Transport	Road transport, lorry	RER	Ecoinvent (2015)
	Road transport, car	RER	〃
	Sea transport	OCE[c]	〃
End of life	Packaging waste management	GB	Defra (2015b)
Energy	Electricity	UK	Own modelling based on 2015 electricity mix DECC (2016)
	Natural gas burned in boiler condensing modulating	〃	Ecoinvent (2015)
Water	Tap water, at user	RER	Ecoinvent (2015)

[a]GLO: global
[b]RoW: rest of world, referring to production outside Europe
[c]OCE: ocean

Beef: UK production covers almost 80% of total consumption, with beef deriving from both the suckler herd and the dairy herd, with almost equal shares (AHDB 2015b). The inventory for beef at farm is based on Williams et al. (2006) for an average of Upland suckler herds (autumn/spring calving) and Hill suckler herds, as 50% of cows contributing to prime carcass beef are suckler herds (EBLEX 2010). Data for slaughtering of cattle are taken from Nielsen et al. (2003) and adapted to UK conditions by using the UK electricity mix. Electricity consumption for freezing of cattle meat is also based on Nielsen et al. (2003).

Salmon: Atlantic salmon farmed in Scotland dominates UK aquaculture harvest and the UK is a leading aquaculture producer in the EU (Ellis et al. 2012). The main steps are fishmeal and oil production, trout feed production, salmon farming and salmon fileting. Although feed ingredients vary between country of origin, historically, the two most important ingredients in fish feed have been fish meal and fish oil (Marine Harvest 2016). Data from Nielsen et al. (2003) are used to model fishmeal and oil production.

Trout feed composition (materials) is modelled based on Nielsen et al. (2003) and utilities input for feed production is based on Winther et al. (2009) adjusted to UK electricity mix. The feed input for salmon production at farm is based on Pelletier et al. (2009), for UK conditions. Data for salmon farming and processing (filleting and freezing) are adjusted to UK conditions from Winther et al. (2009). Ice production is based on Nielsen et al. (2003).

Dairy-based ingredients

Milk production: The life cycle environmental impacts of milk from “cradle to farm gate” are modelled based on Williams et al. (2006b) for animal feed, whereas for manure output data are based on Weiss & St-pierre (2010) and for water requirements data from DairyCo (2013) are used, in addition to energy inputs at farm from Upton et al. (2013). Data for processes beyond the farm gate are taken from Eide (2002) and adapted to UK conditions.

For milk powder, data are based on Nielsen et al. (2003).

Cheese: Because the impacts of cheese depend heavily on the impacts of the milk input, milk production as modelled in this study is used as the feed for yellow cheese production. Yellow semi-hard cheese production is modelled based on Nielsen et al. (2003) and adapted to UK conditions.

Yoghurt production: Yoghurt production is modelled based on data from Quebec, Canada, from Ecoinvent Centre (2015) excluding data for flavoured yoghurts and adapted to UK conditions. The milk input into the yoghurt making process is the same as that for cheese and is described above.

Cereal-based ingredients

Oats: Barley seeds are used as a proxy for oat seeds due to lack of data (Ecoinvent 2015). Information for field operations is taken from Van Zeist et al. (2012); McDevitt & Milà i Canals (2011); Nemecek & Kagi (2007). Fertiliser impacts are considered based on IPCC (2006). For oat flakes production, data from Nielsen et al. (2003) are used and wastes are sent to composting, as the major waste management method in the food and drink industry (Bartlett 2010; Carr and Downing 2014).

Rice flour: US rice at farm is considered from Ecoinvent, while data for wheat flour production are used as a proxy for the subsequent flour production processes (Nielsen et al. 2003).

Pasta: As the European market is dominated by Italy, dry pasta production in this study is based on Lo Giudice et al. (2011), representing Italian pasta made from durum wheat/semolina. Wheat production for global production came from Ecoinvent (2015).

Corn flour: Corn, at farm, from the US is selected from Ecoinvent Centre (2015) based on lack of alternative data sources and the fact that the US is the leader in total global supply of maize (International Grains Council 2016). For corn flour production, data from Nielsen et al. (2003) for rye milling are used as a proxy. For treatment of biowaste, composting is considered (Ecoinvent 2015).

Vegetable and fruit-based ingredients

Tomatoes: Classic loose tomatoes are assumed, as these account for the majority of tomatoes cultivated in the UK (Caspell et al. 2006), the Netherlands and Spain. Data for tomatoes consumed in the UK are based on the value of vegetable imports to the UK by country (Defra 2016a): 20% UK produced, 27% Dutch, 32% Spanish and 21% others (global production). Different systems can be distinguished in the aforementioned countries: Spanish tomatoes are cultivated in open field on soil, while the UK and the Netherlands grow tomatoes in glasshouse greenhouses. Therefore, to be able to compare the systems, energy inputs, water inputs, fertilisers, pesticides, transport and yield are considered. Field tomatoes from Spain are modelled based on Theurl et al. (2014), and greenhouse Dutch tomatoes based on Antón et al. (2012). For the greenhouse UK tomatoes, yield, water and energy input are based on Williams et al. (2006b), while the amount of pesticides and fertilisers are based on similar production conditions in the Netherlands (Antón et al. 2012). Production of pesticides for the UK conditions is based on McDevitt & Canals (2011). To account for the emissions associated with heat, electricity and CO_2 enrichment, the proportion of gas and electricity is calculated based on the Horticultural Development Council (2002). Life cycle inventory data representing global production are sourced from Ecoinvent Centre (2015)

Potatoes: The UK has a potato demand exceeding domestic supply, with main imports from the Netherlands and Belgium (AHDB Potatoes 2016). The only data found in Ecoinvent for Europe are from Switzerland, with a yield of 37.8 t/ha. This is close to the UK equivalent of 44.7 t/ha (AHDB Potatoes 2016). Hence, for the above reasons, Swiss potato is considered.

Carrot: Data on the production of carrots are taken from Ecoinvent (2015), representing global average production conditions for open field cultivation.

Peas : Peas are widely produced in the UK, although the UK is currently a net pea importer (The Andersons Centre 2015); however, no LCA data are found. The main EU exporting countries are the UK, France, the Netherlands, Spain, Belgium and Germany (Ministry of Foreign Affairs 2015). The UK imports peas from France, Germany and Spain. However, based on 2015 data by value, Spain was the highest exporter of peas to the UK (International Trade Centre 2015). Therefore, peas from Spain are selected from Ecoinvent.

Swede & parsnip: For root crops, swede and parsnip, data from Sweden (Davis et al. 2011) are used for global warming potential (carbon dioxide and nitrous oxide) due to a lack of UK equivalent data. Other environmental impact categories could not be accounted for due to a lack of available data.

Zucchini and onions: Data from Ecoinvent are for global conditions due to data availability.

Bananas, apples and pears: As bananas are not produced in the UK, global production data for bananas are used from Ecoinvent. Apples and pears are produced in the UK but due to data availability, global production (that includes UK production) is considered instead.

Berries: Although the UK is a raspberry producer, it also imports both fresh and frozen raspberries from all over the world. However, a lack of LCI data for raspberry production meant that an average global dataset on strawberries from Ecoinvent Centre (2015) had to be used to represent both types of berries.

Cocoa powder: The UK is the seventh largest cocoa grinder in the EU with almost 99% of cocoa beans imported from Ivory Coast (57%) and Ghana (42%) (CBI - Ministry of Foreign Affairs 2016). Although the UK imports beans and grinds them into powder, due to data availability, the inventory used is that of cocoa production and processing in Ghana, including mass allocation between the by-products (Ntiamoah and Afrane 2008). Land use change (LUC) is excluded, despite being considered significant, due to high uncertainty in the results (Jeswani et al. 2015). However, in this study, although the uncertainty is high when accounting for an additional 41 kg CO_2. per kg cocoa beans for production in Ghana (Wiltshire, J.; Wynn, S.; Clarke, J.; Chambers, B.; Cottrill, B.; Drakes, D.; Gittins, J.; Nicholson, C.; Phillips, K.; Thorman, R.; Tiffin, D.; Walker, O.; Tucker, G.; Thorn, R.; Green, A.; Fendler, A.; Williams, A.; Bellamy, P.; Audsley E.; Chatterton 2010), that is not the case when cocoa powder is assessed as part of the mix in the only product containing cocoa: the banana & chocolate pudding. This study's results do not change due to the very small contribution of the cocoa in the recipe mix. NPK fertilisers are assumed to contain 15% wt of N,15% of P_2O_5 and 15 % of K_2O. LCA data are sourced from Thinkstep (2015) as Ecoinvent data are not available for this specific composition.

Oils and sugar- based ingredients

Sunflower oil: For sunflower oil, data from Ecoinvent Centre (2015) are used for global sunflower production, since no data for UK imports are found. Global production of sunflower seed oil is dominated by Russia, Ukraine, Argentina and

Europe (FAO 2010b). For sunflower oil production, process data for rapeseed crushing are used as a proxy (Nielsen et al. 2003).

Rapeseed oil: The UK is the third largest rapeseed producer in the EU, and has a self-sufficiency with the main driver of rapeseed oil demand being the biodiesel industry (Krautgartner et al. 2016). For rapeseed production, data from Ecoinvent Centre (2015) are used, while the crushing and oil production process is based on Nielsen et al. (2003).

Palm oil: Malaysia is the main source of palm oil in the UK so Malaysian palm oil is considered (Defra 2012).

Sugar: Sugar from Brazilian sugar cane is considered from Ecoinvent.

3.2.1.2 Manufacturing

The inputs into the manufacturing stage are summarised in

Table 3.3. Typically, heat is used for cooking and sterilisation and electricity for milling, mixing, homogenisation, packaging and lighting (O'Shaughnessy 2013). Manufacturing data for both lunch and dessert meals are based on Mattsson (1999) according to which 1.5 MJ of electricity, 11.16 MJ of natural gas and 0.014 MJ of diesel are required for the production of 1 kg of carrot puree. These data encompass pre-processing, freezing, storage, cooking, grinding and sterilisation, and are provided by a major Swedish baby food producer. Since all the products considered here are pureed and therefore involve the same processing steps, the above energy demands are applied to all the products. In addition, the amounts of chemicals and water used are based on Mattsson (1999) and the type of chemicals on Eide et al. (2003). It is assumed that all wastewater is treated in a wastewater treatment plant (Ecoinvent 2015). Food waste is assumed at 7% of the product, which is within the range for different commodity groups (Bond et al. 2013; Jeswani et al. 2015). Composting is considered as the waste management method, based on the fact that land-spreading is the major waste management route in the food and drink industry (Bartlett 2010; Carr and Downing 2014).

Table 3.3 Resource use for the production of wet ready-made baby food per functional unit (Mattsson 1999)

	Amount	Unit
Water	5.5	L
Chemicals	0.175	g
Natural gas	1395	kJ
Diesel	1.75	kJ
Electricity	188	kJ

3.2.1.3 Packaging

The packaging specifications assumed in this study are summarised in Table 3.4. As ready-made baby foods are typically found in jars, this type of packaging is considered comprising glass jar, and aluminium lid. White glass data from Ecoinvent Centre (2015) are considered, whereas the lid is a cap based on Amienyo (2012), composed of 84% aluminium and 16% plastic. Data for these materials are taken from Ecoinvent.

Table 3.4 Specification for the packaging used for the ready-made meals

Specifications	Ready-made meal
Dimensions:	
Diameter (m)	0.05
Height (m)	0.08
Materials:	
White glass jar (kg)	0.088
Aluminium (84%) (kg)	0.005
Low density polypropylene (LDPE) (16%) (kg)	0.003

3.2.1.4 Retail

The ready-made meal is then distributed from the manufacturer to the retailer, where based on the best-before date, it has an average shelf-life of 12 months. However, being a fast-moving consumer good (FMCG), it stays at the retailer for a shorter time than this. Therefore, data associated with retailing of FMCG stored at room temperature have been derived from Nielsen et al. (2003), using pasta as a representative FMCG product, in the absence of data for baby food. The data take into account the average flow of products and the area occupied, including energy consumption, heat and electricity (lighting) for a large retail store with 1350 m^2 exposure area. The selection of the retailer size was based on the fact that ready-made baby foods are sold mainly in hypermarkets and supermarkets. Based on Nielsen et al. (2003), the amount of electricity used per functional unit for the lighting of aisle and checkout area is 468 kJ; 273 kJ is used for heating. Food losses at retailer are considered to be 2% of the product sold (Canals et al. 2007). As land-spreading is the major waste management route in the food and drink industry, composting of retail waste is considered (Bartlett 2010; Carr and Downing 2014).

3.2.1.5 Use

The use stage includes heating up the meal, manual washing of the dishes and waste disposal. For hobs in the UK, gas is the dominant fuel, with 61% of household hobs being gas-fired and 38% electric (Defra 2013). Therefore, a gas hob appliance is considered, and an average energy consumption of 0.063 kWh has been determined using a smart meter. For washing up the plates and cutlery, one litre of tap water was used (Defra 2008). The resulting wastewater is treated in a municipal wastewater treatment plant, with LCI data sourced from Ecoinvent Centre (2015). Post-consumer food waste is also considered, assuming 14% post-consumer waste for ready-made baby foods (Holding et al. 2010).

3.2.1.6 Waste management options

The waste management options are summarised in

Table 3.5. As discussed above, losses of 7% are considered for the food manufacturing, 2% for the retail stage, and 14% post-consumer. Food waste at each stage is assumed to be composted and land-spread (Bartlett 2010; Carr and Downing 2014). Household waste is treated following the UK waste management practice (Defra 2015), with 12% of the food waste recycled. The rest is incinerated (55%) and landfilled.

Table 3.5 Material losses and waste treatment

Stage	Losses/waste (%)	Assumed waste treatment options in Ecoinvent	Reference
Raw materials			
Corn flour	3%	Treatment of bio-waste, composting	Nielsen et al. (2003)
Oat flakes	5%	Treatment of bio-waste, composting	〃
Chicken (waste from slaughterhouse)	7%	Disposal, municipal solid waste 22.9% water to sanitary landfill	Foster et al. (2006)
Pasta	6%	Treatment of bio-waste, composting	Lo Giudice et al. (2011)
Rice flour	1%	Treatment of bio-waste, composting	Nielsen et al. (2003)
Packaging (chicken)	0.2%	Disposal plastics mixture 15.3% water to sanitary landfill	Foster et al. (2006)
Manufacturing	7%	Treatment of bio-waste, composting	Holding et al. (2010)
Retailer	2%	Treatment of bio-waste, composting	Bond et al. (2013)
Waste (post-consumer)			
Food waste	14%	Treatment of bio-waste, composting, Treatment of bio-waste municipal incineration, Treatment of municipal solid waste, sanitary landfill	Holding et al. (2010); Defra (2015a)
Aluminium	25%	Disposal aluminium 0% water to sanitary landfill	Defra (2015b) UK rate
	75%	Treatment of aluminium scrap, post-consumer, prepared for recycling, at remelter	〃
Glass	30%	Disposal, glass 0% water, to inert material landfill	〃
	70%	Treatment of waste glass from unsorted public collection, sorting	〃

3.2.1.7 Transportation

Table 3.6 summarises the transportation modes and distances. All road transport data are based on Ecoinvent, assuming the use of a diesel lorry (Euro 3) and a distance of 100 km. The use of transoceanic freight is considered for the transportation of imported ingredients and Google maps have been used to calculate the transoceanic distances. For consumer shopping, 7.9 km is assumed based on the average food shopping distance per week per household (Pretty et al. 2005). Diesel is the main fuel for transport vehicles, except from consumer shopping which is achieved by a petrol car. The transportation from home to waste disposal is not considered.

Table 3.6 Transport data

Stage	Country of origin	Assumed distances and mode of transport	Vehicle	Life cycle inventory data
Raw materials farming to pre-processing				
Durum wheat semolina	IT	70 km by road	Lorry, 16-32 t	Lo Giudice et al. (2011)
Pasta production	IT	117 km by road	Lorry, 16-32 t	〃
Fishmeal and oil production	GB	100 km by road	Lorry, 16-32 t	Ecoinvent (2015)
Salmon farming	GB	3.9 km by road	Lorry, 16-32 t	Pelletier et al. (2009)
Sunflower oil	RoW[a]	1430 km by road	Lorry, 16-32 t	Ecoinvent (2015)
Cornflour	US	6000 km by sea	Transoceanic freight ship	〃
Sugar	BR	8845 km by sea	Transoceanic freight ship	〃
Chicken	GB	100 km by road	Lorry, 7.5-16 t	〃
Tomatoes	ES	2683 km by road	Lorry, 7.5-16 t	〃
Tomatoes	NL	356 km by road	Lorry, 7.5-16 t	〃
Milk powder	GB	150 km by road	Lorry, 16-32 t	〃
Cocoa beans	Ghana	8000 km by sea	Transoceanic freight ship	〃
From raw materials to baby food manufacturing	GLO[b]	100 km by road	Lorry, 7.5-16 t	
Packaging to baby food manufacturer	RER[c]	100 km by road	Lorry, 7.5-16 t	〃
From manufacturer to retailer	GB	100 km by road	Lorry, 7.5-16 t	〃
From retail to use	GB	7.9 km by road	Transport, passenger car	Pretty et al. (2005)

[a]RoW: rest of world, referring to production outside Europe
[b]GLO: global
[c]RER: Europe

3.2.3 Allocation and system expansion

Multiple materials in the life cycle under study have associated by-products, necessitating allocation. These are detailed below.

Oat straw: Oat grains farming generates straw and, in the UK, the majority of straw is used for livestock feed and animal bedding (Kilpatrick 2008). Here, barley straw of metabolisable energy[3] 6.5 MJ/Kg DM (Feedipedia 2017), has displaced barley grain for feed production, of metabolisable energy 13.2 MJ/Kg DM (Macdonald et al. 2018). Consequently, barley straw displaces barley grain with a ratio of 0.49 to 1.

[3] The metabolisable energy value of a foodstuff is the amount of energy that the ruminant is able to use, per unit of dry matter of foodstuff eaten.

Oat bran: For the economic allocation of oat bran from oat milling and production, barley grain is used as proxy on an economic basis of £2.25/kg for oat bran (Healthy Supplies 2016) and £1.19/kg for oat flakes (Buy Whole Foods Online 2016).

Rice bran: Rice flour production generates bran and the system is credited for displacing barley grain feed production, since barley is the second-most used cereal for animal feed after wheat (Defra and AHDB 2015).

Cocoa powder: Mass allocation is considered in the case of cocoa powder and its by-products based on Ntiamoah & Afrane (2008).

Sunflower and rapeseed oil: Mass allocation is performed between sunflower oil and sunflower meal (Nielsen et al. 2003).

Corn flour: Corn flour production also produces bran and the system is credited for displacing animal feed production from barley grain, since barley is the second-most used cereal for animal feed after wheat (Defra and AHDB 2015).

Chicken: In the case of British chicken production, an average nitrogen content in poultry litter of 0.03 kg N/kg (Defra 2010) is used to credit the system for displacing nitrogen fertiliser from field application of poultry manure (Ecoinvent 2015). The mass of manure generated by 1 kg of chicken ready for slaughtering is 0.48 kg (Foster et al. 2006). Hence the nitrogen content of that manure is 14 g per kg of chicken reared at the farm. Consequently, as fertiliser in Ecoinvent is described in terms of its nitrogen content, the system is credited with 14 g of nitrogen fertiliser. For 1 kg of live birds, 0.02 kg of dead birds arise (Foster et al. 2006). This is assumed to be sold on the market for meat and bone meal (Ecoinvent 2015) based on mass allocation (Foster et al. 2006). Furthermore, for 1 kg carcass in the broiler processing industry, 0.891 kg are animal by-products, feather and blood (Foster et al. 2006), sold on the market for meat and bone meal (Ecoinvent 2015). The global process “market for meat and bone meal” from Ecoinvent is used to credit the system for displacing the production of meat and bone meal from other sources according to the global market split.

Beef slaughtering: Cattle slaughtering produces bone, intestines and blood which are sold for meat and bone meal (Ecoinvent 2015). The system has been credited for displacing meat and bone meal production from other sources, consistent with the treatment of broiler waste discussed above.

Salmon farming and processing: Dead salmon arising from salmon farming is used as fishmeal according to Winther et al. (2009). The system has been credited for displacing fishmeal and oil production. For 1 kg farmed salmon, 0.05 kg replaces feed. The same approach has been used for salmon processing, where per kg of salmon processed (head-on, gutted including losses at slaughter plant), 0.217 kg are salmon by-products used as fishmeal. The system has also been credited for these by-products.

Milk production: Economic allocation has been performed between milk and beef, based on the average income from each, resulting in the ratio of 90% milk to 10% beef (Cederberg and Stadig 2003). The predominant cows in the UK, Friesian-Holstein breed (Foster et al. 2007), weigh an average of 600 kg and give almost 40% edible meat (Oklahoma Department of Agriculture Food & Forestry 2013).

The nitrogen in cattle manure of 0.6% content by weight (FAO 2005) has been applied to credit the system for displacing urea fertiliser with 46% nitrogen content (University of Hawai 2016). Approximately 3 kg of manure arise for every 1 kg of milk (Weiss and St-pierre 2010) and every 1 kg nitrogen is equivalent stoichiometrically to 2.16 kg of urea fertiliser.

Economic allocation has also been performed between milk (67%) and cream (33%), based on their respective Actual Milk Price Equivalent (AMPE) for December 2015 (AHDB Dairy 2015).

Cheese production: For cheese production, economic allocation has been used to allocate the impacts between cheese, cream and whey in a ratio of 75%, 20% and 5%, respectively (Sheane et al. 2010).

3.2.4 Weekly diet scenarios

Different menu scenarios are developed for the ready-made meals, following an omnivorous, a vegetarian, a pescatarian and a dairy-free diet. Nutritional qualities are not considered in this study, but rather menu scenarios are based on a type of diet. Therefore, the four diets are derived simply by rotating the sample of 11 ready-made meal options and excluding those that are prohibited in the non-omnivorous diets. The Infant Feeding Survey (IFS) showed that three solid meals a day are given to babies incrementally during their first year, in addition to milk feeds (McAndrew et al. 2012). However, there are no formal recommendations for baby food portion sizes. According to a sample weekly menu for babies seven to nine months old by The Caroline Walker Trust (2011), the total solid food consumption is around 380 g per day, for home-made meals. Three servings of ready-made baby foods are assumed here: breakfast, lunch and dessert. Based on the functional unit (125 per meal), the food intake in one day is therefore 375 g. Drinks are excluded and the assumption is made that both boys and girls consume the same amount of food. The specific weekly menu for each diet is outlined in Table 3.7.

Table 3.7 Four diet scenarios

Type of diet	Cereals	Vegetable & fruits	Meat, poultry and fish	Dairy	Oils & sugar
Omnivore	32%	23%	4%	20%	21%
Vegetarian	30%	23%	0%	23%	25%
Pescatarian	38%	18%	4%	22%	19%
Dairy free	15%	68%	12%	0%	4%

3.3 Results and discussion

The results of the assessment are discussed first in terms of individual meals, then by food group and finally in terms of weekly diet.

3.3.1 Environmental impacts of individual meals

The environmental impacts of the ready-made meals are shown per functional unit in Figure 3.3, with an overview given in a heat map in

Table 3.8. Overall, the lunch meals are found to have higher impacts than the breakfast and dessert options. Among the lunch meals, the products with the highest impacts are spaghetti Bolognese and salmon risotto, whereas the ones with the lowest are strawberry, raspberry and banana as well as apple, pear and banana deserts. Breakfast porridge shows a low impact across most impact categories except AP and POCP. Further details are provided in the following section describing an inter-product comparison for each impact category in turn. When there is a common trend, impact categories are grouped, and so are the life cycle hotspots.

Table 3.8 Heat map comparing the environmental impacts of different ready-made meals

Impacts	Wet porridge	Chicken lunch	Salmon risotto	Spaghetti Bolognese	Vegetable & chicken risotto	Vegetable lasagne	Apples rice	Banana & chocolate pudding	Apple, pear, banana	Strawberry, raspberry & banana	Strawberry yoghurt
ADP elements (µg Sb eq. x 10)											
ADP fossil (kJ x 10)											
AP (g SO2 eq. x 10^{-1})											
EP (g Phosphate eq. x10^{-2})											
FAETP (g DCB eq.)											
GWP (g CO2 eq.)											
HTP (g DCB eq.)											
MAETP (kg DCB eq.)											
ODP (µg R11 eq. x 10^{-1})											
POCP (mg Ethene eq.)											
TETP (g DCB eq. x10^{-1})											
Legend											
	Best										Worst

3.3.1.1 Global warming potential (GWP)

Among the lunch meals the ones with the highest GWP are spaghetti Bolognese with 689 g CO_2 eq./f.u. and salmon risotto with 503 g CO_2 eq./f.u (Figure 3.3). The lowest is chicken lunch at 401 g CO_2 eq./f.u. Among the dessert options, the highest is the banana and chocolate pudding at 432 g CO_2 eq./f.u., and the lowest is the strawberry, raspberry and banana meal at 312 g CO_2 eq./f.u. The impact for the breakfast option, wet porridge, is estimated at 363 g CO_2 eq./f.u.

Hence, the overall range of GWP for the ready-made meals is 312-689 g CO_2 eq./f.u. As expected, the GHG emissions are much higher for the animal-based products than for the plant-based products. Raw materials are particularly dominant for spaghetti Bolognese due to the high emissions associated with beef production and greenhouse tomato cultivation.

3.3.1.2 Abiotic depletion potential of fossil resources (ADPf)

The ADPf results for the ready-made meals are presented in Figure 3.3. Among the lunch meals, the ones with the highest impacts are spaghetti Bolognese with 7.30 MJ/f.u and vegetable lasagne with 5.55 MJ/f.u. The lowest is chicken lunch with 4.49 MJ/f.u. For the dessert options, the highest is banana and chocolate pudding at 4.28 MJ/f.u., followed by apples and rice with 4.11 MJ/f.u. The lowest dessert option is strawberry yoghurt at 3.96 MJ/f.u., while the breakfast porridge has an impact of 3.85 MJ/f.u.

3.3.1.3 *Eutrophication potential (EP)*

The overall trend is similar to that of Acidification potential (AP), with salmon risotto and spaghetti Bolognese providing the highest impacts at 1.81 and 1.51 g Phosphate eq./f.u., respectively (Figure 3.3). The lowest lunch option is vegetable and chicken risotto at 0.75 g Phosphate eq./f.u. For the dessert option the highest impact comes from banana and chocolate pudding at 0.93 g Phosphate eq./f.u and the lowest is the strawberry, raspberry and banana meal at 0.56 g Phosphate eq./f.u. The breakfast option is estimated at 1.03 g Phosphate eq./f.u, slightly higher than the dessert options. Overall, the eutrophication potential varies between 0.52 g and 1.81 g Phosphate eq./f.u.

3.3.1.4 *Photochemical oxidants creation potential (POCP)*

Unusually, the meal with the highest impact is the breakfast option, wet porridge, with 299 mg Ethene eq./f.u.(Figure 3.3) This is mostly due to sugar, with the impact arising during sugar refining. Spaghetti Bolognese and salmon risotto are the next worst options (282 and 220 mg Ethene eq./f.u., respectively). The remaining products are relatively similar to each other, ranging from 136 to 186 mg Ethene eq./f.u.

3.3.1.5 *Terrestrial ecotoxicity potential (TETP)*

Spaghetti Bolognese has by far the highest TETP with an impact of 16.8 g DCB eq./f.u., approximately two-and-a-half times higher than the next highest option, vegetable lasagne (6.8 g DCB eq./f.u.). The best lunch option is vegetable and chicken risotto with a result of 0.7 g DCB eq./f.u. (Figure 3.3). Aside from this, the desserts typically have the lowest impact, ranging from -1.0 g DCB eq./f.u. for the banana and chocolate pudding to 2.3 g BCD eq. for the strawberry yoghurt. Emissions are presented as negative for the chocolate pudding due to the high concentration of rice: the higher the amount of cereals in the mixture, the lower the contribution in the TETP due to uptake of heavy metal from the soil.

3.3.1.6 *Other impact categories*

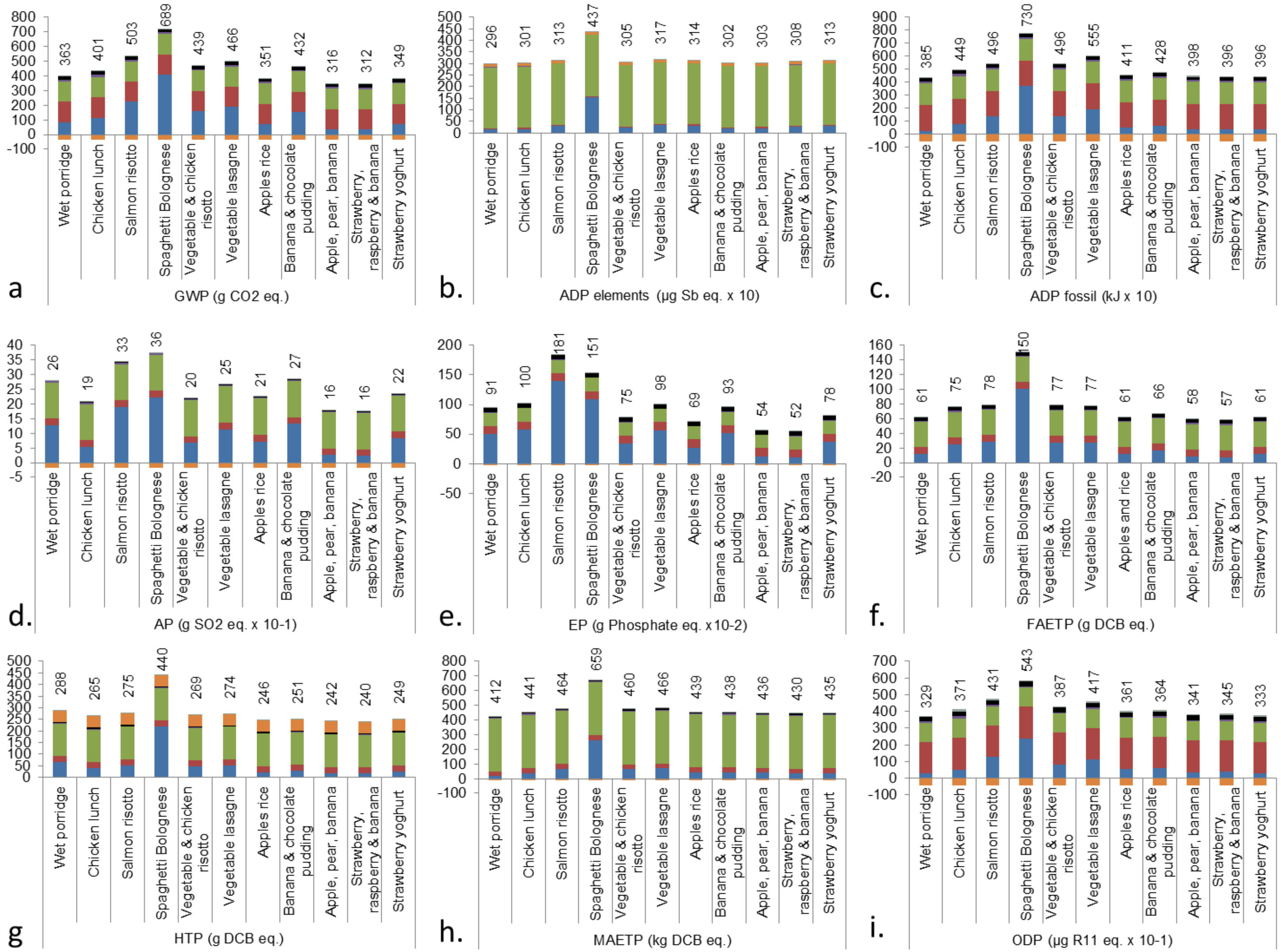
For the rest of the impact categories – ADP elements (ADPe), AP, FAETP, HTP, MAETP and ODP – spaghetti Bolognese is consistently the product with the highest impact. In most cases the second worst option is salmon risotto (AP, FAETP, ODP) or vegetable lasagne (ADPe, MAETP). Consequently, the lunch options typically have higher impacts than the breakfast or dessert options. Excluding spaghetti Bolognese, overall there is little variation between the products: for ADPe, HTP and MAETP, all remaining products are within 20% of each other (

Table 3.8).

3.3.1.7 Life cycle hotspots

Figure 3.3 shows the contribution of individual life cycle stages for each meal. The life cycle stages with the highest contribution across all impact categories are the raw materials, manufacturing and packaging with an average contribution of 2% to 83% across all meals and impact categories. More specifically, the manufacturing stage contributes significantly to ADPf (27%-39%), GWP (16%-20%) and ODP (35%-46%). This is due to the use of energy, and mostly due to natural gas.
The raw materials play a considerable role in GWP (23%-60%), EP (20%-77%) and TETP (93%-221%). These impacts are strongly influenced by fertiliser requirements associated with crops, animal feed and manure. GWP is also affected by methane emissions associated with meat and dairy production.

The raw materials are also a major contributor to POCP (20%-61%) and AP (15%-62%), but this time due to sulphur dioxide and nitrogen oxides from the life cycle of electricity.
The packaging stage dominates ADPe (61%-84%), AP (3%-34%) and POCP (9%-30%). It is also the main contributor (after the raw materials which contribute 53%-67%) to most toxicity-related impact categories, to which it contributes 13%-32% to HTP, 20%-55% to MAETP and 13%-23% to FAETP.
The use stage is only significant for MAETP, to which it contributes 19% due to leachates of nickel and barium from landfills. The highest contribution of end-of-life waste management is to HTP (48.5%), related to dust particles to air due to treatment of aluminium scrap. The influence of retail and transport is small, contributing up to 3% (ODP).



a
363 401 503 689 439 466 351 432 316 312 349
Wet porridge
Chicken lunch
Salmon risotto
Spaghetti Bolognese
Vegetable & chicken risotto
Vegetable lasagne
Apples rice
Banana & chocolate pudding
Apple, pear, banana
Strawberry, raspberry & banana
Strawberry yoghurt
GWP (g CO2 eq.)
b.
296 301 313 437 305 317 314 302 303 308 313
ADP elements (µg Sb eq. x 10)
c.
385 449 496 730 496 555 411 428 398 396 396
ADP fossil (kJ x 10)
d.
26 19 33 36 20 25 21 27 16 16 22
AP (g SO2 eq. x 10-1)
e.
91 100 181 151 75 98 69 93 54 52 78
EP (g Phosphate eq. x10-2)
f.
61 75 78 150 77 77 61 66 58 57 61
Apples and rice
FAETP (g DCB eq.)
g
288 265 275 440 269 274 246 251 242 240 249
HTP (g DCB eq.)
h.
412 441 464 659 460 466 439 438 436 430 435
MAETP (kg DCB eq.)
i.
329 371 431 543 387 417 361 364 341 345 333
ODP (µg R11 eq. x 10-1)

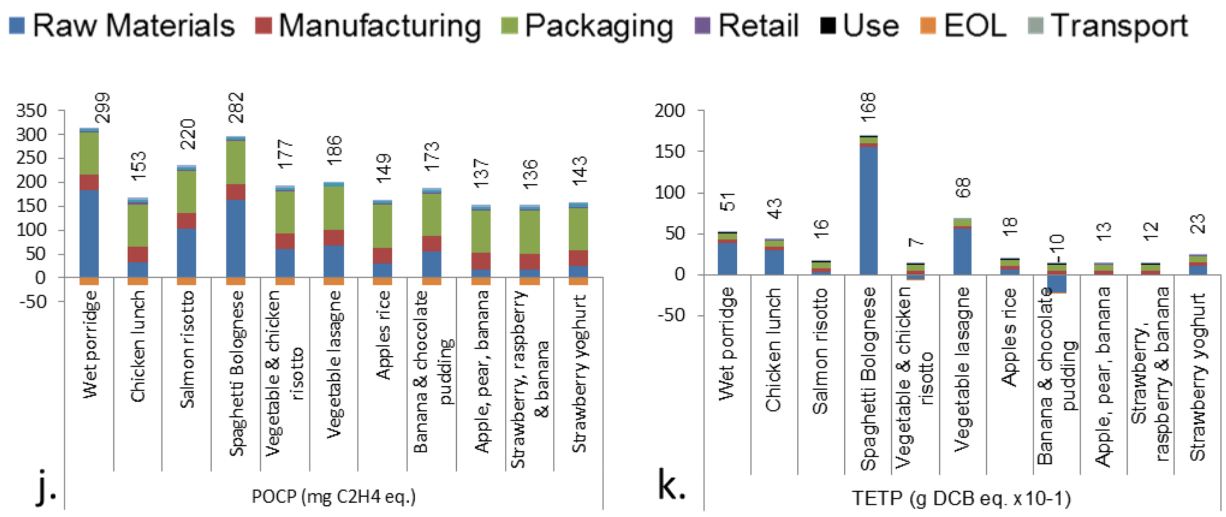


Figure 3.3 Environmental impacts of the ready-made meals: a. Global warming potential (GWP), b. Abiotic depletion potential (elements), c. Abiotic depletion potential (fossil), d. Acidification potential (AP), e. Eutrophication potential (EP), f. Freshwater aquatic toxicity potential (FAETP), g. Human toxicity potential (HTP), h. Marine aquatic ecotoxicity potential (MAETP), i. Ozone layer depletion potential (ODP), j. Photochemical oxidants creation potential (POCP), k. Terrestrial ecotoxicity potential (TETP).

3.3.2 Sensitivity analysis

As discussed earlier, natural gas is the major contributor to the manufacturing stage. The impacts of manufacturing are the same across the different foods due to the same processing assumptions. Therefore, efficiency improvements that result in lower natural gas consumption will reduce all impacts from the manufacturing across the meals. Hence, a sensitivity analyses was conducted, consisting of ±30% variations of natural gas consumption.

For instance, when considering the whole life cycle of a food product such as strawberry yoghurt, a 30% reduction in natural gas consumption during manufacturing translates into a total life cycle reduction of 13% for ADPf, 10% for GWP and 16% for ODP. The remaining environmental impacts show a decrease of 0-6%. The same trend applies for a 30% increase in the consumption of natural gas.

Considering the product with the highest overall impacts – spaghetti Bolognese – a 30% change in the natural gas demand in the manufacturing stage causes a 7% change in total life cycle impacts for ADPf, 5% for GWP and 10% for ODP.

Overall, ±30% variation of natural gas demand during manufacturing results in total life cycle impact variation of <16%.

3.3.3 Environmental impacts of different food groups

To analyse the contributions of different types of ingredient to the overall environmental impacts of ready-made baby foods, the 11 baby foods can be grouped into six food groups, with their contributions to the recipes of the 11 meals shown in brackets: cereals (12%); vegetables and beans (22%); fruits (34%); milk, yoghurt, cheese (15%); oils and sugar (3%); and meat, poultry and fish (4%). However, their contribution to the impacts is quite different from their contribution to the products' formulation. Although the meat, poultry and fish group constitute only 4% of the recipes, their average contribution to the impacts is almost 30% (Figure 3.4). This is followed by a 20% contribution from the milk, yoghurt, cheese group, 16% from the vegetables and beans, 16% from cereals, 10% from the oils & sugar and 10% from the fruits group.

For ADPe the meat, poultry and fish group contributes 34% of the total impact, mainly due to cadmium, copper and lead depletion associated with beef production. This is attributable to operation of the cattle housing and the production of cattle feed (in turn linked to fertiliser production). For ADPf, the vegetable ingredients contribute the most (37%) and this is mostly due to natural gas consumption, particularly for the cultivation of greenhouse tomatoes. For AP and EP, the dairy group contributes 49% and 37% of the total, respectively. This is related to ammonia and nitrate emissions from manure and livestock housing. For FAETP, 36% of the contribution comes from the meat, poultry and fish group due to nickel, vanadium, beryllium and cypermethrin emissions in coal electricity generation and coal mining. For GWP, the dairy products impact the most (27%) due to GHG emissions from cattle and energy production. The meat, poultry and fish meals contribute the most to HTP (35%), mostly because of chromium, arsenic and selenium emissions associated with fertiliser production. For MAETP, this group dominates again (33% of the total) due to hydrogen fluoride and beryllium emissions from energy generation. For ODP, 24% of the total is from cereals, mainly associated with use of halons in the natural gas energy chain, particularly for rice flour and dry pasta production. Most of the POCP is related to oils and sugar (27%) due to oil or petroleum derivatives used as an energy source and carbon monoxide emissions from sugar manufacturing. The same applies to TETP with oils and sugar having 54% contribution.

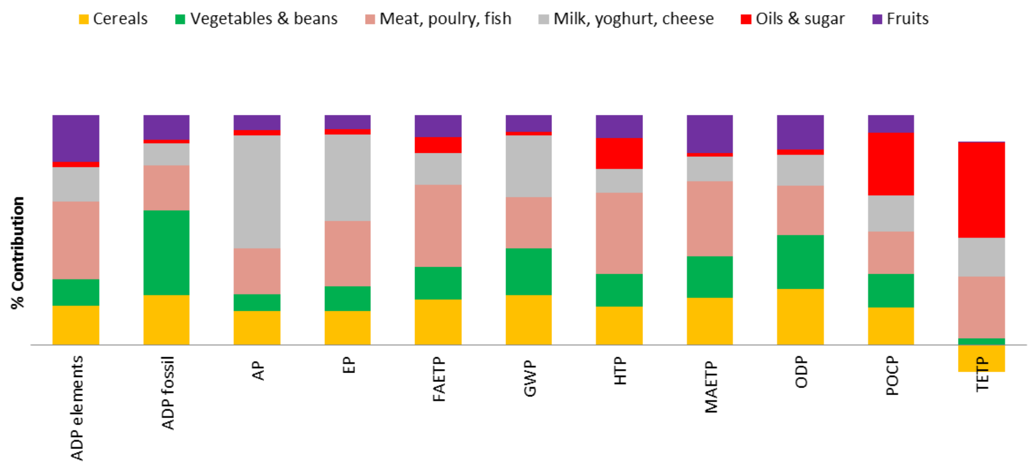


Figure 3.4 Environmental impacts per food group category for 11 food products considered in the study

3.3.4 Environmental impacts of different diets

The impact for four different diets are displayed in Figure 3.5 per baby per week, based on three meals per day (2nd functional unit; see section 0). Figure 3.6 shows the contribution per food group in these diets. As can be seen in Figure 3.5, the variation in impacts between the diets is not significant between the omnivore, pescatarian and vegetarian diets, with the latter having slightly lower impacts. However, the dairy-free diet has significantly higher impacts than the other three. These results are discussed below in more detail, taking the omnivore diet as the baseline. This the most common diet because diversity of food is considered healthy for babies.

Looking at the vegetarian diet first (Figure 3.5), the elimination of the meat, poultry and fish from the diet leads to a slight decrease in most impact categories, with the greatest decrease occurring in EP. The latter is due to reduced phosphate and nitrate emissions from livestock rearing. There is also a slight increase in ADPf and TETP due to the increase in dairy and oils and sugar to compensate for the loss of meat-related ingredients (Figure 3.6d).

For the pescatarian diet, when fish is the only meat-based ingredient on the menu, there is a significant reduction in TETP compared to the omnivorous diet, while AP and EP increase considerably (19% and 91%, respectively). The reduction in TETP is primarily due to the reduced usage of fertilisers and pesticides for cultivation of feed as the meat (beef and chicken) is removed from the menu. AP and EP increase due to the high contribution of salmon for these indicators.

Finally, when the dairy–free diet is considered, all impacts increase by 31-221% relative to the omnivore diet. When dairy is eliminated, there is an increase in the meat, poultry and fish group of almost 8% compared to the baseline as the non-dairy meals are rotated in the menu mix to make up for the lack of dairy products. This leads to a “spill over” of meat-related impacts into the dairy-free diet from the lunch products. The spaghetti Bolognese is the main lunch meal to substitute others as it uses no dairy ingredients, but it has high impacts as discussed in Section 0. Consequently, it is clear that care is needed when substituting ingredients to achieve specific diets due to the related environmental consequences.

In comparison with each other, the vegetarian diet exhibits the lowest impacts and the dairy-free the highest. For instance, the dairy-free diet has >50% higher GWP, AP, POCP than the other diets, as well as a very high EP, 3.2 times higher than the omnivore 4.4 times greater than the vegetarian diet.

Overall, EP increases with the contribution of meat and fish–based meals. ADPe increases with vegetable- and cereal-based meals (as is the case in the pescatarian diet) which, in turn, results in significantly lower TETP. It is notable that the pescatarian diet has much lower impacts than the dairy-free diet, despite the elimination of dairy leading to an increase in the meat, poultry and fish group. This highlights the diversity of impacts across the meat, poultry and fish-based foods, demonstrating that it is preferable to communicate environmental impacts at the ingredients-level rather than the food-group level. This can be challenging for highly processed ready-made baby food that consists of multiple ingredients.

These dietary impacts can be contextualised with reference to the annual GWP of an adult omnivore diet, which is estimated at 1.89 t CO_2 eq. per person (WWF 2017). The annual impact of the baby omnivore diet estimated in this study is 304 kg CO_2 eq. per baby, based on the weekly GWP of 5.84 kg CO_2 eq. (Figure 3.5). This is around 6.2 times lower than the impact of an adult. However, there is also a five times difference in the calorie intake, with adults consuming around 2000 kcal per day and babies around 400 kcal from solid foods (The Caroline Walker Trust 2011), equivalent to 375 g of food eaten daily considered here. Therefore, the results are closely comparable, confirming the validity of the estimates.

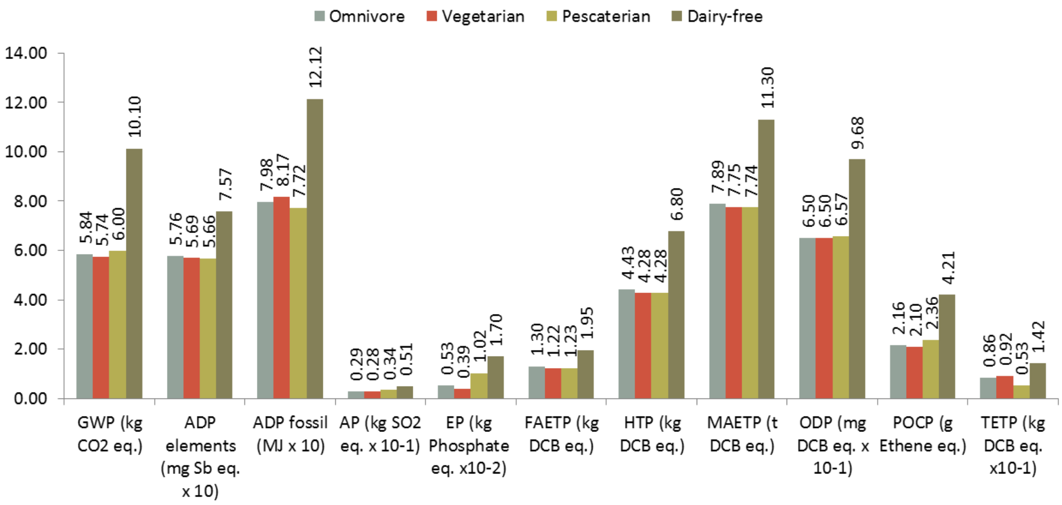


Figure 3.5 Environmental impacts of different diets
(Impacts expressed per baby per week)

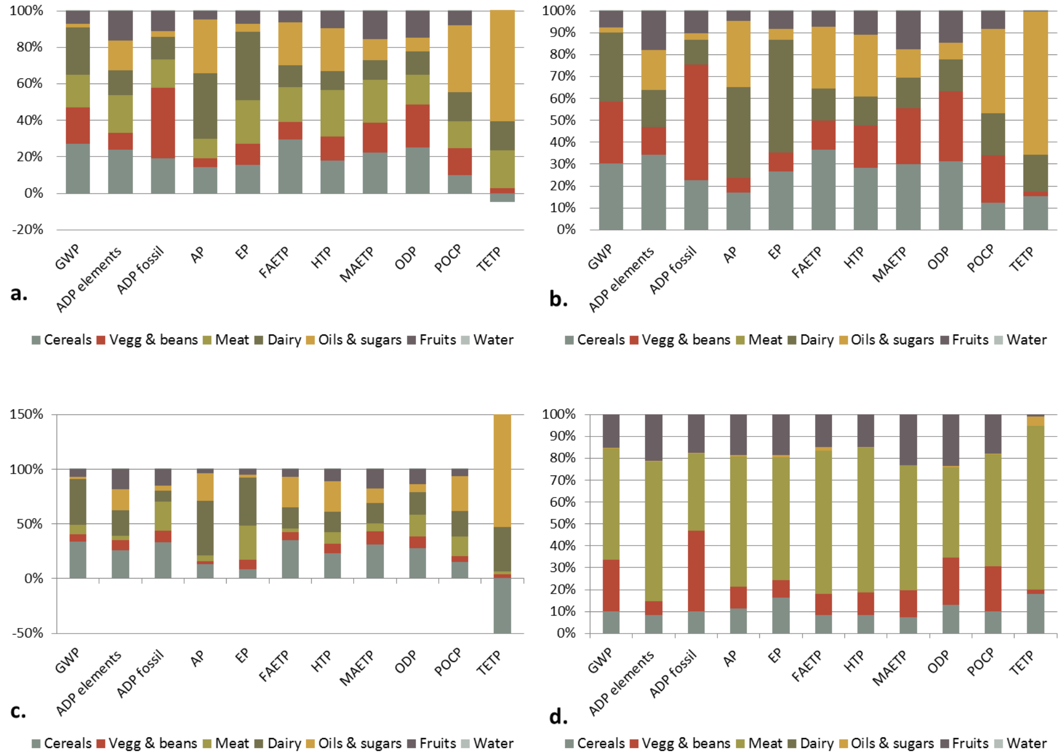


Figure 3.6 Environmental impacts per food group category in each diet: a. Omnivore, b. Vegetarian, c. Pescatarian, d. Dairy free

3.4 Conclusions

This paper has considered the life cycle environmental impacts that arise from the production and consumption of ready-made 'wet' baby foods. Eleven different meals have been considered, together with weekly menus representing different diets. The results show that the key hotspots are raw materials and packaging. Manufacturing also plays a significant role for ADPf, GWP, and ODP due to the fossil fuels used to provide energy for processes, such as cooking and sterilisation.

Lunch meals have the highest and desserts the lowest impacts, with breakfast porridge falling in between. Specifically, the best options are the fruit-based desserts, such as apple, pear and banana, and the strawberry, raspberry and banana. In contrast, the highest impacts are seen for spaghetti Bolognese, which is the worst option for nine out of 11 impacts.

Analysis of different food groups shows that, despite a small share of meat (4%) in the recipes, its contribution to the impacts is on average 30%. On the other hand, fruits constitute 22% of product formulation, but their average contribution to the impacts is 10%.

The impacts between the omnivore, pescatarian and vegetarian diets do not differ significantly, with the latter being a slightly better option. However, the dairy-free diet has the significantly higher impacts than the others. This is due to the increased contribution of the meat, poultry and fish group and especially spaghetti Bolognese (hence beef) in the menu mix. Therefore, avoiding dairy-free diet would reduce the environmental impacts of baby food. However, these results should be interpreted only in the context of the 11 meals considered here as the outcomes may change depending on the meals and the recipes.

Environmental improvements could also be achieved by reducing energy use in the manufacturing process. For instance, sensitivity analysis shows that decreasing natural gas consumption by 30% could reduce the impacts by up to 13%, including GWP, ADPf and ODP. Further improvement opportunities include modifying product formulations to use less impactful ingredients or reduce the amount of those with higher impacts, such as meat, cream and cheese.

Because a baby's diet must fulfill nutritional and nourishment criteria, it naturally occurs to question whether there is a more sustainable alternative production system that could provide the same service. Therefore, in the context of sustainability, alternative methods of providing food can also be considered, such as home-made meals. This is the topic of the next chapter.

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Chapter 4. Life cycle environmental impacts of baby food: ready versus home-made meals

Natalia Sieti, Ximena C. Schmidt Rivera, Laurence Stamford* and Adisa Azapagic

Sustainable Industrial Systems, School of Chemical Engineering and Analytical Science, The University of Manchester, Manchester M13 9PL, UK

*Corresponding author: laurence.stamford@manchester.ac.uk

Abstract

This paper compares the life cycle environmental impacts of home-made baby food meals with their commercially-prepared, ready-made, alternatives. A sample of representative products is considered based on own market research of 513 ready-made baby food products across the five leading companies selling in the UK. The scope is from "cradle to grave" and the functional unit is "preparation and consumption of a meal (125 g)". The results suggest that the impacts of the home-made meals are 50% to 17 times lower than for the equivalent ready-made meals. The best option is a fruit-based home-made dessert. For example, its global warming potential is six times lower than that of the ready-made alternative. Of the ready-made meals, dry porridge has the lowest impacts for nine out of 11 impact categories, including global warming potential. The reason why the home-made meals have lower impacts is the avoidance of the manufacturing and packaging stages, as well generation of less waste due to shorter supply chains. The findings of the study will be of interest to producers, retailers and consumers.

Keywords: baby food, ready-made meals, home-made meals, environmental impacts, LCA

4.1 Introduction

There is growing interest in the role of food production systems in sustainable development (United Nations 1992b; HM Government 2010). Food is one of the most important products groups regarding the environment and the sector has received increasing scrutiny in recent years, particularly from the perspective of GHG emissions and climate change. For instance, the UK food supply chain has been estimated to be responsible for 176 Mt CO_2 eq. (Tassou et al. 2014), equivalent to approximately one third of total UK GHG emissions (BEIS 2018). The food supply chain comprises agricultural production, manufacturing, transportation, retailing, shopping, cooking and waste disposal. Emissions to air, water and soil are generated in all the aforementioned activities in the food supply chain.

Agriculture itself accounts for 70% of global water consumption (Aquastat - FAO 2018), while food accounts for 30% of global energy use (FAO 2011). With the global population expected to reach 9.1 billion in 2050, the Food and Agriculture Organisation (FAO) suggests that food production should increase by 70% (FAO 2009). Hence, unless the current food system undergoes significant transformation, environmental impacts can only increase in future. For instance, a 50% increase in global food production by 2030 will lead to an increase in energy demand by 45% and water demand by 30% (Beddington 2008).

Due to a shift largely related to modern lifestyles, with a high number of parents preferring convenience to traditional methods of cooking, the provision of baby food has been changing over the past decades, moving away from traditional, home-made food to commercially produced ready-made meals. Hence, the ready-made baby food market is growing fast globally. Four out of five British babies are fed food from tinned and jarred products (Rees 2007), while in the US, by the time infants reach 12 months of age, they have consumed about 600 jars of baby food (Stallone and Jacobson 1995). This number goes down to 240 jars for Western European babies and to about 12 jars in Eastern European countries, like Poland (Stallone and Jacobson 1995). Given that until their sixth month babies are solely milk-fed; this number represents approximately three jars per day in the US and one jar in Western Europe. A survey of infants in the US, aged six to 12 months, found that 81% consumed ready-made baby food (Nestle Nutrition Institute 2008).

The UK convenience and baby food sector, characterised by highly processed ready-made food, was worth £611 million in 2012 (including milk formula) with a growth of 51% over the last five years (Mintel 2012). While the sector is highly dependent on scientific research to drive innovation, growth and meet nutritional and health standards, sustainability studies of baby food products are rare and mostly outside the UK. Therefore, there is a need for further research in this field, if the UK is to meet its 2030 resource efficiency goals towards a sustainable and secure food system (HM Government 2010).
However, while uptake of ready-made baby foods has generally been increasing, competition from home-made alternatives has been strong (Mintel 2014). One of the reasons some parents prefer home-made options is due to the greater control they can exert over the ingredients, highlighting their concern for healthiness and safety in the food supply chain. According to Mintel (2013), two thirds of parents trust home-made baby food more than manufactured variants.

Baby foods are subject, to the same trends as products consumed by adults in terms of premium quality and convenience (Agriculture and Agri-Food Canada 2012). With an anticipated increase in the number of infants aged 0-4 (Agriculture and Agri-Food Canada 2012), it is appropriate to consider whether the home-made or their commercial ready-made alternatives are environmentally more sustainable.

Numerous life cycle assessment (LCA) studies have been carried out to assess the environmental sustainability of food and drinks products. However, the assessment of whole meals is limited (Zufia and Arana 2008; Sonesson et al. 2005; Schmidt Rivera et al. 2014; Calderón et al. 2010). Existing studies that compare ready-made to home-made meals are rare with no equivalents existing in the baby food sector. Two studies have been identified comparing industrially prepared and home-cooked meals outside the baby food sector, and their conclusions differ. According to Sonesson et al. (2005), the differences between the home-made and ready-made versions of an adult meal consisting of meatballs and potatoes were too small to draw any conclusions regarding which meal was environmentally more favourable. Raw material use was identified as a critical element in reducing the overall environmental impact of food consumption. Similar trends were reported by Schmidt Rivera et al. (2014) for a chicken roast dinner, where ingredients were also found to be the hotspot. However, in this case, there was a bigger difference between the impacts of the home- and ready-made meal with the former found to be more sustainable. The reason for this was the avoidance of meal manufacturing, reduced refrigeration and a lower amount of waste in the life cycle of the home-made meal (Schmidt Rivera et al. 2014). Although there is lively debate on the home- vs ready-made food for babies, there has been no LCA study comparing these. Therefore, this study aims to fill this gap by estimating for the first time life cycle environmental impacts of home-made baby foods in comparison with their ready-made alternatives. Although the study is based in the UK, the findings are generic enough to be applicable to other similar types of meals around the world.

4.2 Methods

The environmental impacts of both ready and home-made meals are estimated using LCA, according to the ISO 14040/14044 methodology (ISO 2006a; ISO 2006b). The assessment is conducted using GaBi software (Thinkstep 2015). The following sections describe in more detail the methodology, data and the assumptions used in the study.

4.2.1 Goal and scope of the study

The goal of the study is to estimate the environmental impacts of home-made baby foods and to identify the hotspots across the supply chain, with the aim of identifying improvement opportunities. A further goal is to compare these products with their highly ready-made alternatives. The typical meals consumed by babies in the UK and considered here are shown in Table 4.1. These are based on products identified in the introductory chapter via criteria such as popularity and incorporation of the most-consumed ingredients identified in the market.

Table 4.1 Typical UK meals considered in the study

Breakfast	Lunch	Dessert
• Porridge	• Chicken lunch	• Apple, pear and banana;
	• Vegetable and chicken risotto	• Strawberry, raspberry and banana
	• Spaghetti Bolognese	• Strawberry yoghurt
	• Vegetable lasagne	• Apples and rice
	• Salmon risotto	• Banana and chocolate pudding

The scope of the study is from “cradle to grave” and the functional unit is defined as “production and consumption of one baby meal”, equivalent to a serving of 125 g. The product formulations are based on information gathered from the major UK retailers, to ensure that they are representative of recipes across the sector. Assumptions in terms of composition are also made as some recipes do not provide the exact contribution of the ingredients.

The product formulation (recipes) considered in the study can be seen in Figure 4.1.The recipes for both home (HM) - and ready-made meals (RM) are assumed to be identical, as far as possible, except breakfast porridge where indicated as “porridge” or “home-made porridge”

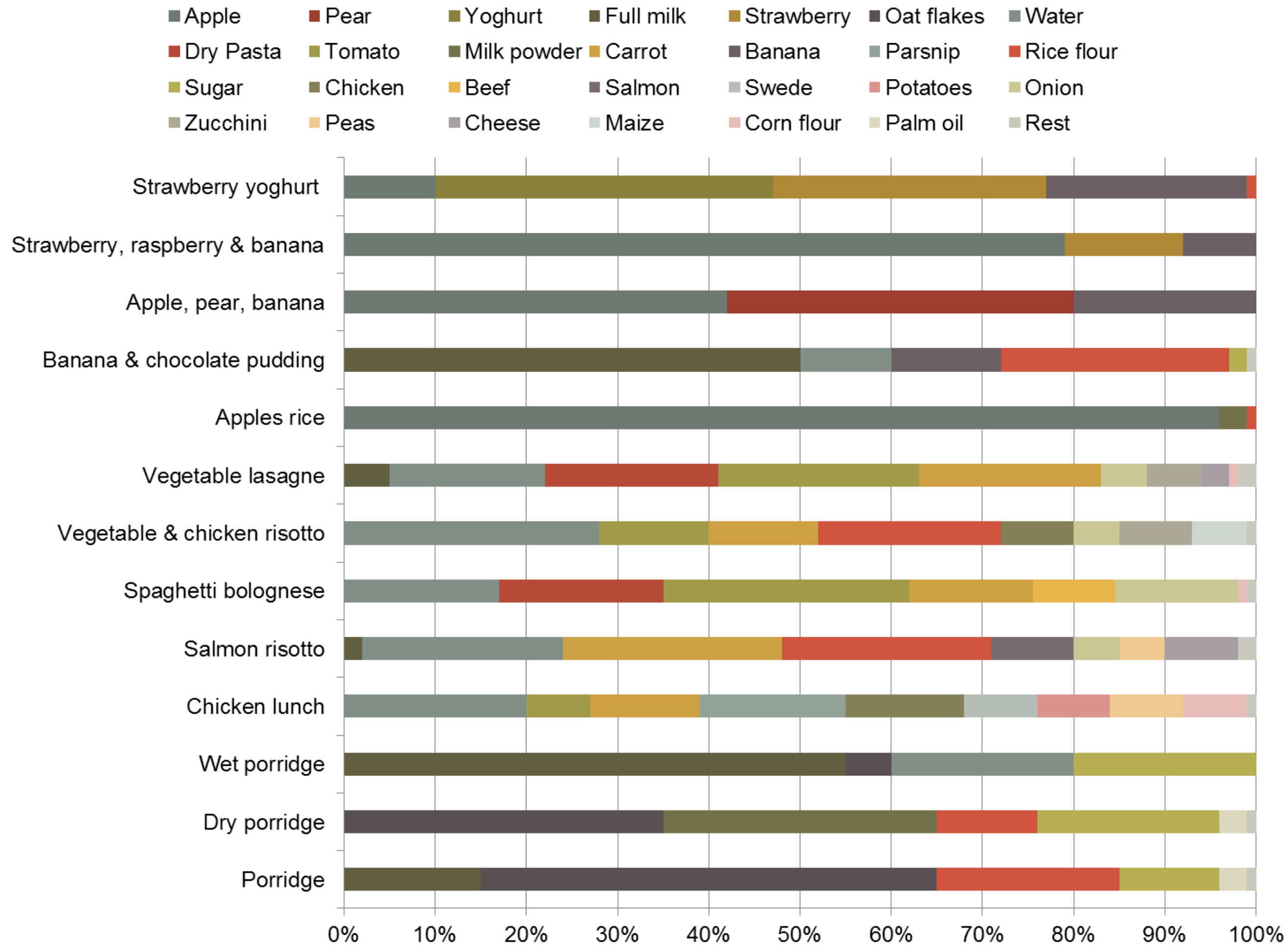


Figure 4.1 Breakdown of breakfast, lunch and dessert ingredients in home- and ready-made meals by mass (all products have a total mass of 125 g) Rest: rapeseed oil, sunflower oil, cocoa and barley

4.2.2 System definition and system boundaries

Figure 4.2 outlines the life cycle stages of the home- and the ready-made meals. For the dry and wet ready-made meals, the system boundaries encompass the production and processing of raw materials (ingredients), the manufacturing of the ready-made baby food, the production of packaging materials, the product distribution, retail, consumption and end-of-life (EoL) waste management. The consumption stage involves heating up the product on a gas hob.

In the case of home-made meals, the stages are similar, except that there is no manufacturing and packaging of the meal but instead the consumer buys the individual ingredients packaged in their packaging and carried in a shopping bag, and prepares the meal at home. This involves cooking and blending of the ingredients for and dairy-based meals, and only blending in the case of fruit-based meals. Preparing breakfast porridge requires milling and cooking on the hob. End-of-life waste management includes packaging for the ingredients and the shopping bag. Wastes generated in other life cycle stages are accounted for in their respective stages. The individual steps involved in each stage are described in Table 4.2.

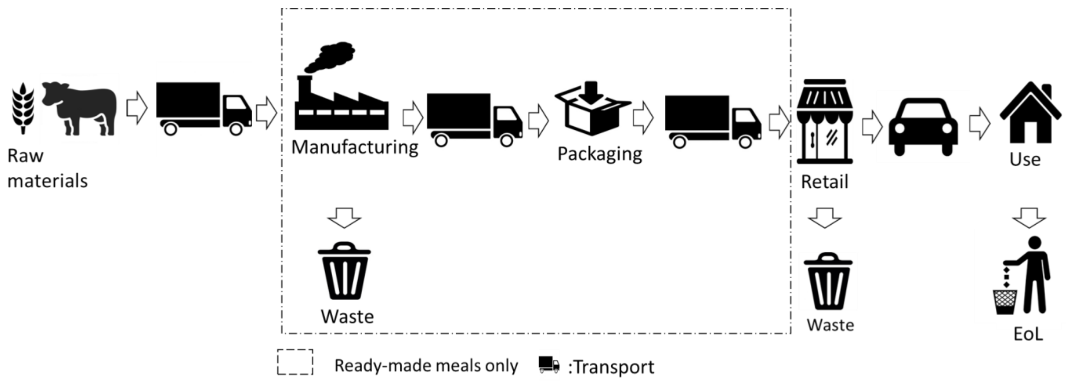


Figure 4.2 The life cycle of ready- and home-made meals (EoL stands for End of Life)

4.2.3 Inventory data and assumptions

Most life cycle inventory data are sourced from the Ecoinvent database (Ecoinvent 2015) and supplemented by data from published literature or own estimates, as summarised in Table 4.2. For further detail on the data and assumptions for the ready-made products, see Chapter 2 and Chapter 3.

4.2.3.1 Raw materials (Ingredients)

UK specific data are used for the ingredients where known and available. The electricity production mix of the UK, for year 2015, is modelled based on DECC (2016). Heat is assumed to be provided by the combustion of natural gas in a modulating condensing boiler based on data from Ecoinvent Centre (2015). Because UK- specific data are not available, European data for tap water are assumed. The data sources for the raw materials can be found in Chapter 2 and Chapter 3.

Table 4.2 Summary of life cycle inventory data for both ready-made and home-made meals

Stage	Meals	Country of origin	Source of LCI data
Raw materials (ingredients)	Chicken farming, slaughtering	GB, BR	Williams et al. (2006); Prudêncio da Silva et al. (2014); Nielsen et al. (2003)
	Beef farming, slaughtering, freezing	GB	Nielsen et al. (2003); Williams et al. (2006)
	Salmon farming & processing	GB	Nielsen et al. (2003); Winther et al. (2009)
	Dairy farming	GB	Williams et al. (2006); Upton et al. (2013)
	Milk production	GB	Nielsen et al. (2003)
	Milk powder production	GB	〃
	Cheese production	GB	〃
	Yoghurt production	GB	Nielsen et al. (2003); Williams et al. (2006); Ecoinvent (2016)
	Cultivation of oats	SE	Ecoinvent (2015)
	Cultivation of rice	US	〃
	Cultivation of sugar	BR	〃
	Cultivation of wheat	RoW b	〃
	Cultivation of corn	US	〃
	Cultivation of barley	DE	〃
	Milling of cereals (oats, rice, corn)	GB	Nielsen et al. (2003)
	Durum wheat semolina production & pasta production	IT	Lo Giudice et al. (2011)
	Barley malt extract dry production	GB	Own calculations
	Cultivation of tomatoes	ES, NL, GB	Theurl et al. (2014); Williams et al. (2006); Antón et al. (2012)
	Cultivation of potatoes	CH	Ecoinvent (2015)
	Cultivation of carrots, zucchini, onion	GLOa	〃
	Cultivation of peas	ES	〃
	Cultivation of swede, parsnip	SE	Davis et al. (2011)
	Cultivation of fruits (apple, pear, banana, strawberries)	GLO	〃
	Cultivation of cocoa beans & cocoa production	Ghana	Ntiamoah and Afrane (2008)
	Cultivation sunflower	RoW	Ecoinvent (2015)

	Cultivation rapeseed	RoW	〃
	Palm oil, at oil mill	MY	〃
	Sunflower oil production	GB	〃
	Rapeseed oil production	GB	Mattsson (1999)
	Tap water, at user	RER	Ecoinvent (2015)
Manufacturing	Baby food manufacturing	GB	Mattsson (1999)
	Waste management	RoW	
Packaging	Packaging manufacturing (Table 4.3, Table 4.4)	RER	Ecoinvent (2015)
Retail	Supermarket details	GB	Brunel University (2008)
Use	Energy consumption, for meal preparation	GB	Own calculations
	Meal preparation techniques	GB	On pack
Transport	Road transport, lorry	RER	Ecoinvent (2015)
	Road transport, car	RER	〃
	Sea transport	OCEc	〃
End of life	Disposal polypropylene, 15,9% water to sanitary landfill	CH	Ecoinvent (2015)
	Disposal, plastics, mixture,15.3% water to sanitary landfill	CH	〃
	HDPE recycling	GB	(Welle 2005)
	Disposal,glass 0% water, to inert material	CH	Ecoinvent (2015)
	System credited for glass	CH	〃
	Energy for glass recycling	RER	〃
	System credited for cardboard recycling	RER	〃
	Energy for cardboard recycling	RER	〃
	Cardboard disposal	CH	〃
Energy	Electricity	UK	Own modelling based on 2015 electricity mix DECC (2016)
	Natural gas, burned in boiler condensing modulating	〃	Ecoinvent (2015)
Water	Tap water, at user	RER	Ecoinvent (2015)

[a]GLO = global; [b]RoW = rest of world, referring to production outside Europe (RER); [c]OCE = ocean

4.2.3.2 Manufacturing

Manufacturing data are only applicable for the ready-made meals, as the home-made meals do not require this processing step. For detailed information on the manufacturing, see Chapter 2 and Chapter 3

4.2.3.2 Packaging

For home-made meals, packaging of the ingredients is based on typical packaging materials found at retailers. Average values for their specifications have been used (Table 4.3) and the life cycle inventory data are sourced from Ecoinvent Centre (2015). For the packaging for the ready-made meals, see Chapter 2 and Chapter 3.

Secondary packaging (plastic crates and wood pallets) used by retailers is also included (Table 4.4). The wood pallets and the plastic crates are landfilled (Ecoinvent 2015). Both the primary and secondary packaging are allocated to the retail stage.

4.2.3.3 Retail

For the home-made meals, it is assumed that dairy and meat/fish ingredients are refrigerated at the retailer for 24 h with a refrigerant leakage rate of 0.015 g per kg of product (Brunel University 2008). Storage of the other ingredients is at ambient temperature and the energy used for shop lighting and heating is given in Table 4.5. Ready-made meals are also stored without refrigeration and the energy data were provided in Chapter 2 and Chapter 3

Food losses at the retailer are assumed to be 2% for both ingredients used for the home-made meals and the ready-made meals. The food waste composted, following common practice in the food and drink industry (Bartlett 2010; Carr and Downing 2014).

Table 4.3 Packaging specification of home-made ingredients (values per kg of product)

Product per kg	Packaging specification	Mass (g)
Rice	Low density polyethylene	19.6
Oats	Low density polyethylene	0.01
	Corrugated board, mixed fibre, single wall	0.04
Milk	High density polyethylene	0.5
Sugar	Corrugated board, mixed fibre, single wall	0.001
Palm oil	Glass	326
	High density polyethylene	0.026
Malt extract	Packaging glass, white	288
	Aluminium alloy	24.7
	Low density polyethylene	4.7
Yoghurt	High density polyethylene	60

Table 4.4 Secondary packaging used by retailers for the home-made meal (values per kg of ingredient)

Material	Crate (kg)[a]	Euro pallet (pcs)
Polypropylene	0.014	
Wood		0.002

[a] Crate weights vary from 10 to 30 kg (Brunel University 2008). An average 14 kg crate with 1000 re-uses is considered, per 1 kg of unit, based on Schmidt Rivera et al. (2014).
[b] Based on (Kellenberger et al. 2007), one piece (pcs) of standard European pallet weights 22 kg and, for food products, can carry 100 kg to 1000 kg of goods. (Brunel University 2008). An average of 500 kg weight is assumed per one pallet.

Table 4.5 Energy used at retailer for home-made meals (per f.u.)

	Amount per functional unit (kJ)	Reference
Porridge	7.08	Own calculations
Chicken lunch	119	〃
Spaghetti Bolognese	119	〃
Salmon risotto	119	〃
Vegetable lasagne	119	〃
Vegetable and chicken risotto	119	〃
Desserts	6	〃

[a] Sourced from: Nielsen et al. (2003) considering electricity and heat consumption allocated to the products based on exposure area and average flow of the products in a large retail store.
[b] Calculated for electricity, heat and air conditioning based on Brunel University (2008).

4.2.3.4 Use

The use stage for the home-made meals includes electrical milling/mixing in a blender and gas cooking on the hob; the energy usage is summarised in

Table 4.6. A plastic bag is also included in the use stage. Water use of 1 L is also considered for washing up of plates and cutlery based on Defra (2008). Wastewater data are sourced from Ecoinvent Centre (2015). Preparation of the wet ready-made meal requires cooking/warming on a gas hob. For the energy use for ready-made meals, see Chapter 2 and Chapter 3

It is assumed that 14% of food is wasted, based on the average for edible purchases (Holding et al. 2010).

Table 4.6 Energy used at home for preparing home-made meals[a]

	Appliance	Energy use per functional unit (Wh)
Porridge	Hob/Blender	26
Chicken lunch	"	326
Spaghetti Bolognese	"	245
Salmon risotto	"	164
Vegetable lasagne	"	103
Vegetable and chicken risotto	"	164
Apples rice	"	83
Banana & chocolate pudding	"	83
Apple, pear, banana	Blender	7
Strawberry, raspberry and banana	"	7
Strawberry yoghurt	"	7

[a] Estimated based on average electricity consumption by a 2000 W hob and a 625 W blender for the cooking times specified by average online recipes for each meal (Nielsen et al. 2003).

4.2.3.5 End-of-life waste management

Assumptions for the end-of-life waste management for the home-made meals are detailed in Table 4.7. These are based on data from Defra (2015b) and background data from Ecoinvent. For the ready-made meals, see Chapter 2 and Chapter 3.

Closed loop recycling is considered and waste not recycled is landfilled (Defra 2015a). Energy used for recycling is considered. The system is credited for the avoidance of virgin packaging material by subtracting the impacts from the production of the virgin materials. For more information, see Chapter 2 and Chapter 3.

The treatment of the household food waste is based on current UK practices for household waste: 12% composting, 48.4% incineration and 39.6% landfill (Defra 2017c).

4.2.3.6 Transportation

The transport modes and distances are summarised in

Table 4.8. The road transport prior to retail is assumed to be by diesel lorry (Euro 3). For the transportation of imported ingredients, the use of transoceanic freight is considered. Transoceanic distances are calculated from the country of origin using Google maps and lorry distances are assumed to be 100 km. For consumer shopping, a round trip of 8 km per week is assumed by passenger car (Pretty et al. 2005). For both the home-made and the ready-made meals, transportation from home to waste disposal is excluded.

4.2.4 Allocation and system expansion

The same allocation and system expansion approaches are used for the home-made meals as described for the ready-made meals in the previous chapter.

Table 4.7 Material losses and waste treatment for the home-made meals

Stage	Losses/waste (%)	Assumed waste treatment options in Ecoinvent	Reference
Ingredients in raw materials (chicken)	0%	Disposal plastics mixture 15.3% water to sanitary landfill	Foster et al. (2006)
Ingredients in raw materials (corn flour)	3%	Treatment of bio-waste, composting	Nielsen et al. (2003)
Ingredients in raw materials (oat flakes)	5%	Treatment of bio-waste, composting	〃
Ingredients in raw materials (chicken)	7%	Disposal, municipal solid waste 22.9% water to sanitary landfill	Foster et al. (2006)
Ingredients in raw materials (pasta production)	6%	Treatment of bio-waste, composting	Lo Giudice et al. (2011)
Ingredients in raw materials (rice flour)	1%	Treatment of bio-waste, composting	Nielsen et al. (2003)
Ingredients at retailer	2%	Treatment of bio-waste, composting	Bond et al. (2013)
Post-consumer food waste	14%	Treatment of bio-waste, composting, Treatment of bio-waste municipal incineration, Treatment of municipal solid waste, sanitary landfill	Holding et al. (2010)
Post-consumer polypropylene	100%	CH: disposal, polypropylene, 15.9% water, to sanitary landfill	Defra (2015b)
Post-consumer HDPE	22.5%	Food grade HDPE recycling process (Welle 2005)	〃, EU rate
	77.5%	Disposal plastics, mixture, 15.3% to sanitary landfill	〃
Post-consumer glass	60%	System credited with addition or proxy energy for recycling	〃
	40%	Disposal glass, 0% water to inert material landfill	〃
Post-consumer cardboard box	60%	System credited, with addition of energy for recycling	〃
	40%	Disposal, packaging cardboard, 19.6% water, to sanitary landfill	〃

Table 4.8 Transport data for the home-made meals

Stage	Country of origin	Assumed distances and mode of transport	Vehicle	Life cycle inventory data
From raw materials to retail				
Ingredients to retailer	GB	100 km by road	Lorry, 7.5-16 t	Ecoinvent (2015)
From retail to use				
Baby food	GB	8 km by road	Transport, passenger car	Pretty et al. (2005)

4.3 Results and discussion

This section compares the environmental impacts of the home- and ready-made meals. Each impact is discussed in turn, followed by an evaluation of the raw materials stage of the life cycle which is the major contributor for the majority of impact categories.

4.3.1 Comparison of home- and ready-made meals

The impacts of the home- and ready-made meals are compared in Figure 4.3. Overall, the home-made variant of each meal has lower impacts than its ready-made equivalent across all impact categories, with a small number of exceptions. Generally, the greatest difference is observed for ADPe and TETP and the lowest for EP. These findings are discussed below in more detail for each impact in turn.

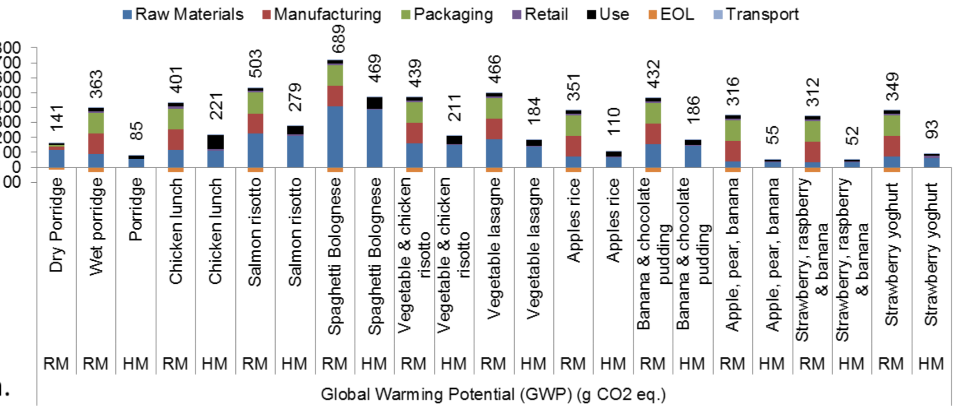
4.3.1.1 Global warming potential (GWP)

As can be seen in Figure 4.3a, home-made meals have the GWP 1.5-6 times lower than the ready-made equivalents. The greatest difference is observed for the strawberry, raspberry and banana meal: 52 vs 312 g CO_2 eq./f.u. This is largely due to manufacturing and packaging that contribute significantly to the GWP of the ready-made meal. Spaghetti Bolognese shows the lowest discrepancy (47%) between the home- and (wet) ready-made variants. The reason for that is the high contribution of the raw materials to both home-made and ready-made meals.

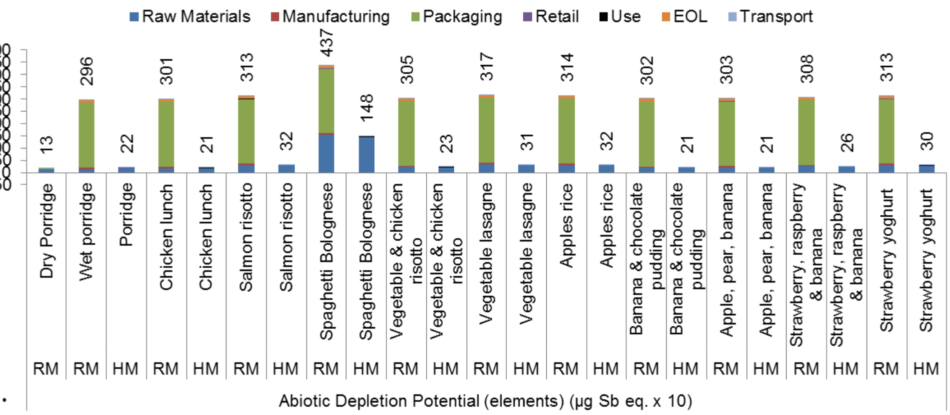
Figure 4.3a also shows the contribution of the life cycle stages to the impacts of each product. For the home-made meals, the contribution of the raw materials stage, across all products, ranges from 50% for the porridge to 90% for the strawberry yoghurt. The use stage contributes from 5-50%, with the lowest being the strawberry yoghurt and the highest the porridge. The retail stage has a small contribution: 2-10% across all products, with the highest being the strawberry, raspberry and banana meal and the lowest spaghetti Bolognese. Consequently, for the home-made meals, the raw materials stage is the major hotspot.

For the ready-made meals, the impacts are typically more evenly distributed throughout the life cycle: raw materials contribute ~33% on average, followed by packaging with 30% and manufacturing with 29%, while the rest of the stages add up to 8%. In the case of the dry ready-made porridge, the raw materials stage contributes almost 80%, with manufacturing adding a further 15%. For the wet ready-made porridge, the raw materials, manufacturing and packaging stages show an equal contribution of ~30%.

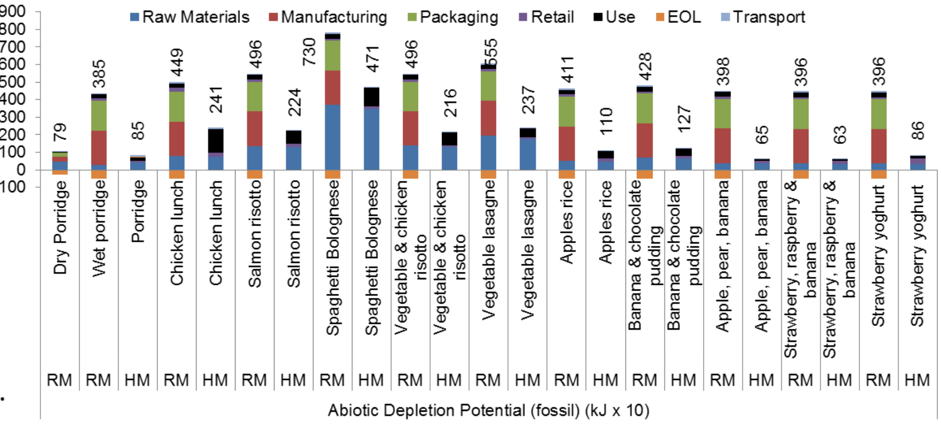
While the absolute values of these results cannot be compared directly to existing literature due to a lack of comparators, the breakdown of the impacts by life cycle stage is in line with literature. According to the Food and Drink Federation (FDF 2008), agriculture typically accounts for 50% of the total GHG emissions related to food production and consumption, while manufacturing represents about 10% of emissions from the food chain. Similarly, Berners Lee et al. (2012) conclude that the majority of the impacts come from the sourcing of ingredients.


Raw Materials
Manufacturing
Packaging
Retail
Use
EOL
Transport
800
700
600
500
400
300
200
100
0
-100
141 363 85 401 221 503 279 689 469 439 211 466 184 351 110 432 186 316 55 312 52 349 93
Dry Porridge
Wet porridge
Porridge
Chicken lunch
Chicken lunch
Salmon risotto
Salmon risotto
Spaghetti Bolognese
Spaghetti Bolognese
Vegetable & chicken risotto
Vegetable & chicken risotto
Vegetable lasagne
Vegetable lasagne
Apples rice
Apples rice
Banana & chocolate pudding
Banana & chocolate pudding
Apple, pear, banana
Apple, pear, banana
Strawberry, raspberry & banana
Strawberry, raspberry & banana
Strawberry yoghurt
Strawberry yoghurt
RM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM
Global Warming Potential (GWP) (g CO2 eq.)

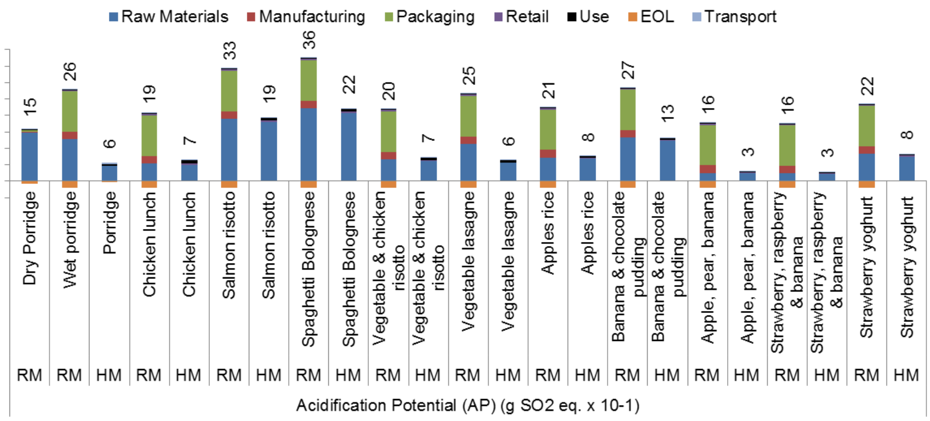
a.


Raw Materials
Manufacturing
Packaging
Retail
Use
EOL
Transport
500
450
400
350
300
250
200
150
100
50
0
-50
13 296 22 301 21 313 32 437 148 305 23 317 31 314 32 302 21 303 21 308 26 313 30
Dry Porridge
Wet porridge
Porridge
Chicken lunch
Chicken lunch
Salmon risotto
Salmon risotto
Spaghetti Bolognese
Spaghetti Bolognese
Vegetable & chicken risotto
Vegetable & chicken risotto
Vegetable lasagne
Vegetable lasagne
Apples rice
Apples rice
Banana & chocolate pudding
Banana & chocolate pudding
Apple, pear, banana
Apple, pear, banana
Strawberry, raspberry & banana
Strawberry, raspberry & banana
Strawberry yoghurt
Strawberry yoghurt
RM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM
Abiotic Depletion Potential (elements) (µg Sb eq. x 10)

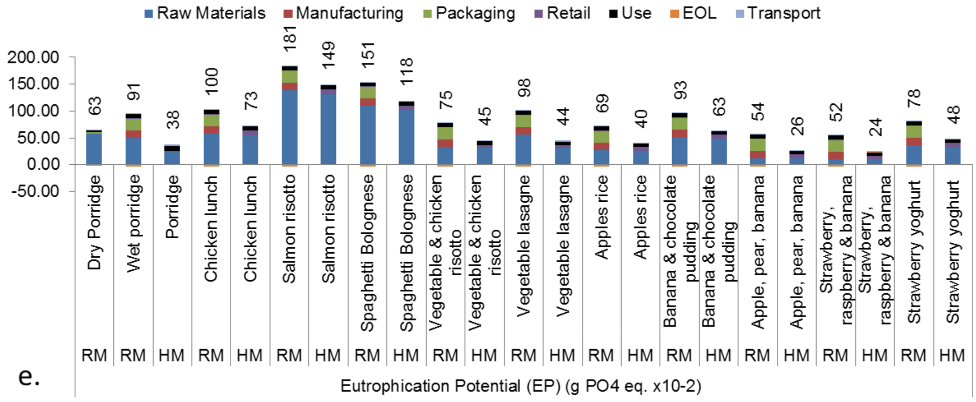
b.


Raw Materials
Manufacturing
Packaging
Retail
Use
EOL
Transport
900
800
700
600
500
400
300
200
100
0
-100
79 385 85 449 241 496 224 730 471 496 216 555 237 411 110 428 127 398 65 396 63 396 86
Dry Porridge
Wet porridge
Porridge
Chicken lunch
Chicken lunch
Salmon risotto
Salmon risotto
Spaghetti Bolognese
Spaghetti Bolognese
Vegetable & chicken risotto
Vegetable & chicken risotto
Vegetable lasagne
Vegetable lasagne
Apples rice
Apples rice
Banana & chocolate pudding
Banana & chocolate pudding
Apple, pear, banana
Apple, pear, banana
Strawberry, raspberry & banana
Strawberry, raspberry & banana
Strawberry yoghurt
Strawberry yoghurt
RM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM
Abiotic Depletion Potential (fossil) (kJ x 10)

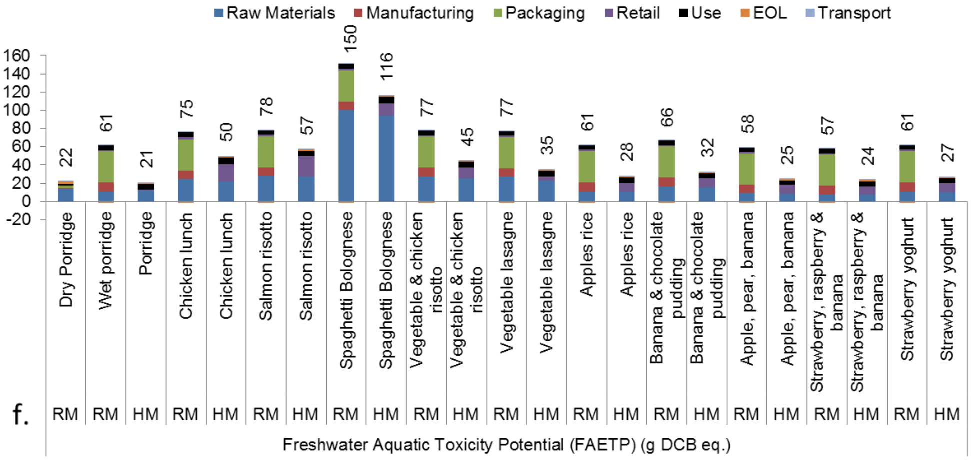
c.


Raw Materials
Manufacturing
Packaging
Retail
Use
EOL
Transport
40
35
30
25
20
15
10
5
0
-5
15 26 6 19 7 33 19 36 22 20 7 25 6 21 8 27 13 16 3 16 3 22 8
Dry Porridge
Wet porridge
Porridge
Chicken lunch
Chicken lunch
Salmon risotto
Salmon risotto
Spaghetti Bolognese
Spaghetti Bolognese
Vegetable & chicken risotto
Vegetable & chicken risotto
Vegetable lasagne
Vegetable lasagne
Apples rice
Apples rice
Banana & chocolate pudding
Banana & chocolate pudding
Apple, pear, banana
Apple, pear, banana
Strawberry, raspberry & banana
Strawberry, raspberry & banana
Strawberry yoghurt
Strawberry yoghurt
RM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM RM HM
Acidification Potential (AP) (g SO2 eq. x 10-1)

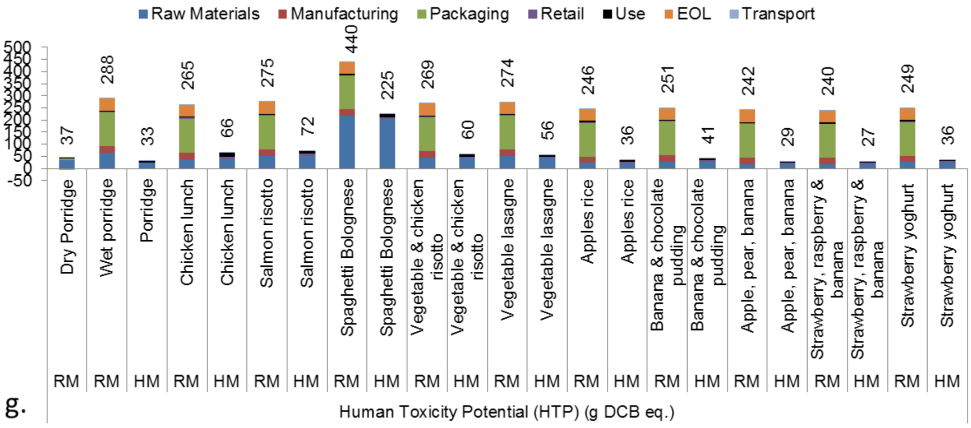
d.


Raw Materials Manufacturing Packaging Retail Use EOL Transport
Eutrophication Potential (EP) (g PO4 eq. x10-2)

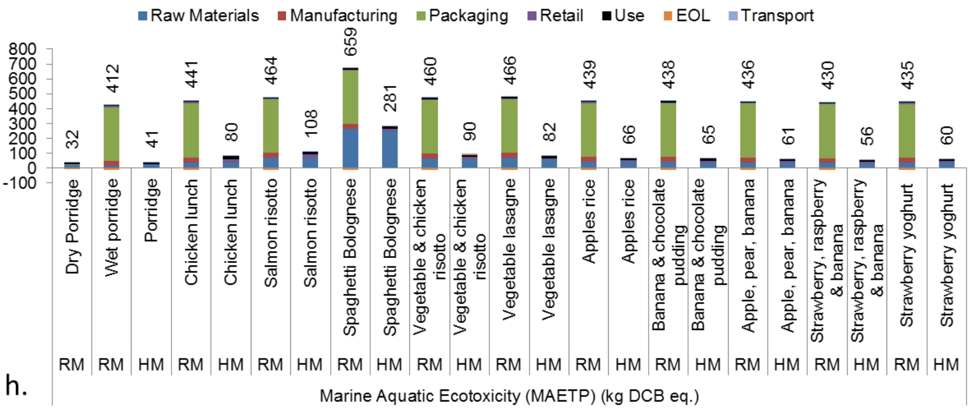
e.


Raw Materials Manufacturing Packaging Retail Use EOL Transport
Freshwater Aquatic Toxicity Potential (FAETP) (g DCB eq.)

f.


Raw Materials Manufacturing Packaging Retail Use EOL Transport
Human Toxicity Potential (HTP) (g DCB eq.)

g.


Raw Materials Manufacturing Packaging Retail Use EOL Transport
Marine Aquatic Ecotoxicity (MAETP) (kg DCB eq.)

h.

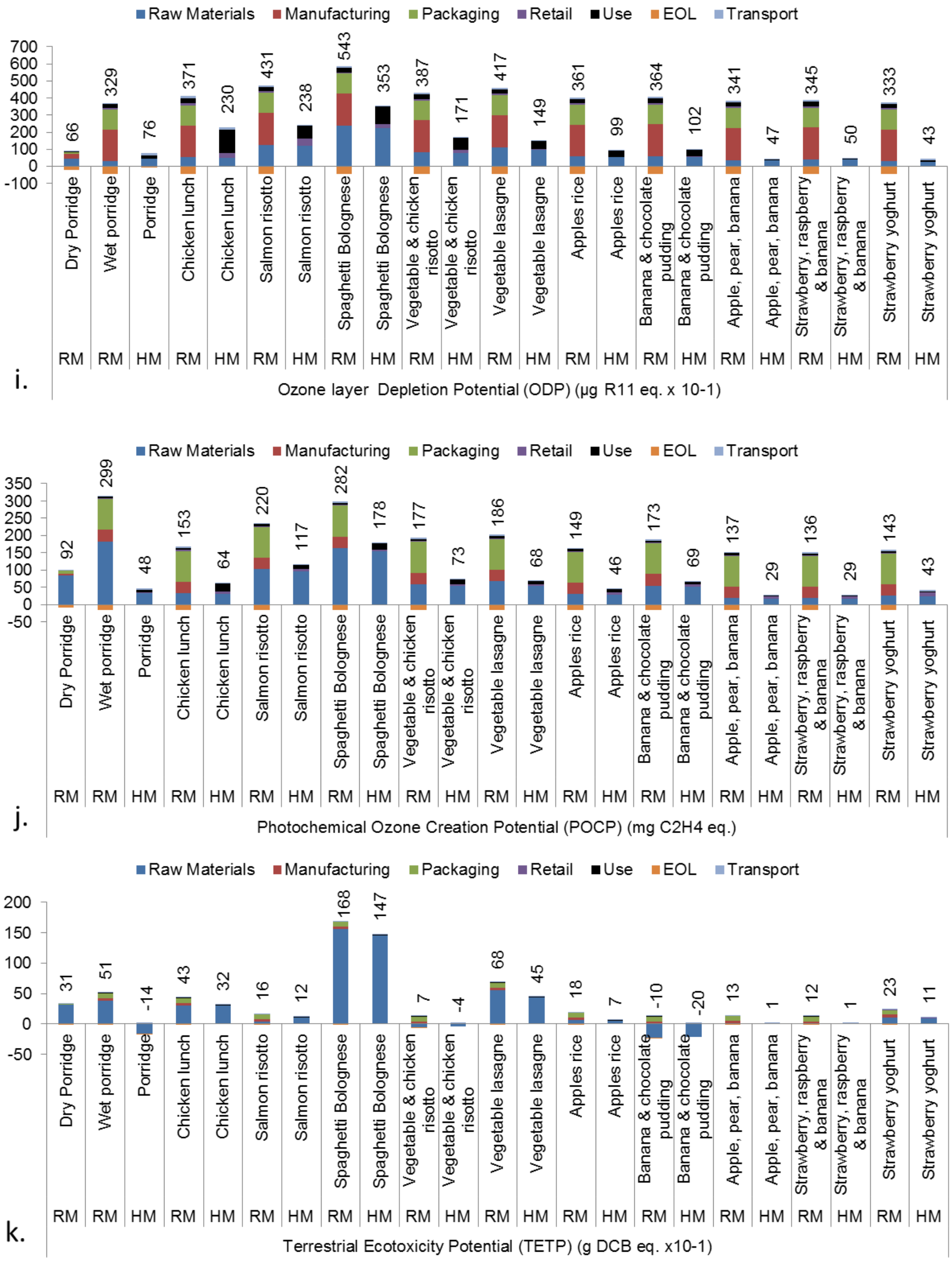


Figure 4.3 Environmental impacts of the ready-made versus home-made meals. (HM: home-made, RM: ready-made).

4.3.1.2 Abiotic depletion potential of elements (ADP elements)

The results show that home-made (HM) meals have ADP elements impacts 3-15 times lower than the ready-made (RM) alternatives. The greatest differences between ready-made and home-made variants are observed between the banana and chocolate pudding, and the chicken lunch, for which the RM variant has an impact 14.6 and 14.5 times higher, respectively (3023 vs 207 μg Sb eq./f.u and 3007 vs 207 μg Sb eq./f.u., respectively). This is because of the important contribution the packaging and manufacturing stages have in these products, both which are minimised or eliminated in the home-made meal.

Spaghetti Bolognese shows the smallest discrepancy between RM and HM versions but, nevertheless, the RM version is still 3 times worse than the home-made in terms of ADP elements. This is because the raw materials stage has a particularly high impact for Spaghetti Bolognese, accounting for 95% of the impact for the HM meal as shown in Figure 4.3b, and the impact of the raw materials stage remains similar in absolute value between the two variants. This impact is due to depletion of non-renewable elements such as lead, copper and cadmium throughout the beef and dry pasta production chains, mainly coming from fertiliser production used in the cereal cultivation (wheat and feedstock).

For the ready-made meals, approx. 80% of the impacts are due to the packaging stage on average, followed by the raw materials stage, with the remaining stages contributing very little. However, the dry porridge is the exception to this trend with a much lower overall impact and a contribution of 90% from the raw materials stage while the packaging contributes 10%. This is due to the different type, and mass, of packaging per 125 g meal: the wet products use a relatively heavy glass jar while the dry porridge uses a light-weight, low impact cardboard box. Consequently, the home-made versions of each meal tend to require far less packaging per unit mass of product.

4.3.1.3 Abiotic depletion potential of fossil resources (ADP fossil)

The ADP fossil impacts are compared in Figure 4.3c. The results for the home-made meals show that their impacts are 1.5-6 times lower that the ready-made alternative meals. The biggest difference is observed in the strawberry, raspberry and banana meal with 3959 kJ/f.u. for the RM version vs 630 kJ/f.u. for the HM, while the smallest discrepancy is observed for the spaghetti Bolognese with 7297 kJ/f.u. vs 4710 kJ/f.u. As described above, this smaller discrepancy is due to the relatively high impacts of the raw materials stage for spaghetti Bolognese which is incurred in both the RM and HM variants.

Figure 4.3c also shows the contribution of the life cycle stages to the impacts of each product. For the home-made meals, approximately 30-90% of the impacts derive from the raw materials stage, where tomato, beef, dry pasta production and rice flour show the highest impacts. The gas and electricity use at home are responsible for the fact that 5-30% of the total impact occurs in the use stage. The retail stage also contributes 2-5% as a result of the energy use for heating and lighting.

The contribution of the stages is different from the home-made meals due to the impacts of manufacturing the much greater packaging used across the life cycle: manufacturing is the highest contributor with 37% on average among all products, mainly due to natural gas burned in boilers. Packaging comes second with 32% on average, while raw materials contribute 21% on average among all products.

4.3.1.4 Acidification potential (AP)

The results in Figure 4.3d show that the AP of home-made meals is approximately 2-6 times lower than that of the ready-made alternatives. The greatest difference is observed for the strawberry, raspberry and banana dessert at 1.6 g SO_2 eq./f.u. vs 0.3 g SO_2 eq./f.u. As for the previous impacts, the smallest difference is seen for the spaghetti Bolognese at 3.6 g SO_2 eq./f.u vs 2.2 g SO_2 eq./f.u. In the former case, the glass jar packaging is the major contributor to AP as a result of its life cycle energy use and consequently high aerial emissions. Thus the HM variant of the meal, which is not packaged in a glass jar, has approximately 80% lower AP.

For the home-made meals, the stage with the most significant contribution is the raw materials, accounting for 80-95% of the total across all impacts with milk, beef and cheese being the greatest contributors. In contrast, for the ready-made meals the packaging is a major contributor (47% on average) with raw materials coming second (44%). Ammonia emissions from livestock explain the raw materials stage's contribution while NOx and SO_2 emission from energy use are mostly responsible for packaging. Finally, the manufacturing stage is much less significant, contributing almost 7%.

4.3.1.5 Eutrophication potential (EP)

The results in Figure 4.3e show that home-made meals have 1-2 times lower EP impacts than the ready-made alternatives. The greatest difference is observed between RM wet porridge and HM porridge, with the former being 2.4 times worse in terms of EP. The salmon risotto shows the least difference with the RM version having only a 21% higher EP than its HM equivalent.

As shown in Figure 4.3e, the difference between HM and RM meals is less pronounced for EP than for many other impact categories. This is because raw materials tend to be the main hotspot for EP as a result of ammonia and nitrate emissions associated with livestock, particularly in liquid milk production, beef rearing and salmon farming, due to the feed production. On average, the raw materials account for 50-90% of the impact for home-made meals and 20-91% for the ready-made. The fact that the raw materials do not change between the HM and RM meals accounts for the lesser difference between the two in terms of EP.

Following raw materials, the stage with the highest contribution is retail for the HM meals (10-40% of the total impact) and packaging for the RM meals (4-43%). The packaging impact arises mostly from phosphate and nitrate emissions during industrial glass production (due to combustion of fossil fuels and coal mining).

4.3.1.6 Freshwater aquatic ecotoxicity potential (FAETP)

The results in Figure 4.3f show that the home-made meals have 1.3-3 times lower EP than the ready-made alternatives. The greatest difference is observed between home-made porridge and its ready-made (wet) alternative at 21 g DCB eq./f.u. vs 61 g DCB eq./f.u. As for most previous impact categories, spaghetti Bolognese shows the smallest difference between RM and HM due to its high raw materials component which is the same between the two variants.

For the home-made meals, the stage with the highest contribution is raw materials (40-80%), followed by retail (20-60%). Among the ready-made meals, the stage with the overall highest contribution is packaging at 45% on average, followed by raw materials at 34%, 10% for manufacturing, 7% for EoL and 5% for the rest. The main emission to fresh water from packaging is vanadium for aluminium alloy production, incurred as a result of the aluminium lid on the glass jar.

4.3.1.7 Human toxicity potential (HTP)

As shown in Figure 4.3g, the home-made meals have 2-9 times lower HTP than their ready-made alternatives. This difference is most pronounced between HM porridge and the wet RM equivalent. In contrast, the dry RM porridge has an HTP very similar to that of the HM porridge (37 g DCB eq./f.u. vs 33 g DCB eq./f.u., respectively). Of the three porridge products, the fact that the RM wet variant has an impact an order of magnitude higher than the other two highlights the impacts of the glass and aluminium packaging. In fact, across all RM meals, packaging is the major hotspot accounting for an average of 48% of the HTP. This is followed by the EoL stage with 21% and raw materials with 20% contribution. The high impact from the packaging stage is mostly due to selenium, vanadium and barium from the industrial activity of packaging production (related to the combustion of fossil fuels). The EoL stage contributes due to release of selenium and thallium in the fresh water during the treatment of the aluminium scrap resulting from post-consumer waste.

For the home-made meals, the raw materials stage is the hotspot for HTP, accounting for 60-90% of the impact (Figure 4.3g). This is primarily attributable to beef, sugar and tomato.

4.3.1.8 Marine aquatic ecotoxicity potential (MAETP)

The MAETP impacts of the RM products are 2-10 times higher than those of the HM alternatives (Figure 4.3h). As is the case for FAETP, the greatest difference is observed between home-made porridge and its ready-made (wet) alternative at 41 kg DCB eq./f.u vs 412 kg DCB eq./f.u., respectively. The smallest difference is observed between spaghetti Bolognese at 281 kg DCB eq./f.u. for the HM meal vs 659 kg DCB eq./f.u. for the RM meal.

As shown in Figure 4.3h, for the RM meals the majority of the impacts derive from the packaging stage with 75% contribution on average, followed by raw materials with 14%, manufacturing 6% and the rest 5%. The main causes are emissions of hydrogen fluoride to air and beryllium to water, from energy consumption and the combustion of coal throughout the energy chain. As both the glass and aluminium components of the packaging require high energy input, the packaging stage is a major hotspot.

In the HM equivalents, where product packaging is absent, the MAETP values are much lower. In this case, most of the impacts derive from the raw materials stage with a contribution of 60-90% to the total. The retail stage follows with 10-35% and use stage with 5-20%. The majority of impacts comes from beryllium emissions to fresh water through the combustion of fossil fuels (primarily coal).

4.3.1.9 Ozone depletion potential (ODP)

The ozone depletion potential of the ready-made and home-made baby meals is sensitive to halogenated organic emissions to air, especially halons which are used as fire retardants and coolants and are often associated with the fossil fuel energy chain. Consequently, as shown in Figure 4.3i, the energy used in the ready-made meal manufacturing stage and the home-made meal use stage is a major determinant of the results. Specifically, for the home-made meals, the use stage accounts for 10-60% of the total impact, while for ready-made meals the major contributor is the manufacturing stage with 43% contribution on average, primarily due to natural gas burned in boilers. Packaging follows with 27% (due to packaging glass production) and raw materials is third, with 19% contribution.

Overall, the ready-made meals still have higher ODP than their home-made equivalents with an average of 35.7 μg R11 eq./f.u. versus 14.2 μg for the home-made meals; across all products, the RM meals are 1.5-8 times worse than their HM equivalents in terms of ODP.

The greatest difference is observed between strawberry yoghurt at 4.3 μg R11 eq./f.u. (HM) vs 33.3 μg R11 eq./f.u. (RM) because the raw materials have very little influence on the ODP of strawberry yoghurt, resulting in manufacturing having a proportionally greater effect due to the aforementioned link between ODP and energy use.

4.3.1.10 Photochemical oxidants creation potential (POCP)

The results in Figure 4.3j for the home-made meals show ODP impacts almost 2-6 times lower than those of the ready-made alternatives. The greatest difference is observed between HM porridge and its RM (wet) alternative with POCP values of 48 mg C_2H_4 eq./f.u, vs 299 mg C_2H_4 eq./f.u, respectively. The smallest difference is observed between spaghetti Bolognese 178 mg C_2H_4 eq./f.u vs 282 mg C_2H_4 eq./f.u. The POCP impact is sensitive to livestock rearing and energy consumption: emissions of methane and non-methane volatile organic compounds are major contributors, as are carbon monoxide and sulphur dioxide from the combustion of fossil fuels.

As a result, the energy use associated with glass and aluminium production cause packaging to be the major hotspot in the RM meals, accounting for 43% of the total on average. This is followed by the raw materials stage with 38%, and manufacturing with 15%.

For the HM meals, VOC emissions from raw material production dominate, causing the raw materials stage to account for 60-90% of the total. This is followed by retail and use, accounting for 10-20% each.

4.3.1.11 Terrestrial ecotoxicity potential (TETP)

As shown in Figure 4.3k, the raw materials stage dominates the TETP impact for both RM and HM meals. In the case of RM meals, raw materials account for an average of 70% of the total TETP, while in HM meals they account for 88%. The majority of these impacts are attributable to increases in the cypermethrin, arsenic and chromium concentrations on agricultural land.

Since raw materials are the main hotspot for TETP, the difference between the HM and RM meals is less pronounced than in most impact categories: the average impact is 2 g DCB eq./f.u. for the HM meals and 3.7 g DCB eq./f.u. for RM. However, exceptions include the strawberry, raspberry and banana dessert due to its very low raw materials impact. In this case the ready-made variant is 17.6 times worse than its home-made equivalent.

As shown in Figure 4.3k, several of the meals show negative emissions. This is due to the heavy metal uptake of harvested rice grains from the soil. Introduction into farm land of heavy metal input arises from seed, fertilizers, plant protection and growth products and deposition (Nemecek and Kagi 2007). This could potentially result in harmful effects to human health during consumption, although the likelihood of the heavy metal content of foods breaching recommended daily intakes is beyond the scope of this work. As a result of this, the higher the amount of cereals in the meal, in particular rice, the lower the contribution to the TETP due to uptake of heavy metals from the soil.

4.3.2 Raw materials stage (Ingredients)

As discussed above and shown in Figure 4.3, the raw materials stage is the major hotspot in every impact category for the home-made meals and is typically the biggest, or second biggest, contributor to the impacts from the ready-made alternatives. Due to this dominance of raw materials, and due to the fact that no previous studies have examine the breakdown of impacts according to food groups, this section considers the relative importance of each food group to each impact.

Firstly, a breakdown of the contribution of each food group to each environmental indicator is displayed in Figure 4.4. As expected, the meat, poultry and fish group has the greatest impact across all environmental indicators, followed by the milk, yoghurt and cheese group. Conversely, oils and sugars have a minimal contribution to the impact, aside from POCP and TETP. As discussed earlier, the latter is due to fossil fuels used for energy provision and carbon monoxide emissions from sugar manufacturing.

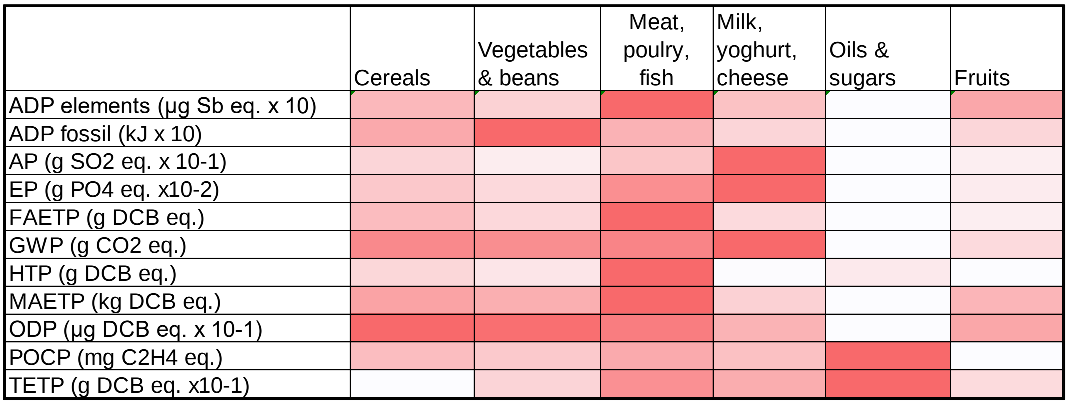


Figure 4.4 Heat map of the food groups per functional unit

A more detailed breakdown of the contribution of each raw material is shown in Figure 4.5 and Figure 4.6. Recipes are displayed in Figure 4.1 Within these food groups, the ingredients with the majority of impacts across all environmental indicators are beef, tomato, rice flour, dry pasta, full milk, chicken, cheese, yoghurt, sugar and apples (Figure 4.5). However, the relative importance of these ingredients varies according to the impact category. The following discussion outlines the top three ingredients, in terms of highest potential emissions, according to each impact indicator, across all products. Selected ingredients across all products are values that rank in the top three of the selected range, i.e. top three values calculated from the maximum value obtained.

In the cases of GWP (Figure 4.6a), ADP fossil (Figure 4.6c) and ODP (Figure 4.6i), the top three ingredients are tomato, beef and rice flour, primarily because of the energy needed to optimise the temperature of greenhouses during the cultivation of tomatoes and the energy consumption and methane emissions incurred during cattle rearing and rice cultivation. For ADP elements (Figure 4.6b) the worst three ingredients are beef, apples and dry pasta due to the use of fertilisers. For AP (Figure 4.6.d), full milk, cheese and beef cause the greatest impact due to ammonia and nitrous oxide emissions from grassland, livestock production, and fertiliser production and application. The same trend applies to EP (Figure 4.6e).

For FAETP (Figure 4.6f), beef, rice flour and chicken are the top three contributors, due to fertiliser and feed production. For HTP (Figure 4.6g) and POCP (Figure 4.6j), beef, sugar and rice flour are the top three contributors as a result of energy consumption during operations: combustion of fossil fuels, methane emissions in beef rearing and rice cultivation. In the case of MAETP (Figure 4.6h), beef, rice flour and apple are the top three contributors due to fertiliser production and application. Finally, for TETP (Figure 4.6k), the worst three ingredients are sugar, beef and dry pasta, because of feed and fertiliser production and application.

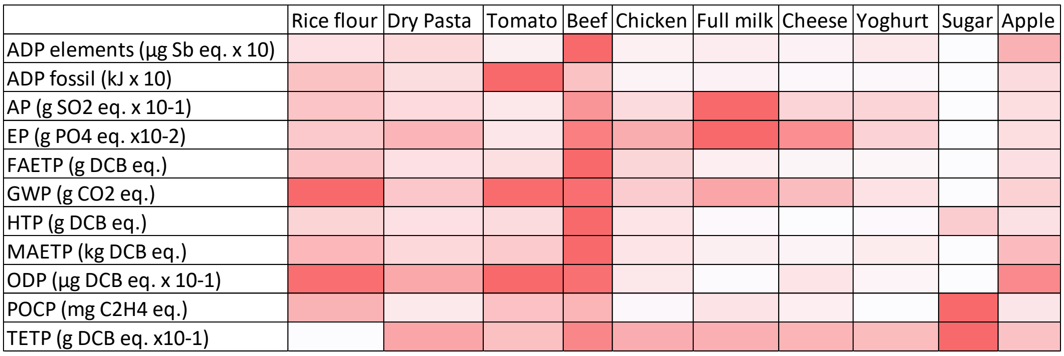
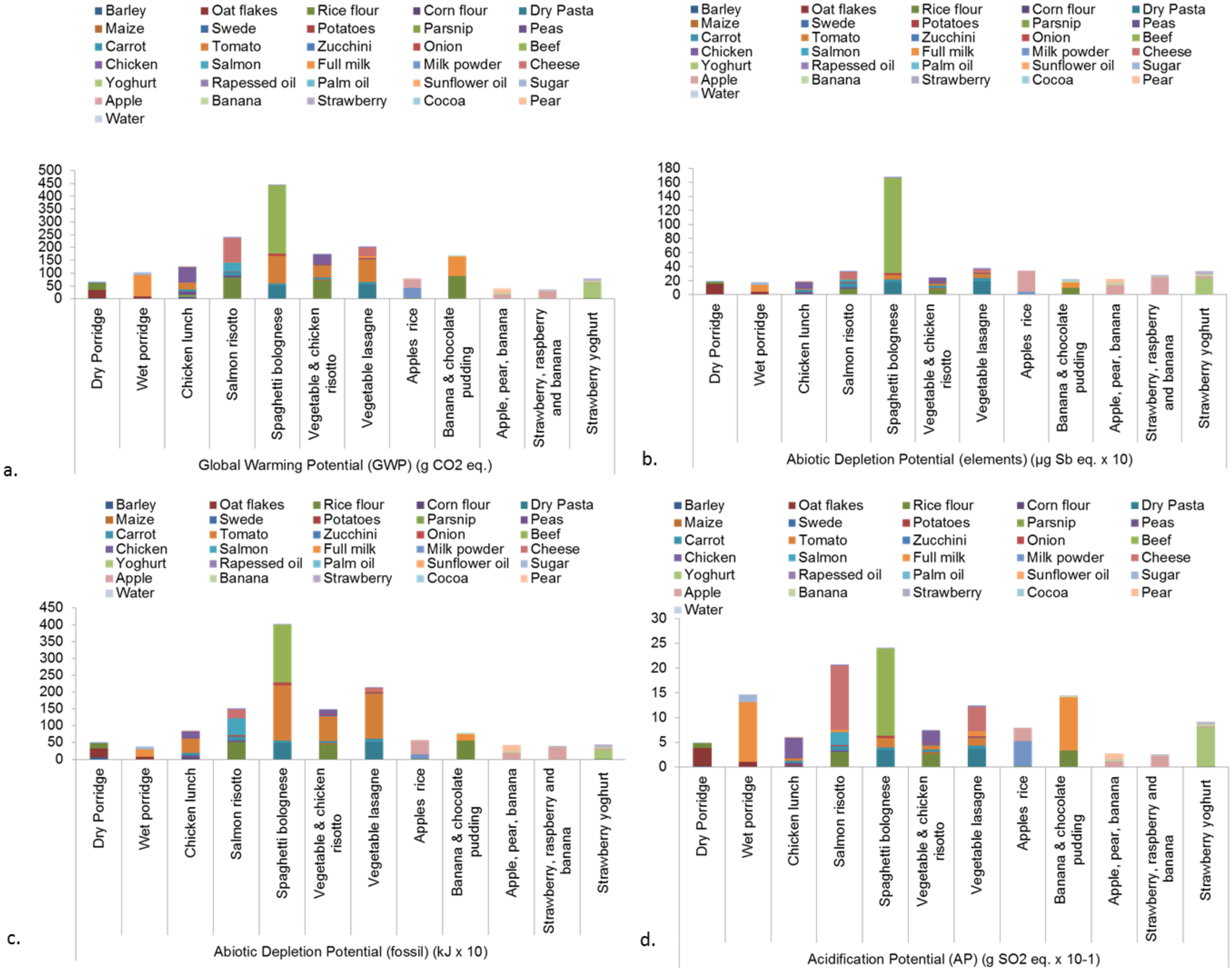
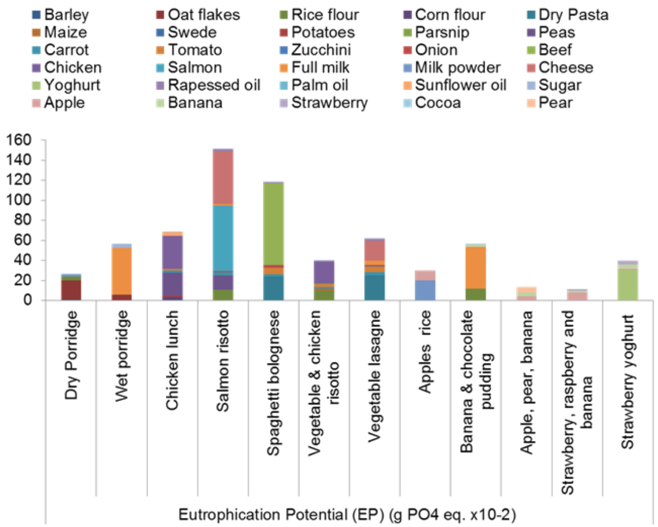


Figure 4.5 Heatmap of the top ten ingredients contributing most to the impacts

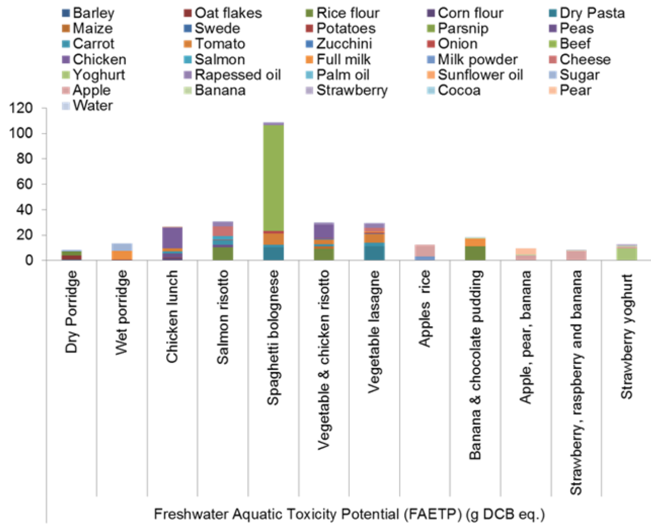
In summary, of the 30 individual ingredients considered in the study, beef and rice flour are the most frequently occurring hotspots across the impact categories, followed by tomatoes and sugar.



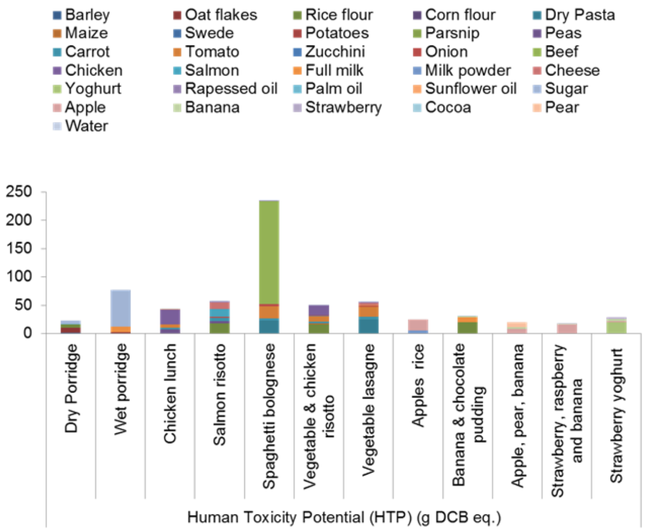
Barley
Oat flakes
Rice flour
Corn flour
Dry Pasta
Maize
Swede
Potatoes
Parsnip
Peas
Carrot
Tomato
Zucchini
Onion
Beef
Chicken
Salmon
Full milk
Milk powder
Cheese
Yoghurt
Rapessed oil
Palm oil
Sunflower oil
Sugar
Apple
Banana
Strawberry
Cocoa
Pear
Water
Dry Porridge
Wet porridge
Chicken lunch
Salmon risotto
Spaghetti bolognese
Vegetable & chicken risotto
Vegetable lasagne
Apples rice
Banana & chocolate pudding
Apple, pear, banana
Strawberry, raspberry and banana
Strawberry yoghurt
a.
Global Warming Potential (GWP) (g CO2 eq.)
b.
Abiotic Depletion Potential (elements) (µg Sb eq. x 10)
c.
Abiotic Depletion Potential (fossil) (kJ x 10)
d.
Acidification Potential (AP) (g SO2 eq. x 10-1)


Barley
Oat flakes
Rice flour
Corn flour
Dry Pasta
Maize
Swede
Potatoes
Parsnip
Peas
Carrot
Tomato
Zucchini
Onion
Beef
Chicken
Salmon
Full milk
Milk powder
Cheese
Yoghurt
Rapessed oil
Palm oil
Sunflower oil
Sugar
Apple
Banana
Strawberry
Cocoa
Pear
0
20
40
60
80
100
120
140
160
Dry Porridge
Wet porridge
Chicken lunch
Salmon risotto
Spaghetti bolognese
Vegetable & chicken risotto
Vegetable lasagne
Apples rice
Banana & chocolate pudding
Apple, pear, banana
Strawberry , raspberry and banana
Strawberry yoghurt
Eutrophication Potential (EP) (g PO4 eq. x10-2)

e.


Barley
Oat flakes
Rice flour
Corn flour
Dry Pasta
Maize
Swede
Potatoes
Parsnip
Peas
Carrot
Tomato
Zucchini
Onion
Beef
Chicken
Salmon
Full milk
Milk powder
Cheese
Yoghurt
Rapessed oil
Palm oil
Sunflower oil
Sugar
Apple
Banana
Strawberry
Cocoa
Pear
Water
0
20
40
60
80
100
120
Dry Porridge
Wet porridge
Chicken lunch
Salmon risotto
Spaghetti bolognese
Vegetable & chicken risotto
Vegetable lasagne
Apples rice
Banana & chocolate pudding
Apple, pear, banana
Strawberry , raspberry and banana
Strawberry yoghurt
Freshwater Aquatic Toxicity Potential (FAETP) (g DCB eq.)

f.


Barley
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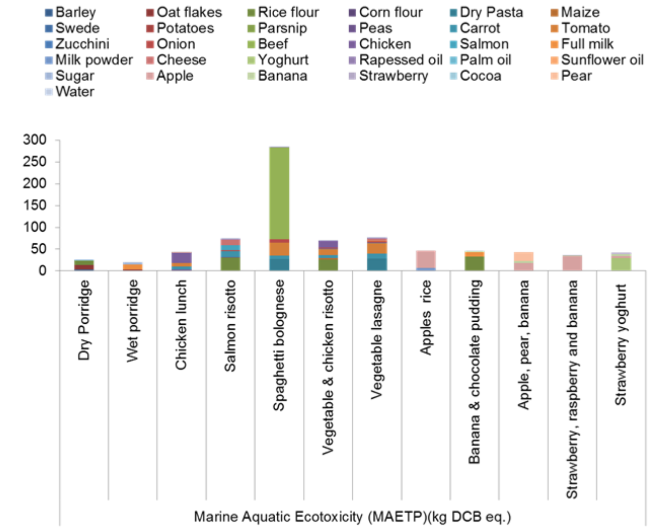
Corn flour
Dry Pasta
Maize
Swede
Potatoes
Parsnip
Peas
Carrot
Tomato
Zucchini
Onion
Beef
Chicken
Salmon
Full milk
Milk powder
Cheese
Yoghurt
Rapessed oil
Palm oil
Sunflower oil
Sugar
Apple
Banana
Strawberry
Cocoa
Pear
Water
0
50
100
150
200
250
Dry Porridge
Wet porridge
Chicken lunch
Salmon risotto
Spaghetti bolognese
Vegetable & chicken risotto
Vegetable lasagne
Apples rice
Banana & chocolate pudding
Apple, pear, banana
Strawberry , raspberry and banana
Strawberry yoghurt
Human Toxicity Potential (HTP) (g DCB eq.)

g.


Barley
Oat flakes
Rice flour
Corn flour
Dry Pasta
Maize
Swede
Potatoes
Parsnip
Peas
Carrot
Tomato
Zucchini
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Beef
Chicken
Salmon
Full milk
Milk powder
Cheese
Yoghurt
Rapessed oil
Palm oil
Sunflower oil
Sugar
Apple
Banana
Strawberry
Cocoa
Pear
Water
0
50
100
150
200
250
300
Dry Porridge
Wet porridge
Chicken lunch
Salmon risotto
Spaghetti bolognese
Vegetable & chicken risotto
Vegetable lasagne
Apples rice
Banana & chocolate pudding
Apple, pear, banana
Strawberry, raspberry and banana
Strawberry yoghurt
Marine Aquatic Ecotoxicity (MAETP)(kg DCB eq.)

h.

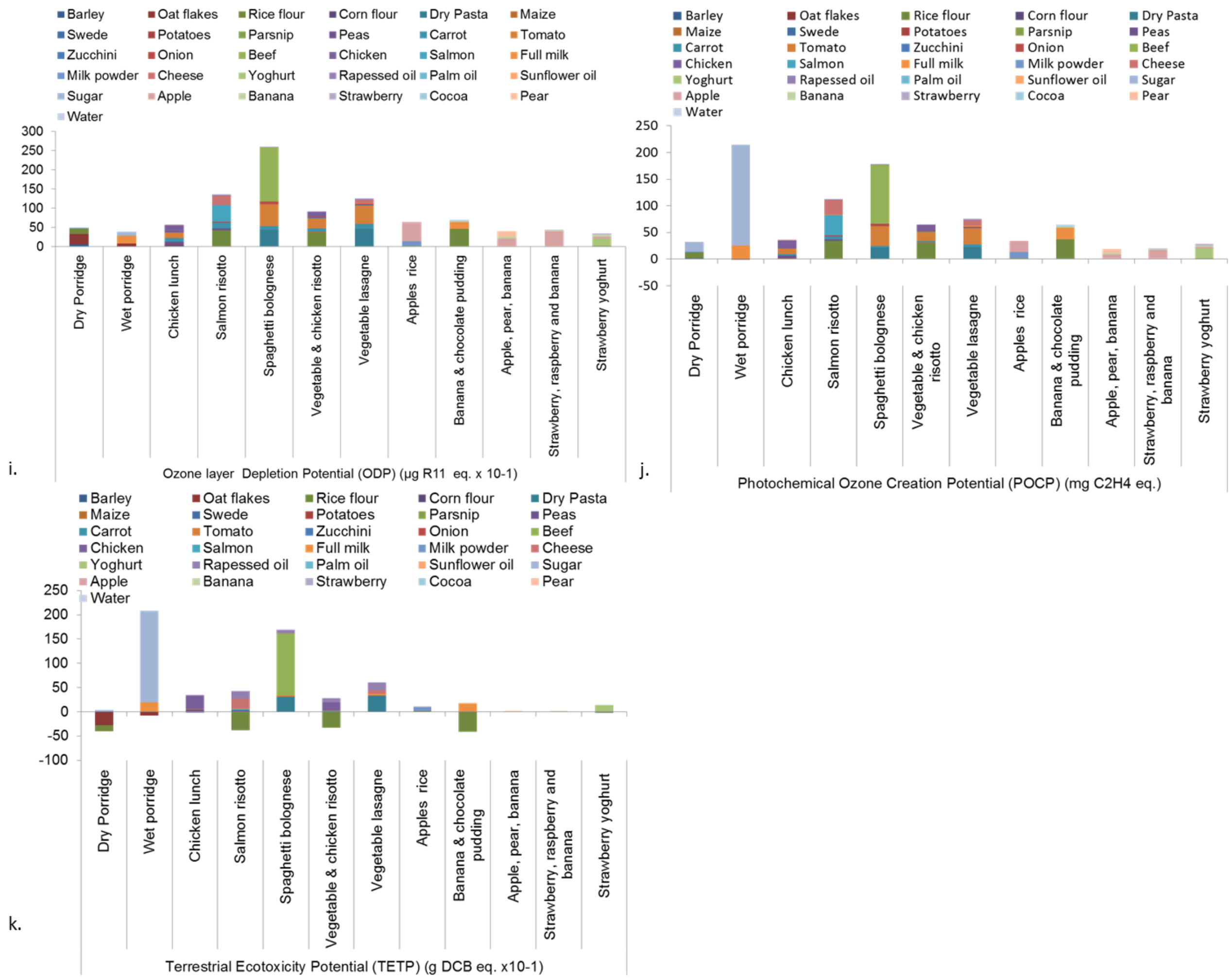

Figure 4.6 Contribution of different ingredient to the impacts of ready- and home-made meals

(NB: except home-made porridge)

4.4 Conclusions

This paper has compared the life cycle environmental impacts of home- and ready-made meals considering 11 types of meal. The results suggest that the impacts of preparing the meals at home from scratch are 50% to 17 times lower than for the equivalent ready-made meals. The main reasons for this are the avoidance of manufacturing, much less packaging and waste in the life cycle of home-made meals.

The raw materials are the hotspot in the home-made meals across all the impact categories. In contrast, for the ready-made meals, packaging is a hotspot for all the impacts, highlighting the need for reduction and improved packaging options in the sector. The raw materials are the second most important contributor to the impacts from the ready-made meals. Of the 30 individual ingredients considered in the study, beef and rice flour are the most frequently occurring hotspots across the impact categories and meal variants, followed by tomatoes and sugar.

The meals with the greatest difference in impacts between the home- and ready-made alternatives are the desserts due to the high contribution of manufacturing and packaging to the ready-made variants. The lunch meals are less sensitive to whether they are home-or ready-made because the ingredients are more important contributors than the other stages.

These findings sit within a market experiencing rapid growth of ready-made product sales, but also an opposing movement by certain groups of parents who wish to maintain greater control over the ingredients and preparation methods of their babies' meals. According to the results, with home-made meals almost universally superior to their ready-made equivalents in terms of environmental impacts, consumers should consider preparing meals at home more often than buying ready-made food. However, as packaging and the energy consumption incurred during manufacturing are shown to be the main discriminators between home-made and ready-made options, there is room for companies to close the gap between the two meal types. Further, as ingredients are shown to be the major contributor to most environmental impacts, both parents and ready-made food manufacturers can make significant improvements to their environmental impacts by minimising the use of certain ingredients where possible. This includes beef, rice, tomato, sugar and dairy products.

The next chapter considers the life cycle costs of home- and ready-made meals together with their environmental impacts, in an attempt to help identify most environmentally and economically sustainable types of meal.

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Chapter 5. Economic and environmental life cycle assessment in the baby foods sector

Natalia Sieti, Ximena C. Schmidt Rivera, Laurence Stamford* and Adisa Azapagic

Sustainable Industrial Systems, School of Chemical Engineering and Analytical Science, The University of Manchester, Manchester M13 9PL, UK

*Corresponding author: laurence.stamford@manchester.ac.uk

Abstract

The ready-made baby food sector is growing rapidly; however, little is known about its environmental and economic sustainability. This paper focuses on the economic and environmental evaluation of the sector by estimating the life cycle costs (LCC), value added (VA) and environmental life cycle assessment (LCA) impacts of 11 ready-made baby meals; additionally, a comparison with the equivalent home-made meals is included. Thus, this is the world's first life cycle sustainability assessment in the baby food sector. A bottom-up, product-based life cycle approach is applied to each product, and the entire ready-made baby food sector is evaluated based on sales volumes of 33,000 t for the year 2014. At the product level, the estimated life cycle costs of the ready-made meals range from £0.08 for a breakfast meal, to £0.26 for a dessert meal, while the equivalent home-made options range from £0.024 to £0.198. The main contributor to the LCC of both types of meals are the raw materials. Value added for the ready-made meals is on average 77% higher than for the home-made alternatives. At the sectoral level, the annual LCC of ready-made meals are estimated at £40 million. The carbon footprint is equivalent to 109 kt CO_2 eq./yr, accounting for only 0.1% of the total climate change impact from the whole food and drinks sector. If both life cycle costs and environmental impacts are compared, the home-made alternatives are more sustainable overall. The findings can be used to inform producers on how to improve the sustainability in the baby food sector by providing a baseline and identifying the hotspots to help the industry could set targets, track performance and communicate its progress. The results also aim to help consumers make more sustainable baby food choices.

Keywords: baby food sector, life cycle cost, life cycle environmental impacts, sustainability

5.1 Introduction

The baby food sector is a sub sector of the food and drinks sector, the latter of which represents the largest sector in the fast moving consumer goods (FMCG) industry (Simms 2012). The FMCG Industry is highly competitive both at a product/manufacturer and at retailer levels. It is divided into three main sectors: food, beverage and household; employing 3.2 million people and accounting for around 8% of gross domestic product (GDP) (Simms 2012). Food and drink is the UK's largest manufacturing sector with a turnover of over £90 billion (UK Goverment 2013).

A survey of infants in the US, aged 6 to 12 months, found that 81% consumed ready-made baby food (Nestle Nutrition Institute 2008). In the UK, ready-made baby food market grew by around 30% between 2009 and 2014 (Mintel 2014). It was worth an estimated £181 million in 2014 (Mintel 2015). Of the 513 baby food products made by five main UK manufacturers, 83% (by mass) are ready-made meals. This growing market leads to various sustainability issues, of which there is little understanding to date.

The economic costs of baby food production and consumption are not available in the public domain. However, one study showed that parents are willing to pay even 30% more for ready-made baby foods than for other products, because of convenience (Agriculture and Agri-Food Canada 2012). This is also reflected in the increasing demand for premium baby food products (Euromonitor International 2014).

Most previous studies in this field have focused on the nutritional and quality aspects of baby food products. Despite its socio-economic importance, studies of sustainability impacts in the baby food sector are rare and mostly based outside the UK, with no studies considering both environmental and economic aspects of sustainability. A literature review revealed only one study focussing on environmental impacts of baby food in Sweden almost 20 years ago (Mattsson 1999) and another one on packaging alternatives for baby food (Humbert et al. 2009).

Moreover, within the food sector there are still relatively few analyses taking a life cycle approach and using life cycle costing (LCC) as a tool to estimate the costs along whole supply chains, from production of ingredients to consumption of food. As Schmidt Rivera & Azapagic (2016) mention, "it is important to analyse the economic costs of food production and consumption, considering costs to both producers and consumers, to help identify hotspots and opportunities for improvement". So far, there are a limited number of analyses involving LCC of products (Iotti and Bonazzi 2014; Schmidt Rivera and Azapagic 2016; Kloepffer 2008; Krozer 2008; Kumaran et al. 2001; Amienyo and Azapagic 2016) or sectors (De Luca et al. 2014), but many products/sectors are still not well represented; one such area is baby food.

Therefore, the aim of this paper is to assess the economic and environmental sustainability of the ready-made baby food sector in the UK. In order to assess the economic pillar of sustainability, the LCC of ready-made baby foods are calculated for individual baby food products, which are then scaled up to estimate the costs in the baby sector as a whole. To help identify more sustainable options from both the economic and environmental perspective, the LCC are combined with the life cycle environmental impacts of the products, based on the work presented in the previous chapters. Finally, to complete the evaluation of the baby food sector, LCC is conducted for home-made baby foods and coupled with prior, the LCA modelling presented earlier in the thesis in order to provide an integrated assessment.

5.2 Methods

To assess the economic dimension of sustainability, life cycle costing is carried out following the methodology proposed by Swarr et al. (2011); in addition, value added is also considered (Hunkeler et al. 2008). Like LCA, LCC follows the life cycle of a product or system within specified system boundaries. However, instead of tracking environmental flows, it considers monetary inputs and outputs throughout the system. Therefore LCC is aligned with the ISO 14040/44 methodology for LCA (ISO 2006a; ISO 2006b). The methods and data sources are detailed in the following sections.

5.2.1 Goal and scope of the study

The main goals of this study are to:

- calculate and evaluate the life cycle costs and value added of ready-made baby foods;
- calculate and evaluate the life cycle costs and value added of the equivalent home-made baby foods;
- scale up individual product analyses to estimate the impacts in the ready-made baby food sector;

- compare the life cycle costs and environmental impacts of ready- and home-made meals to help identify the best options.

This paper builds on the previous work presented in the previous chapters. In line with the prior work, the scope of this study is from "cradle to grave" and the composition of the meals remains the same as before (Figure 4.1).

This study has two functional units:

1. For the product level assessment, the functional unit is defined as ""production and consumption of one baby meal", equivalent to a serving of 125 g;
2. At the sectoral level, the functional unit is defined as "33,000 tonnes of ready-made baby food", corresponding to the annual sales volume in the UK.

As explained in the previous chapters, the meals are selected based on representativeness of the baby food sector and are divided in three categories:

- Breakfast: dry and wet porridge; and home-made porridge.
- Lunch: Chicken; Vegetable and chicken risotto; Spaghetti Bolognese; Vegetable lasagne; Salmon risotto;
- Dessert: Apple, pear and banana; Strawberry, raspberry and banana; strawberry yoghurt; apples and rice; banana and chocolate pudding.

As outlined in Figure 5.1 for the ready-made meals, the life cycle stages encompass the production and processing of raw materials (ingredients), the manufacturing of the ready-made baby food, the production of packaging materials, product distribution, retail, consumption and end-of-life (EoL) waste management. In the case of home-made meals, the stages are similar, except that there is no manufacturing and packaging of the meal but instead the consumer buys the individual ingredients in a shopping bag from a retailer and prepares the meal at home. For further details see Figure 5.1.

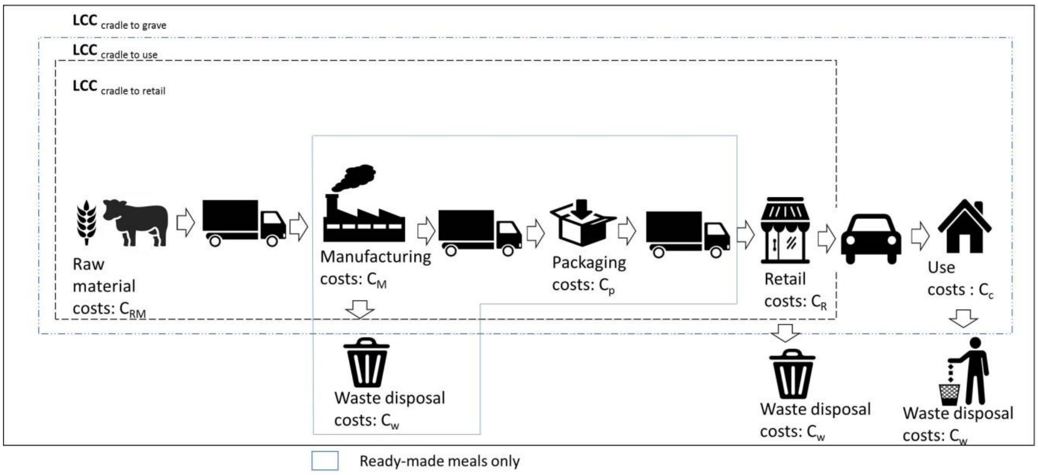

Figure 5.1 Lifecycle stages considered for life cycle costing (LCC) and value added

5.2.2 Calculation of life cycle costs and value added

Following the methodology suggested by Swarr et al. (2011), the total life cycle costs of baby food are calculated as follows:

$$LCC = C_{RM} + C_M + C_P + C_R + C_C + C_W + C_{trans} \qquad (1)$$

where:

LCC	Total life cycle cost of the ready-made baby food product
C_{RM}	Cost of raw materials (cultivation and processing of ingredients)
C_M	Cost of manufacturing the baby food product (ready-made meals only)
C_P	Cost of packaging
C_R	Cost of retail
C_c	Cost of consumption (use) phase
C_W	Cost of waste disposal (including recycling, with the system credited for the resale value of recycled products)
C_{trans}	Cost of transport

The LCC are used to estimate value added (VA), which is defined as the sale price minus the total costs of bought-in materials and/or services; the latter represents the LCC. The VA of the ready-made meal is calculated from “cradle to retail” (Figure 5.1) as this is the last point of value adding, taking into consideration all costs up to the retailer, before purchase by the consumer. The same system boundary applies to the home-made meal. However, in that case, the VA relates to the ingredients as sold by the retailer, rather than an assembly of ingredients, as in ready-made meals.

Value added is calculated as in Schmidt Rivera & Azapagic (2016):

$$VA = RP - LCC_{\text{cradle to retail}} \qquad (2)$$

where:

VA	Value added from "cradle to retail", representing the difference between the sale price and the production cost of a sold unit.
RP	Retail price of the ready-made baby food or the raw materials (ingredients) in the case of home-made food
$LCC_{\text{cradle to retail}}$	Life cycle cost from cradle to retail

5.2.3 Life cycle inventory

As this chapter builds on the previous work by the authors, the economic assessment is based on the material and energy flows from the environmental assessment. The cost data are sourced from various published governmental, sectoral and statistical reports as well as on own market research. A detailed breakdown of the cost data can be found in Table 5.1 for ready-made meals and Table 5.2 for home-made meals.

5.3 Results and discussion

The results for the LCC and the VA of the ready-made meals are presented first in Section 5.3.1, followed by the analysis of the equivalent home-made meals in Section 0. The two analyses are then compared in Section 0. Finally, the economic and environmental assessments at sectoral level are discussed in Section 0.

Table 5.1 Costs and retail prices for different ready-made meals.

RM 1: Dry porridge; RM 2: Wet porridge; RM 3: Chicken lunch; RM 4: Vegetable lasagne; RM 5: Spaghetti Bolognese; RM 6: Salmon risotto; RM 7: Vegetable & chicken risotto; RM 8: Apple, pear & banana; RM 9: Strawberry, raspberry & banana; RM 10: Strawberry yoghurt; RM 11: Apple and rice; RM 12: Banana & chocolate pudding.

Flow or activity (unit/meal)	RM 1	RM 2	RM 3	RM 4	RM 5	RM 6	RM 7	RM 8	RM 9	RM 10	RM 11	RM 12	Cost (£/unit)	Cost data sources	Retail price [4](£/unit)
Raw Materials															
Milk powder (kg)	1.16×10^{-2}										4.08×10^{-3}		0.255	(Agricultural and Applied Economics 2018)	6.83
Oat flakes (kg)	1.42×10^{-2}	6.79×10^{-3}											0.14	(FAOSTAT 2014)	0.95
Palm Oil (kg)	1.09×10^{-3}												0.49	(IndexMundi 2017)	3.0
Sugar (kg)	7.75×10^{-3}	2.72×10^{-2}											0.021	(FAOSTAT 2014)	1.77
Rice flour (kg)	4.47×10^{-3}					3.12×10^{-2}	2.72×10^{-2}			1.36×10^{-3}	1.36×10^{-3}	3.40×10^{-2}	0.543	(FAOSTAT 2014)	1.40
Barley (kg)	4.10×10^{-4}												0.101	(FAOSTAT 2014)	5.38
Full Milk (kg)		7.47×10^{-2}		6.79×10^{-3}		2.72×10^{-3}						6.79×10^{-2}	0.25	(Defra 2017d)	0.43
Chicken (kg)			1.77×10^{-2}				1.09×10^{-2}						1.03	(AHDB 2016)	6.17
Corn flour (kg)			9.54×10^{-3}	1.36×10^{-3}	1.36×10^{-3}								1.00	(IndexMundi 2017)	2.73
Parsnip (kg)			2.32×10^{-2}										0.98	(Defra 2017b)	1.21
Sunflower oil (kg)			1.36×10^{-3}										0.72	(IndexMundi 2017)	1.16
Swede (kg)			1.09×10^{-2}										0.36	(Defra 2017b)	1.97

[4] Retail price is based on average prices from major UK retailers

Tomato (kg)		9.54×10^{-3}	2.99×10^{-2}	3.67×10^{-2}		1.63×10^{-2}						1.01	″	1.73
Potatoes (kg)		1.09×10^{-2}										0.20	(Defra 2016b)	0.54
Peas (kg)		1.09×10^{-2}			6.79×10^{-3}							0.18	(Farmers Weekly 2017)	1.07
Carrot (kg)		1.77×10^{-2}	2.72×10^{-2}	1.83×10^{-2}	3.26×10^{-2}	1.63×10^{-2}						0.35	″	0.45
Onions (kg)			6.79×10^{-3}	1.83×10^{-2}	6.79×10^{-3}	6.79×10^{-3}						0.40	″	0.75
Zucchini (kg)			8.15×10^{-3}			1.09×10^{-2}						0.94	″	1.71
Rapeseed oil (kg)			2.72×10^{-3}	1.36×10^{-3}	$2.72\mathrm{x}\ 10^{-3}$	1.36×10^{-3}						0.70	(IndexMundi 2017)	2.39
Cheese (kg)			4.08×10^{-3}		$1.09\ \mathrm{x}10^{-2}$							1.90	(Defra 2016b)	9.18
Dry Pasta (kg)			2.58×10^{-2}	2.45×10^{-2}								1.02	Calculated	1.40
Beef (kg)				1.22×10^{-2}								3.80	(IndexMundi 2017)	8.67
Salmon (kg)					1.22×10^{-2}							5.15	(NASDAQ 2017)	15.66
Maize grain (kg)						8.15×10^{-3}						0.11	(IndexMundi 2017)	1.73
Apple (kg)							5.71×10^{-2}	1.07×10^{-1}	1.36×10^{-2}	1.30×10^{-1}		0.88	(Defra 2017b)	1.82
pear (kg)							5.16×10^{-2}					0.84	″	1.96
Banana (kg)							2.72×10^{-2}	1.09×10^{-2}	2.99×10^{-2}		1.63×10^{-2}	0.66	(Defra 2017a)	0.76
Strawberry (kg)								1.77×10^{-2}	4.08×10^{-2}			2.91	(Defra 2017b)	7.51
Yoghurt (kg)									5.03×10^{-2}			1.03	Calculated	1.50
Cocoa beans (kg)											1.36×10^{-3}	1.47	(IndexMundi 2017)	7.59
Tap water (kg)	2.72×10^{-2}	2.73×10^{-2}	2.31×10^{-2}	2.31×10^{-2}	2.99×10^{-2}	3.80×10^{-2}					1.36×10^{-2}	0.002	(United Utilities 2018)	

Manufacturing														
Electricity (kWh)	4.00×10^{-2}	5.29×10^{-2}	5.29×10^{-2}	5.29×10^{-2}	5.29×10^{-2}	5.29×10^{-2}	5.29×10^{-2}	5.29×10^{-2}	5.29×10^{-2}	5.29×10^{-2}	5.29×10^{-2}	5.29×10^{-2}	0.08	(DECC 2016a)
Natural gas (kWh)	1.63	3.95×10^{-1}	3.95×10^{-1}	3.95×10^{-1}	3.95×10^{-1}	3.95×10^{-1}	3.95×10^{-1}	3.95×10^{-1}	3.95×10^{-1}	3.95×10^{-1}	3.95×10^{-1}	3.95×10^{-1}	0.02	″
Diesel (L)		4.49×10^{-5}	4.49×10^{-5}	4.49×10^{-5}	4.49×10^{-5}	4.49×10^{-5}	4.49×10^{-5}	4.49×10^{-5}	4.49×10^{-5}	4.49×10^{-5}	4.49×10^{-5}	4.49×10^{-5}	1.50	″
Water (L)	9.08×10^{-2}	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	0.002	(United Utilities 2018)
Cleaning agents (kg)	9.12×10^{-4}	1.78×10^{-4}	1.78×10^{-4}	1.78×10^{-4}	1.78×10^{-4}	1.78×10^{-4}	1.78×10^{-4}	1.78×10^{-4}	1.78×10^{-4}	1.78×10^{-4}	1.78×10^{-4}	1.78×10^{-4}	75.7	(ReAgent 2017)
Waste (kg)	1.46^{-3}	8.89	8.89	8.89	8.89	8.89	8.89	8.89	8.89	8.89	8.89	8.89	0.036	(LetsRecycle 2016)
Wastewater (m^3)	9.85×10^{-8}	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	5.59	0.001	(United Utilities 2018)
Transport (km)	4.49	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7		(DECC 2016a)
Packaging														
Corrugated board box (kg)	7.70×10^{-3}												0.09	(LetsRecycle 2016)
Packaging film (kg)	1.54×10^{-3}												0.33	(WRAP 2016)
Aluminium alloy (84%) (kg)		2.99×10^{-6}	2.99×10^{-6}	2.99×10^{-6}	2.99×10^{-6}	2.99×10^{-6}	2.99×10^{-6}	2.99×10^{-6}	2.99×10^{-6}	2.99×10^{-6}	2.99×10^{-6}	2.99×10^{-6}	0.70	(LetsRecycle 2016)
Polyethylene, (16%) (kg)		3.73×10^{-6}	3.73×10^{-6}	3.73×10^{-6}	3.73×10^{-6}	3.73×10^{-6}	3.73×10^{-6}	3.73×10^{-6}	3.73×10^{-6}	3.73×10^{-6}	3.73×10^{-6}	3.73×10^{-6}	1.24	(WRAP 2016)
Packaging glass (kg)		7.47×10^{-4}	7.47×10^{-4}	7.47×10^{-4}	7.47×10^{-4}	7.47×10^{-4}	7.47×10^{-4}	7.47×10^{-4}	7.47×10^{-4}	7.47×10^{-4}	7.47×10^{-4}	7.47×10^{-4}	0.02	(WRAP 2018)
Retail														
Electricity (kWh)	2.99×10^{-6}	9.41×10^{-1}	9.41×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	0.08	(DECC 2016a)
Natural gas (kWh)	3.73×10^{-6}	3.12×10^{-1}	3.12×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	1.50×10^{-1}	0.02	″
Biowaste, composting (kg)	7.47×10^{-4}	3.60×10^{-2}	3.60×10^{-2}	2.03×10^{-2}	2.03×10^{-2}	2.03×10^{-2}	2.03×10^{-2}	2.03×10^{-2}	2.03×10^{-2}	2.03×10^{-2}	2.03×10^{-2}	2.03×10^{-2}	0.036	(LetsRecycle 2016)
Transport (km)	4.42	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11		(DECC 2016a)

Use														
Electricity (kWh)	1.25×10^{-2}												0.15	(DECC 2016a)
Tap water (kg)	3.44×10^{-1}	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.05	(United Utilities 2018)
Wastewater (m^3)	2.50×10^{-1}	1.00×10^{-3}	1.00×10^{-3}	1.00×10^{-3}	1.00×10^{-3}	1.00×10^{-3}	1.00×10^{-3}	1.00×10^{-3}	1.00×10^{-3}	1.00×10^{-3}	1.00×10^{-3}	1.00×10^{-3}	0.001	〃
Biowaste, composting (kg)	5.43×10^{-3}	1.80×10^{-2}	1.80×10^{-2}	1.80×10^{-2}	1.80×10^{-2}	1.80×10^{-2}	1.80×10^{-2}	1.80×10^{-2}	1.80×10^{-2}	1.80×10^{-2}	1.80×10^{-2}	1.80×10^{-2}	0.036	(LetsRecycle 2016)
Natural gas (kWh)		6.30×10^{-2}	6.30×10^{-2}	6.30×10^{-2}	6.30×10^{-2}	6.30×10^{-2}	6.30×10^{-2}	6.30×10^{-2}	6.30×10^{-2}	6.30×10^{-2}	6.30×10^{-2}	6.30×10^{-2}	0.02	(DECC 2016a)
Road transport (km)	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	1.50	(DECC 2016a)
End of Life														
Recycling Carton (kg)	3.75×10^{-3}													(LetsRecycle 2016)
Disposal Carton (kg)	2.50×10^{-3}													(HM Revenue & Customs 2017)
Disposal Plastic (kg)	1.25×10^{-3}													〃
Disposal Aluminium (25%) (kg)		2.00×10^{-3}	2.00×10^{-3}	2.00×10^{-3}	2.00×10^{-3}	2.00×10^{-3}	2.00×10^{-3}	2.00×10^{-3}	2.00×10^{-3}	2.00×10^{-3}	2.00×10^{-3}	2.00×10^{-3}	0.084	〃
Recycling Aluminium (75%) (kg)		6.00×10^{-3}	6.00×10^{-3}	6.00×10^{-3}	6.00×10^{-3}	6.00×10^{-3}	6.00×10^{-3}	6.00×10^{-3}	6.00×10^{-3}	6.00×10^{-3}	6.00×10^{-3}	6.00×10^{-3}	0.007	(LetsRecycle 2016)
Recycling glass (70%) (kg)		6.16×10^{-2}	6.16×10^{-2}	6.16×10^{-2}	6.16×10^{-2}	6.16×10^{-2}	6.16×10^{-2}	6.16×10^{-2}	6.16×10^{-2}	6.16×10^{-2}	6.16×10^{-2}	6.16×10^{-2}	0.018	〃
Disposal glass (30%) (kg)		2.64×10^{-2}	2.64×10^{-2}	2.64×10^{-2}	2.64×10^{-2}	2.64×10^{-2}	2.64×10^{-2}	2.64×10^{-2}	2.64×10^{-2}	2.64×10^{-2}	2.64×10^{-2}	2.64×10^{-2}	0.084	(HM Revenue & Customs 2017)

Table 5.2 Costs and retail prices of different home-made meals.
HM 1: Porridge; HM 2: Chicken lunch; HM 3: Vegetable lasagne; HM 4: Spaghetti Bolognese; HM 5: Salmon risotto; HM 6: Vegetable & chicken risotto; HM 7: Apple, pear & banana; HM 8: Strawberry, raspberry & banana; HM 9: Strawberry yoghurt; HM 10: Apple and rice; HM 11: Banana & chocolate pudding.

Flow or activity (unit/meal)	HM 1	HM 2	HM 3	HM 4	HM 5	HM 6	HM 7	HM 8	HM 9	HM 10	HM 11	Cost (£/unit)	Cost data sources	Retail price (£/unit)
Raw Materials														
Milk powder (kg)										3.82×10^{-2}		0.255	(Agricultural and Applied Economics 2018)	6.83
Oat flakes (kg)	2.65×10^{-2}											0.14	(FAOSTAT 2014)	0.95
Palm Oil (kg)	1.96×10^{-3}											0.49	(IndexMundi 2017)	3.00
Sugar (kg)	2.84×10^{-3}											0.021	(FAOSTAT 2014)	1.77
Rice flour (kg)	1.05×10^{-2}				2.88×10^{-2}	2.50×10^{-2}			1.28×10^{-3}	1.28×10^{-3}	3.19×10^{-2}	0.543	(FAOSTAT 2014)	1.40
Barley (kg)	6.13×10^{-4}											0.101	(FAOSTAT 2014)	5.38
Full Milk (kg)	4.02×10^{-3}		8.93×10^{-3}		2.55×10^{-3}						6.38×10^{-2}	0.255	(Defra 2017d)	0.43
Chicken (kg)		1.65×10^{-2}				1.02×10^{-2}						1.03	(AHDB 2016)	6.17
Corn flour (kg)			8.93×10^{-4}	1.25×10^{-3}								1.00	(IndexMundi 2017)	2.73
Parsnip (kg)		2.35×10^{-2}										0.98	(Defra 2017b)	1.21
Sunflower oil (kg)		1.27×10^{-3}										0.72	(IndexMundi 2017)	1.16
Swede (kg)		1.09×10^{-2}										0.36	(Defra 2017b)	1.97
Tomato (kg)		1.01×10^{-2}	2.81×10^{-2}	3.44×10^{-2}		1.53×10^{-2}						1.01	″	1.73
Potatoes (kg)		1.17×10^{-2}										0.20	(Defra 2016b)	0.54

						Raw Materials							
Peas (kg)	1.17×10^{-2}			6.38×10^{-3}							0.18	(Farmers Weekly 2017)	1.07
Carrot (kg)	1.68×10^{-2}	2.55×10^{-2}	1.72×10^{-2}	3.06×10^{-2}	1.53×10^{-2}						0.35	″	0.45
Onions (kg)		6.38×10^{-3}	1.72×10^{-2}	6.38×10^{-3}	6.38×10^{-3}						0.40	″	0.75
Zucchini (kg)		7.65×10^{-3}			1.02×10^{-2}						0.94	″	1.71
Rapeseed oil (kg)		2.55×10^{-3}	1.27×10^{-3}	3.82×10^{-3}	1.27×10^{-3}						0.70	(IndexMundi 2017)	2.39
Cheese (kg)		5.10×10^{-3}		1.02×10^{-2}							1.90	(Defra 2016b)	9.18
Dry Pasta (kg)		2.41×10^{-2}	2.25×10^{-2}								1.02	Calculated	1.40
Beef (kg)			1.15×10^{-2}								3.80	(IndexMundi 2017	8.67
Salmon (kg)				1.15×10^{-2}							5.15	(NASDAQ 2017)	15.66
Maize grain (kg)					7.50×10^{-3}						0.11	(IndexMundi 2017)	1.73
Apple (kg)						5.35×10^{-2}	1.01×10^{-1}	1.28×10^{-2}	1.22×10^{-1}		0.88	(Defra 2017b)	1.82
Pear (kg)						4.84×10^{-2}					0.84	″	1.96
Banana (kg)						2.55×10^{-2}	1.02×10^{-2}	2.81×10^{-2}		1.53×10^{-2}	0.66	(Defra 2017a)	0.76
Strawberry (kg)							1.66×10^{-2}	3.83×10^{-2}			2.91	(Defra 2017b)	7.51
Yoghurt (kg)								4.45×10^{-2}			1.03	Calculated	1.50
Cocoa beans(kg)										1.28×10^{-3}	1.47	(IndexMundi 2017)	7.59
Tap water (kg)	1.49×10^{-1}	1.46×10^{-1}	1.46×10^{-1}	1.53×10^{-1}	1.60×10^{-1}					1.28×10^{-2}	0.002	(United Utilities 2018)	

Retail													
Electricity (kWh)	4.85 x10^{-4}	1.28 x10^{-2}	1.09 x10^{-2}	8.93 x10^{-3}	1.84 x10^{-2}	7.89 x10^{-3}	1.62 x10^{-2}	1.62 x10^{-2}	1.62 x10^{-2}	1.62 x10^{-2}	1.62 x10^{-2}	0.08	(DECC 2016a)
EUR pallet (pcs.)		1.97 x10^{-4}	1.60 x10^{-4}	1.57 x10^{-4}	1.33 x10^{-4}	1.13 x10^{-4}	2.98 x10^{-4}	2.98 x10^{-4}	2.98 x10^{-4}	2.98 x10^{-4}	2.98 x10^{-4}	6.00	(Alibaba Group 2018)
Natural gas (kWh)	5.88 x10^{-4}	6.66 x10^{-4}	5.66 x10^{-4}	5.39 x10^{-4}	4.49 x10^{-4}	3.85 x10^{-4}	9.49 x10^{-3}	9.49 x10^{-3}	9.49 x10^{-3}	9.49 x10^{-3}	9.49 x10^{-3}	0.02	(DECC 2016a
Polypropylene (kg)		1.15×10^{-3}	2.86×10^{-3}	2.51×10^{-3}	5.95×10^{-4}	7.88×10^{-4}	2.09 ×10^{-3}	2.09×10^{-3}	2.09 ×10^{-3}	2.09×10^{-3}	2.09×10^{-3}	1.24	(WRAP 2016)
Biowaste, composting (kg)	9.09×10^{-4}	1.99 ×10^{-3}	1.68×10^{-3}	1.60×10^{-3}	1.40×10^{-3}	1.13×10^{-3}	2.98×10^{-3}	2.98×10^{-3}	2.98×10^{-3}	2.98×10^{-3}	2.09×10^{-3}	0.036	(LetsRecycle 2016)
Waste wood (kg)		3.24×10^{-3}	2.64×10^{-3}	2.60×10^{-3}	2.19×10^{-3}	1.86×10^{-3}	4.92×10^{-3}	4.92×10^{-3}	4.92×10^{-3}	4.92×10^{-3}	4.92×10^{-3}	0.03	(LetsRecycle 2016)
Packaging waste (kg)		3.42×10^{-3}	2.86×10^{-3}	2.51×10^{-3}	3.93×10^{-3}	2.07×10^{-3}	2.09×10^{-3}	2.09×10^{-3}	2.09×10^{-3}	2.09×10^{-3}	2.98×10^{-3}	0.084	(LetsRecycle 2016)
Refrigerant (kg)	4.21×10^{-9}	2.45×10^{-7}	2.08×10^{-7}	1.69×10^{-7}	3.59×10^{-7}	1.51×10^{-7}						19.30	(BOC UK 2016)
LDPE (kg)	2.06×10^{-4}											0.33	(WRAP 2016)
Cardboard packaging (kg)	1.40×10^{-6}											0.09	(LetsRecycle 2016)
Polyethylene (kg)	5.01×10^{-8}	3.23×10^{-8}	9.78×10^{-8}	3.26×10^{-8}	9.78×10^{-8}	3.26×10^{-8}						0.33	(WRAP 2016
Packaging glass (kg)	6.26×10^{-4}	3.88×10^{-4}	1.22×10^{-3}	4.08×10^{-4}	1.22×10^{-3}	4.08×10^{-4}						0.02	(WRAP 2018)
Use													
Packaging film (kg)		2.36×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	1.24	(WRAP 2016)
Tap water (L)	6.98×10^{-1}	4.37×10^{-2}	1.54×10^{-1}	1.46×10^{-1}	1.64×10^{-1}	1.74×10^{-1}	1.25×10^{-1}	1.25×10^{-1}	1.25×10^{-1}	1.25×10^{-1}	1.25×10^{-1}	0.002	(United Utilities 2018)
Natural gas (kWh)	2.00×10^{-1}	3.89×10^{-2}	2.55×10^{-1}	2.55×10^{-1}	2.55×10^{-1}	2.55×10^{-1}						0.05	(DECC 2016a
Electricity (kWh)	3.50×10^{-3}	3.57×10^{-3}	7.60×10^{-3}	8.75×10^{-3}	6.25×10^{-3}	6.25×10^{-3}	8.75×10^{-3}	8.75×10^{-3}	8.80×10^{-3}	8.75×10^{-3}	8.75×10^{-3}	0.15	(DECC 2016a
Wastewater (L)	3.00	1.19×10^{-1}	1.25×10^{-1}	1.25×10^{-1}	1.25×10^{-1}	1.25×10^{-1}	1.25×10^{-1}	1.25×10^{-1}	1.25×10^{-1}	1.25×10^{-1}	1.25×10^{-1}	0.001	(United Utilities 2018)
Biowaste, composting (kg)	2.19×10^{-2}	3.57×10^{-3}	2.38×10^{-2}	2.50×10^{-4}	2.38×10^{-2}	2.38×10^{-2}	2.38×10^{-2}	2.38×10^{-2}	2.38×10^{-2}	2.38×10^{-2}	2.38×10^{-2}	0.036	(LetsRecycle 2016)

End of Life													
Recycling Carton (kg)	3.30×10^{-4}											0.085	(LetsRecycle 2016)
Disposal Carton (kg)	2.20×10^{-4}											0.084	(HM Revenue & Customs 2017)
Disposal Plastic (kg)	2.30×10^{-4}											0.084	"
Disposal plastic (kg)	1.47×10^{-4}											1.08	"
Recycling plastic HDPE (kg)	4.00×10^{-5}											0.31	(LetsRecycle 2016)
Recycling glass (kg)	8.40×10^{-4}											0.018	(LetsRecycle 2016)
Disposal glass (kg)	5.60×10^{-4}											0.084	(HM Revenue & Customs 2017)
Plastic waste disposal (kg)		2.40×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	2.50×10^{-4}	0.084	"

5.3.1 Life cycle costs and value added of ready-made meals

5.3.1.1 Life cycle costs

As shown in Figure 5.2, the product with the highest LCC is the strawberry yoghurt with an estimated value of £0.26, followed by the strawberry, raspberry and banana dessert at £0.21. The best options are the wet and dry porridge meals, both at £0.08, 69% lower than the strawberry yoghurt. The difference in the costs of manufacturing across the meals is small (Figure 5.2). This is in contrast with the raw materials, for which the costs vary widely. They also represent a hotspot for most meals, contributing 25-80% to the total LCC, depending on the product. The next most-contributing stage is manufacturing (20-40%). For the manufacturing stage of wet ready-made baby food, the water and chemicals used for cleaning are the most expensive components due to stringent safety standards requiring frequent, high volume cleaning-in-place. The remaining stages are less critical, with packaging contributing 6% on average, the use stage 5%, retail 1% and EoL waste management providing a credit of 2% due to the value of recovered materials. Based on these findings, the weighted average LCC of a 125 g ready-made baby meal is £0.15. The weighted average is based on the percentage contribution of different meal groups to the total sales volume. As discussed in Chapter 1, of the 513 products identified through the market research, 52% by mass are lunch meals, 33% desserts and 15% breakfast porridge. These values have been used to estimate the weighted average LCC (and later the VA) for the ready-made meals

As mentioned earlier, the two breakfast options (wet and dry porridge) have the lowest overall costs. Despite their different ingredients, processing and preparation at home, these balance out to give the same LCC for both products. They also have the smallest contribution from the raw materials (26-28%), with the majority attributable to milk. For these two products, the manufacturing stage is the main cost component (45-53%), predominantly due to natural gas in the case of dry porridge and cleaning-in-place for the wet alternative.

The LCC of lunch meals ranges from £0.12 for the vegetable and chicken risotto to £0.17 for the salmon risotto and spaghetti Bolognese. For the last two, the main cost components are the salmon (37%) and the beef (27%), respectively. This trend of dominance by raw materials is seen across all lunch products, in contrast to the breakfast meals.

For the desserts, the LCC range from £0.10 for the banana and chocolate pudding to £0.26 for the strawberry yoghurt. The highest cost items in this group are strawberries and apples, leading to the high costs of strawberry yoghurt and strawberry, raspberry and banana dessert. In contrast, the banana and chocolate pudding is dominated by the cost of milk.

5.3.1.2 Value added

The Value Added (VA) of the ready-made meals, given in Figure 5.3, varies from £0.32 (apple and rice) to £1.16 (strawberry yoghurt), with an average of £0.77. As detailed in the methodology, these values are calculated by subtracting the LCC (discussed above) from average retail prices obtained from three leading retailers. The retail price varies from £0.49 for apples and rice to £1.42 for strawberry yoghurt.

There is only a slight difference in the VA of the dry and wet porridge (£0.54 vs £0.56, respectively) due to the latter retailing at a slightly higher price. The greatest variation in the VA is found for the dessert meals, ranging from £0.32 for the apple and rice to £1.16 for the strawberry yoghurt. For the lunch meals, the VA varies by a factor of two, from £0.55 for spaghetti Bolognese to £1.09 for vegetable lasagne.

The weighted average VA is almost five times higher than the LCC.

As indicated, there is great variation in the VA of different meals, particularly for the desserts. This is a result of variation in the distribution of costs throughout the life cycle as well as variation in retail price. For the former factor, it is clear that the desserts are more variable than other food categories: the lunches show relatively little difference in cost breakdown, with raw materials contributing 50-65% of the total LCC, and manufacturing 25-35%; in contrast, for the desserts the raw materials contribute anywhere from 42% to 77% of the total cost, and manufacturing 20-41%.

On average the dessert meals have higher LCC, but lower VA compared to the lunches, which have a higher VA but lower LCC. The strawberry yoghurt is unusual in that it has both the highest LCC and highest VA. In this case, yoghurt is an already highly processed ingredient that comes from raw milk, while strawberries are relatively expensive fruits: almost £3/kg compared to £0.88/kg for apples. However, the final product is able to command a high retail price (£1.52/f.u.) which more than offsets these high raw material costs.

The desserts category also contains the product with the lowest VA: apples and rice. In this case, the raw material costs are lower than strawberry yoghurt but still higher than any of the lunch meal options, while the final product retails at only £0.50/f.u. Consequently, it is not able to provide a high VA. Even ready-made porridge, which has the lowest LCC of all the ready-made products, commands a higher retail price and therefore has 75% higher VA than apples and rice.

This is indicative of an overall trend: when comparing the variation in LCC (Figure 5.2) to that in VA (Figure 5.3), it is clear that there is little correlation between a product's LCC and its VA. This is due to the fact that the retail prices of products are not well correlated with their production cost. Products such as apples and rice or spaghetti Bolognese, with high costs and low VA, may have relatively low retail prices due to their nutritional content, competition in the marketplace, or consumer perception of value, driven by a variety of factors such as convenience among others.

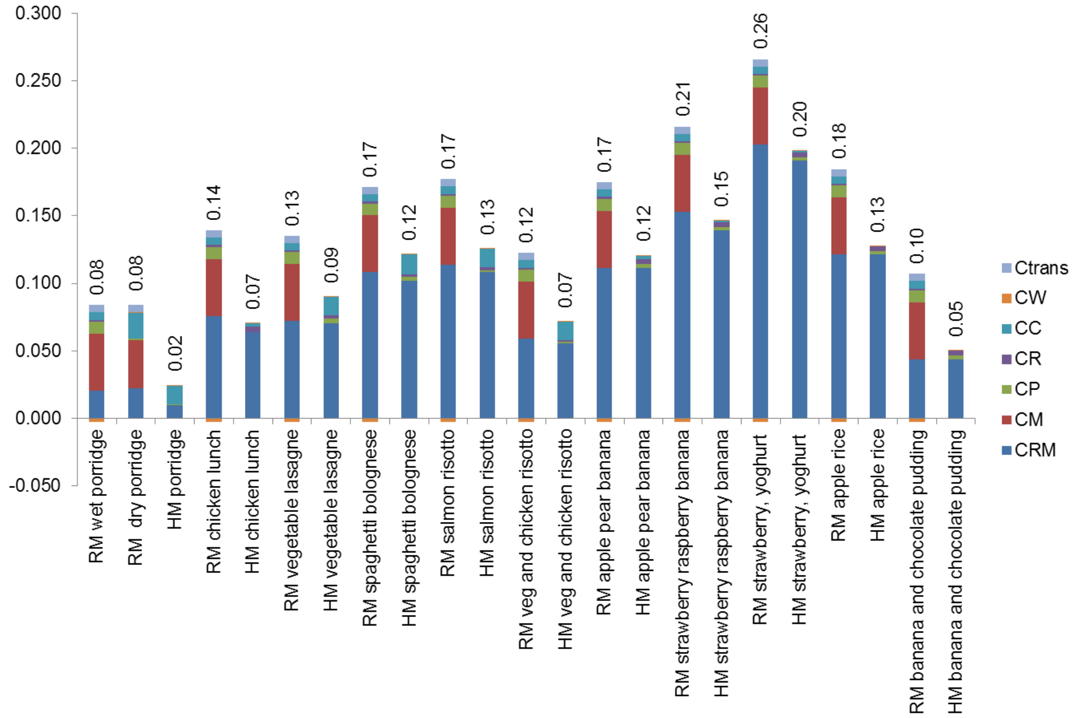

Figure 5.2 Life cycle costs of the ready- and home-made meals

(RM: ready-made; HM: home-made. C_{RM}: Raw materials costs, C_M: Manufacturing costs, C_P: Packaging costs; C_R: Retail costs, C_C: Consumption costs, C_W: Waste costs, C_{trans}: Transport costs etc. For further description see Figure 5.1)

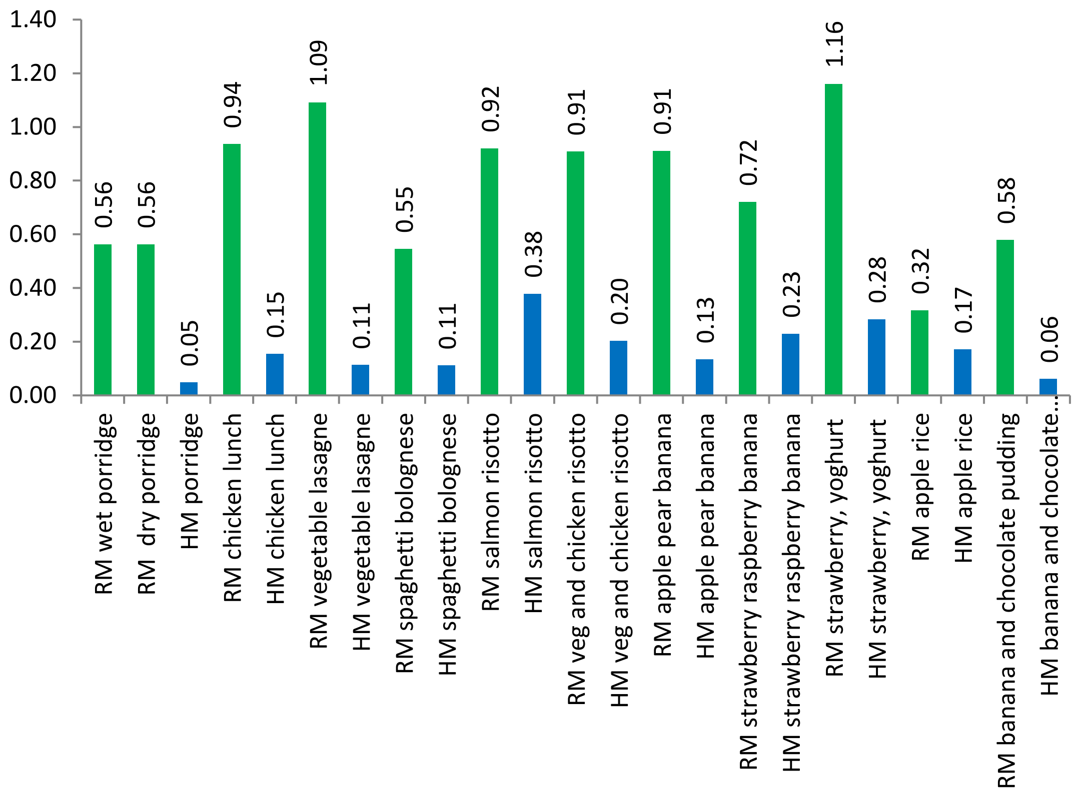

Figure 5.3 Value added of the ready- and home-made meals
(Green denotes ready-made and blue home-made meals)

5.3.2 Life cycle costs and value added of home-made meals

5.3.2.1 Life cycle costs

As indicated in Figure 5.2, the lowest LCC of £0.024 is estimated for the home-made porridge. The next best option is the chocolate pudding at £0.05, the LCC twice as high as that of porridge. The highest value of £0.198 is found for the strawberry yoghurt due to the higher cost of ingredients, such as strawberries, and their amount in the product. Salmon risotto has the highest LCC for the lunch options (£0.176) due to the high cost of salmon.

The main cost hotspots for the home-made meals are the raw materials, contributing almost 40% (porridge) to 95% (strawberry yoghurt) across the products. The use stage adds a further 1% (desserts) to 58% (porridge), the packaging 1-5% and retail 2-7%; the contribution of EoL is negligible. The contribution of the consumption stage in the fresh home-made desserts is lower than the lunch options due to less preparation needed. In the use stage, the main contributor is energy which accounts for 66% of the costs in this stage.

5.3.2.1 Value added

As indicated in Figure 5.3, at £0.38, the salmon risotto has the highest VA, followed by the strawberry yoghurt with £0.28. The lowest VA of £0.05 is estimated for the porridge, followed by the banana and chocolate pudding at £0.06. On average, the VA is almost 60% higher than the LCC.

Unlike the ready-made meals, the home-made lunches show considerable variation in VA, with salmon risotto (£0.38) having three times higher VA than spaghetti Bolognese or vegetable lasagne (£0.11). This is due to the fact that, despite all three meals having very similar costs in the use stage, the retail prices of salmon and cheese in the risotto are high relative to their production cost.

5.3.3 Comparison of LCC and VA of ready- and home-made meals

5.3.3.1 Comparison of life cycle costs

On average, the LCC of the home-made meals is 38% lower than that of the ready-made meals (Figure 5.2). This is largely due to the avoidance of costs of manufacturing and lower costs of packaging and waste treatment in the life cycle of home-made meals.

In addition to this overall trend, some larger differences can be seen between equivalent products. The breakfast porridge shows the greatest disparity between the ready- and home-made options, with the former having four times higher LCC. This is due to porridge being a simple product with low-cost ingredients, leaving manufacturing to dominate the LCC for the ready-made meals; as manufacturing is absent in the home-made version, the total LCC is much lower.

The average difference between the ready- and home-made lunch meals is much lower, with the former having 30-40% higher LCC, due to higher processing costs. In the case of the desserts, the ready-made versions incur 4-5 times higher LCC because of the contribution of the manufacturing and packaging stages to the costs.

5.3.3.2 Comparison of value added

Comparison of the VA for home- and ready-made meals in Figure 5.3 confirms what would be expected: the latter have 3-6 times higher VA. This is due to the higher processing levels for ready-made meals. This difference also incorporates the 'cost of convenience' that the consumer is prepared to pay for. Therefore, while the consumer ultimately pays the cost of higher processing, the other players in the supply chain benefit from the VA associated with ready-made meals.

5.3.4 Comparison of life cycle costs and environmental impacts

As mentioned above, the environmental impacts of the meals have been estimated in Chapter 4. Figure 5.4 uses a heatmap to summarise the environmental impact of ready-made meals alongside the LCC results presented in this chapter. The heatmap uses a colour gradient with darker shades corresponding to higher environmental impacts or life cycle costs. The same approach is taken in
Figure 5.5 for home-made meals.

For the ready-made meals (Figure 5.4), assuming equal importance between all environmental impacts and LCC, the best option overall is dry porridge due to its minor environmental impact and very low LCC. On the contrary, spaghetti Bolognese performs worse, with the highest values for 10 out of 12 criteria including GWP. However, there is not a clear correlation between LCC and environmental impacts: spaghetti Bolognese has an LCC that is only slightly higher than average across all the products (£0.17/f.u. vs £0.151/f.u.), despite being the clear worst option for almost all environmental impacts. In contrast, the highest LCC is found in strawberry yoghurt despite only moderate environmental impacts.

For the home-made meals, as shown in
Figure 5.5, a similar conclusion can be reached: the best option overall is porridge and the worst spaghetti Bolognese, with only a rough correlation between environmental impact and cost. Indeed, in the case of home-made meals, the lowest environmental impacts are incurred by the apple, pear and banana dessert and the strawberry, raspberry and banana dessert, but these products have costs in the top half of the home-made meals (£0.12 and £0.15/f.u., respectively, vs £0.105/f.u. on average).

As discussed in Chapter 3, the majority of environmental impacts are derived from the raw materials stage of both ready- and home-made meal life cycles. While this is also true of costs (as shown in Figure 5.2), the breakdown of costs for any particular product does not necessarily correlate with the breakdown of its environmental impacts. For instance, in the case of ready-made strawberry, raspberry and banana dessert, raw materials are a minor contributor to the environmental impacts. However, as shown in Figure 5.2, raw materials contribute approximately 70% of the total LCC of the same product. This explains why costs and environmental impacts are not aligned.

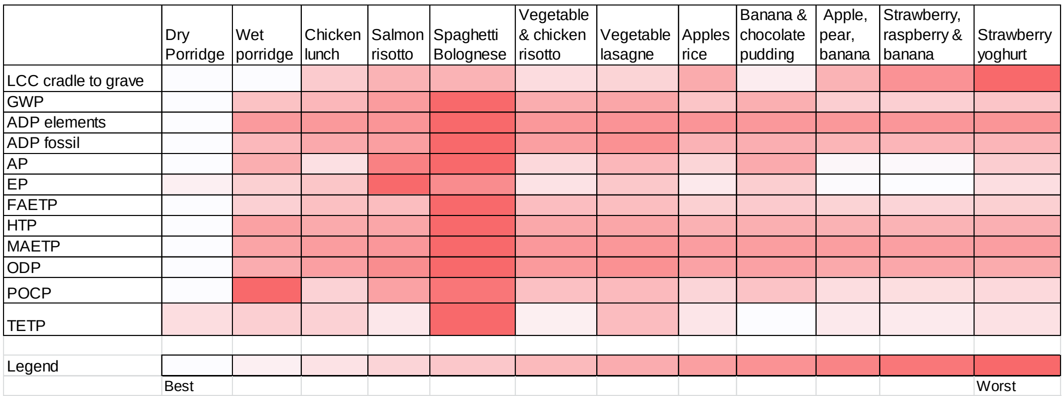

Figure 5.4 Comparison of the life cycle costs and environmental impacts of the ready-made meals

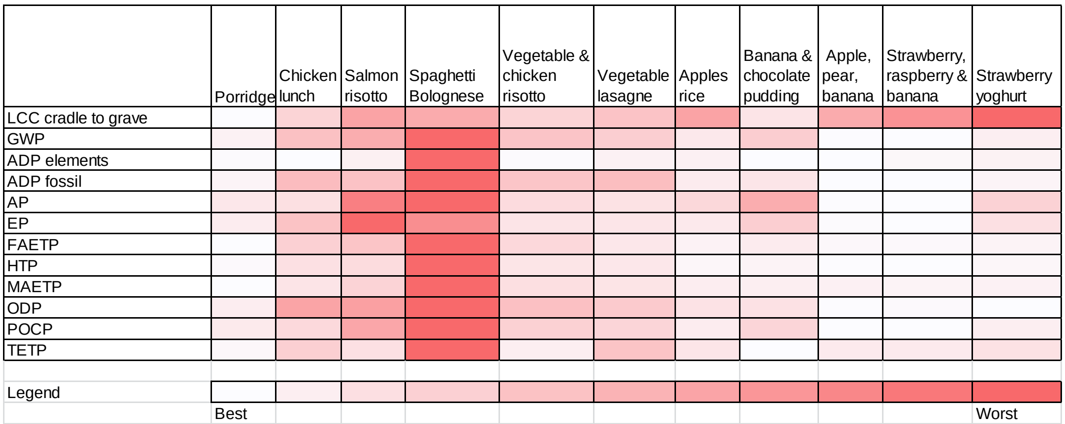

Figure 5.5 Comparison of the life cycle costs and environmental impacts of the home-made meals

To provide further visualisation of the results and help identify improvement opportunities, LCC and GWP are taken as example indicators and their values for the different ready- and home-made products plotted in Figure 5.6 and Figure 5.7, respectively. As can be seen, the ready-made meals are dispersed over a wider area than the home-made alternatives, which are more clustered. Overall, the home-made meals perform better for these two indicators than the ready-made alternatives as all products are clustered more towards the left, lower quadrant of the chart.

In the case of ready-made meals, most products perform similarly, with three notable outliers: the dry porridge performs better for GWP and LCC, while the strawberry yoghurt displays a moderate GWP with high LCC, and the spaghetti Bolognese has a moderately high cost and a very high GWP. The salmon risotto is also positioned towards the top right of the graph with high LCC and GWP. Consequently, spaghetti Bolognese, salmon risotto and strawberry yoghurt appear to be the products most in need of innovation to improve their economic sustainability and GWP. The best products with the lowest LCC and GWP are the porridge options.

In the home-made meals, porridge is again the best option, with the lowest LCC and GWP. This is followed closely by the fruit desserts: apple, pear and banana; and strawberry, raspberry and banana. The second-best option is the chicken lunch. However, other lunch meals perform relatively poorly, with spaghetti Bolognese and salmon risotto being the worst options.

It is notable that, in both the ready- and home-made categories, the spaghetti Bolognese is not the most costly option despite the high cost of beef. In fact, some fruit-based meals, particularly strawberry yoghurt, perform worse in economic terms. The reason for this is the low amount of meat in the spaghetti Bolognese compared to the amount of fruit in the fruit-based meals.

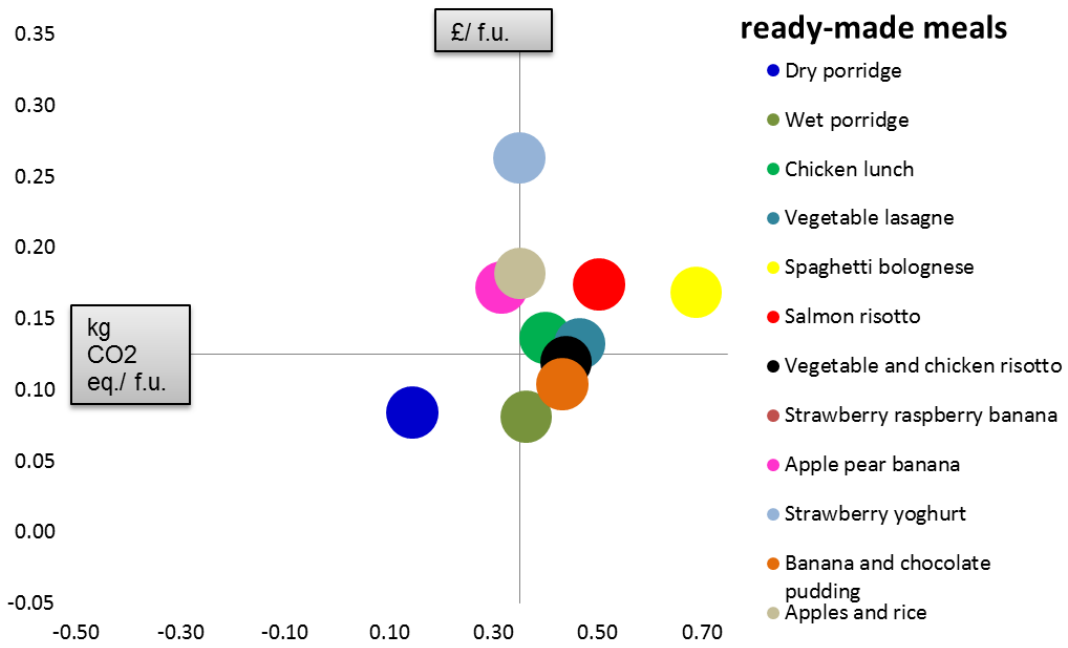

Figure 5.6 Comparison of GWP and LCC for the ready-made baby meals

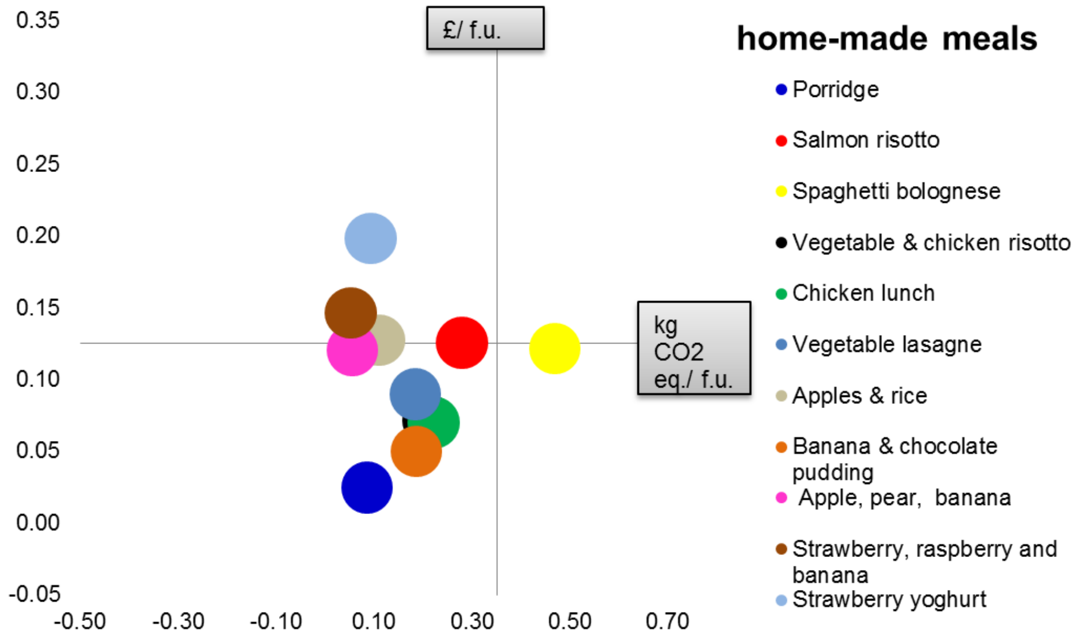

Figure 5.7 Comparison of GWP and LCC for the home-made baby meals

5.3.5 Economic and environmental evaluation in the ready-made sector

This section considers the economic and environmental sustainability in the ready-made meals sector. The home-made meals are not considered at the sectoral level due to a lack of data on the sales volumes of products used at home specifically to produce baby foods. The results of the economic and environmental assessments for the individual ready-made meals have been scaled up to the sectoral level based on the sales volume of baby food in the UK of 33,000 t, with a corresponding retail value of £181 million in 2014 (Mintel 2015). The results are displayed in Figure 5.8, based on a weighted average of the meals examined in this study (see the previous section).

To estimate the sectoral LCC, the average LCC of ready-made meals (£0.15 per 125 g; see the previous section) has been multiplied by the annual sales of baby food (33,000 t) to yield a total LCC of £40 million per year (Figure 5.8).To estimate the sectoral VA, the average VA of ready-made meals (£0.79 per 125 g, see the previous section) has been multiplied by the same annual sales mass to yield a total of almost £208 million per year. This is close to the retail value of £181 million estimated by Mintel (2015).

The environmental impacts have been estimated using the same weighted average approach. For example, the GWP is estimated at 109,000 t CO_2 eq. For context, UK net GHG emissions in 2015 were 496 Mt (BEIS 2017) and the emissions from the food and drink sector, excluding food imports, amounted to115 Mt CO_2 eq. (Tassou et al. 2014). Therefore, the baby food sector adds 0.02% to the UK GHG emissions yearly and 0.09% to the emissions from the whole food and drinks sector. The other impacts are more difficult to put into context due to a lack of data. Therefore another way to put the results in context is based on total food consumption in the UK. The consumption of food commodities was 70,000,000 t in 2005 (WWF 2008). That means that the 33,000 t of the baby food sector used in this study (excluding the organic, formula milk and drinks segments) represent 0.05% of the total food consumption in the UK.

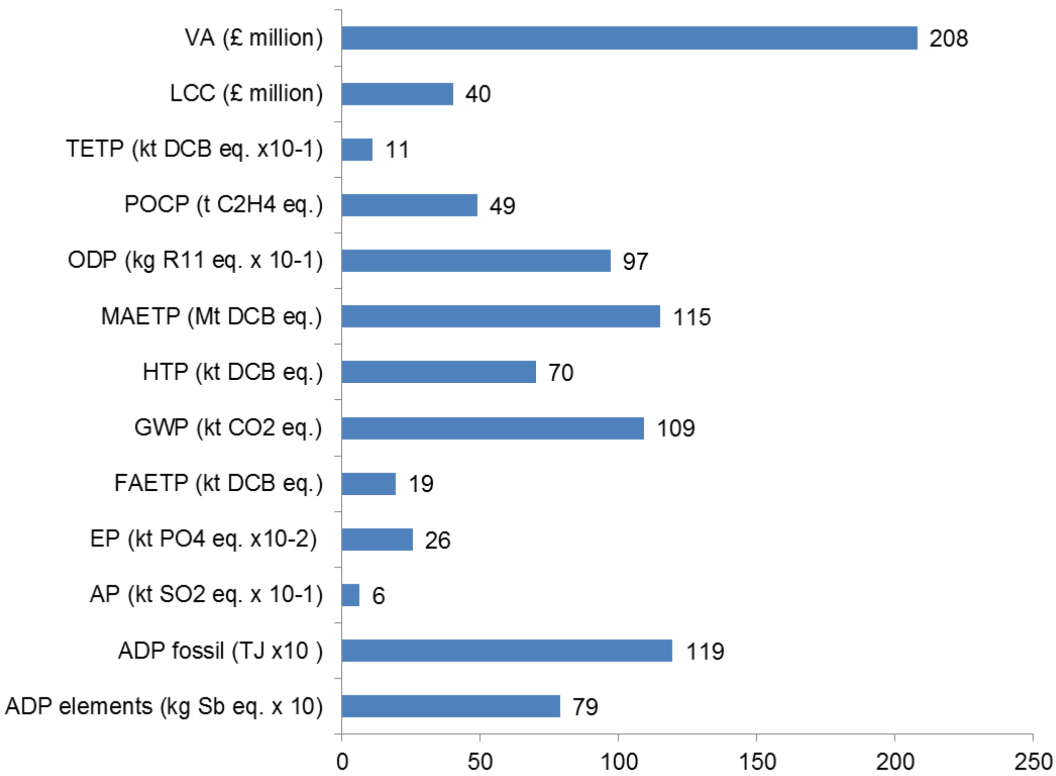

Figure 5.8 Economic and environmental evaluation at the sectoral level based on annual sales of ready-made baby food (33 million kg per year)

Combining the sectoral VA with the annual GWP yields a sectoral eco-efficiency of £1.91/kg CO_2 eq. Equivalent calculations for other sectors are not widespread in the literature, making comparison challenging. However, van Middelaar et al. (2011) calculated the eco-efficiency of Dutch cheese at €0.78/kg CO_2 eq., or £0.68/kg CO_2 eq. using exchange rates at the time of the study's publication (X-Rates 2018). In addition, Maia et al. (2016) estimate an eco-efficiency of €0.186/kg CO_2 eq. for the agricultural sector of Monte Novo, Portugal, equivalent to approximately £0.158/kg CO_2 eq. at the time of that study's publication (X-Rates 2018). A similar value of £0.219/kg CO_2 eq. can be derived for the UK agricultural sector based on 2015 GHG emissions of 51.1 Mt CO_2 eq. (BEIS 2017) and gross value added of £11.2 billion (Office for National Statistics 2017). Consequently, there is a large difference between the eco-efficiency of the baby food sector and that of the agricultural sector. The difference is smaller when comparing to cheese, which is another processed product. This reflects the fact that, as discussed in Chapter 3, the majority of environmental impacts occur in the agricultural stage yet the majority of the value and profit is generated elsewhere, namely in manufacturing and retail.

5.4 Conclusions

This paper has considered the life cycle costs of ready-made and home-made baby foods, both at the product and sectoral levels. The total LCC of ready-made meals ranges from £0.08 for a breakfast meal to £0.26 for a dessert meal. The main contributors to the LCC of ready-made meals are the raw materials (25-80%), followed by manufacturing (20-40%).

Packaging adds 5-10%, the use stage 5-20% and transportation 1-2%. The LCC of home-made meals ranges from £0.02 for porridge to £0.20 to the strawberry yoghurt. The main contributors to the LCC of home-made meals are also the raw materials (40-95%), followed by use stage (1-60%).

The highest VA in the ready-made meals is found for the strawberry yoghurt with £1.16 and the lowest at £0.32 for the apples and rice meal. The VA for the home-made meals varies from £0.05 for the porridge to £0.38 for the salmon risotto.

A comparison of the life cycle costs and environmental impacts of different ready-made meal options indicates that the best option overall is the dry porridge. The worst option is the spaghetti Bolognese meal, with high environmental impacts and a moderate LCC. For the home-made options, the most sustainable option is also porridge and the least sustainable spaghetti Bolognese This information can help consumers decide what products to buy but can also help manufacturers to identify hotspots in their product portfolio and target those for improvements.

At the sectoral level, the LCC of ready-made meals are estimated at £40 million and the VA at £208 million. The sector generates 109,000 t CO_2 eq. annually. This represents 0.02% of the UK GHG emissions and 0.09% of the emissions from the food and drinks sector. The sectoral eco-efficiency is estimated at £1.91/kg of CO_2 eq.

Overall, the home-made baby meals can be considered more sustainable than the ready-made equivalents from the environmental and LCC point of view. However, the ready-made meals are more economically sustainable for business as the value added of home-made meals is on average 78% lower. Ready-made meals are also more convenient for the consumer and hence trade-offs between the costs, environmental impacts and convenience are unavoidable.

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Chapter 6. Conclusions and Recommendations

In this thesis the life cycle environmental and economic sustainability in the baby food sector have been explored. The research objectives specified in the Introduction have been achieved, as follows:

1. Representative baby food products have been identified for each meal category, i.e. breakfast, lunch and dessert;
2. Environmental and economic sustainability assessment of the selected products and their home-made alternatives has been conducted using:
   a. LCA (environmental aspects); and
   b. LCC and Value Added (economic aspects);
3. The environmental and economic sustainability of baby food has been investigated at the UK sectoral level by scaling up the product-level results; and
4. Conclusions and recommendations for improvements have been provided based on the above.

This study represents the first life cycle environmental and economic assessment of individual ready- and home-made baby meals as well as the first such evaluation in the baby food sector.

The main conclusions and recommendations are summarised below, starting with the conclusions from each chapter and finishing with recommendations and suggestions for future work.

6.1 Conclusions

6.1.1 Environmental impacts of baby food: Ready-made porridge products

- Product format (i.e. dry or wet) is important: the environmental impacts of the wet ready-made porridge meals for babies are higher than those of the dry equivalent by 43% to 21 times; GWP is 2.6 times higher.
- The main hotspots for both products are the raw materials, while manufacturing and packaging are also important for the wet product.
- Dairy based ingredients are the hotspots in the raw materials stage of both product meals, however for the dry product the impacts from the raw materials are higher than for the wet alternative because of the powder milk which is not used in the latter.
- For the dry option, potential reduction of impacts can be achieved through alternative product formulations: by reducing the amount of milk powder and increasing the amount of cereals, the impacts reduce by 1%-67% including a 34% reduction in GWP.
- Further reduction of emissions for the dry porridge from manufacturing operations is possible through variation of processing parameters such as reducing the water content of the cereal mixture from 80% to 50% during manufacturing. This results in a 65% reduction in the GWP of the manufacturing stage and an overall decrease in the impact of 9%.
- The studied dry product requires less packaging than wet products. However, when a laminated pouch was considered for the wet product instead of the commonly used glass jar, the environmental impacts decreased by 7%-89%; GWP reduced by 7%.
- The exception to the above is eutrophication, which increases by 15% when a laminated pouch is used, due to a higher impact from waste management.

6.1.2 Environmental sustainability assessment of ready-made baby foods: meals, menus and diets

- The results show that the key hotspots are raw materials and packaging. Manufacturing also plays a significant role for ADPf, GWP, and ODP due to the fossil fuels used to provide energy for processes, such as cooking and sterilisation.
- Lunch meals have the highest and desserts the lowest impacts, with breakfast porridge falling in between.

- Considering all environmental impacts, the best options are the fruit-based desserts, such as apple, pear and banana, and the strawberry, raspberry and banana. In contrast, the highest impacts are seen for spaghetti Bolognese, which is the worst option for nine out of 11 impacts.
- More meat-based recipes are environmentally intensive, with meat contributing 30% of the impacts on average despite accounting for only 4% of the ingredient mass. On the other hand, fruits constitute 22% of product formulation, but their average contribution to the impacts is 10%.
- The lowest impacts come from a vegetarian diet, while the highest impacts come from the dairy-free diet due to the need to substitute dairy-containing foods for those containing meat, poultry and fish. The increase in impacts is particularly attributable to Spaghetti Bolognese, hence beef, in the menu mix.
- The impacts between the omnivore, pescatarian and vegetarian diets do not differ significantly, with the latter being a slightly better option.
- Further environmental improvements could be achieved by reducing energy use in the manufacturing process: decreasing natural gas consumption by 30% could reduce the impacts significantly, particularly GWP (by 10%), ADPf (13%) and ODP (16%).

6.1.3 Life cycle environmental impacts of baby food: ready-versus home-made meals

- Findings suggest that preparing meals at home has a 65% lower potential environmental impact, averaged across all impact categories. This is due to the avoidance of manufacturing, the much lower mass of packaging and the lesser amount of waste in the life cycle of home-made meals.
- Regarding the most critical stage, raw materials serve as the hotspot in both home-made and ready-made meals.
- The inter-product comparison shows that, for the lunch meals, the meal with the highest impacts is spaghetti Bolognese, while the lowest impacts across all categories come from the chicken lunch meal. For the dessert meals, the worst in terms of environmental impacts is the banana and chocolate pudding with the highest impact in 8 out of 11 impacts; while the best are the strawberry, raspberry and banana dessert and the apple, pear and banana dessert. Porridge for breakfast performs relatively well but shows considerable variation between dry and wet formats.

- Overall, the lunch meals perform worse than desserts or breakfasts, due to the fact that beef, rice, tomatoes and sugar have been identified as the most commonly occurring hotspots across the overall range of meals, and three of these four ingredients are lunch ingredients.
- The meals with the greatest difference between the home-made and ready-made alternatives are the desserts, while lunch meals are the less sensitive to the alternative variants. This has to do with the fact that the total contribution in the dessert products is lower for the raw materials stage as opposed to the packaging and manufacturing stages, making them more sensitive to different variations. Therefore, the avoidance of these stages makes the difference more obvious in the dessert products.
- Most of the ready-made products have GWPs less than 500 g CO_2 eq./f.u. except the salmon risotto and spaghetti Bolognese. For the home-made equivalents, most are less than 300 g CO_2 eq./f.u, except the spaghetti Bolognese, the salmon risotto and the vegetable lasagna.

6.1.4 Economic and environmental life cycle assessment in the baby foods sector

- The LCC of home-made meals ranges from £0.02 for porridge to £0.20 for strawberry yoghurt, while the LCC of ready-made meals ranges from £0.08 for a breakfast meal, to £0.26 for a dessert meal.
- The weighted average life cycle cost of ready-made baby foods is estimated at £0.15/f.u. or £1.20/kg of baby food.
- The main contributor to the LCC of both types of meals is the raw materials stage, with 25-95% contribution. For the ready-made meals, the manufacturing stage follows with almost 20-40% contribution to the LCC. For the home-made meals the use stage comes second with almost 1-60% contribution.
- The VA for the home-made meals varies from £0.05 for the porridge to £0.38 for the salmon risotto, while the lowest VA in the ready-made meals is found at £0.32 for the apples and rice meal and the highest VA is found at £1.16 for the strawberry yoghurt.
- In terms of overall sustainability, a comparison of the life cycle costs and environmental impacts of different ready-made meal options indicates that the best option overall is the dry porridge which has low results in both GWP and

LCC. The worst option is the spaghetti Bolognese meal, with a high GWP and a moderate LCC.

- The sectoral LCC is estimated at £40 million per year and in absolute value the GWP of the sector is almost 109 million t CO_2 eq.
- The baby food sector adds 0.02% to the annual UK GHG emissions and 0.09% to the GWP of the whole food and drinks sector.
- The sectoral VA, is estimated at £208 million.
- Based on the above VA and GWP values, the sectoral eco-efficiency is estimated at £1.91/kg of CO_2 eq.
- In terms of economic sustainability, based on value added the ready-made meals are more economically sustainable for business than the home-made meals as the VA of home-made meals is 78% lower on average.
- Conversely, the LCC for the home-made meals is 38% lower, on average, making the ready-made meals less economically sustainable for the consumers.

6.2 Recommendations to industry, government and consumers

The following recommendations can be made to the relevant stakeholders along the supply chain based on the results of this work. Recommendations are presented in order of appearance in the thesis.**6.2.1 Environmental impacts of baby food: Ready-made porridge products**

- Baby food companies could assess the potential for promoting dry porridge due to its lower in environmental impacts.
- Companies could improve their environmental sustainability by product reformulation, such as reducing the contribution of milk. However, the nutritional value of food must also be taken into account.
- Producers should consider sustainable manufacturing practices, such as more energy and water efficient production processes, to reduce the impacts of baby food products. The role of new technologies, such as extrusion cooking, should also be investigated.
- The baby food industry should work with government to introduce best-practice standards for packaging, in terms of material types and packaging systems (e.g. recyclability criteria). Glass jars should be avoided and replaced

by plastic pouches. Recycled packaging materials should be used where possible.

- Manufacturers should work with the rest of the supply chain, including farmers and consumers, to help reduce environmental impacts in the baby food sector.
- Consumers should consider purchasing dry porridge rather than the wet alternative.

6.2.2 Environmental sustainability assessment of ready-made baby foods: meals, menus and diets

- The baby food industry should reduce energy use in the manufacturing process and/or replace fossil fuels, to reduce environmental impacts of baby food products throughout the life cycle.
- Companies should manage better the impacts of products across their life cycle through the identification of hotspots in the supply chain. Specifically, choice of raw materials (ingredients) and product formulation are critical in addressing the environmental hotspots. Reducing the amount of meat and dairy products would help mitigate the impacts, while satisfying the nutritional requirements.
- Consumers could reduce the environmental impacts of baby food by avoiding dairy-free diets for babies.
- Consumers should avoid or minimise meals with high-impact ingredients, such as beef and dairy, where possible.
- Government should help raise awareness among consumers on the environmental impacts of baby food.

6.2.3 Life cycle environmental impacts of baby food: ready-versus home-made meals

- The baby food industry should accelerate its adoption of sustainable practices for ready-made meals to compete environmentally with home-made alternatives.
- Industry should work towards minimising food losses across the supply chains.
- Consumers could consider preparing meals at home more often rather than buying ready-made food.

- Consumers should consider reducing consumption of ingredients with high impacts, including beef, dairy, tomatoes and rice.

6.2.4 Economic and environmental life cycle assessment in the baby foods sector

- The baby food industry should use the sectoral impacts estimated in this work, as well as their own analyses, to set targets, track their performance and form the basis for communication with external bodies and the public.
- Companies should produce regular sustainability reports on the baby food sector for a better understanding of the sectoral sustainability performance.
- The baby food sector eco-efficiency estimated in this work could be used by the industry to benchmark future products and scenarios.

6.3 Recommendations for future work

- Better characterisation of the manufacturing processes for different types of baby food products, with particular focus on energy consumption.
- Environmental and economic evaluation of new technologies in baby food manufacturing, e.g. extrusion cooking and freeze drying.
- Assessment of potential energy variation in the production of smooth to small particulate purées based on level of processing for ready-made baby foods, aimed at different baby developmental stages.
- Detailed assessment of specific product reformulations, including other factors, such as required changes in the production process and increased energy consumption in the manufacturing stage, as well as the nutritional aspects of the product.
- Research into good practices in sustainable manufacturing of baby foods and packaging.
- Development and deployment of recycling strategies for laminated pouch packaging, including design for recycling and end-of-life recycling processes.
- Further research on market lifetime of baby food products and consumer behavioural aspects of baby food, including home-preparation methods and food losses.
- Further research into alternative baby foods (i.e. frozen baby food, gluten-free baby food, organic baby food, Marine Stewardship Council certified baby food).

- Life cycle economic and environmental sustainability assessment of the rest of baby food sector segments, including baby snacks.
- LCA methodological development including best practice standards for food product assessments that incorporate product quality criteria.
- Research to understand water use in baby food products and the water-energy-food nexus.
- Relationship between (new) product development and consumer behaviour to investigate how environmental impacts can be reduced by changing product use patterns.
- Further research into convenience, costs and environmental trade-offs.
- More research on different baby food menus and diets in order to gain a more complete understanding of the environmental impacts from baby food and any trade-offs with nutritional value.
- Social sustainability assessment of the baby food sector following the UNEP/SETAC guidelines of the Social Life Cycle Assessment of products. An example of the methodological approaches that can be followed is by Prasara-A and Gheewala (2018)

6.4 Concluding remarks

This research has assessed the life cycle environmental and economic sustainability in the baby food sector. This has been achieved by analysing the impacts of 11 representative ready-made baby foods and their home-made alternatives, which have then been used to evaluate the sector as a whole. The results show that dairy and meat based wet meals tend to be the least environmentally sustainable options. Home-made meals are found to be more environmentally sustainable than their ready-made alternatives, while being more economically sustainable for consumers but less so for businesses. The raw materials stage is identified as hotspot in both in the environmental and the economic assessment.

The multi-level approach, from individual product assessment to sectoral assessment, has provided micro- and macro-level insights and benchmarking that can be used by various stakeholders across the supply chain, including consumers, industry and policy makers. While the research has focused on the UK, the conclusions of the study are transferable to other countries and regions.

Appendix A. Supplementary information of Chapter 2

Environmental impacts of baby food: Ready-made porridge products

Natalia Sieti, Ximena C. Schmidt Rivera, Laurence Stamford* and Adisa Azapagic

Supplementary information

Table A.1 Inventory data for milk production

		Quantity	Unit (per kg milk)	Reference
Inputs	Barley grain, feed	0.03	kg	Williams et al. (2006)
	Wheat grain, feed	0.06	kg	〃
	Rape meal, feed	0.02	kg	〃
	Grass silage	0.33	kg	〃
	Grass	1.08	kg	〃
	Maize silage	0.08	kg	〃
	Energy, diesel	0.19	MJ	Upton et al. (2013)
	Energy, electricity	0.30	MJ	〃
	Drinking water	6.03	kg	DairyCo (2013)
Outputs	*Products*			
	Milk at farm	1	kg	Williams et al. (2006)
	Manure	3	kg	Weiss and St-pierre (2010)
	Beef, boneless	32	g	Schaefer (2005); Oklahoma Department of Agriculture Food & Forestry (2013)
	Emissions			
	Methane	21	g	Williams et al. (2006)
	Nitrous oxide	0.516	g	〃
	Ammonia	2.6	g	〃

Table A.2 Inventory data for milk powder production

		Quantity	Unit (per kg milk powder)	Reference
Inputs	Milk from farm	7.8	kg	Nielsen et al. (2003)
	Electricity	0.354	kWh	"
	Heat	7.15	MJ	"
	Water	4.7	kg	"
	Transport (lorry)	150	km	Ecoinvent (2015)
Outputs	*Product*			Nielsen et al. (2003)
	Milk powder	1	kg	"
	Emissions to municipal wastewater treatment plant			"
	COD	6.9	g	"
	Nitrogen	0.27	g	"
	Phosphorous	0.11	g	"

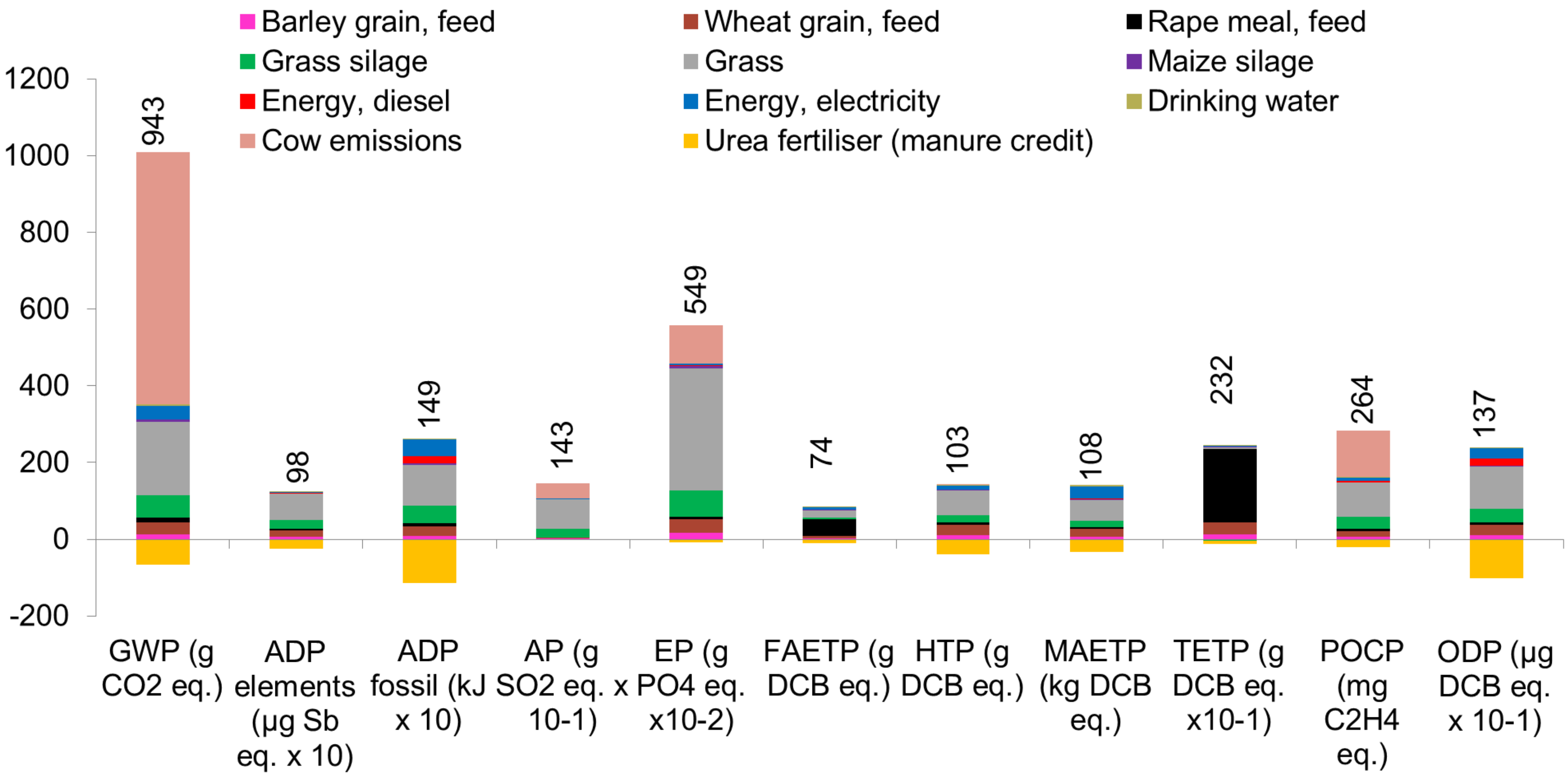


Figure A.1 Environmental impacts of liquid milk
(Impacts expressed per kg of milk. System boundary: from cradle to farm gate. Impacts expressed per functional unit: consumption of one meal (125 g of porridge). GWP: global warming potential; ADPe: Abiotic depletion potential elements, ADPf: Abiotic depletion potential fossil, AP: Acidification potential, EP: Eutrophication potential, FAETP: Freshwater aquatic ecotoxicity potential, HTTP: Human toxicity potential, MAETP: Marine aquatic ecotoxicity potential, TETP: Terrestrial ecotoxicity potential, POCP: Photochemical oxidants creation potential, ODP: Ozone depletion potential, DCB: dichlorobenzene)

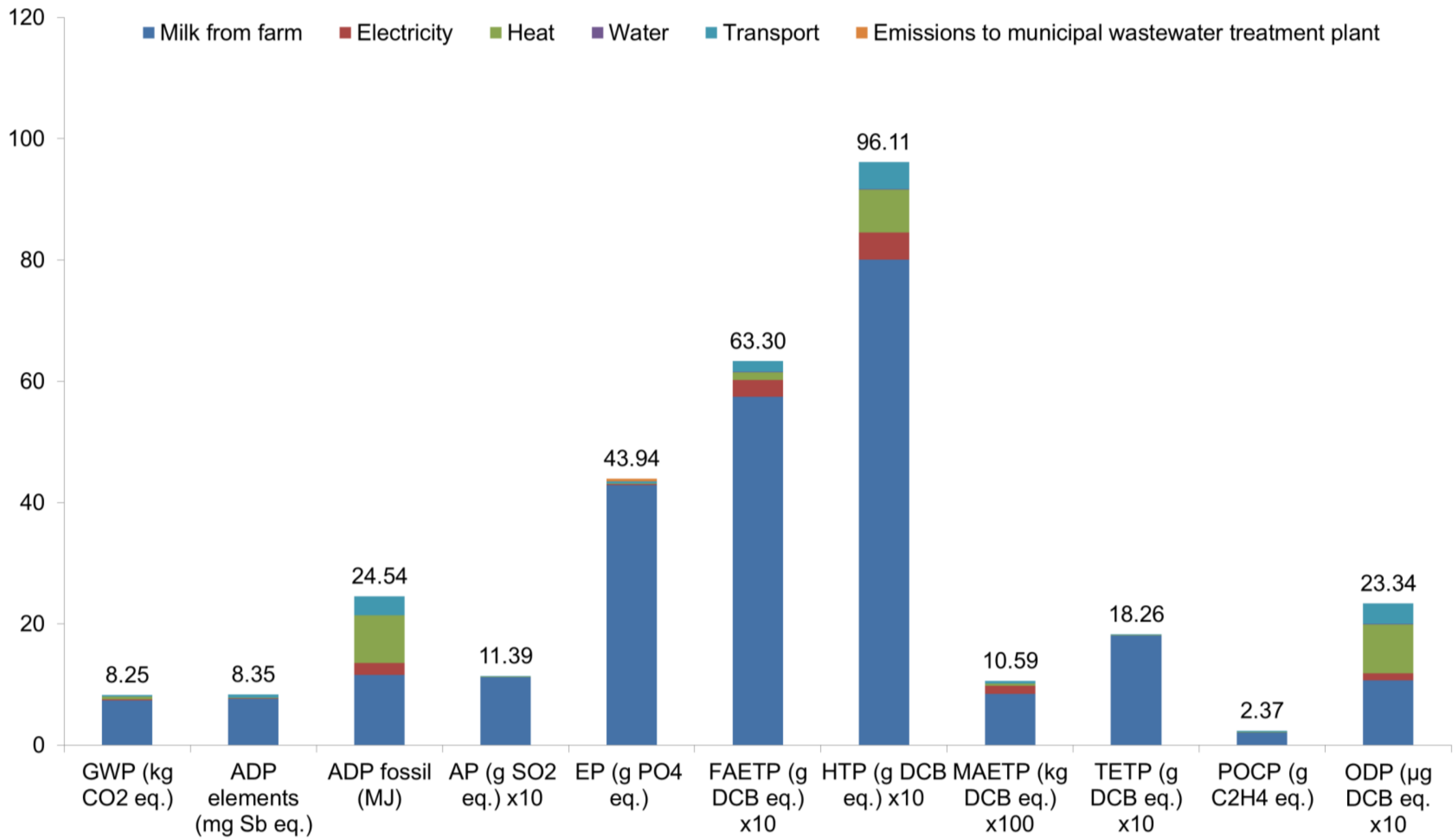


Figure A.2 Environmental impacts of milk powder

(Impacts expressed per kg of milk. System boundary: from cradle to manufacturer's gate. For the impacts nomenclature, see Figure A.1)

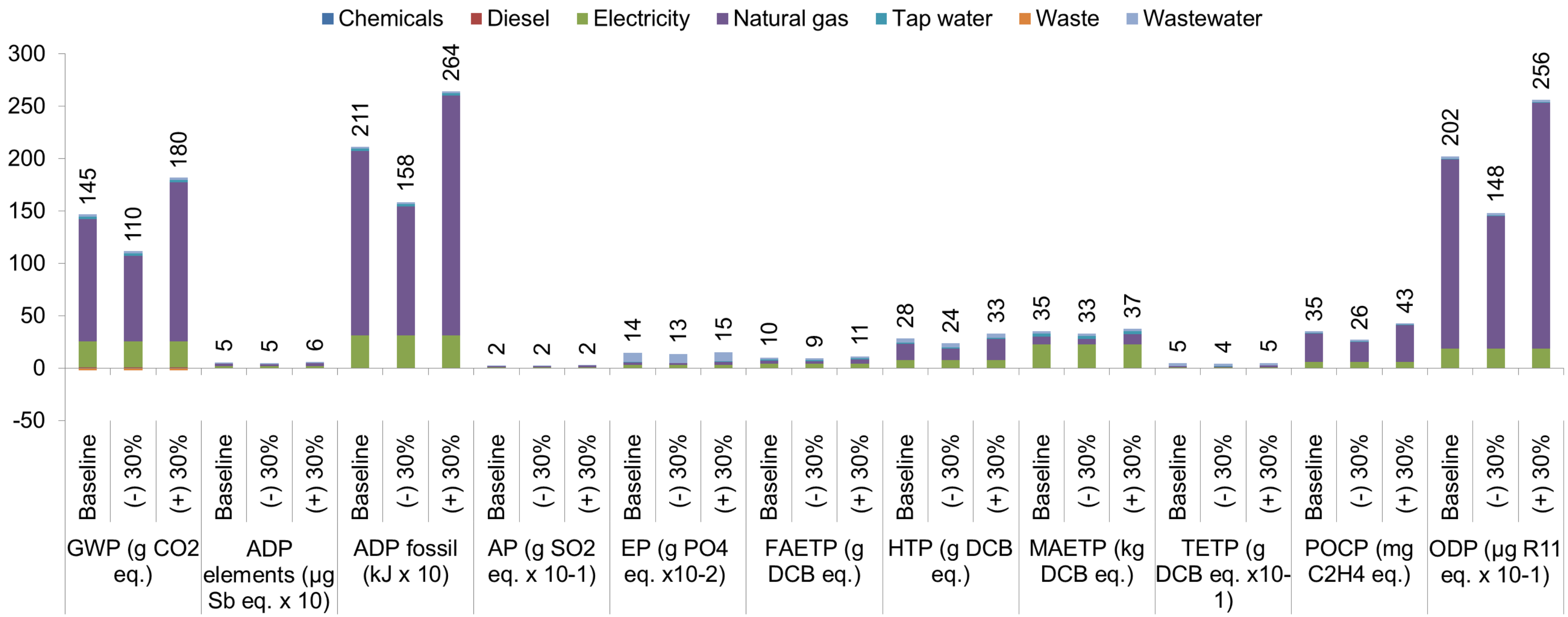


Figure A.3 Sensitivity analysis for the use of natural gas in the manufacture of wet porridge

(Impacts expressed per functional unit (125 g per meal). Energy use varied by +/-30%. For the impacts nomenclature, see Figure A.1)

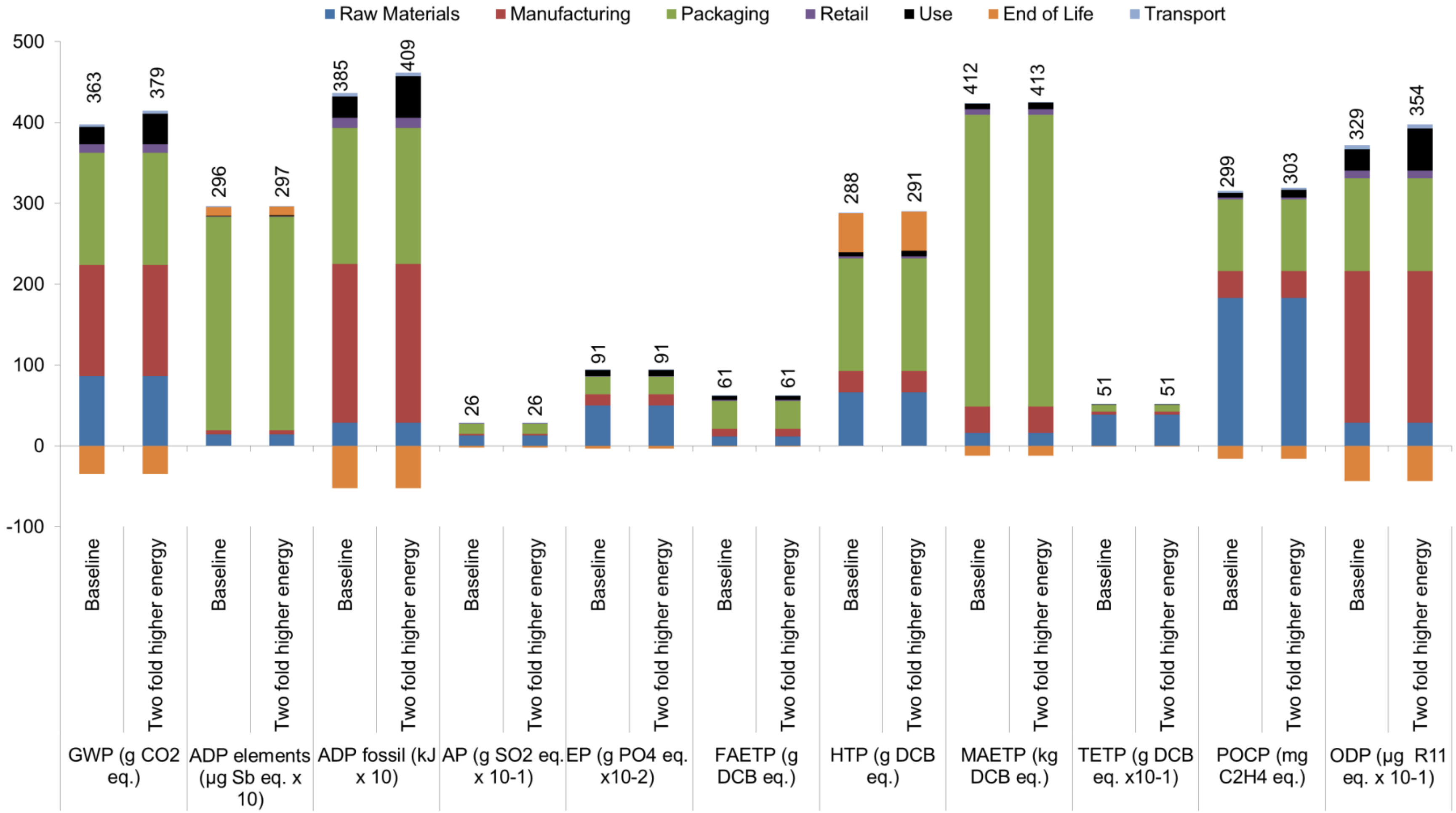
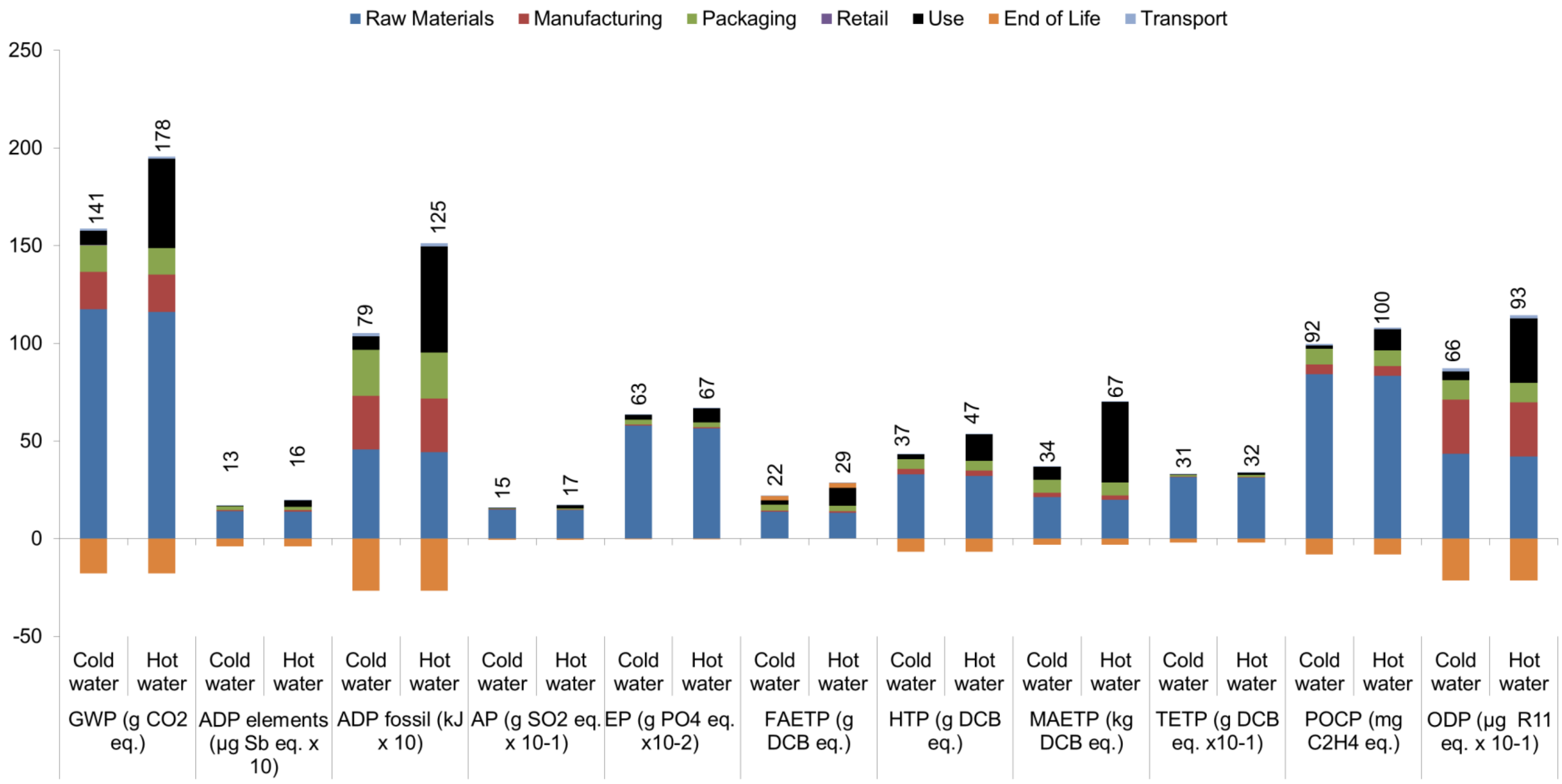
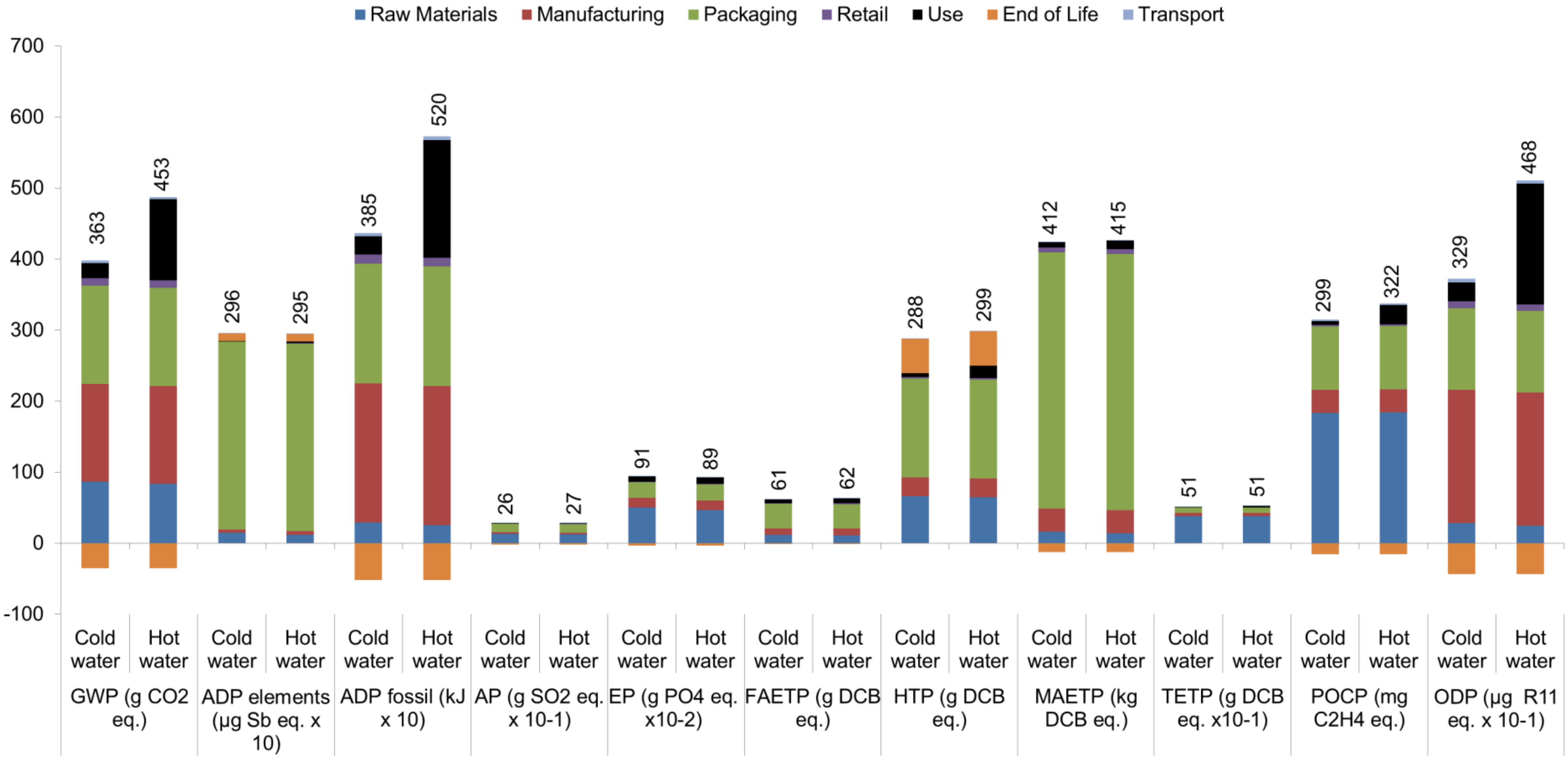


Figure A.4 Sensitivity analysis for heating wet porridge at consumer

(Impacts expressed per functional unit (125 g per meal). For the impacts nomenclature, see Figure A.1)



a) Dry porridge



b) Wet porridge

Figure A.5 Sensitivity analysis for dry (a) and wet (b) porridge comparing cold and hot water for washing up (Impacts expressed per functional unit (125 g per meal). For the impacts nomenclature, see Figure A.1)

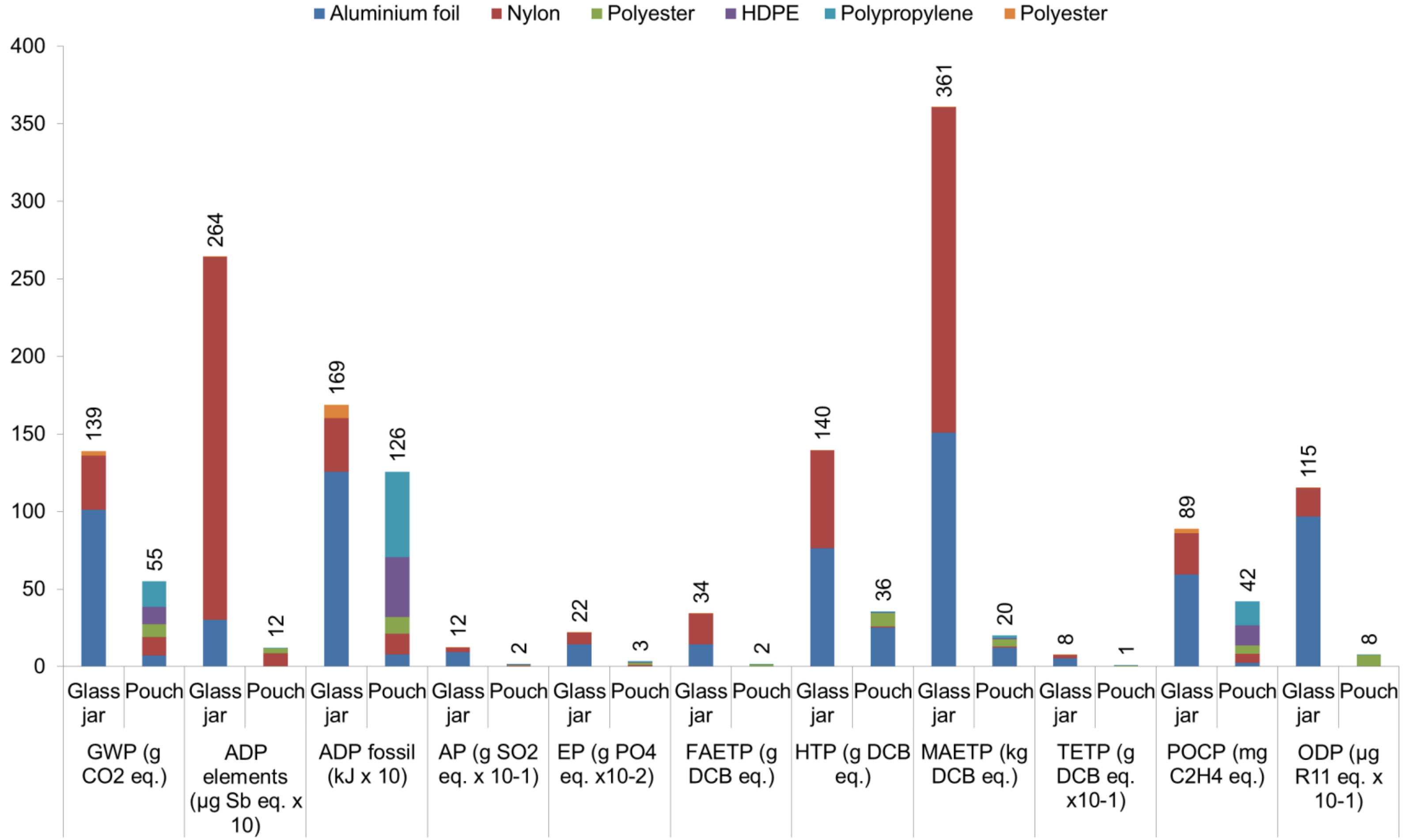


Figure A.6 Contribution of different packaging components to the impacts from packaging for wet porridge (Impacts expressed per functional unit (125 g per meal). For the impacts nomenclature, see Figure A.1)

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Appendix B. Supplementary information of Chapter 3

Environmental sustainability assessment of ready-made baby foods: meals, menus and diets

Natalia Sieti, Ximena C. Schmidt Rivera, Laurence Stamford* and Adisa Azapagic

Supplementary information

Table B.2 Breakfast, lunch and dessert products and the breakdown of their ingredients by mass (g/125 meal)

	Meals	**Breakfast**		**Lunch**					**Dessert**				
Ingredients		*Dry porridge*	*Wet porridge*	*Chicken lunch*	*Salmon risotto*	*Spaghetti Bolognese*	*Vegetable & chicken risotto*	*Vegetable lasagne*	*Apples & rice*	*Banana & chocolate pudding*	*Apple, pear & banana*	*Strawberry, raspberry & banana*	*Strawberry yoghurt*
Cereals	Barley	1	0	0	0	0	0	0	0	0	0	0	0
	Oat flakes	44	6	0	0	0	0	0	0	0	0	0	0
	Rice flour	14	0	0	29	0	25	0	1	31	0	0	1
	Corn flour	0	0	9	0	1	0	1	0	0	0	0	0
	Dry pasta	0	0	0	0	23	0	24	0	0	0	0	0
	Maize	0	0	0	0	0	8	0	0	0	0	0	0
Vegetables & beans	Swede	0	0	10	0	0	0	0	0	0	0	0	0
	Potatoes	0	0	10	0	0	0	0	0	0	0	0	0
	Parsnip	0	0	20	0	0	0	0	0	0	0	0	0
	Peas	0	0	10	6	0	0	0	0	0	0	0	0
	Carrot	0	0	15	30	17	15	25	0	0	0	0	0
	Tomato	0	0	9	0	34	15	28	0	0	0	0	0
	Zucchini	0	0	0	0	0	10	8	0	0	0	0	0
	Onion	0	0	0	6	17	6	6	0	0	0	0	0
Meat, poulry & fish	Beef	0	0	0	0	11	0	0	0	0	0	0	0
	Chicken	0	0	16	0	0	10	0	0	0	0	0	0
	Salmon	0	0	0	11	0	0	0	0	0	0	0	0
Milk, yoghurt & cheese	Full milk	0	69	0	3	0	0	6	0	63	0	0	0
	Milk powder	38	0	0	0	0	0	0	4	0	0	0	0
	Cheese	0	0	0	10	0	0	4	0	0	0	0	0
	Yoghurt	0	0	0	0	0	0	0	0	0	0	0	46
Oils & sugar	Rapeseed oil	0	0	0	3	1	1	3	0	0	0	0	0
	Palm oil	4	0	0	0	0	0	0	0	0	0	0	0
	Sunflower oil	0	0	1	0	0	0	0	0	0	0	0	0
	Sugar	25	25	0	0	0	0	0	0	3	0	0	0
Fruits	Apple	0	0	0	0	0	0	0	120	0	53	99	13
	Banana	0	0	0	0	0	0	0	0	15	25	10	28
	Strawberry	0	0	0	0	0	0	0	0	0	0	16	38
	Pear	0	0	0	0	0	0	0	0	0	48	0	0
	Cocoa	0	0	0	0	0	0	0	0	1	0	0	0
Water	Water	0	25	25	28	21	35	21	0	13	0	0	0
Total		*125*	*125*	*125*	*125*	*125*	*125*	*125*	*125*	*125*	*126*	*125*	*125*