A Sustainable Assessment in the Convenience Food Sector: Ready-made Meals

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List of Abbreviations

ADP	Abiotic depletion potential
AP	Acidification potential
BFFF	British frozen food federation
BSI	British standard institute
C	Consumers
CFA	Chilled food association
CPI	Consumer price index
D	Distribution stage
DECC	Department of energy and climate change
DEFRA	Department of environment, food and rural affairs
EP	Eutrophication potential
FAETP	Fresh aquatic ecotoxicity potential
FAO	Food and agriculture organization of the united nations
FBTS	Food, beverage and tobacco sector
FD	Food and drinks
FDF	Food and drink federation
FDS	Food and drink sector
FNAD	Food and non-alcoholic drinks
FS	Food sector
GDP	Gross domestic potential
GHG	Greenhouse gases
GRI	Global report initiative
GVA	Gross value added
GWP	Global warming potential
HDPE	High density polyethylene
HGV	Heavy good vehicles
HPSIA	Handbook product social impact assessment
HTP	Human toxicity potential
ILO	Institute labour organization
IPCC	Intergovernmental panel on climate change
ISO	International standard organization
LCA	Life cycle assessment
LCC	Life cycle costing
LDPE	Low density polyethylene
M	Manufacturing stage

MAETP	Marine ecotoxicity potential
MFS	Manufacture food sector
MS	Manufacturing Sector
NHS	National health system
NPD	New product development
ODP	Ozone depletion potential
PAS	Publicly available standard
PET	Polyethylene terephthalate
POCP	Photochemical ozone creation potential
PP	Pre-processing stage
R&D	Research and development
RDC	Regional Distribution Centre
RM	Raw materials stage
RMM	Ready-made meal
RMS	Ready-made meal sector
RSP	Retail selling price
S-LCA	Social life cycle assessment
SETAC	Society of environmental toxicology and chemistry
SHDB	Social hotspots database
SI	Social indicators
TETP	Terrestrial toxicity potential
UNEP	United nations environment programme
USDA	United States department of agriculture
VA	Value added
W	Waste or final disposal stage
WHO	World health organisation
WRAP	Waste resource action programme
WRAP	Waste and resources action programme
WTO	World trade organisation

77,079 words

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Abstract

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The food industry has an essential role in society and in the global economy. Nowadays, modern lifestyle demands convenience, which is driving the development of the food sector. This is particularly evident with convenience food, especially ready-made meals, industrially prepared food, which only requires a short preparation time at home by consumers, but has very complex and diverse supply chains and is associated with a range of sustainability issues. Therefore, the aim of this research is to evaluate the environmental, economic and social sustainability in the ready-made meals sector with the focus on the UK market. A life cycle approach has been used for these purposes, using life cycle assessment (LCA) as the tool for the environmental analysis, life cycle costing (LCC) for the economic aspects and social sustainability indicators (SI) for the social issues. Different types of ready-made meal from different cuisines have been considered, including the British, Italian, Chinese and Indian.

The highest environmental impacts are found for the Italian and Indian cuisines, while Chinese meals are environmentally most sustainable, followed by the British. At the sectoral level, the results suggest that from ‘cradle to retailer’ the British ready-made meal sector contributes 4.45 Mt of CO_2 eq. annually, which represents ~4% of the GHG emissions of the food and drink sector and ~1% of the UK GHG emissions. Of this, 3.16 Mt of CO_2 eq. is emitted by chilled and 1.28 Mt of CO_2 eq. by the frozen ready-made meals. The total life cycle costs at the sectoral level from ‘cradle to grave’ are estimated at £2.1 bn, with the chilled ready-made meals market contributing £1.42 bn and the frozen £676 million. The life cycle costs from ‘cradle to retailer’ are £1.02 bn, with the value added of £958 million. The common environmental and cost hotspot for all the meals studied is raw materials. In particular, the meat, fish and seafood are the greatest contributors. For the environmental impacts, the manufacturing and distribution stages are also important, while the consumption stage is the largest contributor to the costs. The major social aspects are the food-related health issues and food security, in particular food affordability. In the supply chain agriculture, wholesale and retailers show high risk for indicators such as wages and employment while the manufacturing presents high risk in fatal injuries.

The study also shows that consumer choices play an important role for the economic and environmental impacts; therefore, educational programmes and better communicational strategies should be implemented by the industry, the government and consumers groups. Moreover, to ensure a sustainable development of the ready-made meals sector, future policies and industrial initiatives should consider a life cycle approach including relevant economic, environmental and social aspects.

Declaration

No portion of the work referred to in this 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.

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It has been a great experience, with ups and downs, but overall an amazing adventure which I am grateful for.

Chapter 1: Introduction

Interest in sustainable development has been growing over the last two decades, particularly after the Rio Summit in 1992 (United Nations 1998). As a result, various regulations and international agreements related to sustainable development have been published (United Nations 1998;ISO 2006a;ISO 2006b;British Standard Institution 2008;Food SCP-RT 2013;ISO 2006;Defra 2010;European Environmental Agency 2005;American Center for Life Cycle Assessment Product Category Rule Committee 2013) compelling governments, industry and communities to engage in the sustainability debate.

However, sustainable development is a concept difficult to define and apply. For instance, the most widely used definition “meeting the needs of the present without compromising the ability of future generations to meet their own needs” (United Nation 1987) states neither the baseline nor the guidelines for the application. A further difficulty is related to the need to integrate all three components of sustainable development: economy, environment and society. For instance, according to Azapagic and Perdan (2011), sustainable development is “an approach to development which focuses on integrating economic activity with environmental protection and social concern”. A number of studies have been targeting general and specific areas where the integration of this concept should and can be incorporated; for instance in the fields such as economics, politics and society (Azapagic and Perdan 2000;Corbière-Nicollier and Jolliet 2002;Azapagic 2003;Adebanjo 2010); and in specific areas as construction, energy systems, beverage and food sectors, among others (Amienyo 2012;Cuellar Franca 2013;Kruse et al. 2009;Santoyo-Castelazo and Azapagic 2014).

The increasing popularity and awareness on sustainability have exhibited the unsustainable patterns that for a long time countries and sectors have been basing their economic and industrial growth; provision of food is one such example. On one hand, last decade has been one of the period with the highest production of food (IRIN 2009), which would have been potentially able to feed the world; on the other hand, an increasing number of people are dying of starvation and suffering from undernourishment, especially in developing countries in Sub-Saharan Africa and Southern and Western Asia (World Hunger Education Service 2013;IRIN 2012;FAO 2009;World Food Programme 2014). At the same time, developed countries and also those with growing economies, have been experiencing a constant increase in obese and overweight population (World Health Organization 2014;Hawkes 2006;Rayner and Scarborough 2005). For example, more than half of the British people are obese or overweight (The NHS Information Centre 2010;Rayner et al. 2006;Scarborough et al. 2011)**.**

Provision of food is one of the most important sectors for every nation, because it provides resources to fulfil one of the basic human needs but also because of its economic and societal relevance. For instance, the British food sector accounts for 13% of the workforce (Defra 2014) and contributes 8% to the gross domestic product (Defra 2010).

In 2012, the gross value added (GVA) of the agri-food sector was 7.4% of the national GVA (Department for Business 2014), reaching £97.1 billion. In the same year, the food manufacturing sector alone contributed £24.4 billion, representing 25% of the agri-food sector (Defra 2014).

In the UK food manufacturing sector, the convenience food, in particular ready-made meals, is one of the most prosperous businesses due to its popularity, which is reflected in the continuous growth and its market position: the UK is the biggest market in Europe and the second worldwide after the US (Key Note 2013) for the ready-made meals. In 2013, the ready meals market accounted £1.97 bn of retail selling price and is expected to grow by 15.4% by 2018 (Key Note 2014).

However the food chain in the UK has also high environmental impacts. For example, in 2013 it contributed 20%-30% of the greenhouse gas (GHG) emissions in the UK (Defra 2013;DECC and National Statistics 2015). The agricultural sector was the most important contributor with 44%, followed by the production and preparation of food with 31%, transportation inside and outside the country accounting for 13%, retailing and packaging 5% each, and finally the waste disposal 2% (Defra 2014).

As mentioned earlier, the overconsumption of food has been showing their effects. In 2008, 25% of the adult population in the UK was obese and around 37% overweight (The NHS Information Centre 2010). The trend is not promising and in the case of children, 16% are considered obese (The NHS Information Centre 2010)**.** The overconsumption of food has also leaded to an increase in diet-related chronic diseases (DRCD), which are related to diabetes, cancer and heart diseases (Scarborough et al. 2011;Rayner and Scarborough 2005). All these health issues lead to a low quality of life, a lower life expectancy and a need for costly treatments. As an example, the NHS has been expending £6 billion annually to treat DRCD (Scarborough et al. 2011;Rayner and Scarborough 2005).

The sustainability issues related to the food industry have been discussed in the literature (van der Werf et al. 2014;Garnett 2011;Notarnicola 2011) and various standards (ISO/TS 2013;Food SCP-RT 2013); however, none of these mentioned the integration of the environmental, economic and social perspectives to either set a baseline for a future development or to determine the contribution of specific food sub-sectors to the overall sector or even to a national sustainability programme. Different actors are aware of that and it has been stated that there is still work to do, especially related to communication of the results, integration of the environmental impacts and the integration of the economic and social perspective to complement the decision-making (S.J.MacLaren and Massey University of New Zeland 2010).

Even though integrated sustainability assessments are rare, in the case of the UK food and drink sector, there is one successful attempt which assessed the sustainability of the British beverage sector under a life cycle perspective (Amienyo 2012); however, there are no similar studies for either the whole food or the convenience food sector.

Therefore, this study focuses on the convenience sector and in particular on the ready-made market to evaluate environmental, economic and social sustainability in an attempt to provide a baseline and help the food industry, policy makers and consumers identify more sustainable options for the future. The aims and objectives of the study are described in the next section.

1.1 Research aim

The main aim of this research is to evaluate the environmental, economic and social sustainability of ready-made meals produced and consumed in the UK. The specific objectives of this research are:

- to identify the main sustainability issues and the key stakeholders in the sector;
- to select and evaluate the most popular types of ready-made meals and assess their life cycle environmental and economic sustainability;
- to identify hotspot and opportunities for improvements along the supply chains for the selected types of meal;
- to use the above results to evaluate the life cycle environmental and economic sustainability at the sectoral level;
- to carry out a social sustainability assessment of the ready-made sector; and
- to develop final recommendation to the key stakeholders for improvements in the production and consumption of ready-made meals in the UK.

This study considers a ready-made meal as an industrially pre-cooked packed meal that must be reheated either in the microwave, on the hob or in the oven before its consumption (Key Note 2014). It is important to clarify that even though pizzas are also ready-made meals, they are outside the scope of this study. Figure 1 shows some examples of the ready-made meals.

As mentioned, the ready-made meals are distinguishing examples of convenience food, which can be defined as food products that help to reduce consumers time and physical and mental effort related to cooking activities (Candel 2001;Darian and Cohen 1995).

Although there are several definitions for convenience food, researches agree that the most common characteristics of these products are time and energy (effort) saving as well as lack of culinary skills (Candel 2001;Brunner et al. 2010;Costa et al. 2001).

Figure 1 Examples of ready-made meals considered in the scope of this study

As far as the author is aware, this is the first attempt of a full sustainability assessment for the ready-made meals sector in the UK.

The environmental and economic sustainability assessments are carried out using Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) as tools, following the ISO 14040-14044 (ISO 2006b;ISO 2006a) guidelines. The economic analysis also includes estimations of value added (VA) to complement the LCC. The social assessment is based on number of social indicators selected for the purposes of this work (Benoît-Norris et al. 2011;UNEP/SETAC 2009).

1.2 Thesis structure

This thesis is presented in the 'alternative format' comprising five papers, as outlined in Figure 2. The first paper is presented in Chapter 2 and it focuses on life cycle environmental impacts of a ready-made meal in comparison to an equivalent home-made meal (Schmidt Rivera et al. 2014).

For these purposes, one of the most common meals consumed in the UK has been chosen: chicken roast dinner. The following Chapter 3 contains the second paper which estimates the life cycle costs and value added of this type of meal. The environmental and economic analysis is then broadened in Chapters 4 and 5, respectively, where papers #3 and #4 discuss the sustainability of 13 ready-made meals from four most popular cuisines in the UK: British, Italian, Indian and Chinese.

Using the results from papers #1-4, paper #5 in Chapter 6 evaluates the sustainability of the ready-made meals sector, by escalating the environmental and economic impacts to sectoral level. This paper also considers the social sustainability of the sector. Finally, in Chapter 7, the conclusions of the study are drawn and further recommendations made for different stakeholders.

The first paper has already been published (Schmidt Rivera et al. 2014) and the second paper has been submitted and is under review. The remaining three papers will be submitted to appropriate journals in the near future.

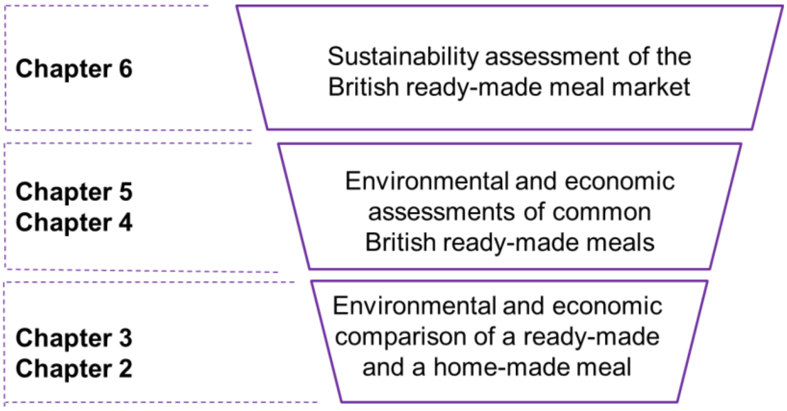

Figure 2 Graphical representation of the thesis structure

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Chapter 2: Life Cycle Environmental Impacts of Convenience Food: Comparison of Ready and Home-made Meals

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The research, consisting of an environmental assessment and comparison of different production and consumption option for a ready- and home-made meal, was designed, implemented and written by the author of this thesis. Co-authors Espinoza Orias N. and Azapagic A. supervised the research and edited the paper.

Life Cycle Environmental Impacts of Convenience Food: Comparison of Ready and Home-made Meals

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Abstract

This paper compares the life cycle environmental impacts of ready-made meals manufactured industrially with meals prepared at home from scratch. A typical roast dinner consisting of chicken meat, vegetables and tomato sauce is considered. The results suggest that the impacts of the home-made meal are lower than for the equivalent ready-made meal. For example, the global warming and human toxicity potentials are up to 35% lower and eutrophication, photochemical smog and ozone layer depletion are up to 3 times lower. The main reasons for this are the avoidance of meal manufacturing, reduced refrigeration and a lower amount of waste in the life cycle of the home-made meal. For the ready-made meal, the lowest impacts are found for the frozen meal prepared from fresh ingredients and heated at home in a microwave. The worst option for most impacts is the frozen ready-made meal with frozen ingredients that is heated in an electric oven. For the same cooking method, chilled ready-made meals have higher impacts than the frozen. The type of refrigerant used in the supply chain influences the impacts, particularly global warming and ozone layer depletion. The contribution of packaging is important for some impacts, including global warming, fossil fuel depletion and human toxicity. The main hotspots for both types of meal are the ingredients, waste and cooking method chosen by the consumer. Using organic instead of conventional ingredients leads to higher impacts. Sourcing chicken and tomatoes from Brazil and Spain, respectively, reduces environmental impacts of the meals compared to sourcing them from the UK, despite the long-distance transport. The findings of the study are used to make recommendations to producers, retailers and consumers on reducing the environmental impacts from food production and consumption.

Keywords: convenience food; home-made meals; ready-made meals; environmental impacts; LCA

1 Introduction

Food production and consumption exert significant pressures on the environment. For example, 29% of global emissions of greenhouse gases (GHG) are from agriculture and food production (Vermeulen et al., 2012). FAO estimate that 3.3 Gt of CO_2 eq. is emitted owing to one third of food being wasted worldwide, making food wastage the third top GHG emitter after USA and China (FAO, 2013). In the EU, food consumption accounts for 20-30% of various environmental impacts and, in the case of eutrophication, more than 50% (Tukker et al., 2006). In the UK, the food and drink sector is responsible for 14% of industrial energy consumption and 7 Mt of carbon emissions per year; it also uses 10% of all industrial water supply and produces 10% of the industrial and commercial waste stream (Defra, 2006).

Economic growth, changing dietary habits and modern lifestyles will only exacerbate environmental impacts of food in the future, particularly because of the increasing demand for meat products in developing countries such as China (USDA, 2010; FAO, 2013) as well as for convenience food in the developed world but also in China (Key Note, 2013). The convenience food sector, in particular, is expanding rapidly, with the global ready-made meals market expected to grow by 3.2% from $1.11 trillion in 2011 to $1.3 trillion in 2016. Much of this growth is expected to come from China which is the fastest growing market for ready-made meals in the world (Key Note, 2013). Currently, the US and the UK are the largest markets in the world, respectively valued at £7.2bn (Sheely, 2008) and £2bn (Key Note, 2013). In Western Europe, the size of the market is estimated at £3.9bn (Sheely, 2008). The majority of this is due to the UK market, which is expected to grow by 20% by 2017 (Key Note, 2013).

Convenience food now constitutes more than a third of the British food market with approximately 8.8 kg of chilled and frozen ready-made meals consumed per capita per year (Millstone and Lang, 2008). This makes Britons the largest consumer of ready-made meals in Europe and the second largest worldwide (after the US); they are also the largest consumers of chilled ready-made in the world (Key Note, 2013). Even meals that have traditionally been prepared at home are gradually being replaced by ready-made meals – now one in four Britons eats ready-made Christmas dinner (MINTEL, 2011). Yet, there is currently scant information on the life cycle environmental impacts of convenience food, and particularly ready-made meals. Whilst numerous life cycle assessment (LCA) studies of single food items have been carried out, there are few studies of complete meals with most focusing on global warming potential (e.g. Carlsson-Kanyama, 1998; Wiltshire et al., 2009; Stichnothe et al., 2008; Espinoza-Orias et al., 2010) or on a limited number of environmental impacts such as acidification, eutrophication and energy consumption (e.g. Sonesson et al., 2005; Davis and Sonesson, 2008; Davis et al., 2010; Berlin and Sund, 2010; Saarinen et al., 2010 & 2012). To date, only two studies have considered a broader range of LCA impacts of ready-made meals, both based in Spain: Calderon et al. (2010) looked at a canned ready-made meal with pork meat and pulses while Zufia and Arana (2008) evaluated a dish with cooked tuna and tomato.

In an attempt to contribute towards further understanding of environmental impacts of the convenience food sector, this paper considers one of the most popular ready-made meals in the UK – roast dinner – consisting of roast chicken, vegetables and an accompanying sauce. The environmental impacts are compared to the same meal prepared at home. A range of different scenarios is examined for both types of meal to explore the influence of different factors on the impacts. Although the study is based in the UK, the findings and recommendations for improvements are generic enough to be applicable elsewhere and to other similar types of meals.

2 Methodology

LCA has been used as a tool to estimate the environmental impacts of both the ready and home-made meals, following the ISO 14040/14044 methodology (ISO, 2006a & b). The methodology, data and the assumptions are described in more detail in the following sections.

2.1 Goal and scope of the study

The main goal of this study is to evaluate the environmental impacts of a ready-made meal prepared industrially and compare it to the impacts from an equivalent meal made at home. A further goal is to analyse the influence on the impacts of different factors such as ingredient sourcing, refrigeration and home-cooking options. The results of the study are aimed at both food producers and consumers.

The functional unit is defined as 'preparation and consumption of a meal for one person'. The weight of the meal is 360 g and it consists of roast chicken and three vegetables - potatoes, carrots and peas – served with tomato sauce. This meal has been chosen for study as it represents a typical British 'roast dinner'. The meal is consumed at home. The scope is from 'cradle to grave' and the study is based in the UK.

2.2 System definition and system boundaries

Figure 3 outlines the life cycles of the ready-made and the meal prepared at home; the individual steps involved in each stage are defined in Table 1. As shown, the life cycle of the ready-made meal involves chicken rearing and cultivation of the vegetables, their processing in a slaughterhouse and at a regional distribution centre (RDC), respectively, preparation of the meal in a factory, its subsequent transport to another RDC, retailer and finally to consumer's home where it is prepared according to manufacturer's instructions. The life cycle of the home-made meal is similar, except that the meal is fully prepared at home, starting from the fresh ingredients.

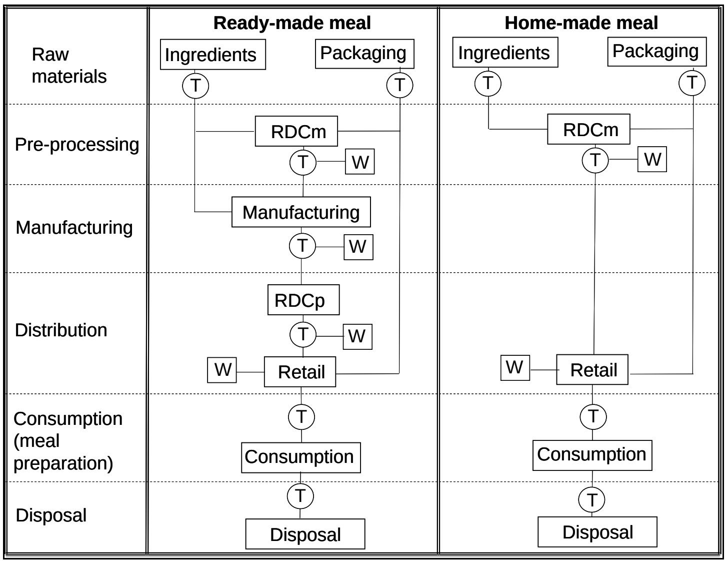


Figure 3 Life cycles of the ready and home-made meals

[RDCm and RDCp: Regional distribution centre for raw materials and products, respectively; T- transport; W - waste]

2.2.1 Raw materials (ingredients)

As shown in Table *2*, the ingredients used for both meals are chicken meat, potatoes, carrots, peas, tomato sauce, salt and oil. All the ingredients are assumed to be produced in the UK, apart from the tomato paste used for the tomato sauce, the majority of which is imported to the UK from Spain (FAO, 2009). In one of the scenarios discussed later, chicken is also assumed to be imported from Brazil (Defra, 2008a; BPEX, 2013).

This stage involves chicken rearing and cultivation of the vegetables. The latter are transported from the farm to the RDCm to be processed while the chicken is processed in the slaughterhouse and transported directly to the meal manufacturer. The tomato paste, oil and salt are also transported directly from their respective manufacturers to the meal producer.

2.2.2 Pre-processing

Pre-processing includes processing the vegetables and slaughtering the chickens, packing and either chilled or frozen storage. The data assumed for this stage are given in Table 3.

The vegetables are processed at RDCm including sorting, peeling, washing and cutting. For frozen ready-made meals, blanching and fast cooling of vegetables is also carried out. Chilled vegetables are packaged in plastic crates and transported by refrigerated trucks to the meal manufacturer. Frozen vegetables are packaged in plastic bags and cardboard boxes and transported to the manufacturer by freezer-trucks. Water used for pre-processing the vegetables is collected and treated (EC, 2006). The waste, including the peel and spoilage, is assumed to be landfilled (see Table 4). However, using the waste for animal feed instead of landfilling is also considered within the sensitivity analysis later in the paper.

The chicken meat is processed in a slaughterhouse (Nielsen et al., 2003), where it is packaged and stored ready to be delivered to the retailer. Chicken waste (offcuts and carcass) are used for bone-meal production.

2.2.3 Manufacture

This stage involves cooking of the ready-made meal (from fresh or frozen ingredients), its packing and either chilled or frozen transportation to the RDCp. Vegetables and tomato sauce are cooked together while the chicken meat is cooked separately. The cooked ingredients are then combined, packaged and refrigerated or frozen. The utilities used in the manufacturing process are listed in Table 5.

2.2.4 Distribution

The ready-made meals are first stored at the RDCp and then distributed to the retailer in refrigerated or freezer-trucks while the ingredients for the home-made meal are distributed directly from RDCm to retailer in refrigerated trucks. The ready-made meals and the ingredients for the home-made meal are then transported by the consumer for consumption at home. The data used for this stage are specified in Table 6.

Table 1 Stages considered in the life cycle of the ready and home-made meals

Stage	Ready-made meal	Home-made meal
Raw materials (ingredients)	Cultivation of vegetables and tomatoes	Cultivation of vegetables and tomatoes
	Chicken rearing	Chicken rearing
	Manufacture of tomato paste	-
	Manufacture of packaging	Manufacture of packaging
	Waste management	Waste management
	Transport to RDCm[a]	Transport to RDCm
Pre-processing of ingredients	Processing of vegetables at RDCm	Processing of vegetables at RDCm
	Slaughtering, processing and storage of chicken meat	Slaughtering, processing and storage of chicken meat
	Packing	Packing
	Waste management	Waste management
	Transport to manufacturer	-
Manufacture of meal	Meal manufacturing	-
	Packing	-
	Waste management and water treatment	-
	Chilled or frozen storage	-
	Transport to RDCp[b]	-
Distribution	Chilled or frozen storage at RDCp	-
	Transport to retailer	Transport to retailer
	Chilled or frozen storage at retailer	Chilled storage at retailer
	Waste management	Waste management
	Packaging (shopping bags)	Packaging (shopping bags)
Consumption (meal preparation)	Transport of the meal from retailer to consumer's home	Transport of the ingredients from retailer to consumer's home
	Refrigerated storage at home	Refrigerated storage at home
	Cooking of the meal (oven or microwave)	Cooking of the meal (chicken roasting, vegetables boiling, tomato sauce cooking)
Final disposal of waste	Waste transport and management (packaging and food waste)	Waste transport and management (packaging and food waste)

[a] RDCm - Regional distribution centre for raw materials (vegetables)

[b] RDCp - Regional distribution centre for products (ready-made meal)

Table 2 Composition of the ready and home-made meal as served

Ingredients	Weight (g)	Contribution (%)
Chicken	98	27.22
Potatoes	87.5	24.31
Carrots	35	9.72
Peas	35	9.72
Tomato sauce	94.5	26.25
Tomato paste	*66.2*	*70*
Onions	*28.3*	*30*
Salt	1	0.28
Vegetable oil	9	2.50
Total	**360**	**100**

Table 3 Storage times, utilities and refrigerant used in the pre-processing stage

	Processing[a] (amount per meal)	RDCm[b] (amount per meal)
Chilled raw materials		
Storage time (hr)	-	12
Electricity (Wh)	5.8	0.0778
Water (l)	1.127	-
Steam (Wh)	0.3	-
Refrigerant (ammonia) charge (mg)	-	180.5
Refrigerant (ammonia) leakage (mg)[c]	-	27.1
Frozen raw materials		
Storage time (hr)	-	158
Electricity (Wh)	5.9	0.739
Steam (Wh)	0.4	-
Water (l)	2.43	-
Refrigerant (ammonia) charge (mg)	-	211
Refrigerant (ammonia) leakage (mg)[c]	-	31.7

[a] Data source: EC (2006)

[b] Data source: Brunel University (2008)

[c] Assuming walk-in chillers/freezers in RDCm, refrigerant leakage rate is 15% (Brunel University, 2008)

Table 4 Assumptions for waste

Stage	Waste	Reference
Pre-processing	15% of chilled ingredients [a] 17% of frozen ingredients [b] 27% of whole chicken	Milà i Canals et al. (2008), EC (2006), Brunel University (2008) Nielsen and Pontoppidan (2003)
Manufacture	16% of ingredients 0.65% of final product	BIS (2011) BIS (2011)
RDCp and retail	2% for chilled and 1% for frozen	Brunel University (2008)
Consumption	18% of vegetables and 8% of meat & tomato paste for preparation of home-made meal 24% of the ready and home-made meals as post-consumer waste	WRAP (2009) WRAP (2009)

[a] 13% for pre-processing, including the peel and spoilage, and 2% from chilled storage.

[b] 11% from raw materials to frozen (including the peel and spoilage), 5% from frozen to packaged and 1% during frozen storage.

Table 5 Storage time, utilities and refrigerant used in the manufacturing stage

	Amount per meal[a]
Storage time (hr)	12
Fuel oil (l)	0.0397
Electricity (kWh)	0.326
Water (l)	4.285
Refrigerant (R22) charge (mg)	76
Refrigerant (R22) leakage (mg)	11.4[b]

[a] Data source: meal manufacturer

[b] Data source: Brunel University (2008)

2.2.5 Consumption

This stage includes storage and meal preparation at home. The ready-made meal can be cooked in a microwave or a conventional oven. The assumptions for storage and preparation of the ready-made meal are listed in Table 7. Note that refrigerated storage considers the electricity used but no refrigerant leakage as this is negligible for domestic refrigerators and freezers.

As mentioned earlier, the home-made meal is made from fresh ingredients with the chicken roasted in an electric oven and the vegetables cooked on an electric hob or in a microwave (see Table 8). The tomato sauce can be prepared either from a tomato paste or from scratch. The amount of paste and tomatoes needed in each case are shown in Table 9, together with the amount of tomato sauce used in the ready-made meal, for comparison. Note that the total amount of tomato sauce given in Table 9 is slightly different for the home and ready-made meals owing to the different amount of waste in the two systems: 8% for the home-made sauce and 16% for manufacturing the ready-made sauce (see Table 4). This is also the reason why the amount of ready-made sauce appears to be higher (76.7 g per meal) than the amount given in Table 2 (66 g) as the former represents the total amount required before the waste is taken into account.

Water consumption is also considered in the study. For the home-made meal, a total of 4.5 litres is assumed to be used (Defra, 2008 b&c) for washing the ingredients, boiling the vegetables and washing up the dishes by hand. It is also assumed that boiling the vegetables on the hob needs 525 ml of water, while using the microwave requires only 31.5 ml (Defra, 2008c). For the ready-made meal, water is only used for washing up so that the total water consumption is 1 litre (Defra, 2008 b&c).

2.2.6 Disposal

This stage considers only the waste generated in the consumption stage; the waste from the other life cycle stages is considered within each stage. The assumptions for post-consumer waste are summarised in Table 4. All the waste and packaging, including the shopping bag, are assumed to be landfilled. These assumptions are in accordance with the prevalent UK waste management practice for food-related products and packaging (Defra, 2011).

2.2.7 Packaging

All the primary, secondary and tertiary packaging has been considered, including the ingredients and ready-made meal packaging, shopping bags, crates, boxes, drums and pallets. The packaging data are summarised in Table 10 and Table 11.

Table 6 Storage times, utilities and refrigerant used in the RDCp and at retailer

	RDCp[a] (amount per meal)	Retailer[b] (amount per meal)
Chilled ready-made meal		
Storage time (hr)	12	48
Electricity (Wh)	0.0463	52.8
Refrigerant (R134a) charge (mg)	-	150.7
Refrigerant (R134a) leakage (mg)	-	22.6
Refrigerant (ammonia) charge (mg)	180.8	-
Refrigerant (ammonia) leakage (mg)	27.1	-
Frozen ready-made meal		
Storage time (hr)	158	120
Electricity (Wh)	0.61	136.8
Refrigerant (R134a) charge (mg)	-	47.76
Refrigerant (R134a) leakage (mg)	-	7.16
Refrigerant (ammonia) charge (mg)	314.5	-
Refrigerant (ammonia) leakage (mg)	47.2	-
Chilled ingredients for the home-made meal		
Storage time for chicken meat (hr)	-	48
Storage time for vegetables (hr)	-	72
Electricity chicken (Wh)	-	4.5
Electricity vegetables (Wh)	-	10
Refrigerant (R134a) charge (mg)	-	36.25
Refrigerant (R134a) leakage (mg)	-	5.44

[a] Data source: Brunel University (2008)

[b] Medium-size supermarket (floor area 1400 m^2); includes consumption of energy for chilled and frozen storage, lighting and heating, ventilation and air conditioning. Data source: Brunel University (2008).

Table 7 Storage at home and cooking assumptions for the ready-made meal

Storage	Storage (days)	Electricity consumption for storage[a] (Wh/meal)	Cooking option	Cooking specification	Cooking time[b] (min)	Energy consumption for cooking[c] (Wh/meal)
Chilled	0.5	2	Microwave	750 W	6.5	78.6
Frozen	2	18		800 W	9	391.5
Chilled	0.5	2	Oven (electric)	200 °C	25	1270
Frozen	2	18		200 °C	40	2033

[a] Estimated based on Nielsen et al. (2003), assuming the volume of the product of 750 cm^3 and half empty fridge or freezer

[b] Based on manufacturer instructions

[c] Estimated based on average electricity consumption by micowaves of 0.0435 MJ/min and by electric ovens of 0.183 MJ/min (Jungbluth, 1997). For sensitivity analysis, gas ovens are used assuming energy consumption of 0.12 MJ/min (Jungbluth, 1997).

Table 8 Storage at home and cooking assumptions for the home-made meal

Ingredients	Refrigerated storage (days)	Cooking option	Cooking specification	Cooking time (min)	Energy consumption for cooking (Wh)[a]
Roast chicken	0.5	Oven (electric)	200 °C	10	508
Tomatoes/tomato sauce	-	Hob (electric)	-	7	158
	-	Microwave	700 W	5	85
Vegetables	0.5	Hob (electric)	-	15	474
		Microwave	700 W	6.5	78.9

[a] Estimated based on average electricity consumption by electric hobs of 0.114 MJ/min and electric ovens of 0.183 MJ/min (Jungbluth, 1997). For sensitivity analysis, gas hob and oven are used, assuming average energy consumption of 0.108 MJ/min and 0.12 MJ/min, respectively (Jungbluth, 1997).

Table 9 Tomato sauce for the home and ready-made meals

Meal type	**Amount (g/meal)**
Home-made meal: tomato sauce from tomato paste	
Tomato paste	47.6
Water	23.8
Home-made meal: tomato sauce from fresh tomatoes	
Fresh tomatoes	132.3
Ready-made meal: tomato sauce prepared in a factory	
Tomato paste	51.1
Water	25.6

Table 10 Packaging for the ready-made meal

Packaging specification	**Meal packaging**[a]	**Crate**[b]	**Box**[c]	**Euro pallet**[d]	**Shopping bag**[e]
Material					
Polyethylene film (kg)	0.01	-	-	-	-
Polyethylene terephthalate (kg)	0.025	-	-	-	-
Cardboard (kg)	0.015	-	0.365	-	-
Polypropylene (kg)	-	2.8	-	-	-
Low-density polyethylene (kg)	-	-	-	-	0.01
Wood (kg)	-	-	-	21	-
Weight per unit (kg)	-	20	8	750-1000	4.5
Units per pallet (number)	-	32	70	-	-
Re-use rate (number)	-	1000	-	1000	-

[a] Data source: Meal manufacturer
[b] Data source: Brunel University (2006) and Solent Plastic (2013). Crate volume: 26.5 l
[c] Data source: Brunel University (2006) and Packaging Calculator (2013)
[d] Data source: Brunel University (2006) and Fox's Pallets (2013)
[e] Data source: Brunel University (2006)

2.2.8 *Transport*

The transport assumptions are summarised in Table 12. All road transport is by diesel vehicles, assuming an empty return trip. The exception to this is consumer's car which is run on petrol. The chicken imported from Brazil (used in one of the scenarios discussed later in the paper) is shipped to the UK by a bulk carrier. Refrigerated or frozen transport is considered as appropriate and the assumptions for the refrigerant are given in Table 13.

2.3 Data sources

The data sources are summarised in Table 14. As shown, most data for the ingredients correspond to their country of origin considered in this study. The exceptions are the data for carrots and onions which are not available for the UK so that Danish data have been used instead (Nielsen et al., 2003). Furthermore, data for peas are also not available so that proxy data for green beans have been used following recommendations by Milà i Canals et al. (2011) on dealing with data gaps in the food sector. No data were available for organic onions and peas so that only conventional produce is considered in the organic version of the meal.

As also indicated in Table 14, the LCA data for wastewater treatment and waste management sourced from Ecoinvent (2009) are for the Swiss conditions as the inventory data for UK are not available.

2.4 Allocation

Allocation was necessary in the manufacturing stage since several products are produced in the same factory and only annual operational data have been available from the manufacturer. The allocation has been carried out on a mass basis, related to the total annual production of the ready-made meals considered here, relative to the total production in the factory. Economic allocation was not possible owing to the confidentiality of cost data. Mass allocation was also used in the pre-processing and distribution stages to allocate the utilities and refrigerant use as well as between the chicken meat and bone meal. System expansion was used to credit the system for using vegetable waste from pre-processing to displace animal feed, an option considered within the sensitivity analysis.

Table 11 Packaging for tomato paste

Packaging specification	**Can**[a]	**Drum**[b]	**Bag**[c]
Material			
Tinplate (kg)	0.065	-	-
Glass (kg)	-	-	-
Stainless steel (kg)	-	27.13	-
Low-density polyethylene (kg)	-	-	0.5
Units per box (number)	24	-	-
Units per pallet (number)	80	4	16

[a] The can contains 400 g of tomato paste

[b,c] Data source: FAO (2009) and EC (2006)

Table 12 Transport distances

Stage	**Country of origin**	**Distance and transportation mode**	**Vehicle**[a]
To farm			
Fertilizer, pesticides, etc.	UK	100 km by road	Truck, 7.5-16 t
From farm to RDCm/slaughterhouse			
All ingredients [a]	UK	200 km by road	Truck, 32 t
Tomato paste	Spain	1300 km by road to the UK	Truck, 32 t
Chicken	Brazil[b]	10,000 km by sea to the UK	Transoceanic freight ship
		400 km by road from Brazilian farm to harbour and from UK harbour to meal manufacturer or retailer	Truck, 32 t
From RDCm/slaughterhouse to manufacturer or retailer	UK	100 km by road	Truck, 32 t
From manufacturer to RDCp[c]	UK	100 km by road	Truck, 32 t
From RDCp to retailer[c]	UK	100 km by road	Truck, 32 t
From retailer to consumer's home[d]	UK	7.5 km by road	Petrol car
From consumer's home to waste treatment[d]	UK	25 km by road	Articulated lorry, 21 t

[a] All truck types assumed to be Euro 5

[b] Considered in one of the scenarios

[c] Data on refrigerated transport from Brunel University (2006)

[d] Assumption based on Pretty et al. (2005)

Table 13 Refrigerant used for refrigerated transport

	Chilled (mg/meal)	Frozen (mg/meal)
Refrigerant charge (R134a)	5.77	6.35
Refrigerant leakage	1.36	1.5

[a] Trucks operate 250 days/yr for 10 hr/day. The average leakage rate: 23.6%. Data source: Brunel University (2008).

Table 14 Overview of sources of life cycle inventory data used in the study

Stage	Detail	Life cycle inventory data	Data specific to country
Raw materials	British conventional & organic chicken	Williams et al. (2006)	UK
	Brazilian conventional chicken	Da Silva et al. (2010)	Brazil
	British conventional & organic tomatoes	Williams et al. (2006)	UK
	Spanish conventional tomatoes	Anton et al. (2005)	Spain
	British conventional & organic carrots	Nielsen et al. (2003)	Denmark
	British conventional onions	Nielsen et al. (2003)	Denmark
	British conventional peas[a]	Milà i Canals et al. (2008)	UK
	Tomato paste	EC (2006); FAO (2009)	Spain
	Slaughterhouse	Nielsen et al. (2003)	Denmark
	Polypropylene crate	Brunel University(2008)	UK
	Shopping bags	Brunel University (2008)	UK
	Cardboard box	Brunel University (2008)	UK
	Pallet	Brunel University (2008)	UK
RDCm	Fresh pre-processing	Brunel University (2008); EC (2006)	UK
	Frozen pre-processing	Brunel University (2008); EC (2006)	UK
Manufacturing	Ready-made meal	UK manufacturer 2010[b]	UK
	Emissions from food manufacture	EC (2006)	EU
RDCp	Energy consumption	Brunel University (2008)	UK
Retail	Supermarket details	Brunel University (2008)	UK
Consumption (meal preparation)	Microwave and oven electricity; water consumption	Jungbluth (1997); Defra (2008b&c); Ecoinvent (2009)	UK
Wastewater	Waste treatment sewage	Ecoinvent (2009)	CH
Waste management	Food landfilling	Ecoinvent (2009)	CH
	Landfill of cardboard, packaging	Ecoinvent (2009)	CH
	Landfill of wood	Ecoinvent (2009)	CH
	Landfill of plastics (PP, HDPE)	Ecoinvent (2009)	CH
	Landfill of metal (tin)	Ecoinvent (2009)	CH
Transport	Road transport (diesel vehicles)	Ecoinvent (2009)	EU
	Bulk sea carrier	Ecoinvent (2009)	EU
	Refrigerated transport	Brunel University (2008)	EU

[a] Green beans used as proxy owing to a lack of data

[b] Confidential

2.5 Scenarios

To examine the influence of different parameters on the environmental impacts, several scenarios have been developed for the ready and home-made meals. As shown in Table 15, the ready-made meal scenarios RM-1 to RM-8 assume that the ingredients are sourced from conventional farms in the UK, except for the tomato paste, which is imported from Spain (FAO, 2009). The difference between these scenarios is that they consider either fresh or frozen ingredients; fresh or frozen meal; and meal cooking at home in a microwave or an electric oven. The remaining three ready-made meal scenarios (RM-9 to RM-11) consider respectively the effect of ingredient sourcing by substituting the British chicken with the Brazilian, Spanish with the British tomatoes for the tomato sauce, and conventional with organic ingredients.

The reason for considering the Brazilian chicken in particular is that Brazil is the largest chicken-meat exporter worldwide (FAOstat, 2011) and the fourth exporter of processed chicken meat to the UK with 21,456 tonnes exported in 2012 (BPEX, 2013). Regarding the tomato sauce, although the majority of tomato paste used for the sauce is imported into the UK from Spain (FAO, 2009), scenario RM-10 explores how the impacts change if domestic tomatoes are used instead. Finally, organic ingredients are considered as there is a growing market for organic produce in the UK (Soil Association, 2013) which is gradually starting to be reflected in the ready-meals market (Key Note, 2013). The data sources for these scenarios are summarised in Table 14. Note that in the meal with the organic ingredients, peas and onions are from conventional farms owing to a lack of data for organic production.

Four scenarios are considered for the home-made meal (Table 16). Scenario HM-1 is similar to RM-1, assuming that all the ingredients are sourced from conventional farms and that they are cooked fresh with the chicken roasted in an electric oven and the vegetables and tomato sauce prepared on an electric hob; the tomato sauce is made from the Spanish ready-made tomato paste. HM-3 is exactly the same and HM-1, except that the vegetables and tomato sauce are cooked in a microwave. On the other hand, HM-2 assumes the use of all-British organic ingredients and preparation of tomato sauce from fresh tomatoes. The fourth, HM-4, scenario is the same as HM-1 but here the British chicken is replaced by the Brazilian.

Table 15 Scenarios for the ready-made meal

Scenario	**Raw materials**	**Pre-processing**	**Manufacture & distribution**	**Consumption (meal preparation)**
RM-1	Chicken & vegetables: British, conventional Tomato paste: Spanish tomatoes, conventional	Fresh (chilled)	Fresh (chilled)	Microwave
RM-2	As RM-1	Fresh (chilled)	Fresh (chilled)	Oven
RM-3	As RM-1	Fresh (chilled)	Frozen	Microwave
RM-4	As RM-1	Fresh (chilled)	Frozen	Oven
RM-5	As RM-1	Frozen	Fresh (chilled)	Microwave
RM-6	As RM-1	Frozen	Fresh (chilled)	Oven
RM-7	As RM-1	Frozen	Frozen	Microwave
RM-8	As RM-1	Frozen	Frozen	Oven
RM-9	Chicken: Brazilian, conventional All other ingredients: as in RM-1	As RM-1	As RM-1	As RM-1
RM-10	Tomato paste: British tomatoes, conventional All other ingredients: as in RM-1	As RM-1	As RM-1	As RM-1
RM-11	Chicken, carrots, potatoes: British, organic[a] All other ingredients: as in RM-1	As RM-1	As RM-1	As RM-1

[a] Organic is defined as a system that avoids the use of artificial fertilizers and pesticides using crop rotation and other forms of husbandry to maintain soil fertility. The weed, pests and diseases control is made through appropriated husbandry techniques and where necessary pests and disease are control with permitted materials (Defra 2014).

Table 16 Scenarios for the home-made meals

Scenario	**Raw materials**	**Pre-processing**	**Distribution**	**Consumption (preparation)**
HM-1	Chicken & vegetables: British, conventional Tomato paste: Spanish tomatoes, conventional	Fresh (chilled)	Fresh (chilled)	Chicken roasted in electric oven; vegetables and ready-made tomato sauce cooked on electric hob
HM-2	Chicken, potatoes, tomatoes and carrots: British, organic Onions and peas: British,	As HM-1	As HM-1	As HM-1 with tomato sauce made from fresh tomatoes

	conventional			
HM-3	As HM-1	As HM-1	As HM-1	Vegetables and ready-made tomato sauce cooked in microwave; chicken as HM-1
HM-4	Chicken: Brazilian, conventional All other ingredients: as HM-1	As HM-1	As HM-1	As- HM-1

3 Results and discussion

This section first presents the environmental impacts of the ready-made meal for different scenarios. This is followed by an equivalent discussion for the home-made meal in section 3.2. Next, the environmental impacts of the two types of meal for different scenarios are compared and discussed in section 3.3. Finally, in section 3.4, a sensitivity analysis is performed to examine the influence of some further parameters on the impacts of the two types of meal. The impacts have been estimated according to the CML 2011 method (Guinée et al., 2002) using Gabi LCA software V4.4 (GaBi 2011).

3.1 Ready-made meal

The environmental impacts of the ready-made meal for different scenarios are presented in Figure 4-Figure 6. The results comparing the influence of different refrigeration and cooking options (scenarios RM-1 to RM-8 and RM-11) indicate that the best option for most impacts is scenario RM-3, which corresponds to the frozen meal made with fresh (chilled) conventionally-farmed ingredients and cooked in a microwave (Figure 4). The effect on the impacts of ingredient sourcing (RM-9 and RM-10) is mixed. These results are discussed in more detail below.

3.1.1 Influence of refrigeration and cooking (scenarios RM-1 to RM-8)

3.1.1.1 Global warming potential (GWP)

As shown in Figure 4a, the lowest GWP of 2.4 kg CO_2 eq./meal is estimated for the frozen microwaved meal (RM-3 and RM-7). The highest impact of 3.6 kg CO_2 eq. is found for the oven-cooked meal, regardless of whether the ingredients or the meal are fresh or frozen (RM-2, RM-4, RM-6 and RM-8). Therefore, cooking of the meal at home is the most important differentiating factor for the GWP of the considered ready-made meal with the GWP of oven-cooking the frozen meal (RM-4 and RM-8) being 6.5 times higher than microwaving the chilled meal (RM-1 and RM-5). Another differentiator, although to a smaller extent than cooking, is whether the meal is chilled or frozen with the former having a 15% higher GWP (2.9 g CO_2 eq. for RM-5) than the latter (2.4 kg CO_2 eq. for RM-3 and RM-7) for the same cooking method at home. This is due to the higher usage and leakage of refrigerants during storage of the chilled meal at retailer (see Table 6) because they are kept in open refrigerators while frozen meals are stored in closed display cabinets. Hence, despite much longer storage times of the frozen meals, the refrigerant consumption and leakage are much higher for the chilled meals, leading to a higher GWP. A further reason is the higher amount of waste in the chilled chain compared to the frozen (see Table 4).

The main contributor to the GWP across all the scenarios is the ingredients contributing on average 42% (Figure 4a). As illustrated by the example of RM-1 in Figure 5, among the ingredients, chicken contributes the majority of GWP (82%), mainly from the chicken feed and the chicken manure.

The next largest contributor is the tomato paste (9%), largely because of its manufacture and transport to the UK from Spain. The total contribution of the vegetables is small (6%).

3.1.1.2 Abiotic depletion potential (ADP)

The results for the depletion of elements and fossil resources are presented in Figure 4b&c.

$\underline{ADP_{elements}}$: There is little difference between the scenarios for this impact which ranges from 5.0-5.2 g Sb eq./meal with the frozen meals being slightly better than the chilled. This is because there is more waste in the supply chain of the chilled meal (Table 4) requiring overall a higher amount of raw materials, which contribute the large majority (>99%) to the depletion of elements (see Figure 2b). However, the results for this impact should be treated with caution throughout the paper owing to limited data availability for the $ADP_{elements}$ for some of the ingredients.

$\underline{ADP_{fossil}}$: A similar trend is noticed for fossil fuel depletion as for the GWP but the lowest value (16.5 MJ/meal) is now found for the chilled meal RM-1 and the highest for the frozen RM-8 (34 MJ). However, the contribution of the life cycle stages is slightly different compared to the GWP: here, the consumption contributes on average 36%, followed by the meal manufacture (26%). Packaging and distribution add further 16% and 8%, respectively. Unlike the GWP, the contribution of raw materials is small (8%) as is that from pre-processing (5%) and disposal (1%).

3.1.1.3 Acidification potential (AP)

The lowest AP is for RM-7 (45.3 g SO_2 eq./meal) and the highest for RM-4 (49.6 g SO_2 eq./meal). This impact is also mainly from the raw materials which contribute around 90% across all the scenarios (Figure 4d). This is due to the fertilisers and pesticides used for the cultivation of vegetables as well as the chicken feed and manure. The rest of the impact is contributed by the consumption stage (5%) and meal manufacture (2.6%), with the remaining stages contributing less than 2% each. The main difference for this impact between the different scenarios is related to the preparation of the meal, with oven cooking of the frozen meal having around 8% higher total AP than for the microwaved meal; the equivalent difference in the options for the chilled meal is 5%.

3.1.1.4 Eutrophication potential (EP)

Similar to the $ADP_{elements}$, there is little difference in this impact between the eight scenarios considered. It ranges between 15.3 g PO_4 eq./meal for RM-3 and 16.2 g PO_4 eq. for RM-6, suggesting that neither the fresh or frozen options nor the different cooking methods influence this impact significantly (see Figure 4e). The main contribution is from the raw materials (~74%), mainly due to the agricultural stage, particularly from fertilisers and chicken manure.

The other two significant stages are post-consumer waste disposal (~10%), mainly because of the landfilling of the waste food and packaging. Pre-processing and manufacture contribute 7% and 5%, respectively; the contribution of the remaining stages is small (<2%).

3.1.1.5 Freshwater aquatic ecotoxicity potential (FAETP)

As shown in Figure 4f, the lowest FAETP of 602.3 g DCB eq./meal is found for RM-3 and the highest for RM-6, equal to 653.2 g DCB eq. Waste disposal contributes most to this impact, on average 38% across all the scenarios. Manufacture and raw materials are responsible for 20% each and pre-processing for 14%. Although the contribution of both distribution and consumption is small (5% and 3%, respectively), these two stages are the main source of the difference in this impact between the scenarios, with the impact from the other stages being quite similar across the different meal options.

3.1.1.6 Human toxicity potential (HTP)

This impact ranges from 254.5 g DCB eq./meal for RM-3 to 382.9 g for RM-8 (Figure 4g). The consumption stage is the main source of the HTP, contributing around 33%, largely because of the life cycle of electricity used for cooking. For example, the HTP for oven preparation of the chilled meal (RM-1 and RM-5) is 23% higher than for the microwave cooking (RM-2 and RM-6). This difference increases to 32% for the frozen meals. The remaining impact is from manufacturing (17%), disposal (15%) and packaging (12%). Finally, the raw materials contribute 11% with pre-processing and distribution contributing 6% each.

3.1.1.7 Marine aquatic ecotoxicity potential (MAETP)

As shown in Figure 4h, the MAETP increase from 0.6 t DCB eq. for the microwaved meals (RM-1, RM-3, RM-5 and RM-7) to 1.3 t DCB eq./meal for the frozen oven-cooked meals (RM-4 and RM-8).

The consumption stage is responsible on average for 31% of this impact, mainly because of the electricity. Therefore, similar to the effect on the HTP, all the scenarios with microwaving have a 41% lower impact for the chilled meals and 52% for the frozen meals, relative to oven cooking. The next largest contributors are meal manufacture with 24% and post-consumer waste disposal with 19%. Pre-processing and distribution are each responsible for 8% while the raw materials and packaging add 5% and 4%, respectively.

3.1.1.8 Ozone layer depletion potential (ODP)

The ODP is only sensitive to one parameter – whether the meal is chilled or frozen. It is 11 times higher for the chilled than frozen meal, increasing from 1.5 mg R11 eq./meal to 16.7 mg (Figure 4i). This is because the distribution stage contributes ~95% to the ODP in the chilled-meal chain.

The main reason for this is the manufacturing of R134a – although the refrigerant itself has a zero ODP, other refrigerants used in its manufacture are ozone-depleting substances, particularly R113, R12 and R124 (Ecoinvent, 2010). The other stages contribute less than 2%.

3.1.1.9 Photochemical ozone creation potential (POCP)

This impact ranges from 2.4 g C_2H_4 eq./meal for the frozen microwaved meal (RM-3 and RM-7) to 2.7 g for the frozen oven-cooked meal (RM-4 and RM-8; see Figure 4j). Around 70% of the POCP is due to the ingredients and in particular chicken rearing. The next significant stage and the main differentiating parameter between the scenarios is the consumption stage, contributing 8% for the chilled and 16% for the frozen meal, owing mainly to the electricity used to cook the meal. This is followed by meal manufacturing (~7%), packaging (~4%), pre-processing and distribution (~3% each), all largely related to the energy use.

3.1.1.10 Terrestrial ecotoxicity potential (TETP)

As shown in Figure 4k, the best options for this impact are again the scenarios in which the frozen meal is microwaved, estimated at around 46.9 g DCB eq./meal (RM-3 and RM-7). This is 8% lower than the frozen meal prepared in the conventional oven for which the impact is equal to 50.9 g DCB eq./meal (RM-4 and RM-8). With an average contribution of 89%, the ingredients are the main hotspot for all the scenarios; this is due to the pesticides used in the agricultural stage, particularly in the life cycle of oil. The next contributing stage is consumption with up to 10% for the frozen meal, largely because of the life cycle of electricity used for meal preparation. The contribution of the remaining stages is insignificant.

3.1.2 Influence of ingredient sourcing (scenarios RM-9 to RM-11)

This section consideres the effect on the impacts of different ingredient-sourcing options: replacement of the chicken rared in the UK with that imported from Brazil (RM-9), use of British instead of Spanish tomatoes for the tomato sauce (RM-10) and substitution of conventionally-cultivated with organic ingredients (RM-11). All three scenarios are assumed to be the same as RM-1 except for the difference in the source of the ingredients, respectively.

3.1.2.1 Brazilian vs British chicken

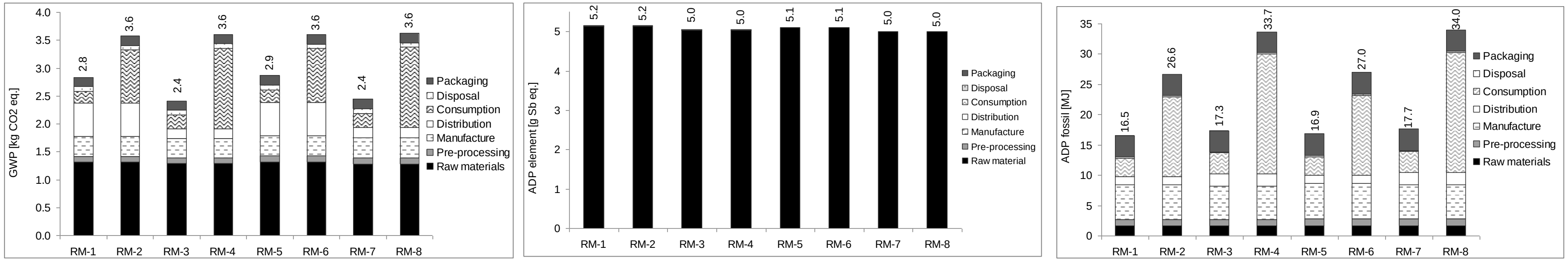
As indicated in Figure 6, replacing British with the Brazilian chicken (RM-1 vs RM-9 scenarios) results in an improvement of four impacts, despite the long-distance transport: the GWP is reduced by 32%, the AP by 75% and the EP and POCP by about 60%. This is due to the lower impacts from chicken rearing for the Brazilian chicken compared to the British. The scenario with the latter option (RM-1) is better marginally for only two impacts: the HTP and TETP, which are lower by 2%. The reason for this is the avoidance of transportation from Brazil and lower impacts from British chicken rearing.

The two options are almost identical for the remaining impacts as they are mainly from the consumption, distribution and manufacturing stages which are not influenced by chicken sourcing. Thus on balance, using the Brazilian chicken may be environmentally a better option than using the British chicken, despite the long-distance transport.

3.1.2.2 Spanish vs British tomatoes

As can be seen in Figure 6, the Spanish tomato paste (RM-10) is better for five impacts with the remaining impacts being quite similar between the two options. The greatest difference in favour of Spanish paste is found for the $ADP_{elements}$ (86%), EP (39%), GWP (24%), AP (11%) and POCP (6%).

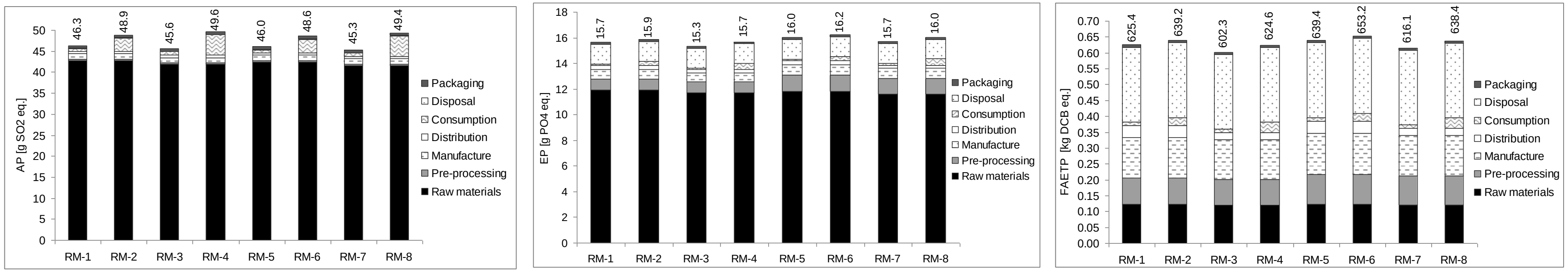
There are two main reason for this: different use of fertlisers to grow the tomatoes in the two countries and the use of electricity for heating greenhouses, where the majority of tomatoes are grown in the UK. Therefore, based on these results, scenario RM-1 using the Spanish tomato paste is arguably a better option, regardles of the transport from Spain. These findings, together with the those for the Brazilian chicken discussed in the previous section, provide a further illustration that ‘food miles’ typically do not contribute much to the impacts of food and that other life cycle stages are often much more significant.



a) Global warming potential (GWP100)

b) Abiotic depletion potential ($\text{ADP}_{\text{elements}}$)

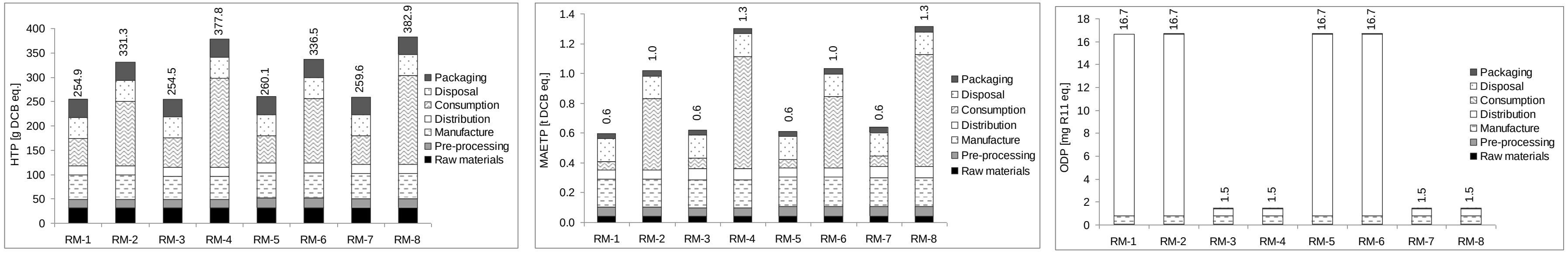
c) Abiotic depletion potential ($\text{ADP}_{\text{fossil}}$)



d) Acidification potential (AP)

e) Eutrophication potential (EP)

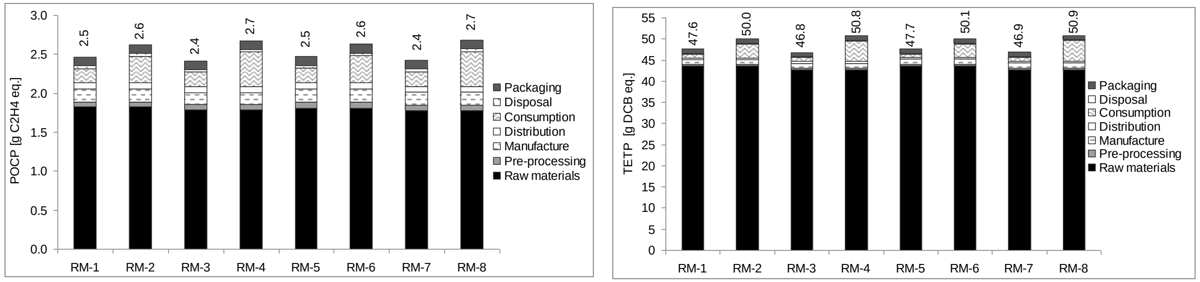
f) Freshwater aquatic toxicity potential (FAETP)



g) Human toxicity potential (HTP)

h) Marine aquatic ecotoxicity potential (MAETP)

i) Ozone layer depletion potential (ODP)



j) Photochemical ozone creation potential (POCP)

k) Terrestrial ecotoxicity potential (TETP)

Figure 4 Environmental impacts of the ready-made meal for different scenarios showing life cycle contributions

[All impacts expressed per meal. For scenario descriptions, see Table 15]

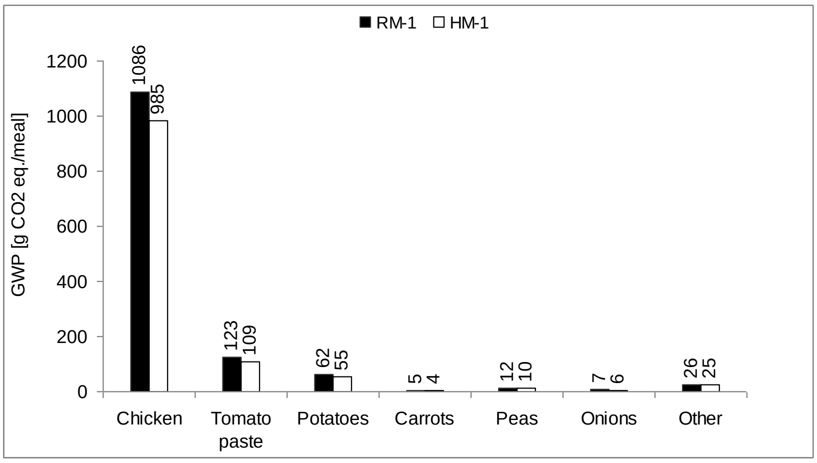


Figure 5 Contribution of the ingredients to the GWP of the ready (RM-1) and home-made (HM-1) meals

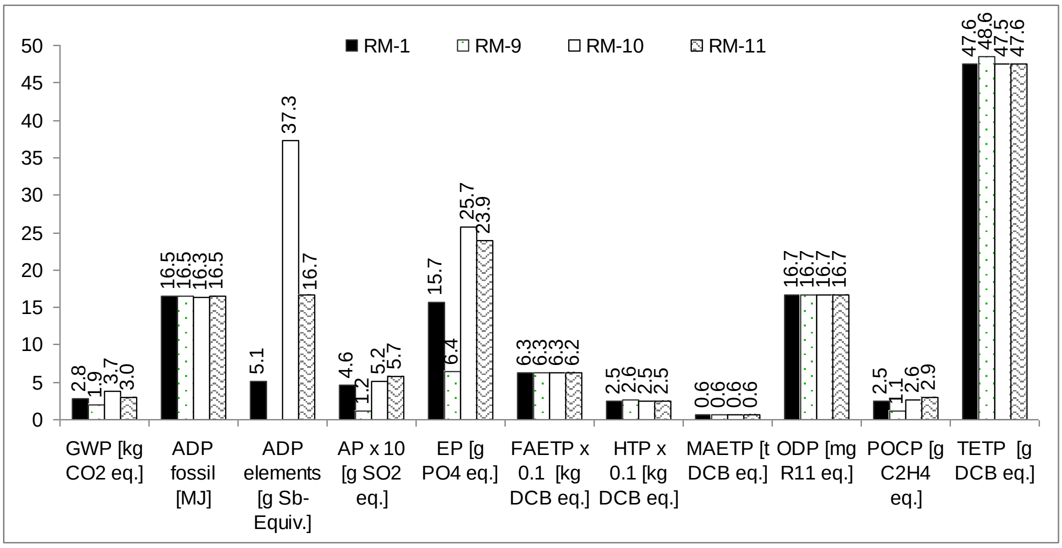


Figure 6 The influence of ingredient sourcing on the environmental impacts of the ready-made meal

[All impacts expressed per meal. $ADP_{elements}$: Abiotic depletion potential for elements; ADP fossil: Abiotic depletion potential for fossil fuels; AP: Acidification potential; EP: Eutrophication potential; FAETP: Freshwater aquatic ecotoxicity potential; GWP: Global warming potential (100 years); HTTP: Human toxicity potential; MAETP: Marine aquatic ecotoxicity potential; ODP: Ozone depletion potential; POCP: Photochemical oxidant creation potential; TETP: Terrestrial ecotoxicity potential. $ADP_{elements}$ for the Brazilian chicken is not shown owing to a lack of data. Some impacts have been scaled to fit. The original values can be obtained by multiplying with the factor shown in brackets against the relevant impacts.]

3.1.2.3 Conventional vs organic ingredients

Comparing conventional (RM-1) and organic ingredients (RM-11) in Figure 4 indicates that using the latter leads to an increase in five impacts, with the remaining six impacts being similar between the two meal options. In particular, the greatest increase is found for the $ADP_{elements}$ (69%), followed by the EP (35%), AP (19%) and POCP (15%). The GWP also goes up by ~5%. The lower yield in the organic production systems is the main reason for the higher impacts for RM-11. Therefore, the meal with the conventional ingredients appears to be environmentally a better option.

3.2 Home-made meal

Figure 7 shows the environmental impacts of the home-made meal HM-1 with the contribution of different life cycle stages given in Figure 8. As indicated in Figure 8, unlike the equivalent ready-made meal RM-1, the contribution to the impacts is quite different for HM-1: as there is no manufacturing and little pre-processing of the ingredients before they reach the retailer and then the consumer, the majority of the impacts are from the ingredients and the consumption stage. The exceptions to this are FAETP which is largely due to post-consumer waste disposal and ODP which is from the distribution stage.

As shown in Figure 9, using organic ingredients (HM-2) instead of conventional (HM-1) has a similar effect on the impacts as seen for the organic ready-made meal RM-11 (see the previous section). Specifically, the GWP increases from 2.3 kg CO_2 eq. to 2.4 kg CO_2 eq. The other affected impacts are the $ADP_{elements}$ which goes up by 72%, AP by 20%, EP by 40%, HTP by 4% and POCP by 16%. Again, the main reason for the higher impacts is the lower yield of the organic produce compared to the conventionally-cultivated ingredients. The change in the remaining impacts is small (<2%).

Figure 7 also reveals that cooking the vegetables on the hob (HM-1) has higher impacts than cooking in the microwave (HM-3). The greatest improvements are found for the GWP (13%), ADP fossil (26%), HTP (16%) and MAETP (26%). The other impacts improve on average by 2%. These changes in the results are congruent with the contribution to these impacts of meal preparation in the consumption stage (see Figure 8).

The meal with the Brazilian chicken (HM-4) also leads to improvements in the impacts: the GWP is lower by 31%, AP by 68%, EP by 59% and POCP by 55%. The TETP and HTP are higher, however, by 3% and 6%, respectively. The remaining impacts are largely unaffected. A similar pattern was found for the ready-made meal, as discussed in the previous section.

Therefore, it can be concluded from these results that preparing the home-made meal using the Brazilian chicken and cooking the conventionally-grown vegetables in the microwave is the best option environmentally – these represent a combination of best options from scenarios HM-3 and HM-4.

3.3 Comparison of ready and home-made meals

The environmental impacts of the ready and home-made meals are compared in Figure 9 for the best options for the ready-made meal (RM-3 and RM-9) and for the home-made meal prepared in a conventional way (HM-1 and HM-4) rather than using microwave as this is a more prevalent practice in the UK for home cooking. For reference, the results for the home-made meal with organic ingredients (HM-2) are also shown.

The results indicate that the impacts of preparing the meal at home using conventionally-cultivated ingredients (HM-1) are lower than for the equivalent ready-made meal (RM-3) for ten out of the 11 impacts considered. The greatest improvement is found for the ODP which is 3 times lower with the remaining eight impacts reduced from 6% (GWP) to 28% (FAETP). The main reason for the reduction in the impacts is the avoidance of manufacturing and the related waste as well as fewer storage stages in the life cycle of the home-made meal. However, the MAETP is higher by 7% because of the higher electricity consumption for the preparation of the home meal compared to the ready-made.

A similar trend is found when the home-made meal with the Brazilian chicken (HM-4) is compared with the ready-made meal (RM-3), but the improvements for some of the impacts are much greater. For example, the GWP is 35% lower for the home-made meal; the AP, EP, ODP and POCP are all lower by around 3 times. Again, the only impact that is worse for the home-made meal is MAETP which is 8% higher.

However, a different trend is observed when the home-made meal with the British ingredients (HM-1) is compared to the ready-made meal prepared with the Brazilian chicken (RM-9). In this case, the ready-made meal is a better option for five impacts: the GWP, AP, EP, MAETP and POCP. The difference in the impacts ranges from 9% for the MAETP to 3.6 times for the AP. This is largely due to the differences in the agricultural impacts related to the British and Brazilian chickens. However, the meal prepared at home is a better option for the ADP_{fossil} (7% lower), FAETP (30%), HTP (26%), ODP (34 times lower) and TETP (7%), for the same reasons explained for the comparison with RM-3. Moreover, when both types of meal are prepared with the Brazilian chicken (RM-9 and HM-4), the home-made option has eight impacts lower than the ready-made meal; the largest reduction is found for the ODP, with a 34 times lower value. The other impacts are lower by between 4% for the ADP_{fossil} and TETP to 30% for FAETP. However, two impacts are higher for the home-made meal: AP by 12% and MAETP by 10%.

If, on the other hand, the organic home-made meal (HM-2) is compared to the ready-made meal (RM-3) the picture is mixed, with each being better for half the impacts considered. For example, the home-made meal has lower FAETP and HTP lower by 28% and 21%, respectively, but the ready-made meal has a 3 times lower $ADP_{elements}$. A similar trend is found when comparing the ready-made meal with the Brazilian chicken (RM-9) and the organic home-made meal (HM-2). The ready-made meal has 18% lower GWP and ~70% lower AP and EP. However, the ODP is still 34 time higher.

Therefore, these results suggest that the home-made meal using ingredients from conventional farms is a better option than the ready-made meal for most environmental impacts. Thus, it could be concluded that home-made meals are more sustainable environmentally than the ready-made, for the assumptions used in this study.

Among the home-made meal options, the one with the Brazilian chicken (HM-4) has the lowest GWP (1.6 kg CO_2 eq./meal; see Figure 9), one of the main policy drivers in the UK and Europe. This meal cooked in a microwave instead in the electric oven and the hob would be a better option still. However, that would require significant changes in consumer lifestyle, cooking habits and abilities as well as taste, the consideration of which is outside the scope of this paper.

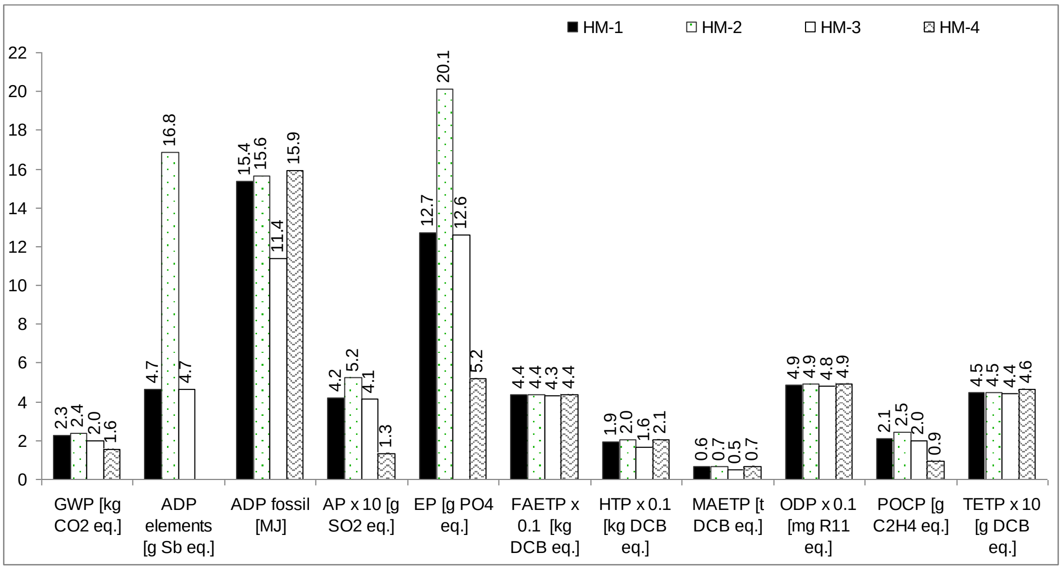


Figure 7 Environmental impacts of the home-made meal for different scenarios

[All impacts expressed per meal. For impacts nomenclature, see Figure 6. $ADP_{elements}$ for the Brazilian chicken is not shown owing to a lack of data. Some impacts have been scaled to fit. The original values can be obtained by multiplying with the factor shown in brackets against the relevant impacts.]

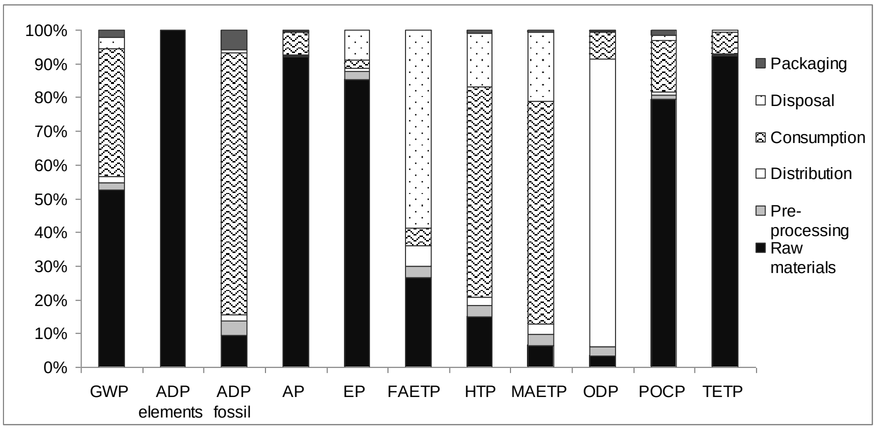


Figure 8 Contribution of the life cycle stages to the impacts of the home-made meal (scenario HM-1)

[For impacts nomenclature, see Figure 6.]

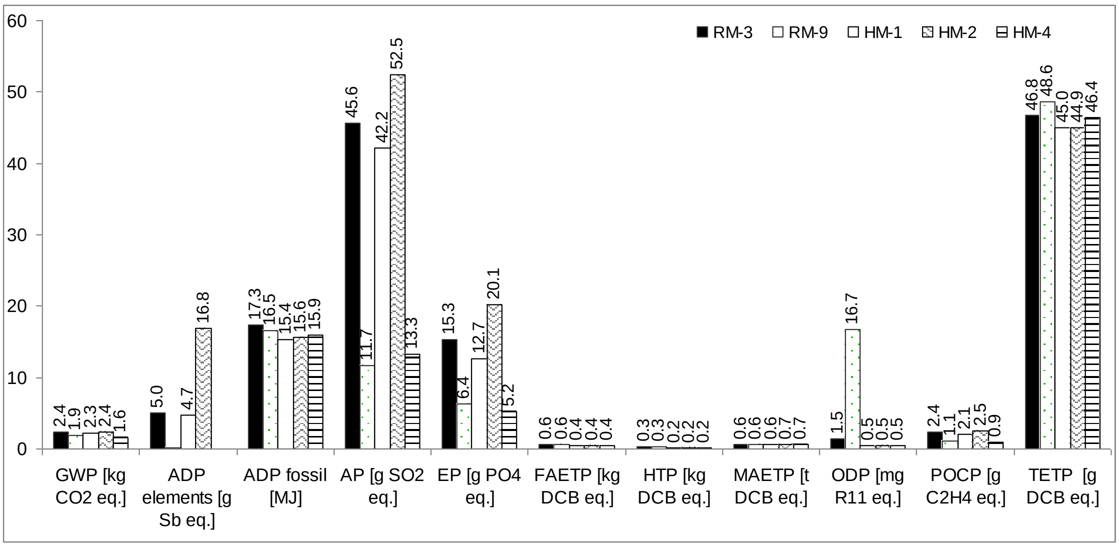


Figure 9 Comparison of environmental impacts of the ready and home-made meals

[All impacts expressed per meal. Note that ADP$_{\text{elements}}$ for the Brazilian chicken is not shown owing to a lack of data. For impacts nomenclature, see Figure 6.]

3.4 Sensitivity analysis

This section examines the effect on the results of some other parameters not considered in the scenarios that could potentially influence the results. This is carried out first for the ready-made meal and then for the meal prepared at home. The results are presented in Figure 10 to Figure 12, and are discussed below.

3.4.1 Ready-made meal

Sensitivity of the results for the ready-made meal is examined for the following parameters:

i) credits for vegetable waste from pre-processing for use as animal feed;

ii) energy efficiency in the manufacturing process;

iii) source of energy for the oven used by the consumer to cook the meal at home; and

iv) type of refrigerant used.

3.4.1.1 Credits for waste as animal feed

As mentioned in section 2.2.2, the vegetable waste from the pre-processing stage has been assumed to be landfilled. This section examines the influence of this assumption on the results by assuming that the waste is used as animal feed, replacing wheat as the most widely used feed in the UK (Defra, 2013).

The system has been credited for animal feed using two bases: mass and calorie content of the waste to displace the equivalent amount of wheat. The amount of vegetable waste generated in the pre-processing stage is equal to 33.82 g[1] so that the system has been credited for this amount of animal feed when using the mass basis. For the credits based on the calorie content, using the mass contribution of different vegetables (see Table 2) and their respective calorie content[2], the total calorie content of vegetable waste is estimated at 19.32 cal/kg. Taking into account the calorie value for the wheat[2], this amount of waste replaces 5.4 g of wheat per meal so that the system is credited for this amount of animal feed.

Scenario RM-1 is considered as an example and the results are compared to HM-1. As indicated in Figure 10, the effect on the results is small, with the impacts reducing on average by around 4% when the credits are made on the mass basis and 3% on the basis of calorie content. The greatest improvement is for the toxicity-related impacts and particularly the FAETP which is 12% lower. This is due to the avoidance of these impacts from wheat cultivation. However, even with these credits, the equivalent home-made meal (HM-1) still remains a better option across all the impacts except for the MAETP, as discussed before.

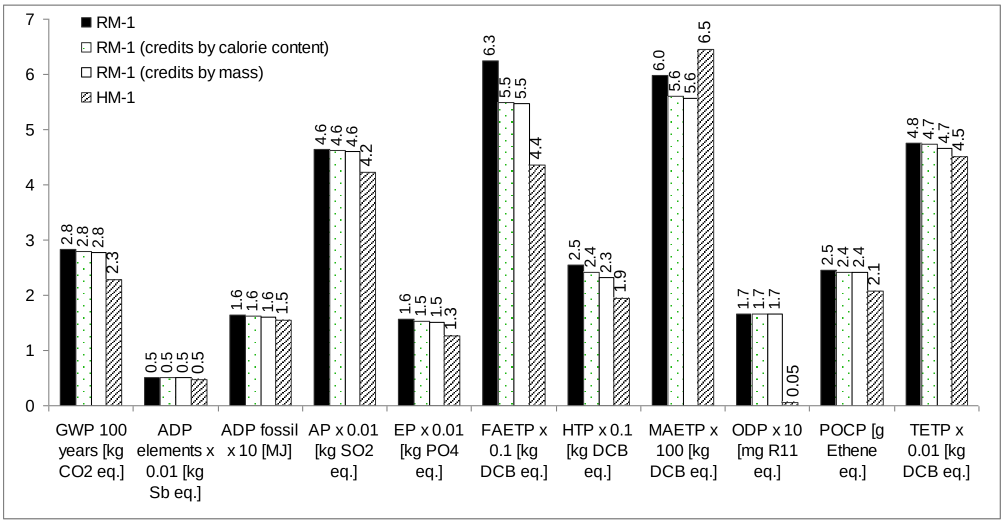


Figure 10 Sensitivity analysis for the ready-made meal: the influence of credits for waste from pre-processing used as animal feed

[All impacts expressed per meal. For impacts nomenclature, see Figure 4. Some impacts have been scaled to fit. The original values can be obtained by multiplying with the factor shown in brackets against the relevant impacts.]

3.4.1.2 Energy efficiency

Energy use in the manufacturing process can differ from producer to producer depending on the type and age of equipment. For this reason, different energy use values have been considered within the sensitivity analysis, ranging from 30% higher to 30% lower compared to the original

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[1] Based on the total amount waste in the life cycle of the meal given in

(excluding post-consumer waste), the total amount of vegetables needed per meal in the pre-processing stage is 259.32 g. Assuming 15% waste in that stage gives 33.82 g.

[2] Calorie content in kcal/100 g: potatoes: 58; onions: 44; carrots: 42; peas: 80.7; wheat: 358.

value assumed in the study (for the latter, see Table 5). The results given in Figure 11a indicate that the environmental impacts improve only slightly with the energy efficiency, on average by 2% across all the impacts. The highest effect is observed for the ADP_{fossil} which reduces by 8% for a 30% reduction in energy use.

This is followed by the MAETP and HTP which go down by 6% and 3%, respectively; the GWP is reduced by around 2%. The effect on the other impacts is small (<1%). Therefore, these findings suggest that the results of the study are robust with respect to the originally assumed energy use in the manufacturing process.

3.4.1.3 Electric vs gas ovens

In the UK, both electric and natural gas ovens are used widely. The study has assumed the use of electric ovens (see Table 7) so that the influence on the impacts of using gas ovens is considered here. These results are compared in Figure 11b and Figure 11c for the chilled (RM-2) and frozen meal (RM-4), respectively. As shown, the impacts are lower if natural gas is used instead of electricity. This effect is more pronounced for the frozen than the chilled meal, with the impacts reducing on average by 12% for the former and 18% for the latter. The greatest reduction is observed for the MAETP (44% and 55% for the chilled and frozen meal, respectively) and GWP (22% and 35%, respectively). The only two exceptions to this trend are the $ADP_{elements}$ and ODP which remain the same as these impacts are not affected much by the consumption stage (see Figure 11b&i).

3.4.1.4 Type of refrigerant

Refrigeration is an important contributor to some of the impacts from the ready-made meal, particularly the GWP and ODP. In this study, the refrigerants used are ammonia (in RDC), R22 (manufacturing) and R134a (retail and transportation). In order to analyse their effect on the impacts, three options are considered within the sensitivity analysis: only R134a or R22 are used; only R134a is used; and only R22 is used in the whole supply chain. As can be seen in Figure 9d, using only R134a increases the GWP by 4% and ODP by 16% compared to the base case (RM-1). The other impacts remain unchanged. When R22 is used instead, the impacts are reduced relative to the base case: the GWP by 10% and ODP by 62%. However, the MAETP goes up by 10% owing to the higher impact in the manufacture of this refrigerant. Similar to the option with R143a, the other impacts are unaffected.

3.4.2 Home-made meal

This section considers the effect on the environmental impacts of the source of energy used for cooking the meal and the provenance of tomatoes for the sauce. The following options are examined:

i) preparing the meal using gas appliances (oven and hob); and

ii) preparing the home-made tomato sauce using either Spanish or British tomatoes.

3.4.2.1 Gas vs electrical appliances

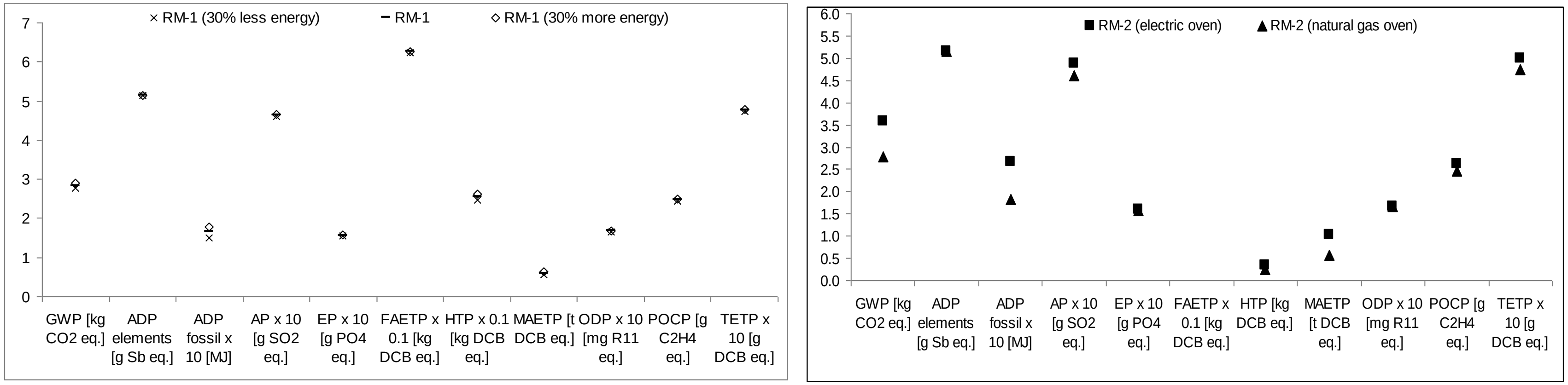
Figure 12a compares the impacts of using gas appliances to the base case which assumed the use of an electric oven and a hob (HM-1) or a combination of an electric oven and a microwave (HM-3) to cook the meal. As can be seen, the use of natural gas reduces all impacts on average by 18% compared to HM-1 and by 12% compared to HM-3. The latter may at first look surprising as it would be expected that the microwave option has lower impacts than gas but HM-3 also uses an electric oven (for roasting the chicken) which has higher impacts than the gas. The biggest improvements in both cases are found for the GWP (31% and 21% compared to HM-1 and HM-3, respectively), ADP_{fossil} (46% and 27%), HTP (38% and 26%) and MAETP (62% and 49%).

Therefore, using gas appliances would make home-made meal even more environmentally sustainable than the ready-made meal with the impacts being on average lower by 33% relative to the best option (RM-3).

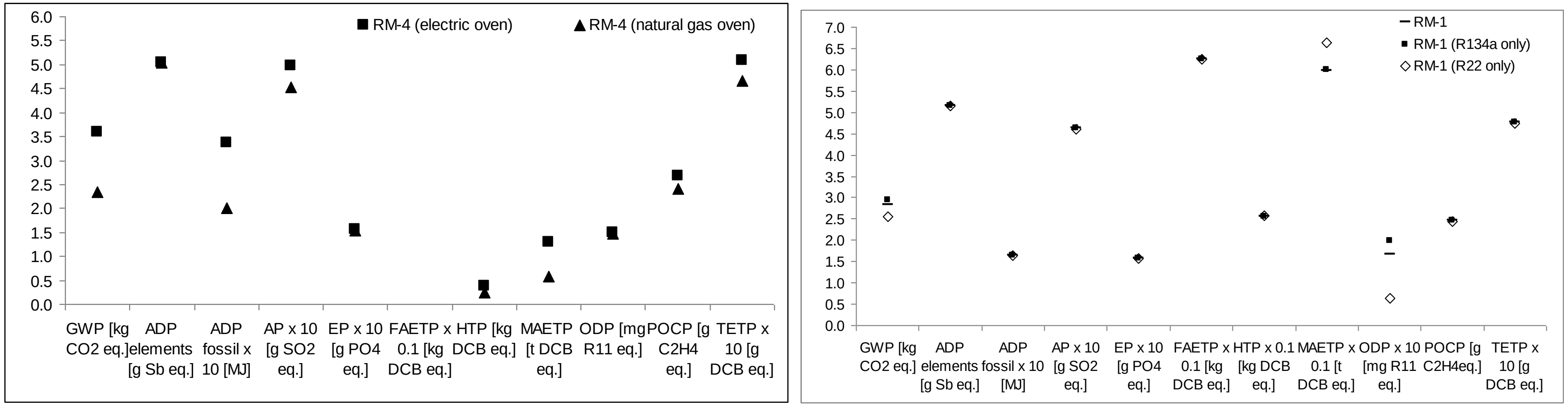
3.4.2.2 Home-made tomato sauce from British vs Spanish tomatoes

For the purposes of this sensitivity analysis, HM-2 scenario is considered as it involves home-made tomato sauce. However, it has been modified by replacing the organic with the ingredients sourced from conventional farming systems for comparability with HM-1, which assumes conventional ingredients and ready-made tomato sauce.

Substituting British tomatoes with the Spanish to make a home-made tomato sauce reduces four environmental impacts: the GWP by 15%, $ADP_{elements}$ by 78%, AP by 6% and EP by 29% (Figure 12b). This is due to the avoidance of electricity-heated greenhouses used to grow British tomatoes. The remaining impacts are largely unaffected, except for the HTP which increases by 18% owing to the difference in fertilisers used in the two countries. Comparison of the impacts between the ready-made tomato sauce (HM-1 in Figure 7) and that prepared at home (HM-2 with Spanish tomatoes in Figure 12b) reveals that there is little difference between the two options (<2%). Finally, the impacts from HM-2 with the Spanish tomatoes are on average 17% lower than for the best ready-made meal option (RM-3), except for MAETP which is 10% higher. A similar trend was found when comparing HM-1 with RM-3 (see Figure 9).



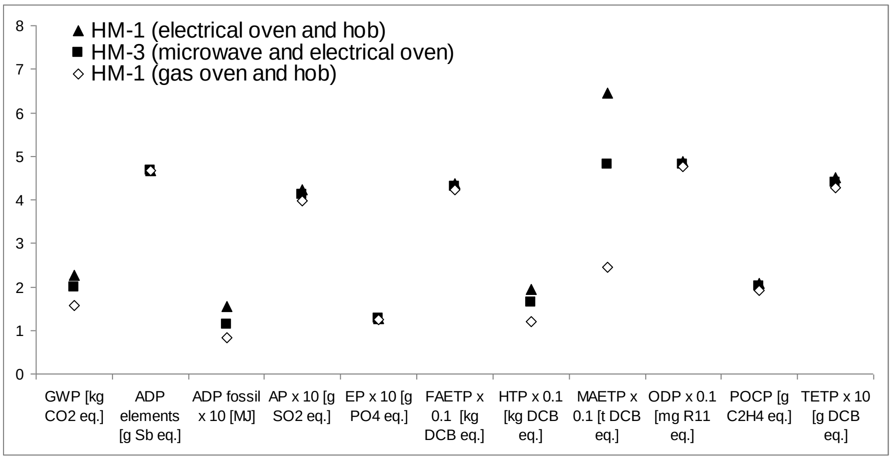
a) Influence of energy efficiency in the manufacture of chilled ready-made meal b) Influence of using gas or electricity oven to cook of chilled ready- made meal at home



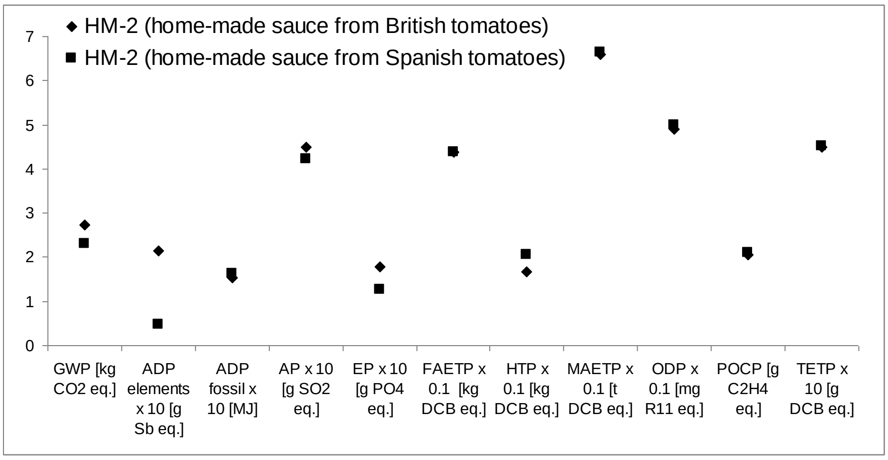
c) Influence of using gas or electricity oven to cook frozen ready-made meal at home d) Influence of the type of refrigerant

Figure 11 Sensitivity analysis for the ready-made meal

[All impacts expressed per meal. For impacts nomenclature, see Figure 4. For assumptions on energy use by appliances, see Table 7. Some impacts have been scaled to fit. The original values can be obtained by multiplying with the factor shown in brackets against the relevant impacts.]



a) Influence of using gas or electricity appliances to cook the home-made meal



b) Influence of using Spanish instead of British tomatoes to cook home-made tomato sauce

Figure 12 Sensitivity analysis for the home-made meal

[HM-2 has been modified from the original by substituting organic with conventionally-grown ingredients. For assumptions on energy use by appliances, see Table 8. All impacts expressed per meal. For impacts nomenclature, see Figure 4. Some impacts have been scaled to fit. The original values can be obtained by multiplying with the factor shown in brackets against the relevant impacts.]

4 Conclusions

This paper has compared the life cycle environmental impacts of a ready and home-made meal consisting of roast chicken meat, vegetables and tomato sauce. The results suggest that the impacts of preparing the meal at home from scratch are lower than for the equivalent ready-made meal. The main reasons for this are the avoidance of manufacturing, reduction in refrigerated storage and a lower amount of waste in the life cycle of the home-made meal.

For the ready-made meal options considered in the study, the lowest impacts are found for the frozen meal prepared from fresh ingredients and heated at home in a microwave. This is due to the higher usage and leakage of refrigerants during storage of the chilled meal at retailer because they are kept in open refrigerators while frozen meals are stored in closed cabinets.

The worst option for most impacts is the frozen meal with frozen ingredients that is heated in an electric oven. For some of the impacts, consumer choice of the heating method is the most important differentiating factor between the different ready-made meal options considered. For example, cooking the frozen meal in an electric oven has a 6.5 times higher GWP than microwaving the chilled meal. Another differentiator is whether the meal is chilled or frozen with the former having a 15% higher global warming potential than the latter for the same heating method. The type of refrigerant used in the supply chain also influences the results, with R22 being the best option for the global warming potential and ozone layer depletion but worst for marine ecotoxicity. The contribution of packaging is also important for some impacts, including GWP, depletion of fossil fuels and human toxicity.

In addition to the consumer choice of the cooking method, another hotspot for both types of meal is the ingredients. Using organic instead of conventional ingredients leads to higher impacts. Sourcing chicken and tomatoes from Brazil and Spain, respectively, reduces environmental impacts of the meals compared to sourcing them from the UK, despite the long-distance transport. This finding is in contrast to the concept of ‘food miles’ widely publicised in an attempt to encourage consumers to buy locally to help reduce the environmental impact of food. However, as the results of this work suggest, transport is not a significant contributor to the impacts and that, instead, the other life cycle stages mentioned above should be targeted for improvements.

Thus, this work demonstrates that producers, retailers and consumers could all play a role in reducing the environmental impacts of food by making more informed choices. In particular, producers should consider sourcing their ingredients taking into account a growing knowledge and information available on life cycle environmental impacts of different ingredients. Furthermore, both producers and retailers should work on reducing the amount of packaging and waste in the supply chain. Minimising refrigeration time and using low-impact refrigerants would also lead to environmental improvements. Retailers should also replace open with closed refrigerators – the concern that this may inconvenience and deter the consumer may be unfounded as closed display cabinets are becoming common practice in some countries. However, this ‘choice-editing’ may require a concerted action by retailers to ensure that the replacement is carried out across the sector to avoid potentially disadvantaging retailers who make the change compared to those who opt out.

Furthermore, consumers should consider preparing meals at home more often rather than buying ready-made food and cooking using gas instead of electrical hob and oven, or better still, using a microwave. One of the most significant behavioural changes needed, though, is reducing post-consumer waste – given that one third of food is thrown away globally, this is the single most important factor for reducing the environmental impacts of food. In the specific case considered here, a quarter of the meal is estimated to be wasted by the consumer which means that the impacts related to the ingredients would be reduced by a quarter just by avoiding this waste as the amount of raw materials required to make the meal would be that much lower. Unlike some other options, reducing consumer food waste should be relatively simple to achieve as it does not require lifestyle changes and has direct financial benefits for the consumer. However, most consumers do not make a connection between food waste and environmental impacts so that an intensive awareness-raising programme could help reduce the amount of post-consumer waste.

However, the above choices by the different actors will often be driven by other issues such as cost, availability, health, cooking abilities, taste, convenience and lifestyle. These are particularly important for consumers and, for most, the choice is unlikely to be either a home or a ready-made meal; conventional or organic ingredients; microwave or oven etc., but rather some combination of different options, depending on their individual circumstances. Nevertheless, it is important to understand the life cycle impacts of producer, retailer and consumer choices related to meals – currently, there is scant information available requiring much more research in this area.

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Chapter 3: Life Cycle Costs and Environmental Impacts of Ready and Home-made Meals

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Life Cycle Costs and Environmental Impacts of Ready and Home-made Meals

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Abstract

Purpose: The aim of this paper is to estimate and compare the life cycle costs (LCC) of ready-made meals with equivalent meals prepared at home. The analysis of value added and consumer costs are also carried out to examine different cost perspectives. A meal consisting of chicken meat, vegetables and tomato sauce is considered for these purposes. Different production and consumption choices are evaluated, including different sourcing of ingredients, ambient or refrigerated supply chains, and different appliance to prepare the meal. The economic costs are also compared to life cycle environmental impacts estimated in a previous study by the authors, to help identify the best options. The study seeks to raise the awareness in the food industry of the relevance of LCC as a management tool; it also aims to inform consumers on how important their choices are, not only at a personal level also but across whole supply chains.

Methods: The life cycle costs are estimated following the life cycle assessment methodology. The study is from cradle to grave and considers production and pre-processing of ingredients, manufacturing, distribution and consumption of the meal as well as end-of-life waste management. The functional unit is defined as ‘preparation and consumption of a meal for one person’.

Results and Discussions: The total life cycle cost of the ready-made meal ranges from £1.41–£2.54, while that of the home-made meal is between £1.54 and £1.91. The consumption stage is the largest contributor to the costs of the ready-made meal because of the cost of electricity used to heat the meal and the transport. Using gas instead of electrical appliances reduces the LCC of the ready-made meal by 42%. For the home-made meal, the biggest reduction in costs (13%) is achieved when the ready-made tomato paste is replaced by tomato sauce made at home using fresh tomatoes. The results suggest that the chilled ready-made meal has the highest value added for the supply chain, compared to the frozen and the home-made meal. From the consumer perspective, the cheapest option is the home-made meal and the most expensive the chilled ready-made option. Comparing the options for both the environmental and economic impacts, of the ready-made meal options considered, the frozen meal made from fresh ingredients and heated in a microwave oven is the best option while the frozen meal made from frozen ingredients and heated in the electric oven is the worst. Among the home-made meals considered, the best option economically and environmentally is the meal made from conventional ingredients cooked in the electrical oven and in the microwave (HM-3).

Conclusion: Overall, the home-made meal is economically and environmentally more sustainable than the ready-made options. However, other aspects will also influence consumer choices, including convenience, health and taste, and need to be explored alongside the economic costs and environmental impacts.

Keywords: LCC, LCA, ready-made meal, home-made meal

1 Introduction

The convenience food sector is growing rapidly, with the global ready meals market predicted to grow by 3.2% from $1.11 trillion in 2011 to $1.3 trillion in 2016 (Key Note, 2013). The majority of the expansion is expected to occur in China, the fastest growing market for ready-made meals in the world (Key Note, 2013). At present, the USA and the UK hold the largest market share in the world, estimated at £7.2 bn (Sheely 2008) and £1.97- bn (Key Note 2014), respectively. By comparison, the value of the whole Western European market is equivalent to £3.9 bn (Sheely, 2008), most of which is due to the UK market, which increased by 47% on the value in 2007 (Key Note 2013). Chilled meals contribute the vast majority of the market share (70%) with the rest belonging to frozen meals (Key Note 2014). It is expected that the market will grow by a further 15.4% by 2018, reaching an estimated value of £2.34bn (Key Note 2014). Currently, a third of the British adult population consumes ready-made meals once a week, while in countries such as France, only 15% of adults buys prepared meals). Overall, 8.8 kg of chilled and frozen ready-made meals are consumed in the UK per capita per year (Millstone and Lang 2008).

The market is affected by many economic factors, including inflation, unemployment and household disposable income (Key Note 2013). These are particularly apparent during an economic crisis when salaries freeze and employment goes down, while prices of value-added foods such as ready-made meals rise, affecting both consumers and manufacturers. In the UK, food prices increased sharply since the economic crisis started in 2007, with the processed food being one of the most affected (Downing and Harker 2012). A survey conducted by WHICH? (2013) shows that 80% of consumers are worried about food prices and 60% have changed their shopping options because of the constant rise in food prices; as always, the most affected are the lower-income earners and households with children (Green et al. 2013).

Food affordability is a key factor in food poverty (Sustain 2013) with the rise in food prices affecting the welfare of the population (IGD 2014). In the UK, the National Health Service (NHS) spends £6bn a year on food-related illnesses (Scarborough et al. 2011). Therefore, it is important to analyse the economic costs of food production and consumption, considering costs to both producers and consumers, to help identify the hotspots and opportunities for reducing the costs. This can be achieved by 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 preparation to consumption of food.

Currently, life cycle costs of food are poorly understood with few studies available in the literature. For example, Iotti and Bonazzi (2014) considered the Parma PDO ham sector to apply the LCC in a long-term basis; the outcome was the confirmation of the LCC as an effective approach to test the convenience-cycle management of the sector in a short and long term. Another study (de Luca et al. 2014) analysed the sustainability of a citrus production system considering conventional, integrated and organic options; the integration of the LCA and LCC helped to identify and rank the performance of those three options to assist with the decision making. Moreover, Krozer (2008) applied the LCC methodology to ten case studies (three food items), which were divided in ‘short-cycle’ and ‘durable’ products. The aim was to analysed alternative innovation for the different goods, and the main conclusion was that in the case of the ‘short-cycle’ items as food, the high cost-saving innovations are usually found in the agriculture and in the disposal stages.

Finally, other studies highlight the needs of the integration of LCA and LCC in the food sector, proposing different methodologies and economic approaches. For example Settanni et al. (2010) reviewed different economic methods to be integrated with a LCA analysis; for instance the chapter reviewed microeconomic perspectives using life cycle costing (LCC) and also macroeconomic viewpoint applying hybrid methods and materials flow analysis. Kloepffer (2008) proposed guidelines as a compatible boundaries and comparable results between the sustainability aspects while Senthil et al. (2003) proposed the integration of new categories called eco-cost. As far as the authors are aware, no LCC studies of ready-made meals have been carried out as yet.

Thus, this paper focuses on ready-made meals, aiming to estimate the life cycle costs and compare them to a home-made alternative. In addition to the LCC, value added and consumer costs are also considered. Finally, to help identify more sustainable options overall, the meals are also compared for the environmental impacts, based on the previous work by the authors (Schmidt Rivera et al. 2014).

2 Methodology

The LCC methodology applied in this work follows the approach proposed by Swarr et al. (2011) and Hunkeler et al. (2008) and is congruent with the ISO 14040/44 methodology for life cycle assessment (LCA) (ISO 2006a;ISO 2006b). This is detailed in the following sections.

2.1 Goal and scope

The main goals of this study are:

- to estimate the life cycle costs of a ready-made meal and compare them to the costs of an equivalent home-made meal, considering different processing, distribution and consumption alternatives;
- to analyse the influence on the costs of different factors such as ingredient sourcing, refrigeration and home-cooking options;
- to estimate the value added along the supply chain as well as the costs of the meal to the consumer; and
- to compare the life cycle costs and environmental impacts of ready- and home-made meals to help identify the most sustainable options.

As the paper builds on the previous LCA study of ready-made meals by the authors (Schmidt Rivera et al. 2014), the scope, the functional unit and the composition of the meal in both studies are the same, to enable comparisons of different options for both costs and environmental impacts. Thus, the scope of the study is from 'cradle to grave', considering all life cycle stages from production and processing of ingredients to manufacture, distribution and consumption of the meal, including end-of-life waste management. The functional unit is defined as 'preparation and consumption of a meal for one person'. The meal chosen for consideration represents a typical British 'roast dinner' and consists of roast chicken and three vegetables (potatoes, carrots and peas) served with tomato sauce. The meal weighs 360 g with the recipe details given in Table 1.

Table 17 Composition of the ready- and home-made meals as served

Ingredients	**Weight (g)**	**Contribution (%)**
Chicken	98	27.22
Potatoes	87.5	24.31
Carrots	35	9.72
Peas	35	9.72
Tomato sauce	94.5	26.25
Tomato paste	*66.2*	*70*
Onions	*28.3*	*30*
Salt	1	0.28
Vegetable oil	9	2.50
Total	**360**	**100**

2.2 System definition

As outlined in Figure 13, the life cycle of the ready-made meal involves chicken rearing and cultivation of the vegetables, their processing in a slaughterhouse and at a regional distribution centre (RDC), respectively, preparation of the meal in a factory, its subsequent transport to another RDC, retailer and finally to consumer's home where it is prepared according to manufacturer's instructions. The life cycle of the home-made meal is similar, except that the meal is fully prepared at home, starting from the fresh ingredients. For further details, see Schmidt Rivera et al. (2014)

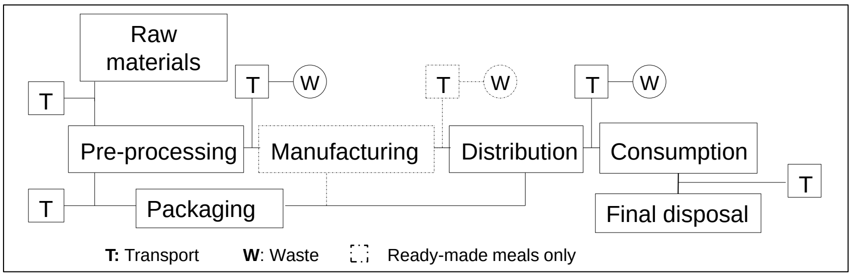

Figure 13 ***The life cycle of ready- and home-made meals (adapted from Schmidt et al. 2014)***

[Distribution includes regional distribution centres and retailers. Consumption comprises the transport by car, energy and water used to store the meal/ingredients, prepare the meal and wash the dishes.]

2.3 Calculation of life cycle costs and value added

Total life cycle costs are estimated from 'cradle to grave' (see Figure 14) according to the following equation:

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

where:

LCC	total life cycle cost of the ready- or home-made meal
C_{RM}	costs of the raw materials (meal ingredients)
C_{PP}	costs of pre-processing of raw materials
C_M	costs of meal manufacturing (ready-made meal only)
C_P	costs of packaging (ready-made meal only)
C_D	costs of distribution (ready-made meal only)
C_C	costs of meal consumption (meal preparation)
C_W	costs of disposal of waste from the meal

In addition to the LCC, value added (VA) is also considered in this work. VA is defined as sales less the costs of bought-in materials and services (DTI 2007), in effect representing a profit margin. It therefore provides an insight into the value to manufacturers and to society at large, the latter through the value added tax.

For these purposes, the VA of the ready-made meal is estimated from 'cradle to distribution', taking into account all the costs up to and including its distribution to retailers (Figure 14). In the case of the home-made meal, the system boundary is the same, except that the VA relates to the ingredients, rather than the meal. Therefore, the VA is calculated as follows:

$$VA = RP - LCC_{Cradle\ to\ distribution} \tag{2}$$

where:

VA	value added from ‘cradle to distribution’
RP	retail price of the meal (ready-made) or raw materials (home-made meal)
$LCC_{Cradle\ to\ distribution}$	life cycle cost from ‘cradle to distribution’

Finally, in order to consider the consumer perspective, the consumer cost is calculated from ‘cradle to consumer’ (Figure 14) according to equation (3):

$$RC_C = RP + C_C \tag{3}$$

where:

RC_c	real consumer costs from ‘cradle to consumer’
RP	retail price of the meal (ready-made) or ingredients (home-made meal)
C_C	cost of meal consumption (energy and water used to prepare the meal)

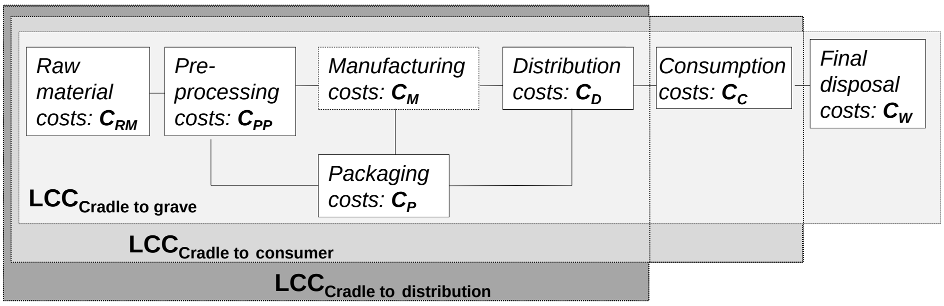

Figure 14 Life cycle stages considered in the calculation of the total life cycle costs, value added and costs to consumers

[System boundaries: $LCC_{Cradle\ to\ grave}$: total life cycle costs; $LCC_{Cradle\ to\ consumer}$: consumer costs; $LCC_{Cradle\ to\ distribution}$: retail price and value added.]

2.4 Scenarios

To examine the influence of different parameters on the LCC, several scenarios are considered for the ready- and home-made meals as summarised in Table 18. To enable comparisons with the influence on the life cycle environmental impacts, the scenarios are the same as in the previously mentioned LCA study of the meals (Schmidt Rivera et al. 2014).

2.5 Data and assumptions

Cost data have been obtained from a variety of sources as indicated in Table 19-Table 22 which also provide a breakdown of costs in different life cycle stages for the ready- and home-made meals. The retail prices of the ready-made meal used to estimate value added are summarised in Table 24 and the prices of the ingredients used in the home-made meal are given in Table 23. All costs are expressed in British Pounds (£).

It can be noted that the packaging costs in Table 19 and Table 20 are accounted for in the packaging stage while the costs of packaging waste management are considered within the life cycle stages where the waste arises. Similarly, all other waste is considered in the stages where it arises. Owing to a lack of data for packaging manufacturing, only the costs of packaging materials are considered. Furthermore, the cost of polyethylene and polyethylene terephthalate are assumed to be the same, again because of a lack of data. It should also be noted that chicken waste from the slaughterhouse is shown as revenue (Table 19 and Table 20) as it is sold to the rendering industry.

Table 18: Scenarios for the ready- and home-made meals (based on Schmidt et al. 2014)

Scenario	**Raw materials**	**Pre-processing**	**Manufacture & distribution**	**Consumption**
Ready-made meals				
RM-1	British conventional chicken and vegetables; Spanish conventional tomato paste	Fresh (chilled)	Fresh (chilled)	Microwave
RM-2	As RM-1	Fresh (chilled)	Fresh (chilled)	Electric oven
RM-3	As RM-1	Fresh (chilled)	Frozen	Microwave
RM-4	As RM-1	Fresh (chilled)	Frozen	Electric oven
RM-5	As RM-1	Frozen	Fresh (chilled)	Microwave
RM-6	As RM-1	Frozen	Fresh (chilled)	Electric oven
RM-7	As RM-1	Frozen	Frozen	Microwave
RM-8	As RM-1	Frozen	Frozen	Electric oven
RM-9	As RM-2	As RM-2	As RM-2	Gas oven
RM-10	As RM-4	As RM-4	As RM-4	Gas oven
RM-11	Brazilian conventional chicken; all other ingredients as in RM-1	As RM-1	As RM-1	As RM-1
RM-12	British conventional tomato paste; all other ingredients as in RM-1	As RM-1	As RM-1	As RM-1
RM-13	British organic chicken, potatoes and carrots; British conventional tomatoes, peas and onions	As RM-1	As RM-1	As RM-1
Home-made meals				
HM-1	British conventional chicken and vegetables Spanish conventional tomato paste	Fresh (chilled)	Fresh (chilled)	Chicken roasted in electric oven; vegetables and ready-made tomato sauce cooked on electric hob
HM-2	British organic chicken, potatoes, tomatoes and carrots; British conventional onions and peas	As HM-1	As HM-1	As HM-1 with tomato sauce made from fresh tomatoes
HM-3	As HM-1	As HM-1	As HM-1	Vegetables and ready-made tomato sauce cooked in microwave; chicken as HM-1
HM-4	As HM-1 with Brazilian chicken	As RM-1	As RM-1	As RM-1
HM-5	As HM-1	As HM-1	As HM-1	Gas oven and hob

HM-6	As HM-2 with Spanish conventional tomatoes	As HM-1	As HM-1	As HM-1
HM-7	As HM-2 with British conventional tomatoes	As HM-1	As HM-1	As HM-1

Table 19 Life cycle inventory and costs for different ready-made meal scenarios

	Flow or activity (unit/meal)	**RM-1**	**RM-2**	**RM-3**	**RM-4**	**RM-5**	**RM-6**	**RM-7**	**RM-8**	**Cost (£/unit)**	**Cost data sources**
Raw materials[a]	Conventional UK chicken (kg)	$1.67x10^{-1}$	$1.67x10^{-1}$	$1.63x10^{-1}$	$1.63x10^{-1}$	$1.65x10^{-1}$	$1.65x10^{-1}$	$1.62x10^{-1}$	$1.62x10^{-1}$	$8.69x10^{-1}$	UK Government and Defra (2013
	Conventional UK potatoes (kg)	$1.25x10^{-1}$	$1.25x10^{-1}$	$1.22x10^{-1}$	$1.22x10^{-1}$	$1.28x10^{-1}$	$1.28x10^{-1}$	$1.25x10^{-1}$	$1.25x10^{-1}$	$1.54 x10^{-1}$	UK UK Government and Defra (2013)
	Conventional UK carrots (kg)	$4.98x10^{-2}$	$4.98x10^{-2}$	$4.89x10^{-2}$	$4.89x10^{-2}$	$5.11x10^{-2}$	$5.11x10^{-2}$	$5.01x10^{-2}$	$5.01x10^{-2}$	$4.14 x10^{-1}$	UK Government and Defra (2013)
	Conventional UK peas (kg)	$4.98x10^{-2}$	$4.98x10^{-2}$	$4.89x10^{-2}$	$4.89x10^{-2}$	$5.11x10^{-2}$	$5.11x10^{-2}$	$5.01x10^{-2}$	$5.01x10^{-2}$	1.05	UK Government and Defra (2013)
	Conventional UK onions (kg)	$4.03x10^{-2}$	$4.03x10^{-2}$	$3.95x10^{-2}$	$3.95x10^{-2}$	$4.13x10^{-2}$	$4.13x10^{-2}$	$4.05x10^{-2}$	$4.05x10^{-2}$	$4.33x10^{-1}$	UK Government and Defra (2013)
	Spanish tomato paste[b] (kg)	$5.36x10^{-2}$	$5.36x10^{-2}$	$5.26x10^{-2}$	$5.26x10^{-2}$	$5.36x10^{-2}$	$5.36x10^{-2}$	$5.26x10^{-2}$	$5.26x10^{-2}$	3.04	UK Government and Defra (2013)
	Salt [kg]	$1.05x10^{-3}$	$1.05x10^{-3}$	$1.03x10^{-3}$	$1.03x10^{-3}$	$1.05x10^{-3}$	$1.05x10^{-3}$	$1.03x10^{-3}$	$1.03x10^{-3}$	$5.31x10^{-2}$	Credit Chem Group (2014)
	Vegetable oil (kg)	$9.42x10^{-3}$	$9.42x10^{-3}$	$9.24x10^{-3}$	$9.24x10^{-3}$	$9.42x10^{-3}$	$9.42x10^{-3}$	$9.24x10^{-3}$	$9.24x10^{-3}$	$6.69x10^{-1}$	IndexMundi (2012)
	Road transport in the UK (km kg)	88.3	88.3	86.6	86.6	89.4	89.4	87.6	87.6	$3.09x10^{-5}$	DECC (2014), VTT (2010)
	Road transport from Spain (km·kg)	69.7	69.7	68.3	68.3	69.7	69.7	68.3	68.3	$2.53x10^{-5}$	DECC (2014), VTT (2010)
Pre-processing	**Slaughterhouse**										
	Electricity (MJ)	$1.2x10^{-1}$	$1.20x10^{-1}$	$1.18x10^{-1}$	$1.18x10^{-1}$	$1.19x10^{-1}$	$1.19x10^{-1}$	$1.17x10^{-1}$	$1.17x10^{-1}$	$2.69 x10^{-2}$	DECC (2014)
	Heat (MJ)	$6.0x10^{-2}$	$6.0x10^{-2}$	$5.88x10^{-2}$	$5.88x10^{-2}$	5.94X10-2	$5.94x10^{-2}$	$5.83x10^{-2}$	$5.83x10^{-2}$	$4.83 x10^{-1}$	DECC (2014)
	Water (l)	1.5	1.5	1.47	1.47	1.49	1.49	1.46	1.46	$1.59x10^{-3}$	United Utilities (2014)
	Chicken waste (kg)	$4.53x10^{-2}$	$4.53x10^{-2}$	$4.45x10^{-2}$	$4.45x10^{-2}$	$4.49x10^{-2}$	$4.49x10^{-2}$	$4.4x10^{-2}$	$4.4x10^{-2}$	($3.63x10^{-1}$)[c]	Fao Stat (2009)
	Cooling (meat)										
	Electricity (MJ)	$2.62x10^{-5}$	$2.62x10^{-5}$	$2.57x10^{-5}$	$2.57x10^{-5}$	$7.34x10^{-4}$	$7.34x10^{-4}$	$7.19x10^{-4}$	$7.19x10^{-4}$	$2.69x10^{-2}$	DECC (2014)
	Ammonia (kg)	$2.25x10^{-5}$	$2.25x10^{-5}$	$2.2x10^{-5}$	$2.2x10^{-5}$	$1.05x10^{-4}$	$1.05x10^{-4}$	$1.03x10^{-4}$	$1.03x10^{-4}$	$3.35 x10^{-1}$	Technicold Service Inc. (2003)
	Meat losses and waste (kg)	$2.43x10^{-3}$	$2.43x10^{-3}$	$2.38x10^{-3}$	$2.38x10^{-3}$	$1.20x10^{-3}$	$1.20x10^{-3}$	$1.18x10^{-3}$	$1.18x10^{-3}$	$9.3x10^{-2}$	Eunomia Reaserach & Consulting Ltd (2013)
	Road transport (km·kg)	1.45	1.45	1.39	1.39	1.43	1.43	1.38	1.38	$3.09x10^{-5}$	DECC (2014), VTT (2010)
	Pre-processing (vegetables)										

	Electricity (kWh)	3.71x10^{-5}	3.71x10^{-3}	3.63x10^{-3}	3.63x10^{-3}	3.74x10^{-3}	3.74x10^{-3}	3.66x10^{-3}	3.66x10^{-3}	9.7x10^{-2}	DECC (2014)
	Water (l)	7.2x10^{-1}	7.2x10^{-1}	7.06x10^{-1}	7.06x10^{-1}	1.54	1.54	1.51	1.51	1.59x10^{-3}	United Utilities (2014)
	Steam (kWh)	1.92x10^{-4}	1.92x10^{-4}	1.88x10^{-4}	1.88x10^{-4}	2.53x10^{-4}	2.53x10^{-4}	2.48x10^{-4}	2.48x10^{-4}	3.41x10^{-2}	Spirax Sarco Limited (2014)
	Vegetables losses and waste (kg)	3.44x10^{-2}	3.44x10^{-2}	3.37x10^{-2}	3.37x10^{-2}	4.34x10^{-2}	4.34x10^{-2}	4.26x10^{-2}	4.26x10^{-2}	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Waste water (l)	6.48x10^{-1}	6.48x10^{-1}	6.36x10^{-1}	6.36x10^{-1}	1.38	1.38	1.36	1.36	1.13x10^{-3}	United Utilities (2014)
	RDCm[d] (vegetables)										
	Electricity (kWh)	4.88 x10^{-5}	4.88x10^{-5}	4.78x10^{-5}	4.78x10^{-5}	4.88x10^{-5}	4.88x10^{-5}	4.78x10^{-5}	4.78x10^{-5}	9.7x10^{-2}	DECC (2014)
	Ammonia (kg)	5.01x10^{-4}	5.01x10^{-4}	5.01x10^{-4}	5.01x10^{-4}	5.01x10^{-4}	5.01x10^{-4}	5.01x10^{-4}	5.01x10^{-4}	3.35 x10^{-1}	Technicold Service Inc. (2003)
	Vegetable losses and waste (kg)	6.76x10^{-4}	6.76x10^{-3}	6.63x10^{-3}	6.63x10^{-3}	3.41x10^{-3}	3.41x10^{-3}	3.35x10^{-3}	3.35x10^{-3}	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Road transport (km·kg)	22.6	22.6	22.1	22.1	22.6	22.6	22.1	22.1	3.09x10^{-5}	DECC (2014), VTT (2010)
Manufacturing	Fuel oil (l)	4.13x10^{-2}	4.13x10^{-2}	4.08x10^{-2}	4.08x10^{-2}	4.13x10^{-2}	4.13x10^{-2}	4.08x10^{-2}	4.08x10^{-2}	5.32x10^{-1}	DECC (2014)
	Electricity (kWh)	3.39x10^{-1}	3.39x10^{-1}	3.35x10^{-1}	3.35x10^{-1}	3.39x10^{-1}	3.39x10^{-1}	3.35x10^{-1}	3.35x10^{-1}	9.7x10^{-2}	DECC (2014)
	Water (l)	4.46	4.46	4.4	4.4	4.46	4.46	4.4	4.4	1.59x10^{-3}	United Utilities (2014)
	Food waste (kg)	6.81 x10^{-3}	6.81x10^{-3}	6.59x10^{-3}	6.59x10^{-3}	6.81x10^{-3}	6.81x10^{-3}	6.59x10^{-3}	6.59x10^{-3}	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Packaging waste (kg)	8.51x10^{-8}	8.51x10^{-8}	8.4x10^{-8}	8.4x10^{-8}	8.51x10^{-8}	8.51x10^{-8}	8.4x10^{-8}	8.4x10^{-8}	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Wastewater (l)	4.01	4.01	3.96	3.96	4.01	4.01	3.96	3.96	1.13x10^{-3}	United Utilities (2014)
	Road transport (km·kg)	37.5	3.75	37	37	37.5	37.5	37	37	3.09x10^{-5}	DECC (2014), VTT (2010)
Packaging	Low density polyethylene (kg)	1.01x10^{-2}	1.01x10^{-2}	1.08x10^{-2}	1.08x10^{-2}	1.01x10^{-2}	1.01x10^{-2}	1.08x10^{-2}	1.08x10^{-2}	1.57	Plastics Informat (2012)
	Polypropylene (kg)	1.17X10-4	1.17x10^{-4}	4.41x10^{-8}	4.41x10^{-8}	1.17x10^{-4}	1.17x10^{-4}	4.41x10^{-8}	4.41x10^{-8}	1.69	Plastics Infomart (2012)
	Polyethylene (kg)	1.04x10^{-2}	1.04x10^{-2}	1.4x10^{-2}	1.4x10^{-2}	1.04x10^{-2}	1.04x10^{-2}	1.4x10^{-2}	1.4x10^{-2}	1.37	Plastics Infomart (2012)
	Polyethylene terephthalate (kg)	2.6x10^{-2}	2.6x10^{-2}	3.5x10^{-2}	3.5x10^{-2}	2.6x10^{-2}	2.6x10^{-2}	3.5x10^{-2}	3.5x10^{-2}	1.37	Plastics Infomart (2012)
	Cardboard (kg)	1.56x10^{-2}	1.56x10^{-2}	2.23x10^{-2}	2.23x10^{-2}	1.56x10^{-2}	1.56x10^{-2}	2.23x10^{-2}	2.23x10^{-2}	1.4 x10^{-1}	LetsRecycle (2014)
	Steel (kg)	6.34x10^{-3}	6.34x10^{-3}	6.22x10^{-3}	6.22x10^{-3}	6.34x10^{-3}	6.34x10^{-3}	6.22x10^{-3}	6.22x10^{-3}	2.16x10^{-1}	Grupo Lyrsa (2014)
	Wood (kg)	1.18x10^{-5}	1.18x10^{-5}	1.16x10^{-5}	1.16x10^{-5}	1.18x10^{-5}	1.18x10^{-5}	1.16x10^{-5}	1.16x10^{-5}	2.47x10^{-1}	IndexMundi (2011)
	Road transport (km·kg)	8.12	8.12	8.83	8.83	8.12	8.12	8.83	8.83	3.09x10^{-5}	DECC (2014), VTT (2010)
Distri buti	**RDCp[e]**										
	Electricity (kWh)	4.72x10^{-5}	4.72x10^{-5}	6.16x10^{-4}	6.16x10^{-4}	4.72x10^{-5}	4.72x10^{-5}	6.16x10^{-4}	6.16x10^{-4}	9.7 x10^{-2}	DECC (2014)

	Ammonia (kg)	1.84 x10^{-4}	1.84x10^{-4}	3.18x10^{-4}	3.18x10^{-4}	1.84x10^{-4}	1.84x10^{-4}	3.18x10^{-4}	3.18x10^{-4}	3.35x10^{-2}	Technicold Services, Inc. (2003)
	Packaging waste (kg)	1.27x10^{-2}	1.27x10^{-2}	1.24x10^{-2}	1.24x10^{-2}	1.27x10^{-2}	1.27x10^{-2}	1.24x10^{-2}	1.24x10^{-2}	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Road transport (km·kg)	36.7	36.7	36.4	36.4	36.7	36.7	36.4	36.4	3.09x10^{-5}	DECC (2014), VTT (2010)
	Product losses (kg)	6.63x10^{-3}	6.63x10^{-3}	3.28x10^{-3}	3.28x10^{-3}	6.63x10^{-3}	6.63x10^{-3}	3.28x10^{-3}	3.28x10^{-3}	9.3 x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Retail										
	Electricity (kWh)	5.28x10^{-2}	5.28x10^{-2}	1.37x10^{-2}	1.37x10^{-2}	5.28x10^{-2}	5.28x10^{-2}	1.37x10^{-2}	1.37x10^{-2}	9.7x10^{-2}	DECC (2014)
	Refrigerant (R134a) (kg)	1.51x10^{-4}	1.51x10^{-4}	4.78x10^{-5}	4.78x10^{-5}	1.51x10^{-4}	1.51x10^{-4}	4.78x10^{-5}	4.78x10^{-5}	12.8	Stoody Industrial & Welding Supply Inc. (2006)
	Product losses (kg)	7.2x10^{-3}	7.2x10^{-3}	3.6x10^{-3}	3.6x10^{-3}	7.2x10^{-3}	7.2x10^{-3}	3.6x10^{-3}	3.6x10^{-3}	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
Consumption	Storage (kWh)	2x10^{-3}	2x10^{-3}	1.8x10^{-2}	1.80x10^{-2}	2x10^{-3}	2x10^{-3}	1.8x10^{-2}	1.8x10^{-2}	1.55 x10^{-1}	DECC (2014)
	Cooking (kWh)	7.86x10^{-2}	4.58	0.39	7.32	7.86x10^{-2}	0.39	0.39	7.32	1.55 x10^{-1}	DECC (2014)
	Water use (l)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.59 x10^{-3}	United Utilities (2014)
	Water waste (l)	9.0x10^{-1}	9.0x10^{-1}	9.0x10^{-1}	9.0x10^{-1}	9.0x10^{-1}	9.0x10^{-1}	9.0x10^{-1}	9.0x10^{-1}	1.26 x10^{-3}	United Utilities (2014)
	Road transport[f] (l)	5.9x10^{-1}	5.9x10^{-}	5.9x10^{-}	5.9x10^{-}	5.9x10^{-}	5.9x10^{-}	5.9x10^{-}	5.9x10^{-}	1.32	DECC (2014)
Final disposal	Food waste (kg)	8.64x10^{-2}	8.64x10^{-2}	8.64x10^{-2}	8.64x10^{-2}	8.64x10^{-2}	8.64x10^{-2}	8.64x10^{-2}	8.64x10^{-2}	9.3 x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Plastic packaging (kg)	4.5x10^{-2}	4.5x10^{-2}	4.5x10^{-2}	4.5x10^{-2}	4.5x10^{-2}	4.5x10^{-2}	4.5x10^{-2}	4.5x10^{-2}	9.3 x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Cardboard (kg)	1.5x10^{-2}	1.5x10^{-2}	1.5x10^{-2}	1.5x10^{-2}	1.5x10^{-2}	1.5x10^{-2}	1.5x10^{-2}	1.5x10^{-2}	9.3 x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Road transport (km·kg)	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.09x10^{-5}	DECC (2014), VTT (2010)

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[a] Note that the amount of raw materials is different here from the amount of ingredients in the meal as served (Table 1) as the data here include the loses along the supply chain.

[b] For the breakdown of production costs, see Table 5.

[c] Revenue from the sales of chicken waste to the rendering industry.

[d] Regional distribution centre for raw materials.

[e] Regional distribution centre for products (meals).

[f] The average fuel consumption is based on the average car size selected using data for the best-selling cars in the UK in 2013 (Lee Boyce 2013;Car Buyer 2014;Matt Bird 2013) and the average distance is 7.5 km (Pretty et al. 2005).

Table 20 ***Life cycle inventory and costs for different home-made meal scenarios***

	Flow or activity (unit/meal)	**HM-1**	**HM-2**	**HM-3**	**HM-4**	**Cost (£/unit)**	**Cost data sources**
Raw materials[a]	Conventional UK chicken (kg)	1.51x10^{-1}	-	1.51x10^{-1}	-	8.7x10^{-1}	UK UK Government and Defra (2013)
	Organic UK chicken (kg)	-	1.51x10^{-1}	-	-	9.6x10^{-1}	UK Government and Defra (2013)
	Brazilian chicken (kg)	-	-	-	1.51x10^{-1}	9.2x10^{-1}	Fao Stat (2009)
	Conventional potatoes (kg)	1.1 x10^{-1}	-	1.1 x10^{-1}	1.1 x10^{-1}	1.5x10^{-1}	UK Government and Defra (2013)
	Organic potatoes (kg)	-	0.11	-	-	8.2x10^{-1}	UK Government and Defra (2013)
	Conventional UK carrots (kg)	4.42x10^{-2}	-	4.42x10^{-2}	4.42x10^{-2}	4.1 x10^{-1}	UK Government and Defra (2013)
	Organic carrots (kg)	-	4.42x10^{-2}	-	-	1.01	UK Government and Defra (2013)
	Conventional UK peas (kg)	4.42x10^{-2}	-	4.42x10^{-2}	4.42x10^{-2}	1.05	UK Government and Defra (2013)
	Organic peas (kg)	-	4.42x10^{-2}	-	-	4.02	UK Government and Defra (2013)
	Conventional UK onions (kg)	3.61x10^{-2}	-	3.61x10^{-2}	3.61x10^{-2}	0.43	UK Government and Defra (2013)
	Organic onions (kg)	-	3.61x10^{-2}	-	-	1.03	UK Government and Defra (2013)
	Tomato paste[b] (kg)	4.38x10^{-2}	0.17	4.38x10^{-2}	4.38x10^{-2}	3.04	UK Government and Defra (2013)
	UK tomatoes (kg)	-	-	-	-	2.31	UK Government and Defra (2013)
	Salt (kg)	1x10^{-3}	1x10^{-3}	1x10^{-3}	1x10^{-3}	5.31x10^{-2}	Credit Chem Group (2014)
	Vegetable oil (kg)	9x10^{-3}	9x10^{-3}	9x10^{-3}	9x10^{-3}	6.67 x10^{-1}	IndexMundi (2012)
	Road transport in the UK (km·kg)	79.3	113	79.3	79.3	6.18x10^{-3}	DECC (2014), VTT (2010)
	Road transport from Spain (km·kg)	56.9	-	56.9	56.9	3.29x10^{-2}	DECC (2014), VTT (2010)
	Road transport in Brazil (km·kg)	-	-	-	60.5	5.55x10^{-3}	VTT (2010), Global Petrol Prices (2014)
	Transoceanic transport from Brazil to the UK (km·kg)	-	-	-	1.51x10^{-1}	5.07x10^{-7}	VTT (2010), Global Petrol Prices (2014); Baumel, C .P. et al. (1985)
Pre-processing	**Slaughterhouse**						
	Electricity (MJ)	1.1 x10^{-1}	1.1 x10^{-1}	1.1 x10^{-1}	1.1 x10^{-1}	2.69x10^{-2}	DECC (2014)
	Heat (MJ)	5.44x10^{-2}	5.44x10^{-2}	5.44x10-2	5.44x10^{-2}	0.48	DECC (2014)
	Water (l)	1.36	1.36	1.36	1.36	1.59x10^{-3}	United Utilities (2014)
	Chicken waste (kg)	4.11x10^{-2}	4.11x10^{-2}	4.11x10^{-2}	4.11x10^{-2}	(0.36)[c]	Fao Stat (2009)

	Cooling						
	Electricity (MJ)	2.38x10^{-5}	2.38x10^{-5}	2.38x10^{-5}	2.38x10^{-5}	2.69x10^{-2}	DECC (2014)
	Ammonia (kg)	2.04x10^{-5}	2.04x10^{-5}	2.04x10^{-5}	2.04x10^{-5}	0.34	Technicold Services, Inc. (2003)
	Meat losses (kg)	2.2x10^{-3}	2.2x10^{-3}	2.2x10^{-3}	2.2x10^{-3}	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Transport (km·kg)	1.19	1.19	1.19	1.19	3.09x10^{-5}	DECC (2014), VTT (2010)
	RDCm^{d} (vegetables)						
	Electricity (MJ)	1.83x10^{-4}	3.13x10^{-4}	1.83x10^{-4}	1.83x10^{-4}	2.69x10^{-2}	DECC (2014)
	Ammonia (kg)	1.18x10^{-4}	2.02x10^{-4}	1.18x10^{-4}	1.18x10^{-4}	0.34	Technicold Services, Inc. (2003)
	Vegetables losses and waste (kg)	4.7x10^{-3}	8.05x10^{-3}	4.7x10^{-3}	4.7x10^{-3}	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Road transport (km·kg)	5.42	15.9	5.42	5.42	3.09x10^{-5}	DECC (2014), VTT (2010)
Packaging	Cardboard (kg)	1.81x10^{-3}	-	1.81x10^{-3}	1.81x10^{-3}	0.14	LetsRecycle (2014)
	Polypropylene (kg)	1.27x10^{-7}	7.04x10^{-8}	1.27x10^{-7}	1.27x10^{-7}	1.37	Plastics Infomart (2012)
	Wood (kg)	2.55x10^{-6}	-	2.55x10^{-6}	2.55x10^{-6}	2.5x10^{-1}	IndexMundi (2011)
	Tin (kg)	7.74x10^{-3}	-	7.74x10^{-3}	7.74x10^{-3}	20.5	LME (2014)
	Low density polyethylene (kg)	1.0x10^{-2}	1.0X10^{-2}	1.0x10^{-2}	1.0x10^{-2}	1.57	Plastics Infomart (2012)
	Road transport (km·kg)	1.96	1.0	1.96	1.96	3.09X10^{-5}	DECC (2014), VTT (2010)
Distribution	**Retail (vegetables)**						
	Electricity (MJ)	5.98x10^{-3}	1.02x10^{-2}	5.98x10^{-3}	5.98x10^{-3}	2.69x10^{-2}	DECC (2014)
	Natural gas (MJ)	7.48x10^{-3}	1.28x10^{-2}	7.48x10^{-3}	7.48x10^{-3}	8.10x10^{-3}	DECC (2014)
	Packaging waste (kg)	4.18x10^{-4}	7.17x10^{-4}	4.18x10^{-4}	4.18x10^{-4}	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Product losses (kg)	1.15x10^{-2}	1.98x10^{-2}	1.15x10^{-2}	1.15x10^{-2}	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Retail (chicken)						
	Electricity (MJ)	5.77x10^{-2}	5.77x10^{-2}	5.77x10^{-2}	5.77x10^{-2}	2.69x10^{-2}	DECC (2014)
	Natural gas (MJ)	1.23x10^{-2}	1.23x10^{-2}	1.23x10^{-2}	1.23x10^{-2}	8.1x10^{-3}	DECC (2014)
	Refrigerant R134a (kg)	4.0x10^{-5}	4.0x10^{-5}	4.0x10^{-5}	4.0x10^{-5}	12.8	Stoody Industrial & Welding Supply Inc. (2006)
	Product losses (kg)	2.16x10^{-3}	2.16x10^{-3}	2.16x10^{-3}	2.16x10^{-3}	9.3X10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
Consumption	Cooking (MJ)	4.11	4.34	2.44	4.11	4.29x10^{-2}	DECC (2014)
	Storage (kWh)	1.59x10^{-3}	2.35x10^{-3}	1.59x10^{-3}	1.59x10^{-3}	1.54x10^{-1}	DECC (2014)

	Water (l)	4.50	4.50	4.50	4.50	1.59x10^{-3}	United Utilities (2014)
	Waste water (l)	4.05	4.05	4.05	4.05	1.26x10^{-3}	United Utilities (2014)
	Road transport[e] (l)	5.9x10^{-1}	5.9x10^{-1}	5.9x10^{-1}	5.9x10^{-1}	1.32	DECC (2014)
Final disposal	Food waste (kg)	0.12	0.14	0.12	0.12	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Plastic bag (kg)	1.0x10^{-2}	1.0x10^{-2}	1.0X10^{-2}	1.0x10^{-2}	9.3X10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Tin (kg)	7.74x10^{-3}	-	7.74X10^{-3}	7.74x10^{-3}	9.3X10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)
	Road transport (km·kg)	3.51	3.86	3.51	3.51	3.09x10^{-5}	DECC (2014), VTT (2010)

[a] Note that the amount of raw materials is different here from the amount of ingredients in the meal as served (Table 1) as the data here include the loses along the supply chain.

[b] For the breakdown of production costs, see Table 5.

[c] Revenue from the sales of chicken waste to the rendering industry.

[d] Regional distribution centre for raw materials

[e] The average fuel consumption is based on the average car size selected using data for the best-selling cars in the UK in 2013 (Lee Boyce 2013;Car Buyer 2014;Matt Bird 2013) and the average distance is 7.5 km (Pretty et al. 2005).

Table 21 Production costs of Spanish tomato paste

	Unit	Cost (£/unit)	Cost data sources
Inputs			
Electricity (kWh)	9.8x10^{-2}	9.3x10^{-2}	DECC (2014)
Steam (kg)	2.53	2.4x10^{-2}	Spirax Sarco Limited (2014)
Tomatoes (kg)	6	0.44	Euro Stat (2014)
Water (kg)	156	1.0x10^{-3}	iagua (2013)
Road transport (km·kg)	1,200	2.53x10^{-5}	DECC (2014), VTT (2010)
Outputs			
Tomatoes waste (kg)	1.89x10^{-1}	3.7x10^{-2}	Ventosa and Martínez (2012)
Waste water (l)	137.5	1.0x10^{-3}	Modelo Factura (2013)
Packaging waste from farm (mg)	4.5x10^{-5}	3.7x10^{-2}	Ventosa and Martínez (2012))
Tomato paste (kg)	**1**	**3.04**	

Table 22 Transportation costs

Transport type	UK	Spain	Brazil	Cost data sources
Euro 5 lorry (42 t)[a]				
Half load (£/km)	0.40	0.33	0.18	VTT (2010)
Full load (£/km)	0.49	0.40	0.22	VTT (2010)
Transoceanic tanker (50,000 dwt[b]) (£/km)	-	-	2.5x10^{-3}	Baumel et al. (2008)
Consumer car[c]:				
Average fuel consumption (l/km)	7.8x10^{-2}			EPA (2006); Sprit Monitor (2014); AA (2014)
Diesel (£/l)	1.40	1.15	0.63	DECC (2014); Global Petrol Prices (2014)
Petrol (£/l)	1.33			DECC (2014)

[a] Euro 5 lorry: one of the latest series of standard heavy-duty vehicles stated under the EC regulation. The emissions and particle matter specifications are described in 715/2007/EC (2007)

[b] dwt: deadweight tonnage.

[c] The average car size was selected using data for the best-selling cars in the UK in 2013 (Lee Boyce 2013;Car Buyer 2014;Matt Bird 2013).

Table 23 Retail prices for the ready-made meals[a]

	Costs (£/kg)	Costs (£/meal)
Chilled meal		
Price range	4.00-9.21	1.44-3.32
Average	7.56	2.72
Frozen meal		
Price range	3.75-7.35	1.35-2.65
Average	5.01	1.80

[a] Retail prices obtained in March 2014 from the websites of the UK largest retailers: Tesco (2014), Asda (2014), Sainsbury's (2014), Iceland (2014), Morrisons (2014) and Lidl (2014).

Table 24 Average retail prices for the ingredients of the home-made meal[a]

	HM-1			HM-6,7[c]: conventional			HM-2		
Ingredients[b]	**Weight (g)**	**Unit cost (£/kg)**	**Total cost (£/meal)**	**Weight (g)**	**Unit costs (£/kg)**	**Total cost (£/meal)**	**Weight (g)**	**Unit costs (£/kg)**	**Total cost (£/meal)**
Chicken	105.8	3.5	0.370	105.8	3.5	0.370	105.8	6.49	0.690
Potatoes	103.3	0.93	9.6x10^{-2}	103.3	0.93	0.10	103.3	1.27	0.13
Carrots	41.3	0.94	3.9x10^{-2}	41.3	0.94	0.04	41.3	1.32	0.05
Peas	41.3	7.48	0.31	41.3	7.48	0.31	41.3	7.48	0.31
Onions	33.4	0.86	2.9x10^{-2}	33.4	0.86	0.03	33.4	1.41	0.05
Tomatoes	43.8	2.74	0.12	156.1	2.05	0.32	156.1	4.19	0.65
Oil	9	1.43	1.3x10^{-2}	9	1.43	1.3x10^{-2}	9	1.43	1.3x10^{-2}
Salt	1	0.61	1.0x10^{-3}	1	0.61	1x10^{-3}	1	0.61	1x10^{-3}
Total	**378.8**	**18.5**	**1.00**	**491.2**	**17.8**	**1.2**	**491.2**	**24.2**	**1.9**

[a] Retail prices obtained in March 2014 from the websites of the UK largest retailers: Tesco (2014), Asda (2014), Sainsbury's (2014), Iceland (2014), Morrisons (2014) and Lidl (2014).

[b] The amount of ingredients is the one needed in the consumption stage including the cooking losses.

[c] The variations in the consumer’s prices for tomatoes are large and also not all the supermarkets specified the sources.

3 Results

The results are first presented for the LCC and VA of the ready-made meal (sections 3.1 and 3.3), followed by an equivalent analysis for the home-made options (sections 3.3 and 3.4). The two types of meal are then compared in section 3.5. for LCC, VA, consumer costs and life cycle environmental impacts to help identify a more sustainable option.

3.1 Life cycle costs of ready-made meal options

As shown in Figure 15, the highest LCC of £2.54 is estimated for the frozen meal made from frozen ingredients and heated in the electric oven (RM-8). A similar option made from fresh ingredients (RM-4) improves the cost by only 1%.

The best option is the chilled meal made from fresh ingredients and heated in the microwave (RM-1), with the total cost of £1.41, almost half that of the frozen meal. The difference in the costs of the meals heated in the microwave (RM-1, RM-3, RM-5 and RM-7) is small (<4%).

The greatest variation in the costs is found between the meals heated in the microwave and those heated in the oven, with the latter being on average 65% higher than the former, going up to 74% in the case of the frozen meals heated in the electric oven (RM-4 and RM-8). This is due to the high electricity cost, which contributes between 48% and 59% to the costs from the consumption stage, which itself is the largest contributor, making up on average 65% of the total LCC (Figure 3).

The contribution of consumer transport to buy the meal is also significant, particularly if microwave is used for heating, adding between 92% and 98% to the costs from the consumption stage, depending on whether the meal is frozen or chilled. If the meal is heated in the oven, transport contributes between 52% and 41% to the costs in this stage.

The second most important stage is the raw materials, which varies between 17% for the frozen meals heated in the oven (RM-4 and RM-8) to 30% for the chilled meal heated in the microwave (RM-1 and RM-5). Chicken and tomato paste contribute collectively 70% to the costs of raw materials and the peas add a further 12%.

The contribution of the remaining stages is small. In particular, packaging adds between 3% and 6%, with the frozen ingredients requiring more packaging than the fresh, in particular more plastic bags and cardboard boxes. Meal manufacturing contributes another 5%, while pre-processing, final disposal and distribution add only 1.5%, 0.8% and 0.5% of the total cost.

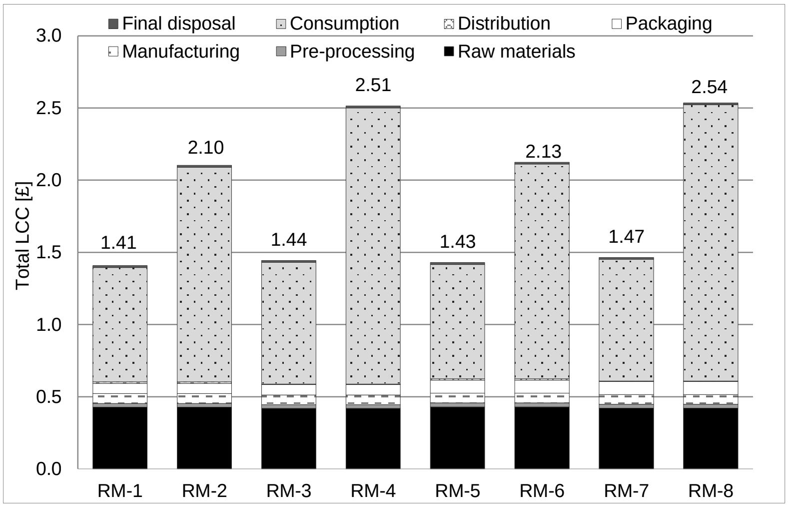

Figure 15 Life cycle costs (LCC) of different ready-made meal scenarios

[For description of the different meal options, see Table 18.]

3.2 Sensitivity analysis

To explore how the LCC change for different options, the sensitivity analysis focuses on the two life cycle stages contributing to the LCC most: meal consumption and the ingredients. The former examines the implications of using different appliances to heat the meal while the latter considers different sourcing of ingredients as discussed below.

3.2.1.1 Influence of appliances

Three options for heating the ready-made meal are considered: microwave, gas and electrical ovens. The energy consumption by these appliances for the chilled and frozen meals is summarised in Table 25.

Table 25 Energy consumption by different appliances for chilled and frozen ready-made meals

Appliance	**Energy costs (£/kWh)**[a]	**Chilled meal (RM-9)**	**Frozen meal (RM-10)**
Microwave (kWh)	1.55×10^{-1}	0.28	0.39
Electric oven (kWh)	1.55×10^{-1}	4.58	7.32
Gas oven (kWh)	4.75×10^{-2}	3	4.8

[a] The energy costs were obtained from DECC (2014)

The results in Figure 16 suggest that using the gas oven (RM-9) instead of electric (RM-2) to heat the chilled meal, saves 32% in total LCC cost, reducing it from £2.10 to £1.44. This is due to two reasons: the cost of gas is much lower compared to electricity (3.25 times) and the energy consumption in gas ovens is lower because of higher efficiency (Table 9). On the other hand, as also shown Figure 16, there is little difference in costs (2%) between heating the meal in the microwave (RM-1) and gas oven (RM-9).

For frozen meals, the cost differential is even greater with a saving of around 42% or £1.06 per meal if the gas oven is used instead of the electric (RM-4 vs RM-10). Similar to the chilled meal, the difference in costs between the gas oven (RM-10) and microwave (RM-3; Figure 15) is small.

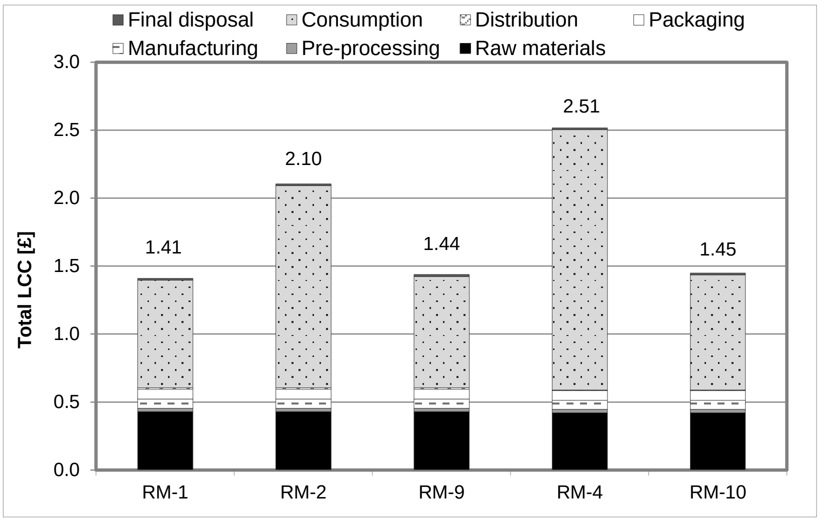

Figure 16 Sensitivity analysis for the ready-made meals for the gas and electric ovens

[Meal preparation options: RM-1: chilled meal heated in microwave; RM-2: chilled meal in electric oven; RM-9: chilled meal in gas oven; RM-4: frozen meal in electric oven; RM-10: frozen meal in gas oven.]

3.2.1.2 Influence of ingredient sourcing

The following three variations on the base-case scenario RM-1 are considered with respect to the sourcing of ingredients: Brazilian instead of British chicken (RM-11), British tomatoes instead of Spanish tomato paste (RM-12) and organic instead of conventionally-produced ingredients (RM-13). The results are compared in Figure 17.

Sourcing the chicken from Brazil (RM-11) as opposed to the UK leads to a negligible (0.6%) reduction in the total LCC compared to the base-case scenario (RM-1). This is despite the additional transportation costs associated with the chicken imported from Brazil but that adds only 5 pence on the costs of the British chicken (£0.87 vs £0.92; see Table 3).

However, using British tomato paste (RM-12) instead of Spanish paste assumed in the base-case (RM-1) increases the costs more significantly, from £.1.41 to £1.65. Similar to the chicken imported from Brazil, the cost of importing the paste from Spain is insignificant compared to the higher costs of production of tomato paste in the UK, which is the main cause for difference in the LCC.

Finally, using organic ingredients instead of conventional also increases the total LCC, from £1.41 in RM-1 to £1.71 for RM-13. This is unsurprising as organic produce is more expensive (Table 19).

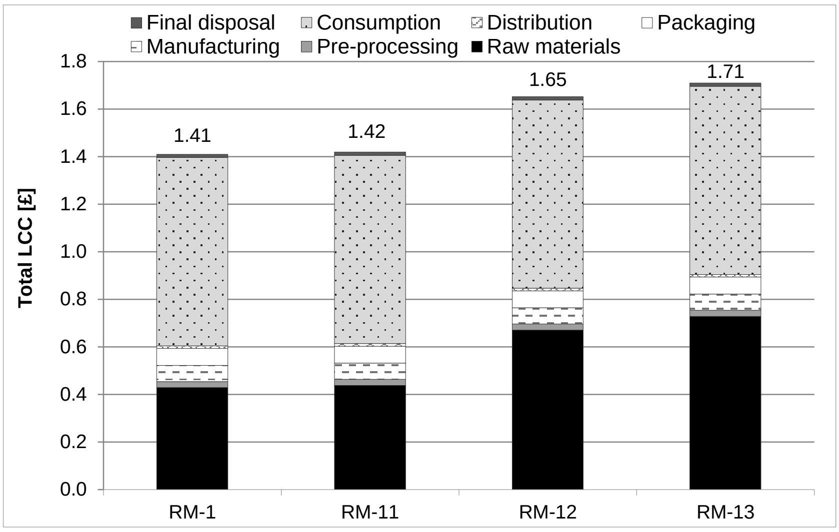

Figure 17 ***Sensitivity analysis for the ready-made meals assuming different sourcing of ingredients***

3.3 Value added of ready-made meal options

Two options are considered here as an illustration of the VA: the chilled and frozen ready-made meal. The results obtained using eq. (2) and given in Figure 18 indicate that the VA of the chilled meal (RM-1) varies from £0.84 to £2.71 with an average value of £2.12. This variation is due to the different prices of the meals sold by different retailers, also shown in Figure 18 (based on the values given in Table 23), together with the life cycle costs up to and including the distribution stage. As can be seen, for the most expensive meal, the VA represents 82% of the retail price and for the cheapest it represents 58%. For the frozen meal, the VA is lower, ranging from £0.76–£2.06. The average VA is equivalent to £1.21, representing 67% of the average retail price. Thus, these results suggest that the chilled ready-made meal adds a greater value to the supply chain than the frozen option. This is despite the fact that the production costs of chilled and frozen meals are similar (~£0.60) – the slightly higher energy costs from freezing are countered by lower wastage along the supply chain (Schmidt et al., 2014). Nevertheless, as consumers generally prefer fresh to frozen meals, retailers can demand higher prices (30% on average), thus inflating the VA. However, it is unclear if and how the VA benefits are shared along the supply chain.

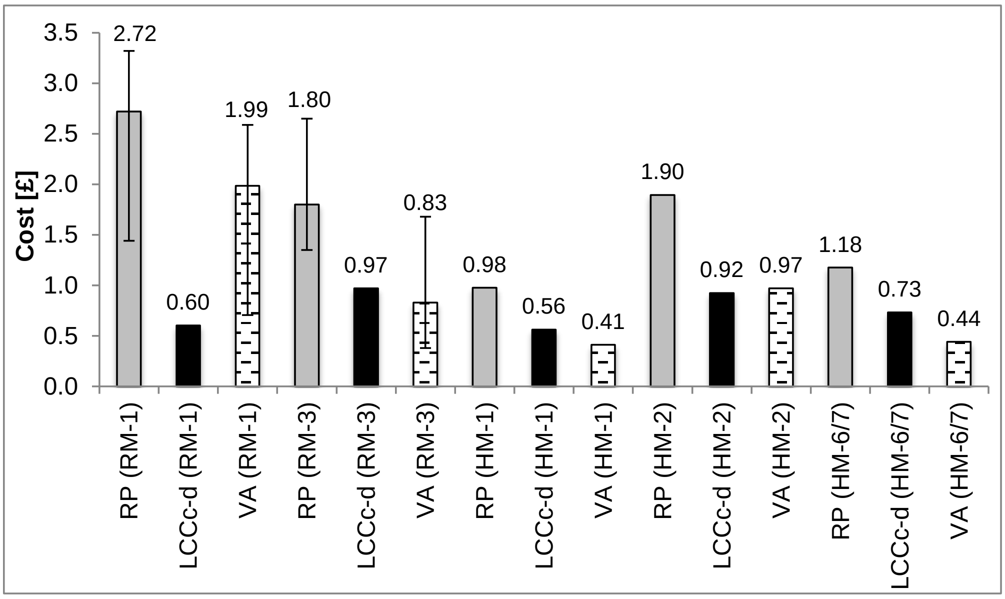

Figure 18 Value added (VA) of ready-made and home-made meal options

[RM-1 and RM-3: chilled and frozen ready-made meal, respectively. HM-1: home-made meal with conventional ingredients and pre-prepared tomato paste (HM-1); HM-2: home-made meal with organic ingredients and home-made tomato sauce (HM-2); HM-6/7: home-made meals with conventional ingredients and with tomato sauce made from scratch with conventional British or Spanish tomatoes. RP: retail price; LCCc-d: life cycle costs from cradle to distribution to the retailer. Error bars represent minimum and maximum costs related to the variation in the retail price of ready-made meals – for details, see Table 23].

3.4 Life cycle costs of home-made meal options

As indicated in Figure 19, the lowest LCC of £1.47 are found for meal prepared from conventionally-cultivated ingredients and pre-prepared tomato paste where the vegetables and the tomato sauce are cooked in microwave (HM-3). The next best option at £1.54 is HM-1, which is similar to HM-3 except that the vegetables and the sauce are cooked on an electric hob. This means that cooking part of the meal in microwave save the consumer 7 pence or 5% per meal.

The meal with organic ingredients and home-made tomato sauce (HM-2) has the highest LCC, estimated at £1.91, or 20% higher than the base case option (HM-1). This is due to the higher costs of the raw materials: £0.88 for HM-2 compared to £0.37 for HM-1.

Finally, using chicken imported from Brazil instead of the British chicken has a similarly negligible effect on the LCC as for the ready-made meal, increasing the total cost compared to HM-1 by 1% to £1.55.

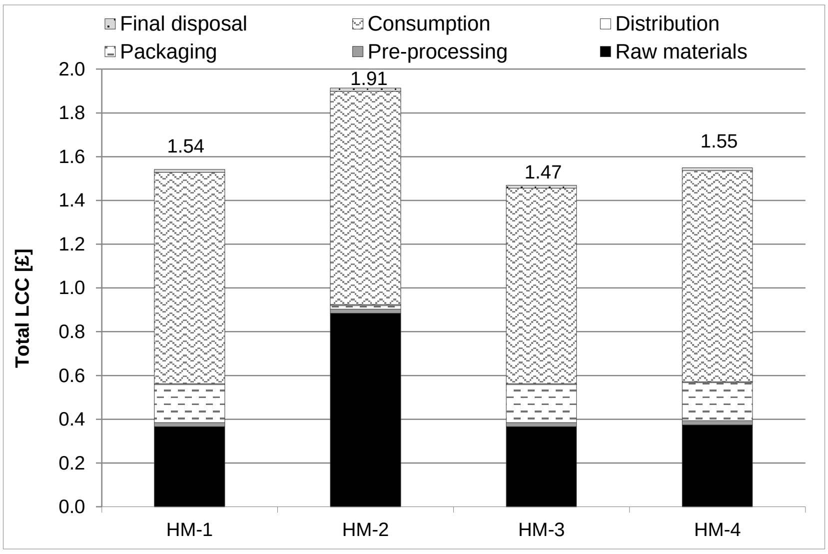

Figure 19 Life cycle costs (LCC) of different home-made meal options

Like the ready-made meal, the main cost hotspots for the home-made options are the consumption stage and the raw materials (Figure 19). The former contributes on average 60% to the total LCC, and the latter 24%. The only exception is HM-2, where consumption accounts for 50% of the costs and the raw materials for 46%, because of the organic ingredients which have higher costs.

The costs of packaging contribute on average 9% to the total, which is higher than for the ready-made meal (5%). However, in the case of the organic meal (HM-2), the packing adds only 1% to the LCC. The reasons for this are two-fold: higher costs of organic ingredients and lower amount of packaging because the tomato paste is made from scratch, thus avoiding the packaging used for the ready-made tomato paste. The contribution of the remaining stages is small (<2%).

With respect to the ingredients, the highest contributors are the chicken and tomatoes/tomato paste with around 36% each and the peas with 12%. In the case of the organic meal (HM-2), the contribution is slightly different: the tomatoes contribute 44%, the peas 20% and the chicken and potatoes 16% and 20% respectively.

In the consumption stage, the main contributor is consumer transport which accounts for 80-87% of the costs from this stage, with the energy consumption adding the remaining 13-20%.

3.4.1 Sensitivity analysis

A similar sensitivity analysis has been carried out for the home-made meal as for the ready-made options, considering the impact on the costs of different appliances and sources of the ingredients. These results are displayed in Figure 20.

The use of gas oven and hob (HM-5) instead of the electric (HM-1) reduces the total LCC from £1.54 to £1.41 because of the lower cost of natural gas compared to electricity (see Table 19).

The use of British (HM-7) or Spanish tomatoes (HM-6) to make the sauce as well as the conventional ingredients reduces the overall meal costs by 10% and 30%, respectively, compared to the option with the organic ingredients (HM-2). Furthermore, replacing Spanish ready-made tomato paste (HM-1) by the one made at home from Spanish tomatoes (HM-6) reduces the LCC by 13%. On the other hand, using British tomatoes (HM-7) increases the costs by 12%.

This is because Spanish tomatoes are cheaper than the British as a result of different agricultural practices: British tomatoes grow indoors and have to be heated while the Spanish are cultivated outdoors.

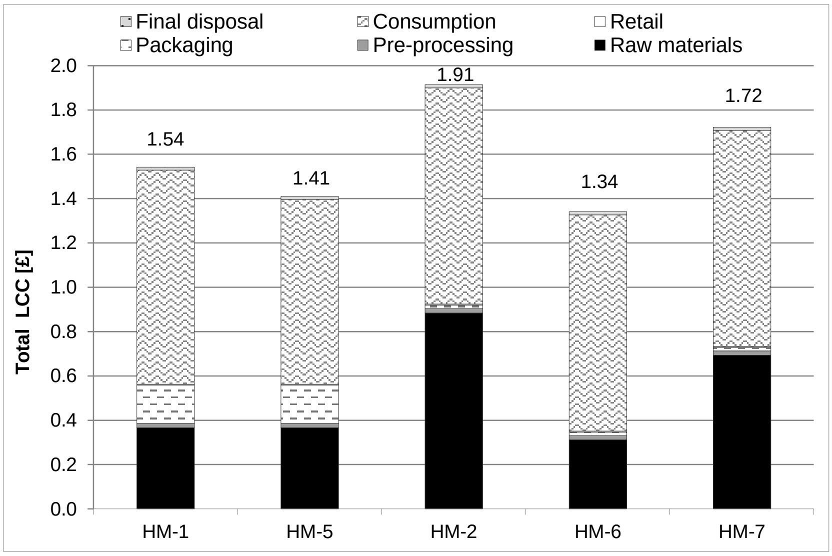

Figure 20 Sensitivity analysis for the home-made meals assuming the use of different appliances and sourcing of the ingredients.

[HM-5: as HM-1 but using gas appliances; HM-6: as HM-2 but using Spanish conventional tomatoes; HM-7: as HM-2 but using British conventional tomatoes.

3.5 Value added of home-made meal options

The following three illustrative options are considered for the estimation of the VA for the home-made meals: the base-case scenario (HM-1), the meal with organic (HM-2) and conventional ingredients (HM-6/7).

As can be observed in Figure 18, the VA for the base-case scenario (HM-1) is estimated at £0.41, which represents 42% of the retail price of the ingredients of 0.98 (see also Table 24). In the case of the meal prepared from the organic ingredients (HM-2), the VA is almost twice as high, totalling £0.97, or 51% of the ingredients' retail price. Finally, at £0.44, the option with the conventional ingredients and with the tomato sauce made from scratch from Spanish or British tomatoes (HM-6/7) has the lowest VA, equivalent to 38% of the retail price.

Therefore, these results suggest that from the supply chain perspective, the meal prepared from the organic ingredients provides higher VA, almost double that of the other two options.

However, from the consumer's perspective, this meal option is the most expensive. Using ready- or home-made tomato paste made from Spanish/British tomatoes makes little difference for the supply chain but former is more expensive for the consumer.

3.6 Comparison of ready- and home-made meals

This section compares various ready- and home-made options first for the life cycle costs and then for the VA and consumer costs. The final section compares them for both the LCC and life cycle environmental impacts, using the results of the LCA study carried out previously by the authors for the same meal options (Schmidt et al., 2014).

3.6.1 Comparison of life cycle costs

Due to space restrictions, only selective meal options are compared here, focusing on similar ingredient sources but different meal options. Therefore, the selected meals are the ready-made meals chilled (RM-1) and frozen (RM-3) base case scenarios and the organic chilled options (RM-13). Those are compared with their correspondent home-made meal alternatives: the home-made base scenario (HM-1) and the alternative home-made meals made from scratch with organic (HM-2) and conventional (HM-6) ingredients.

As shown in Figure 21, the chilled ready-made meal (RM-1) has lower LCC than the base-case home-made meal (HM-1): £1.41 vs £1.54. In other words, the LCC of the home-made meal is 9% higher. The frozen ready-made alternative (RM-3) also has lower LCC (by 6%). This is due to the higher energy consumption for the home-made meal in the consumption stage and the packaging cost associated with the tomato paste. In the case of the later, food in small size containers has higher ratio of packaging than the one in bigger containers, and also in the case of this study, the price of the materials is higher.

On the other hand, with the tomato sauce prepared at home from Spanish tomatoes (HM-6), the life cycle costs go down to £1.34 which is the best option among those considered in Figure 21, 5% lower than the for chilled meal (RM-1) and 7% than for the frozen option (RM-3). This is due to the avoidance of the packaging for the tomato paste and the lower costs of fresh tomatoes than the ready-made paste.

A similar trend can be observed for the organic options (RM-13 and HM-2): the ready-made meal has lower LCC than the home-made on average by 12%; this is due to the higher amount of tomatoes used in the home-made meal to prepare the sauce compared to the ready-made paste.

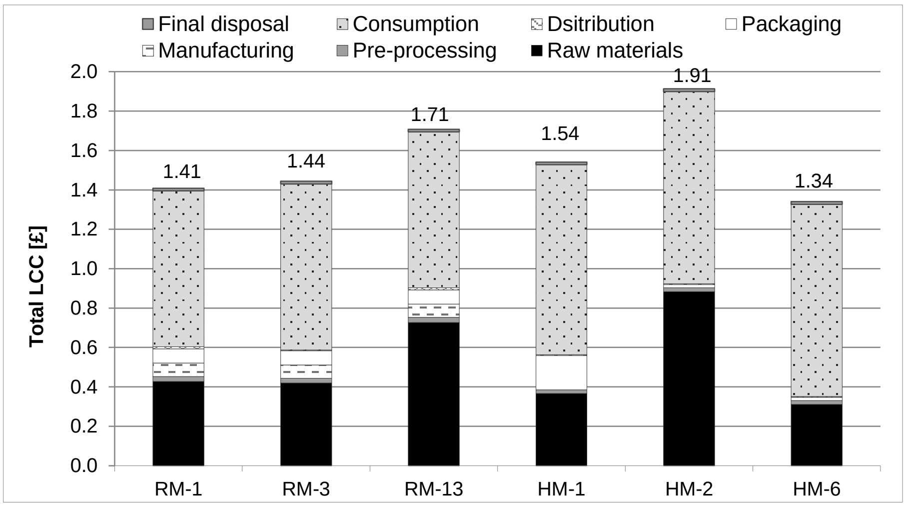

Figure 21 Comparison of life cycle cost of the ready- and home-made meals

[For description of the difference meal options, see Table 18.]

3.6.2 Comparison of value added

The following options are compared for their VA: the ready-made meals base case scenarios are chosen, the chilled (RM-1) and the frozen (RM-3) options. Those are compared with their correspondent home-made meal alternatives: the home-made base scenario (HM-1) and the alternative home-made meals made completely from scratch with organic (HM-2) and conventional (HM-6/7) ingredients.

The results in Figure 18 suggest that for the highest retail price the VA of chilled ready-made meal (RM-1) is 4.6 times higher than the VA of the home-made option (HM-1). For the lowest retail price of the ready-made meal, this difference between the two meal options is only 27%. If the average retail price is considered, the VA of the ready-made meal is around five times the value of the home-made. In the case of the frozen ready-made meal (RM-3), the value added is almost double that of the home-made.

Therefore, the actors in the supply chain benefit from the higher VA associated with the ready-made meals in comparison to the home-made, particularly for the chilled options. However, the trend is quite different when considering consumer costs, as discussed below.

3.6.3 Comparison of consumer costs

Figure 22 compares the costs of the base case chilled (RM-1) and frozen (RM-3) ready-made meals with the base case ready-made meal (HM-1). Three types of costs are considered: consumer costs to prepare the meal at home (energy and water), the life cycle costs from ‘cradle to consumer’ and the real consumer cost of the meals.

The results indicate that the lowest meal preparation costs are for the chilled meal at £0.79 and the highest for the home-made options (£0.97). However, the opposite if found for the LCC from ‘cradle to consumer’, with the home-made meal having the lowest costs of £1.35.

The next best option is the chilled ready-made meal at £1.40 while the frozen meal is the worst option with the cost of £1.81.

A similar trend can be noticed for the real cost to the consumer from ‘cradle to consumer’ (see eq. (3) for calculation) with the best option being home-made meal (HM-1) with the cost of £1.91 and the worst chilled ready-made meal RM-1 with an average cost of £3.51. The average cost of the frozen meal (RM-3) is £2.64.

Therefore, these results suggest that the home-made meal has lower consumer costs than the ready-made option.

This, as well as perceived health benefits of home-cooked as opposed to industrially processed food, may be important drivers for some consumers to consider home cooking. However, for others, factors such as convenience, lack of time and cooking skills may lead to choosing ready-made meals, regardless of the costs. Furthermore, some consumers may be motivated by environmental reasons when making purchasing choices. Therefore, in the next section we compare and contrast the life cycle costs with environmental impacts of ready- and home-made meals.

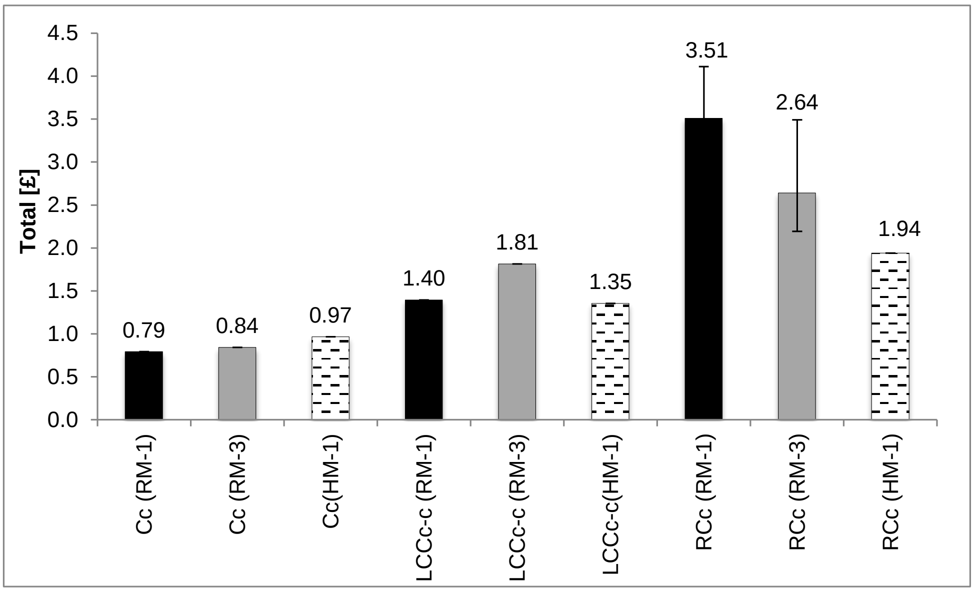

Figure 22 Comparison of consumer costs of ready-made and home-made meals

[Cc: costs of meal preparation (energy and water); LCC $_{c-c}$: life cycle costs from cradle to consumer. RCc: real costs to consumer. For description of different meal options, see Table 18].

3.6.4 Comparison of life cycle costs and environmental impacts

As mentioned earlier, the environmental impacts of the meal options considered here have been estimated in a previous work by the authors (Schmidt et al., 2014) and are not repeated here. Instead, we summarise those results in Figure 23, using a qualitative approach to identify the best meal options for both the LCC and environmental impacts. The results in the figure are obtained by assuming that all the criteria considered are of equal importance, with white boxes indicating the lowest costs and impacts and the black the highest. This so-called ‘heat map’ helps to visualise the differences between the options and identify the best as well as the worst meal scenarios.

Thus, according to Figure 23, the best option among the ready-made meals is RM-3 with seven out of 12 criteria, including the GWP, being the lowest. However, its LCC are slightly higher than for RM-1 which is the second best option, but it has the lowest values only for three criteria. The worst option is RM-8, for which seven out of 12 criteria, including the LCC and GWP, have the highest values.

For home-made meals, the best option is HM-3 with six out of 12 criteria, including LCC and GWP. On the other hand, the worst option is HM-2 with seven out 12 criteria, having the greatest impacts in LCC and GWP.

To find out how significant the differences between the best and worst meal options may be, they are compared quantitatively in Figure 24. The results indicate that the best ready-made meal option is RM-3 with overall 23% lower impacts than the RM-8; having 43% lower LCC and 34% lower GWP. In the case of the home-made meal options, HM-3 is the best choice with on average 18% lower impacts than HM-2; having 23% lower LCC and 17% lower GWP.

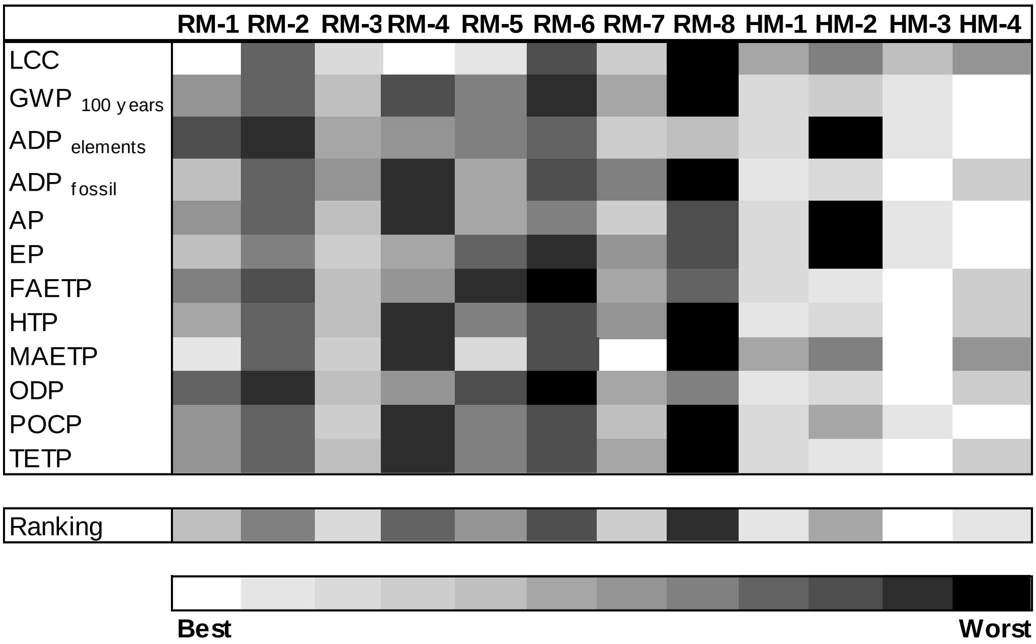

Figure 23 Comparison of the life cycle costs and environmental impacts of ready- and home-made meals

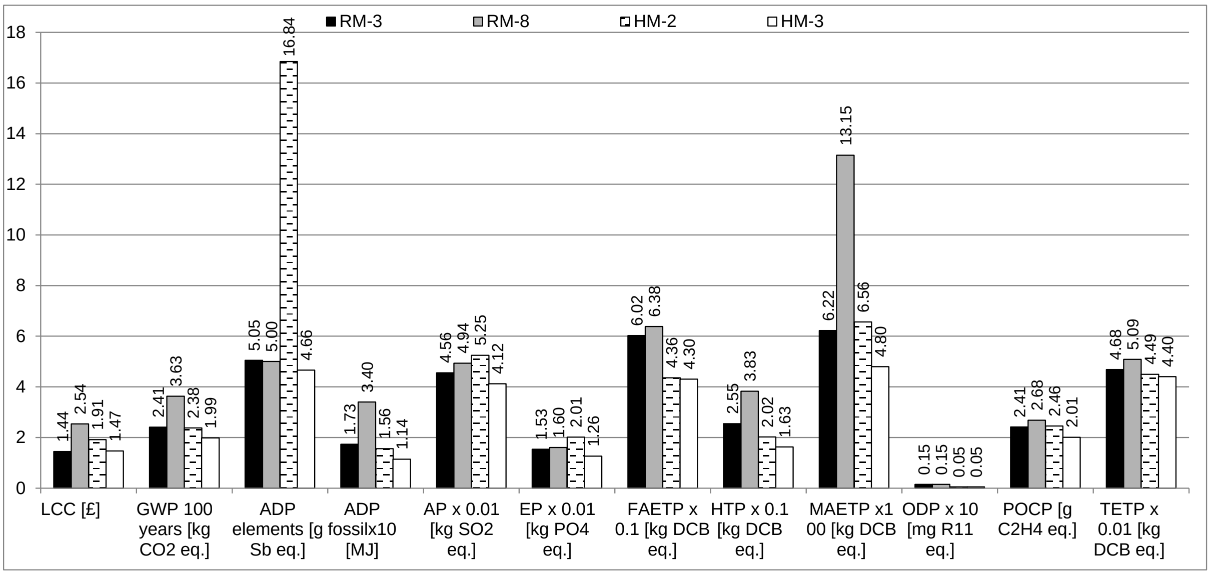

Figure 24 Comparison of the life cycle costs and environmental impacts for the best ready- and home-made meal options

4 Conclusions

This paper has considered the life cycle costs (LCC) of ready- and home-made meals. The total LCC of the ready-made meals range from £1.41 for the chilled meal made from fresh ingredients and heated in the microwave (RM-1) to £2.54 for the frozen ready-made meal made from frozen ingredients and heated in an electric oven (RM-8). The main contributor to the LCC is the cost of energy used to heat the meal at home, with electric oven accounting for 65% of the total. The raw materials are the second largest contributors to the LCC, with chicken and tomato representing collectively 70% of the ingredient costs. Sourcing the chicken from the UK or Brazil does not affect the costs but using British tomatoes or British organic ingredients increases the total by around 20%.

The LCC of home-made meals range from £1.47 to £1.91 with the best option being the home-made meal made from conventional ingredient and cooked in the electric oven and in the microwave (HM-3). Similar to the ready-made options, the major cost contributors are the meal preparation and raw materials. The higher LCC is found for the meal made from organic ingredients (HM-2).

The results suggest that the chilled ready-made meal (RM-1) has 8% lower LCC than the base-case home-made meal (HM-1): £1.41 vs £1.54. However, if the best scenario for the home-made meal is considered (HM-6), its LCC are 5% lower than for the ready-made option (£1.34).

The highest value added is found for the chilled (RM-1), followed by the frozen (RM-3) ready-made meal, and followed by the home-made meal made with organic ingredients (HM-2). Therefore, from the supply chain perspective, the chilled ready-made meal generates greater economic benefits to different players in the supply chain. However, from the consumer's perspective, the home-made meal (HM-1) has the lowest costs followed by the frozen (RM-1) ready-made meal.

A comparison of the life cycle costs and environmental impacts of different ready-made meal options indicates that the best option overall is the frozen ready-made meal made from fresh ingredients and heated in the microwave (RM-3). The worst option is the frozen ready-made meal made from frozen ingredients heated in the electric oven (RM-8). However, overall, home-made meal made from conventional ingredients and cooked in the electric oven and in the microwave (HM-3) is the best option overall.

These results help to increase both producer and consumer awareness of both economic and environmental consequences of convenience food, compared to home cooking. However, it is important to note that this analysis did not consider aspects such as health, nutritional value and convenience that also play an important role in consumer purchasing decisions. It is recommended that these issues be explored in future research.

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Chapter 4: Environmental Assessment of Common British Ready-made Meals

This paper is currently being prepared for submission to a peer reviewed journal and the possible options are the Journal of Cleaner Production and the International Journal of Life Cycle Assessment.

The research, consisting of an environmental impact assessment of common ready-made meals consumed in the UK, was designed, executed and written by the author of this thesis. Co-author Azapagic A. supervised the research and edited the paper.

Environmental Assessment of Common British Ready-made Meals

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Abstract

A sense of convenience is one of the main drivers in modern society and products such as ready-made meals play an important role; the constant growth of these products has been also raised sustainability issues, which have not been well studied yet. Therefore this study aims to assess the environmental impacts of thirteen common British ready-made meals from four popular cuisines: British, Italian, Indian and Chinese; evaluating 11 impacts under a life cycle perspective (LCA), and also integrating issues as nutrition, meat consumption reduction and nutrition-environmental efficiency. The results suggest that overall the most environmentally sustainable cuisine is the Chinese, then the British and finally the Italian and Indian. In terms of meals, the best environmentally sustainable options are the roast dinners, in particular the pork roast dinner. The worst options are the classic lasagne, spaghetti Bolognese, and cottage and shepherds' pies. For instance, global warming potential ranges from 2.15 kg CO_2 eq. per meal in the case of pork roast dinner to 5.03 kg CO_2 eq. for classic lasagne. However, if the nutrient-environmental efficiency is considered, Indian chicken korma curry and British fisherman's pie are the best options after the pork roast dinner. The results also indicate that the main hotspots are the raw materials, the manufacturing and distribution stages. Where the meat and dairy products account for above 50% of the meal (by mass), the raw materials stage contributes 40% - 70% of the GWP. A similar trend is found in impacts as abiotic depletion of elements, acidification potential and eutrophication potential.

The study also found that reducing the amount of meat and replacing it with seitan or granule soy improves the GWP, AP, EP ADP $_{\text{elements}}$ and EP by 17% to 27%. However this is not necessarily the case for using tofu as a replacement: four impacts were improved upon, but five were significantly/slightly worse. These results are greatly affected by the lack of availability of full inventories; therefore, the authors encourage the development of more studies in the field. Finally the results of this study look to generate awareness on the consumer and industry choices; in the former about their consumption of the different meals as well as the opportunities to demand healthier and environmentally efficient products. In the case of the industry, the study outcomes highlight the impact of raw materials selection, and also the integration of environmental parameters in new product development, which could improve the environmental and health performance of the products.

1 Introduction

Time-saving and convenience is a significant driver in our society's consumption patterns. As a result, the ready-made meal industry has thrived globally. A clear example of this is the fast growth of these typically western products in markets such as Asia, Latin America and Eastern Europe (Key Note 2013).

In the case of the British market, the sector has exhibited fast growth since 2008, where the market value at retail prices (rsp) rose from £1.62bn to £1.98bn in 2013 (Key Note 2013;Key Note 2014). Moreover, ready-made meals were the fifth highest-grossing category of fresh food product sold in UK supermarkets between March 2012 and March 2013, after vegetables and fruits, milk and cheese, (Warwicker 2013) with sales of around £2.55bn (Kantar Worldpanel 2013). In terms of consumer preferences, ready meals are the second most consumed food after sandwiches with a penetration of 90%: 9 out of 10 households buy ready meals (Wall 2013).

A number of issues have affected the sector, with unexpected results. For instance in 2013 the horsemeat scandal economically affected the frozen ready-made meal market: a number of products claiming to contain beef were found to instead use horsemeat, resulting in an 8% reduction in sales (Garner 2013). Although the chilled ready-made meals were also affected in volume (reduction in sales of 5% in volume), they did grow in value by 2.3% (Key Note 2013;Key Note 2014). However, an apparent beneficiary of the scandal was the vegetarian ready meals; for example Quorn Food declared that their sales increased by 13% during 2013 (Key Note 2013;Key Note 2014).

The chilled ready meals market is the largest within the sector. Since 2008, it has grown by 38.3%, reaching £1.38bn in 2013 and was estimated to reach £1.71bn by 2018(Key Note 2014). In 2013, the chilled ready meals represented 70% of the ready-made meals market (Key Note 2014).

Although this fast growth has contributed to the overall UK economy, the environment has been adversely affected due to the high energy and water consumption, as well as waste generation, of the sector. For instance, in 2011 the agri-food supply chain, the largest contributor to global warming is the food and drink sector (FDS) with associated emissions of around 61 Mt CO_2 eq. per year, compared to 13 Mt CO_2 eq. from the manufacturing industry, 12 Mt CO_2 eq. from transport and 11 Mt CO_2 eq. from retailers (Defra 2014). Households also play an important role with a contribution of 18 Mt CO_2 eq. (Defra 2014).

In terms of energy usage, the manufacturing industry uses 62.64 MWh (5.2 Mtoe) in 2011, where the main sources are natural gas (62%) and electricity (30%), alongside petroleum, oil and coal (8%). In terms of waste, the UK FDS generates 15 million tonnes of waste yearly, where the manufacturing sector produces 3.2 mt per year. The government and industry have been working together to reduce some of these impacts through different voluntary engagements aimed at minimising water and energy usage, CO_2 emission and waste production (WRAP 2014;FDF 2013;FHC 2014). Examples of these engagements are the Courtauld Commitment, a voluntary initiative within the retail sector to reduce waste (packaging and food waste) and improve the use of resources (WRAP 2014), as well as the Federation House Commitment, a voluntary agreement within the FDS to reduce water usage by 20% by 2020 (FHC 2014).

Due to the significant contribution of the food sector to greenhouse gas emissions, several LCA studies have been published for different food items (Ruini et al. 2012;Saarinen et al. 2012;Alberto Calderon et al. 2010;Cappelletti et al. 2010) and the impact of different diets on associated environmental impacts (González et al. 2011;Tukker et al. 2009;Schau and Fet 2008;Saxe et al. 2013;Friend of the Earth 2012;Pathak et al. 2010). However, only two studies have conducted comprehensive environmental studies of ready-made meals, one in Sweden (J. Berlin and V.Sund 2010) and the other in the UK (Schmidt Rivera et al. 2014). Comprehensive studies analysing a greater variety of ready-made meals as well as nutritional content have not been researched yet.

Therefore, this study seeks to apply life cycle assessment methodology (LCA) to determine the environmental impacts associated with thirteen common British ready-made meals available in the market.

Moreover, the research also integrates the nutritional aspect into the analysis, by defining environmental-nutritional efficiency factors for each meal. Finally, the study also tests different options to reduce the environmental impacts by incorporating meat replacements to the recipes. The results will help to understand the environmental impact generated by the different meal options available in the market as well as the interaction between the environmental impacts and the nutritional content of the meal. The following section presents the methodological approach before detailing the results and discussion in section 3. Finally, conclusions and recommendations are made in section 4.

2 Methodology

The study applies the LCA methodology following the ISO 14040/14044 standards (ISO 2006a;ISO 2006b). To estimate the environmental impacts, the study uses GaBi software (PE International 2011) and the CML 2001 method (Guinée et al. 2002). The following sections detail the methodology, assumptions and data used within the model.

2.1 Goal and scope

The aims of this study are:

- to estimate and compare the environmental impacts of ready-made meals available in the UK market;
- to identify the life cycle hotspots in order to identify and assess potential improvements;
- to analyse the nutrition-environmental efficiency of the ready-made meals studied, through the integration of the nutritional content with the environmental impacts analysed; and
- to deliver recommendations to consumers and industry.

The scope is from ‘cradle to grave’ and the functional unit is defined as ‘a personal chilled ready-made meal of 360 g, consumed at home in the UK’. The research includes meals from the four major cuisine groups: British, Italian, Indian and Chinese. The selection of the meals was made as follow:

First, using the classification of the retailers and the market, the selection of the major cuisines was made based on the market share (Figure 25) and consumers surveys (Key Note 2011). From there, four cuisines were selected, representing 85% of the market.

Second, due to the complexity of the products and time constraint, two recipes (meals) were selected from each cuisine as an attempt to determine the impacts of the different meal options and also the range of environmental impacts across the breadth of the ready-made meal sector; the only exception was the British cuisine, where seven different recipes were studied due to this is one of the most purchased meal-type (Key Note 2011) and also because it is the national cuisine.

Finally, the selection of the specific meals for each cuisine was based on an online market screening of the major retailers in the UK; the criteria were the common meals across all the sources (retailers) and, as much as possible, the availability of them as chilled and frozen options. All the brands were included and also other minor retailers were assessed too.

Summarising, the British cuisine is represented by three pies (cottage, shepherd and fisherman’s) and by four roast dinner options (beef, lamb, pork and chicken). The Italian cuisine considers two dishes: classic lasagne and spaghetti Bolognese, while the Indian cuisine is represented by chicken korma and lamb masala curries. Finally, the Chinese cuisine is represented by pork and prawns (P&P) fried rice and chicken noodles.

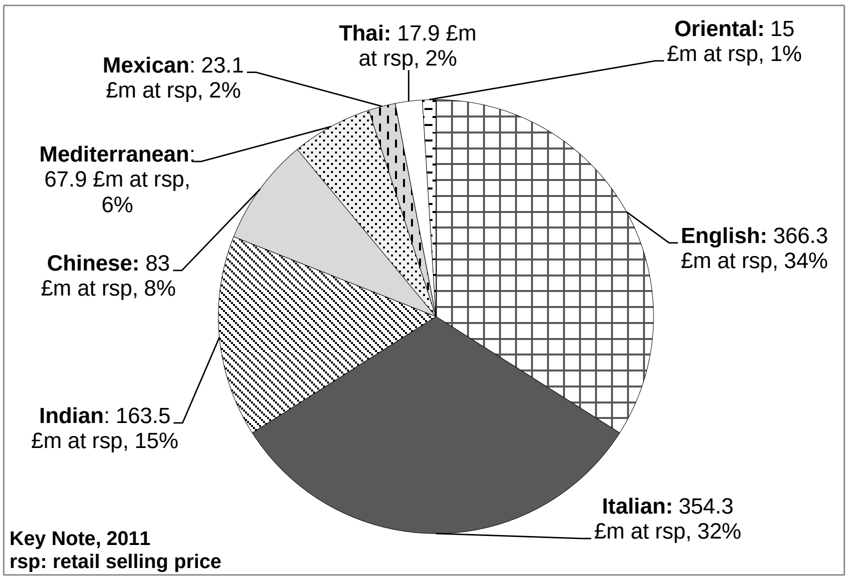

Figure 25 ***The UK Chilled ready-made meals market share by retail selling prices (rsp) by 2010***

In order to analyse the nutritional environmental efficiency of the meals, the following equation is used:

$$Efficiency = \frac{\text{Nutritional parameter}}{Environmental\ impacts} \tag{1}$$

The nutritional parameters analysed are the energy content (kcal), the fat and saturated fat, the carbohydrates and sugar content, the protein content and the fibre and salt content. In the case of the environmental impacts, global warming potential, acidification potential and the eutrophication potential are selected. The results are presented in section 3.4.

2.2 System definition

The studied system comprises the complete supply chain to produce and distribute the products, as well as to consume and dispose of the waste. A summary of the system is presented in Figure 26. The raw material stage includes the agricultural and farming activities, as well as the manufacturing of processed ingredients (flour, tomato paste, etc.). The raw ingredients are then transported to the pre-processing stage where the vegetables are cleaned and stored, whilst livestock is processed within the slaughterhouse and refrigerated. After this stage, all the ingredients are sent to the manufacturing facilities where the meal is cooked, packaged and sent to the distribution stage to be sold. The meal is then purchased by the consumer, who transports it home, stored in the fridge or freezer and then heated up in the microwave. The packaging and leftovers are sent to the final disposal stage where they are landfilled.

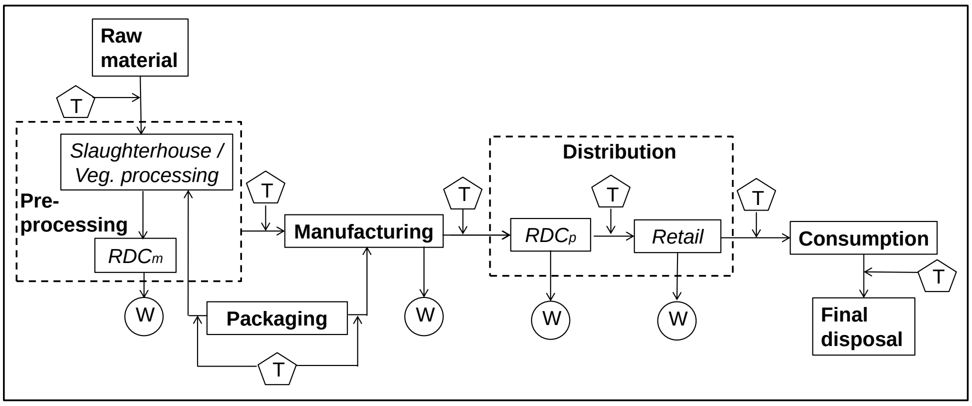

Figure 26 Life cycle of the chilled ready-made meals

[RDC: regional distribution centre for raw materials (m) and for final products (p)]

The following sections present a detailed description of each life cycle stage alongside the data used and assumptions made for the study.

2.2.1 Raw materials (ingredients)

This stage includes the agricultural and farming activities required to produce the ingredients, as well as the manufacture of the processed ingredients. Table 26 gives details of all the ingredients used in the study, in terms of origin and data source. From this stage, the raw materials are transported by road to the pre-processing stage (described in Section 2.2.5). The study assumes the use of British raw materials where possible and when there is no available data, it is adapted (UK grid, water sources, etc.) or imported (the transportation is included).

The proportion of ingredients used in each recipe is presented in Table 27. These proportions are based on the average composition across the similar meals from the different manufacturers analysed. Where data on specific ingredient proportions was not available, the recipes were completed based on typical home-made recipes (BBC 2014). Moreover, variations in the meal recipes are also investigated in the study, the details of which are given in Table 28. It is important to clarify that some ingredients are not included due to the lack of available LCI data. Such ingredients are spices, herbs, coconut milk, and nuts, among others. These exclusions are not expected to impact significantly upon the results as each ingredient accounts for less than 2% of the meal recipes.

Moreover, this research also includes sensitivity analysis of different raw material options, in particular meat and meat replacements.

Table 26 Details of the ingredients use in the ready-made meals

Ingredients	Country	References
Beef	UK	Williams et al. (2006)
Lamb	UK	Williams et al. (2006)
Pork	UK	Williams et al. (2006)
Chicken	UK	Williams et al. (2006)
Eggs	UK	Williams et al. (2006)
Fish (mackerel [b])	Spain	Vázquez-Rowe et al. (2010)
Prawns (shrimps [c])	Denmark	Nielsen PH et al. (2003)
Potatoes	UK	Williams et al. (2006)
Tomatoes	Spain	Antón et al. (2005)
Carrots	Denmark	Nielsen PH et al. (2003)
Onions	Denmark	Nielsen PH et al. (2003)
Peas	Denmark	Milà i Canals et al. (2008)

Ingredients	Country	References
Tomato paste [d]	Spain	European Commission (2010), FAO (2009);
Flour [d]	Denmark	Nielsen PH., et al. (2003)
Wheat	Switzerland	Ecoinvent (2009)
Sugar (sugar beet)	Europe	Ecoinvent (2009)
Cream [d]	Denmark	Nielsen PH., et al. (2003)
Milk	UK	Williams et al. (2006)
Olive oil	Italy	Salomone and Ioppolo (2012)
Vegetable oil	Europe	Ecoinvent (2009)
Salt	Europe	Ecoinvent (2009)
Soy beans [a]	Brazil	Ecoinvent (2009)
Wine	Australia	Amienyo (2012)
Butter [d]	Denmark	Nielsen PH et al. (2003)
Bread [d,e]	Denmark	Nielsen PH et al. (2003)
Granule soy	Austria	SERI (2012)
Tofu [d]	Sweden	Håkansson et al. (2005)
Seitan	Austria	Nussinow (1996)

[a] Component of soy sauce, adapted from home-made recipe (Forte 2014)

[b] Best available data (completeness)

[c] Proxy for Prawns

[d] Data of the processing

[e] Proxy for Bread crumbs.

Table 27 Composition of the ready-made meals considered in the study

Ingredients [a] (g)	**Cottage pie**	**Shepherd's pie**	**Fisherman's pie**	**Beef roast**	**Lamb roast**	**Pork roast**	**Chicken roast**	**Classic lasagne**	**Spaghetti Bolognese**	**Chicken korma curry**	**Lamb masala curry**	**P&P fried rice**	**Chicken noodles**
Rice	-	-	-	-	-	-	-	-	-	134	134	196.8	-
Pasta/noodles	-	-	-	-	-	-	-	47	119	-	-	-	111.6
Mashed potatoes	180	180	164	-	-	-	-	-	-	-	-	-	-
Potatoes	167	167	153	-	-	-	-	-	-	-	-	-	-
Milk	7	7	7	-	-	-	-	-	-	-	-	-	-
Butter	5	5	5	-	-	-	-	-	-	-	-	-	-
Meat													
Beef	58	-	-	41	41	41	-	72	58	-	-	-	-
Lamb	-	58	-	-	-	-	-	-	-	-	74	-	-
Pork	-	-	-	-	-	-	-	-	-	-	-	57.6	-
Chicken	-	-	-	-	-	-	75.6	-	-	74	-	-	65.9
Fish	-	-	59	-	-	-	-	-	-	-	-	-	-
Prawns	-	-	18	-	-	-	-	-	-	-	-	9	-
Vegetables and Sauce													

Potatoes	-	-	-	93.6	93.6	93.6	93.6	-	-	-	-	-	-
Carrots	-	6	-	44.3	44.3	44.3	44.3	14	19	-	-	-	45
Peas	-	11	17	43.2	43.2	43.2	43.2	-	-	-	-	25.6	-
Onions	59	15	-	-	-	-	13.2	23	49	113	35	18.9	45
Tomatoes	-	15	-	-	-	-	-	94	76	-	87	-	-
Tomato paste	3	-	-	-	-	-	-	-	-	-	3	-	-
Cream	-	-	-	-	-	-	-		-	20	9	-	-
Flour	1	-	4	10.9	10.9	10.9	4	9	-	2	-	-	-
Sugar	-	-	-	-	-	-	-		-	7	-	-	-
Wine	15	-	-	-	-	-	-		27	-	-	-	-
Beef stock (water)	39	73	-	106	106	106	75.6		-	-	-	-	-
Milk			87	12.9	12.9	12.9	-	88	-			-	-
Butter			9	-	-	-	-	9	-			-	-
Bread	-	-	-	-	-	-	5.2	-	-	-	-	-	-
Eggs	-	-	-	7.1	7.1	7.1	3.4	-	-	-	-	20.4	-
Soy sauce	-	-	-	-	-	-	-	-	-	-	-	12.8	92.5
Oil (vegetable/olive)	5	2	-	-	-	-	0.9	3	11	8	17	18.9	-
Salt	1	1	1	1	1	1	1	1	1	2	1	-	-
Total	360	360	360	360	360	360	360	360	360	360	360	360	360

[a] The recipes were developed with public information from manufacturers (product labels) and home-made recipes (BBC food, 2014). However, there were also adapted based on available LCA data.

Table 28 Variation in the composition of the ready-made meals[a]

	Cottage pie		**Shepherd's pie**		**Fisherman's pie**		**Beef/lam/ pork roast**		**Chicken roast**		**Classic lasagne**		**Spaghetti Bolognese**		**Lamb masala curry**		**Chicken korma curry**		**P&P fried rice**		**Chicken noodles**	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Rice/ Mashed potatoes/ Pasta (%)	60	47	50	50	48	41	50.3	57	50.3	57	13	13	37	23	41	36	41	36	85	81	37	25
Meat and sauce (%)	40	53	50	50	52	59	-	-	-	-	87	87	63	77	59	64	59	64	-	-	-	-
Meat (%)	44	*14*	40	*23*	29	14	13	9	22	20	27	16	31	17	50	26	50	26	15	19	20	17
Sauce (%)	56	86	60	*77*	23	45	36.7	34	27.7	23	73	84	69	83	50	74	50	74	-	-	55	46

[a] The recipes are based on popular products found in British supermarkets: Asda (2014), Sainsbury's (2014); Tesco (2014); Morrisons (2014);Iceland (2014);Lidl (2014)

2.2.2 Pre-processing, manufacturing and distribution

The first step in the manufacturing chain is the pre-processing stage. For the vegetables, this includes cleaning, chopping and packaging processes (Milà i Canals et al. 2008;European Commission 2010), then transport to the Regional Distribution Centre (RDC$_m$) where they are stored (Defra and Brunel University 2008). For the meat ingredients, this stage considers the slaughterhouse (Nielsen PH et al. 2003), refrigerated storage and delivery to the next stage (Defra and Brunel University 2008). The details of the utilities are presented in Table 30.

The second stage is the manufacturing where all the ingredients are cooked, packed and delivered to the regional distribution centre for products (RMC$_p$). The data (utilities) for the manufacturing stage comes from a manufacturer (confidential source) and it was calculated using the annual utility consumption of the industry (electricity, fuel oil and water bills). Then they are allocated based on the annual production (tonnes of products manufactured yearly). It is important to note that there is no distinction between the different products produced during the year; therefore it is not possible to allocate the utility consumption to each product. In order to allocate between products, cooking time (roasting and cooking) and energy requirements were taken from home-made recipes (preparation method) and then rated to use the data (see Table 31).

Finally, within the distribution stage the products are stored at the RDC$_p$ and then distributed to the retailer, where the ready-meal is stored and displayed (Defra and Brunel University 2008); in the store, chilled food is display in open cabinets. In this stage, the annual refrigerant leaks are assumed to be 15% per year (Defra and Brunel University 2008).

Table 29 presents the details of the energy consumption, water and refrigerant usage for the pre-processing and distribution stages. This table was adapted from Schmidt Rivera et al. (2014).

Table 29 Utilities of the industrial chain in the life cycle of ready-made meals

Utilities (amounts per meal)	**Pre-processing**	**Distribution**
Storage time (h)	12	60
Electricity (Wh)	5.88	52.8
Fuel oil (l)	-	-
Water (l)	1.13	-
Steam (Wh)	0.3	-
Refrigerant charge (mg)[a]:		
R134a	-	150.7
Ammonia	180.5	180.8
R22	-	-
Refrigerant leakage (mg)[a]:		
R134a		22.6
Ammonia	27.1	27.1
R22	-	-

[a] The pre-processing and regional distribution centres use ammonia while the retail uses R134a; for bot type of refrigerants, the leakage rate is 15% (Defra and Brunel University 2008).

***Table 30 Utility used in the slaughterhouse and fish/seafood processing*[a]**

Utilities (amount per kg of product)	**Cattle**	**Pigs**	**Chicken**	**Fish**	**Shrimps**[b]
Electricity (MJ)	0.14	0.41	0.989	0.983	2.86
Natural gas (MJ)	-	-	-	0.22	10.42
Heat (MJ)	0.17	0.63	0.495	-	-
Water (l)	2	2.7	12.363	5.3	-
ammonia (g)	-	-	-	0.12	-
Waste (kg)	0.65	0.35	0.374	0.167	1.98
Raw materials [kg]	1.65	1.35	1.374	1.18	3.02

[a] Data source: (Nielsen PH et al. 2003)

[b] Shrimp are used as proxy for prawns

Table 31 Electricity and fuel oil consumption in the manufacturing stage for the ready-made meals

Cuisine	**Recipes**	**Energy [a,b,c] Consumption (MJ)**	**Electricity (kWh)**	**Fuel oil (l)**
British cuisine	Cottage pie	1.9	0.36	0.04
	Shepherd's pie	1.9	0.36	0.04
	Fisherman's pie	1.9	0.36	0.04
	Beef roast dinner	2.38	0.44	0.05
	Lamb roast dinner	2.38	0.44	0.05
	Pork roast dinner	2.84	0.53	0.06
	Chicken roast dinner	2.52	0.47	0.06
Italian cuisine:	Classic lasagne	2.1	0.39	0.05
	Bolognese spaghetti	1	0.18	0.02
Indian cuisine:	Chicken korma curry	1.7	0.32	0.04
	Lamb masala curry	1.7	0.32	0.04
Chinese cuisine:	P&P fried rice	1	0.19	0.02
	Chicken noodles	1	0.19	0.02

[a] The home-made recipes are based on BBC (2014).

[b] The cooking preparation methods for the roast dinners are based on roasting times (2014).

[c] The electricity consumption for the oven and hobs are coming from Jungbluth (1997).

2.2.3 Consumption

This stage includes the transportation of the meal from the retailer to the consumer’s home (by car), storage, cooking (using the microwave) and the water used for washing-up. The details are presented in Table 32.

The storage only considers the electricity consumption (Nielsen PH et al. 2003) while refrigerant leakages are assumed to be negligible. The microwave electricity consumption is assumed to be 0.0435 MJ/min (Jungbluth 1997) and the time is derived from typical cooking instructions. The water consumption is based on data from Defra (2008b);DEFRA (2008a).

Table 32 ***Electricity and water consumption in the consumption stage***

Activity (per meal)	**Electricity (Wh)**	**Water (l)**
Storage	2	
Microwave	78.6	
Wash-up		1

2.2.4 Waste

The different waste and loss rates accounted for in every stage are detailed in Table 33. It is important to clarify that the waste produced is accounted for in each stage that the waste occurs; the only exception is the waste produced in the consumption stage, where the leftovers and the packaging are sent to the final disposal stage where they are treated. The waste management option is landfill (Ecoinvent 2009). The only exception is the animal waste (rendering) which is included as part of the slaughterhouse (blood and bone industry) (Nielsen PH., et al. 2003).

Table 33 Waste in the life cycle of the ready-made meals

Stage	**Waste rate**	**Reference**
Pre-processing	15% of vegetables	Milà i Canals et al. (2008)
	27% of chicken	Nielsen PH et al. (2003)
	26% pork	Nielsen PH et al. (2003)
	39.39% cattle	Nielsen PH et al. (2003)
Manufacturing	16% of ingredients	BIS (2011)
	0.65% of products	Confidential information
Distribution	2% on each sub-stage	Defra and Brunel University (2008)
Consumption	24%of the meal	WRAP (2009)

2.2.5 Transport

Table 34 presents the details of the transport steps used in every stage. All transport vehicles use diesel, except for the consumer’s car that uses petrol. All trips account for an empty vehicle return.

Table 34 Transportation in the life cycle of ready-made meals

Stage	**Distance [km]**	**Transport**	**Reference**
From farm to pre-processing			
In UK	200	Truck, 32t	Ecoinvent (2009)
In Italy	1720	Truck, 32t	Ecoinvent (2009)
In Spain	1300	Truck, 32t	Ecoinvent (2009)
From pre-processing to manufacturing	100	Truck, 32t	Ecoinvent (2009)
From manufacturer to RDCp	100	Truck, 32t	Ecoinvent (2009)
From RDCp to retail	100	Truck, 32t	Ecoinvent (2009)
From retail to consumer’s home	7.5	Petrol car	Pretty et al. (2005); Ecoinvent (2009)
From consumer’s home to disposal facilities	25	Lorry 21t	Ecoinvent (2009)

2.2.6 Packaging

The study considers the primary, secondary and tertiary packaging of the raw materials and products. The details are presented in Table 35.

Table 35 Packaging of the life cycle of the ready-made meals

Meal packaging [a]		**Box [b]**		**Crates [c]**		**Euro pallet [d]**		**Plastic bag [e]**	
Type	***Unit***	***Details***	***Unit***	***Details***	***Unit***	***Details***	***Unit***	***Details***	***Unit***
Polyethylene film (kg)	0.01	Cardboard (kg)	0.37	Propylene (kg)	2.8	Wood [kg]	21	Low density Polyethylene (kg)	0.01
Polyethylene terephthalate (kg)	0.025	Weight per unit (kg)	8	Weight per unit (kg)	20	Weight per unit (kg)	750-1000	Weight per unit (kg)	4.5
Cardboard (kg)	0.015	Unit per pallet (u)	70	Unit per pallet (u)	32	Re-use rate (u)	1000		
		-	8	Re-use rate (u)	1000	-	750-1000	-	

[a] Data source: Meal manufacturer.
[b] Data source: Defra and Brunel University (2008) and Packaging calculator (2014)
[c] Data source: Defra and University (2008) and Solent Plastic (2013). Crate volume: 26.5 l.
[d] Data source: Defra and Brunel University (2008) and Fox's Pallets (2013).
[e] Data source: Defra and Brunel University (2008)

2.3 Allocation

The study uses mostly secondary data, which has been allocated under different criteria. In the case of the animal and derived products, the allocation is made based on economic criteria. In the case of the pre-processing, regional distribution centres, manufacturing and retailers the energy and water usage, the allocation is made on a mass basis.

3 Results and discussion

This section presents the results and discussion of the environmental assessment of common British chilled ready-made meals. First, in section 3.1, the environmental impacts are analysed for each meal, including the life cycle stage contribution and the influence of the recipe variations. Then section 3.2 details the change in environmental impacts associated with replacing meat with non-animal sources. Finally in section 3.3, the nutritional composition of each meal is presented and the nutritional-environmental efficiency is analysed for the each meal.

3.1 Environmental impacts assessment

Figure 27 presents the 11 estimated environmental impacts for each meal considered. Based on these impacts, the results indicate that the most environmentally benign options are the roast dinners, in particular the pork based meal. The Italian meals (lasagne and spaghetti) exhibit the highest impacts, followed by the Indian lamb masala curry and the British Cottage and Shepherd's pies.

In terms of stage contribution, the main hotspots are the raw materials (49% of total on average across all impacts), the distribution (14%) and manufacturing (12%) stages. Moreover, the effects of the recipe variations on the environmental impacts are significant, ranging from reductions by 33% in the case of lamb masala curry, cottage pie and spaghetti Bolognese, to an increase of 42% in the case of Cottage pie; this is largely due to the change in meat composition which has a large impact, in particular lamb and beef. Overall, the lowest variations are found in the Chicken roast dinner and Chicken noodles. The results are presented and discussed below.

3.1.1 Global Warming Potential

As seen in Figure 27a, GWP ranges from 2.2 kg to 5 kg CO_2 eq. per meal. The highest GWP is found in the classic lasagne and lamb masala curry with 5 kg and 4.9 kg CO_2 eq. per meal respectively, whilst the pork roast dinner is the lowest with 2.2 kg CO_2 eq. Almost half of the recipes present GWP in the range of 2 kg to 3 kg CO_2 eq. per meal, which are chicken korma curry (2.9 kg CO_2 eq.), fisherman's pie (2.8 kg CO_2 eq.), P&P fried rice (2.8 kg CO_2 eq.), chicken noodles (2.6 kg CO_2 eq.), chicken roast dinner (2.5 kg CO_2 eq.) and the pork roast dinner. Only 15% of the recipes have GWP between 3 kg and 4 kg CO_2 eq., specifically the beef and lamb roast dinner with 3.2 kg and 3.3 kg CO_2 eq., respectively. In the highest range, around 39% of the recipes show a GWP between 4 kg and 5 kg CO_2 eq.; shepherd's pie, cottage pie and spaghetti Bolognese have similar values, with 4.4 kg, 4.3 kg and 4.20 kg CO_2 eq. per meal.

Even though the main hotspots are clearly distinguished, the raw materials (~55%) and distribution (~19%) stages, the contributions vary significantly depending on the meal. For the lamb masala curry and the classic lasagne, the raw materials stage contributes ~70%.

In the case of the lamb curry, the lamb component of the meal is almost entirely responsible, representing 91% of the raw material stage impact. For the lasagne, the beef is the main contributor with 83% of raw material impacts followed by butter with 10%. For the cottage pie, shepherd's pie and spaghetti Bolognese, the contribution of the raw materials is ~65%, with the meat being responsible for ~89% in the three scenarios.

For the chicken korma curry, beef and lamb roast dinner and P&P fried rice, the raw materials stage has a contribution of ~50% to GWP. In the case of the curry, chicken contributes with 56% to this stage; the cream contributes around 30% while the rice contributes 10%, and the other ingredients less than 2% each. In the case of the beef and lamb roast dinners, the main contributor is the meat (beef and lamb) with ~90%, followed by the eggs (ingredient of the Yorkshire putting) and potatoes with 4%; the other ingredients contribute less than 1%. For the P&P fried rice, the main contributor is the pork with 57%, followed by the rice and eggs with 16% and 15%, respectively. The prawns contribute with 7% and the oil with 4%. All the other ingredients contribute with less than 1%.

Finally, fisherman's pie, chicken roast dinner and chicken noodles present the lowest raw material contribution with ~43%. In the case of the former, the main contributor is butter with 58%, followed by prawns and fish with 15% and 9% respectively. The milk and the potatoes contribute with 10% and 8%, respectively. For the chicken roast dinner, the main contributor is chicken with ~84%, followed by the potatoes and the eggs with 7% and 3%; the other ingredients contribute with less than 1%. Lastly for chicken noodles, chicken (66%) is mainly responsible for the raw materials stage followed by pasta with 28%. The soybeans from the soy sauce contribute with 35%, while the rest of the ingredients add less than 1%.

Thus, the type and quantity of meat have the largest effect on GWP. Beef and lamb have the greatest GWP with 16 - 17 t CO_2 eq. per tonne of carcass, compared with less than a half in the case of pork and chicken (6.4 ton and 4.6 t CO_2 eq. per tonne of carcass) (Williams et al. 2006). Factors such as efficiency of feed conversion, the reproduction rates (breeding stock) and digestion type are critical factors affecting the environmental impacts. In the case of cattle, the reproduction rate is lower than pigs and poultry; only one (maximum two) calf per adult compared with an average eight in the case of pigs and several yearly in the case of poultry. Also, the gestation time is different among them, therefore if a year is considered, poultry and pigs are the most efficient too. Similarly for feedstock, the amount of feedstock consumed per carcass is lower in poultry and pigs than in cattle. Additionally, cattle are ruminant animals where the emitted methane has 33 times higher effects than carbon dioxide into GWP.

The recipe composition (percentage of the ingredients) varies depending on the manufacturer's recipes, which also varies the nutritional content. In order to account for these variations, the effect of different ranges of compositions based on the market screening (mentioned in Table 3) was investigated for every meal. Figure 27a also presents the effect on GWP for each meal.

As can be seen in Table 28, the variations in the recipes are related to the proportion between the meat composition (sauce, fillings or meat) and the side dish (rice, pasta or vegetables) or the mashed potatoes in the case of pies. Overall, variations in GWP range from reductions of 32% in the case of the Cottage pie to an increase of 33% in the lamb masala curry. The fisherman's pie, Chicken noodles, Pork and Chicken roast are the least affected by the recipe variations with overall fluctuations lower than 3% across all the impacts. The only exception is the reduction found in the pork roast dinner, with a decreased GWP of 8%. The main reason for this low variation is that the meat composition, which typically has the greatest impact on GWP, changes by only 4%.

The highest variations (~20%) are found in Cottage pie, Spaghetti and Lamb roast. For the Cottage pie, the recipe variation increases the GWP by 22% to 5.2 kg CO_2 eq. per meal with high proportion of beef and reduces it by 32% to 2.9 kg CO_2 eq. per meal with low proportion of beef. Similarly, the GWP of spaghetti Bolognese increases by 24% to 5.2 kg CO_2 eq. per meal when beef is increased by 17.5% and is reduced by 17% to 3.5 kg CO_2 eq. per meal under a scenario with 13% of meat. These are due to the variations in the meat composition but also due to the variations in the pasta and the sauce (tomatoes and tomato paste) composition. Finally, Lamb masala curry has the greatest increase in GWP impact, 32% higher due to the increase of 30% of lamb. A reduction of 19% to 4.1 kg CO_2 eq. per meal occurs when lamb is reduced by 23%. As can be seen here, the composition of meat in the recipes plays a fundamental role in the case of beef and lamb based meals, because the vegetables and side dishes (rice and pasta) do not have as high impacts as meat.

Therefore, the recipe variation makes the Lamb masala curry the worst option with products presenting a GWP around 6.5 kg CO_2 eq.; a similar situation is found in the case of cottage pie, Shepherd's pie and Spaghetti which could increase greenhouse emission to values between 5.0 kg to 5.5 kg CO_2 eq. per meal. On the other hand, the reductions found due to the recipe variations do not present larger changes. The best option is still the Pork roast meal with a possible GWP lower than 2 kg CO_2 eq. per meal. Only four meals reduce their GWP to values lower than 3 kg CO_2 eq. per meal: those are Cottage pie, Chicken korma curry, Beef and Lamb roasts.

Finally, in terms of cuisines, on average the lowest GWP is found in the Chinese cuisine with a GWP of 2.7 kg CO_2 eq. The highest GWP is observed in the Italian cuisine with 4.6 kg CO_2 eq. British and Indian cuisines hold the second and third positions with 3.9 kg and 3.6 kg CO_2 eq. respectively.

3.1.2 Abiotic depletion potential of elements ($ADP_{elements}$)

Figure 27b shows the $ADP_{elements}$ for the thirteen meals studied. This impact ranges from 2.8 g Sb eq. to 7.1 g Sb eq. per meal. The highest $ADP_{elements}$ is found in the Lasagne while the lowest in the Lamb and Pork roast dinner. The fisherman's pie, beef roast dinner and chicken noodles exhibit an $ADP_{elements}$ of 3.57 g, 3.52 g and 3.4 g Sb eq. per meal. There are five recipes ranging between 4 g and 5 g Sb eq. per meal: chicken roast dinner has the lowest within the range with 4.2 g Sb eq.; P&P fried rice and shepherd's pie is 4.4 g and 4.6 g Sb eq. per meal. The highest values are found in the lamb masala curry and in the spaghetti Bolognese with 4.69 g and 4.72 g Sb eq. per meal. In the next range, between 5 g and 6 g Sb eq., there are two meals: chicken korma curry and cottage pie with 5.1 g and 5.8 g Sb eq. per meal.

The main contributor of this impact is the raw materials (99% across the different meals), in particular the animal sources. Beef and eggs have the highest $ADP_{element}$ with 36 kg Sb per tonne of carcass and 38 kg Sb per tonne[3] (Williams et al. 2006) while for example, potatoes has 0.9 kg Sb eq. per tonne. The main reason for the higher values is due to the resources used to produce fertilizers and pesticides. Therefore, it is expected that the recipes with lower proportion of meat are going to present lower $ADP_{elements}$. It is important to note that there is a lack of data availability for this impact.

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[3] The calculation is based on average egg weight of 50 g.

The source of the data used was Williams et al. (2006) and based on a study focussed on British agriculture and commodities but more disaggregated data for other ingredients and other stages would be useful in order to have more acquired and complete results.

When the effect of the changes in the ingredients composition (see Table 3) are studied, the greatest $ADP_{elements}$ increases are observed in spaghetti Bolognese, chicken and lamb curry, reaching values as high as Lasagne: 6.8 g, 6.87 g and 6.82 g Sb eq., respectively. However, Lasagne is still the meal with the highest associated $ADP_{elements}$, with 7.9 g Sb eq. per meal. On the other hand, the $ADP_{elements}$ associated with lamb and pork roast dinner is lower than 2 g Sb eq. per meal (reduction of 30%) when the meat content is decreased.

In terms of cuisines, the Chinese and British cuisine presents the lowest $ADP_{elements}$ with an average of 3.9 g and 4.3 g Sb eq. per meal. The highest is found in the Italian cuisine with around 5.9 g Sb eq. per meal. The Indian shows an average of 4.9 g Sb eq. per meal.

3.1.3 Abiotic depletion potential of fossil fuels (ADP_{fossil})

Figure 27c shows the results for ADP_{fossil}. The manufacturing and the packaging stages are the main contributors to this impact, contributing ~34% and ~22% due to the high energy consumption during these stages. The third contributor is the consumption stage with ~ 19%. The raw materials stage contributes by ~11%, but it ranges from 2% to 20% depending on the recipe; this is mainly due to the energy consumption in the processed ingredients such as pasta, tomato paste, flour, among others. Therefore the recipes with lower processed ingredients have lower contribution from the raw materials stage.

Overall, this impact is not greatly affected by the recipe variations mainly because the highly energy intensive stages (manufacturing and packaging) do not vary significantly, and also because the utilities used in the manufacturing stage are based on meal preparation and not in each ingredient. However, the Chinese chicken noodles meal presents a significant range; in this case it is owing to the high variation of the composition of noodles which implies a higher usage of energy by the noodle production.

In terms of cuisines, the lowest ADP_{fossil} is found in the British cuisine with an average of 15.4 MJ per meal, followed by the Indian and Chinese cuisines with 16.7 MJ and 17.6 MJ. The worst option is the Italian cuisine with 18.1 MJ.

3.1.4 Acidification potential (AP)

As presented in Figure 27d, the highest AP is found in Lasagne with 95.4 g SO_2 eq. per meal and the lowest in Pork roast dinner with 18 g SO_2 eq. per meal. The fisherman's pie and the chicken noodles are also low with 22.2 g and 32.9 g SO_2 eq. per meal. Higher impacts are found in lamb masala curry, cottage pie and spaghetti Bolognese, with an average of 75 g SO_2 eq.; shepherd's pie and P&P fried rice have an average AP of 62.6 g SO_2 eq. per meal. Finally beef, lamb and chicken roast dinner have 54.5 g, 44.4 g and 37.8 g SO_2 eq. per meal.

The major contributor is the raw material stage with an average contribution of 90%, ranging from 82% to 97% across meals. The cultivation of vegetables and animal feedstock cause the majority of the impact, mainly due to the use of fertilizer and pesticides and also the manure, which all contain nitrogen. The acidification is caused by the ammonia, nitrogen oxides and sulphur oxides present in these fertilizers and pesticides.

The greatest impact increase due to the recipe variation is found in lamb curry and spaghetti Bolognese with 48% and 43%, followed by the cottage pie with 37%. The increase in the proportion of meat and processed ingredients increases AP to up to 110 g SO_2 eq. per meal. On the other hand, the greatest reduction is found in the cottage pie with 55%, followed by pork roast dinner and the spaghetti with 30%. As was the case with the GWP impact, this impact is mainly affected by the type of meat and the composition in the recipe.

Consequently, the highest increases in impact occur for meals with the highest increase in beef or lamb composition. The same trend follows with the reductions.

In terms of cuisines, the lowest AP is found in the Chinese and British recipes, with on average 48.3 g and 49.8 g SO_2 eq., respectively. The worst options are the Italian recipes, followed by the Indian recipes with 84.4 g SO_2 eq. and 59 g SO_2 eq. per meal.

3.1.5 Eutrophication potential (EP)

Figure 27e presents the EP for different chilled ready-made meals. The highest EP is found in the lamb masala curry with 44.2 g PO_4 eq. per meal while the lowest is found in fisherman's pie and pork roast dinner with around 10 g PO_4 eq. per meal. Chicken korma curry, chicken roast dinner and chicken noodles exhibit similar EP with 15.3 g, 13.3 g and 12.2 g PO_4 eq. per meal, respectively.

Four meals, the British cottage and shepherd's pies and the Italian classic lasagne and Spaghetti Bolognese, show an average of 35.4 g PO4 eq. per meal. The last three meals, beef and lamb roast dinner and P&P fried rice are approximately 23.2 g PO_4 eq. per meal.

As with the AP impact, the main contributor to EP is the raw materials stage with an average of 83%. The contribution varies from 67% in the case of fisherman's pie to 94% in lamb masala curry. The cause of this large impact is from nitrogen and phosphorus leaching from high levels of fertiliser and pesticides used for animal feedstock as well as manure management emissions from the landfill (final disposal), which contribute 1.5 g PO4 eq. per meal to the total EP.

As with the GWP and AP impacts, the greatest increase in EP from the variation of recipe composition is found in the Indian lamb masala curry with 49% (65.2 g PO_4 eq. per meal) followed by the Cottage pie and the Spaghetti with 32% and 36%, with values up 45 g PO_4 eq. per meal. The greatest reductions are found in the cottage pie (50%) decreasing to 17 g PO_4 eq. per meal when the composition of meat is the lowest.

Finally, the Chinese and British cuisines present the lowest EP with an average of 16.4g and 24.4 g PO_4 eq., respectively. The worst options are the Italian and Indian cuisines with 29.8g and 36 g PO_4 eq. per meal.

3.1.6 Fresh aquatic ecotoxicity potential (FAETP)

FAETP ranges from 0.41 kg DCB eq. per meal for the Italian classic lasagne to 0.59 kg DCB eq. per meal for P&P fried rice. The main contributor is the final disposal stage, which accounts for an average of 50% of the total (0.24 kg DCB eq. per meal) mainly due to the emissions from food waste and plastic landfilling, followed by the manufacturing stage with around 18%, also due to the waste treated in the stage (food and packaging landfill). The pre-processing, distribution and raw materials stages present similar contributions with 12%, 10% and 8% respectively.

As seen in Figure 3f, the variation of the raw materials contribution is relatively high; from 0.5% in the case of Beef, Lamb and Pork roast dinner to 36% in the case of P&P fried rice. This variation is because of data availability and the effects of the processed ingredients on it. The data availability affects the results due to the lack of full set of inventories or impacts assessments for all the ingredients analysed, increasing the impacts when the recipe contains data; also, the lack of data increases the importance of the processed ingredients, especially due to the waste and waste management in the manufacturing of those ingredients.

The highest effects of the recipe variations are found in lamb masala curry and cottage pie, followed by the chicken korma curry and spaghetti Bolognese, due to the changes in the composition of ingredients with information for this impact such as wine and processed ingredients.

In summary, the Italian cuisine presents the lowest average FAETP impact with 0.44 kg DCB eq. per meal followed by the British meals with 0.49 kg DCB eq. per meal.

The highest FAETP is observed in the Indian cuisine with 0.55 kg DCB eq. per meal. Finally, the Chinese cuisine presents an FAETP average of 5.1 kg DCB eq. per meal.

3.1.7 Human ecotoxicity potential (HTP)

In Figure 27g, the HTP results of the ready meals are presented. The highest value is for British fisherman's pie with 37.8 kg DCB eq. per meal; followed by the Italian spaghetti Bolognese and then by British cottage pie with 8.9 kg and 4.8 kg DCB eq. per meal respectively. All others meals present similar values between 0.23 kg to 0.58 kg DCB eq. per meal.

The main life cycle stage that impacts upon HTP is the raw material stage. In the case of the fisherman's pie, the main contributor is fish while for the spaghetti Bolognese and the cottage pie, it is the wine and olive oil. As with the FAETP and $ADP_{elements}$ impacts, this is due to one of the main limitations of the study: the lack of full available inventories or impact assessments for the ingredients. In the case of curries, P&P fried rice and chicken noodles, the raw materials contribute with around 26%; mainly because of rice and pasta; classic lasagne is an exception with the raw materials stage contribution of 60% due the pasta In the other recipes the contribution of the raw materials is lower than 7%.

The other stages have a similar contribution: the consumption stage is around 17% mainly due to the emissions of VOC and heavy metals from the consumer's car (petrol) while the manufacturing and the final disposal are 13% due to the emission of the heavy metals to the air from electricity generation and the long term emission to the water from plastic landfilling; the packaging is contributes on average 11% due to emissions during the production of plastics (specially PET); finally the distribution stage contributes with 6%.

The cottage pie, classic lasagne and spaghetti Bolognese increase their HTP with the variation in the recipe composition, in particular in the sauce ratio (wine and olive oil in particular) and the amount of pasta and rice. In the case of the former, the variation is by 34% reaching 6.4 kg DCB eq. while the other two increase by 17% and 26% reaching 0.62 kg and 11.3 kg DCB eq. per meal, respectively. The greatest reductions are found in lamb masala curry and P&P fried rice with around 50% followed by the cottage pie with 33%.

The lowest HTP is found in the Indian and Chinese meals with an average of 0.27 kg and 0.29 kg DCB eq. per meal. The highest HTP is found in the British recipes with 10.77 kg DCB eq. per meal. The Italian recipes also present a high HTP with 4.74 kg DCB eq.

3.1.8 Marine aquatic ecotoxicity potential (MAETP)

As shown in Figure 27h, MAETP presents similar values for the different ready-made meals. The impact ranges from 0.52 t DCE eq. per meal for Beef and Lamb roast dinner, to 0.59 t DCB eq. per meal for Fisherman's pie and Spaghetti.

The main contributors are the manufacturing and final disposal stages with 31% and 28%, respectively. For the manufacturing stage, inorganic emissions to the air arise from the electricity generation. For the final disposal stage, emissions from landfilling food and plastics are the main contributors. The distribution and consumption stages contribute with 11% and 10% mainly due to the emission from the electricity usage.

Finally, the pre-processing, packaging and raw materials stages contribute with an average of 7%. For the raw materials and the pre-processing stages, the variation across meals is significant: from 3% (lamb masala curry and the classic lasagne) to 10% (chicken roast dinner and cottage pie) for raw materials and from 1% (beef, lamb and pork roast dinner) to 14% (spaghetti Bolognese) for pre-processing. In the case of the raw materials, the ingredients with long distance transportation and higher processing (energy consumption) present higher contribution, mainly due to the emissions from the fuels and the electricity.

When the recipe variation is considered, the greatest increase is for fisherman's pie with 34% making it the worst possible option with respect to MAETP. In the case of the reductions, the largest is found in the Lamb masala curry (8%).

In terms of cuisines, the Indian meals presents the lowest MAETP with 0.548 t DCB eq. per meal, followed by the Chinese with 0.556 t DCB eq. and British with 0.558 t DCB eq. per meal. The highest is observed in the Italian cuisine with 0.562 t DCB eq. per meal.

3.1.9 ODP

Figure 27i presents the ozone depletion potential for different ready-made meals, which is 1.67 mg of R11 eq. across all recipes. The variations are small, almost negligible mainly because the main contributor is the distribution stage (95%), which is exactly the same for all the options. The main contributor is the usage of R134 in the retail stage, specifically the production of the refrigerant. The manufacturing stage contributes with 5%. Finally, the recipe variation does not affect this impact.

3.1.10 POCP

Figure 27j shows the photochemical ozone creation potential for the thirteen ready-made meals. The POCP ranges from 1.2 g C_2H_4 eq. (pork roast dinner) to 4.4 g C_2H_4 eq. per meal (classic lasagne). The fisherman's pie has the second lowest impact with 1.73 g C_2H_4 eq. per meal followed by the chicken roast dinner and the chicken noodles with 2 g C_2H_4 eq. per meal. The cottage pie and spaghetti Bolognese present the second largest impact with on average 3.6 g C_2H_4 eq. per meal.

The main contributor of this impact is the raw materials with an average of 75%. The contribution varies from 50% for pork roast dinner to 86% in the case of classic lasagne. Beef and lamb contribute 66% and 85% to the raw materials while the pork and chicken contribute 36% and 64% in the case of roasts. This impact is also affected by the lack of data availability for some ingredients. For instance, the different meat sources have data for this impact; therefore their contribution is notably higher.

The contribution of the other stages are lower than 10%; the manufacturing and consumption stages contribute with 6% and 8%, and the packaging stage is 5%.

The greatest increase due to the recipe variation is observed in lamb masala curry with an increment of 40% followed by spaghetti (34%), cottage pie (31%) and chicken korma curry (28%). On the other hand, the recipe variation reduces the POCP by almost 50% in the Cottage pie. The other recipes are not greatly affected, remaining in similar positions.

In terms of cuisine, the British presents the lowest POCP with 2.58 g C_2H_4 eq. per meal, followed by the Chinese and Indian with 2.6 g and 2.88 g C_2H_4 eq. per meal. Finally, the Italian cuisine has a POCP of 4.02g C_2H_4 eq. per meal.

3.1.11 Terrestrial ecotoxicity potential (TETP)

As indicated in Figure 27k, fisherman's pie presents the highest TETP with 465.3 g DCB eq., followed by spaghetti Bolognese and P&P fried rice with 114.2 g and 95.6 g DCB eq. The lowest TETP is found in beef, lamb and pork roast dinners with around 4 g DCB eq. per meal. Chicken roast dinner, chicken noodles and classic lasagne are around 9.5 g DCB eq. per meal.

The main contributor is the raw materials ranging from ~10% in the case of the beef, lamb and pork roasts to ~60% in the case of shepherd's pie, chicken roast dinner, classic lasagne and chicken noodles, to ~99% for the rest of the recipes. As with the other toxicity impacts, the lack of full impact assessments or available life cycle inventories for some ingredients influence the results. The main contributor to this impact is the wine, olive oil and fish, due to the availability of data for this impact.

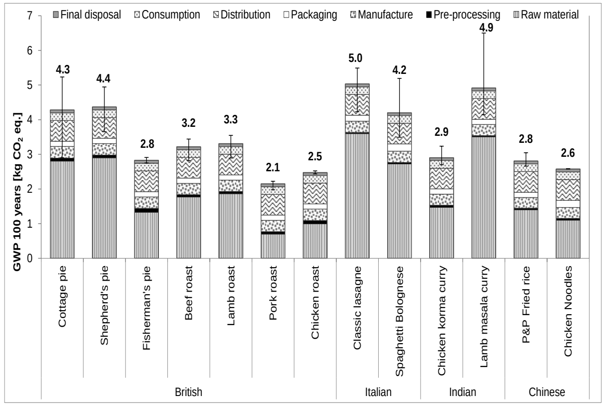
The manufacturing and packaging stages contribute around 11% and 10%. The consumption stage contributes with 7% and the other stages with less than 3%. The contribution of the stages varies between the different recipes. In the case of the curries, it is due to the oil, while in the case of spaghetti Bolognese is due to the wine and olive oil used in the sauce. In the case of the P&P fried rice and fisherman pie, the main contributors are the fish and shrimps.

The British cottage pie and fisherman's pie are the most affected by their recipe variations, increasing the TETP by 33% and 22%. The same recipes decrease by 32% and 15% respectively. A greatest reduction of almost 80% is found in P&P fried rice. The main reason is because of the variations on the composition of key ingredients as wine and olive oil as well as fish.

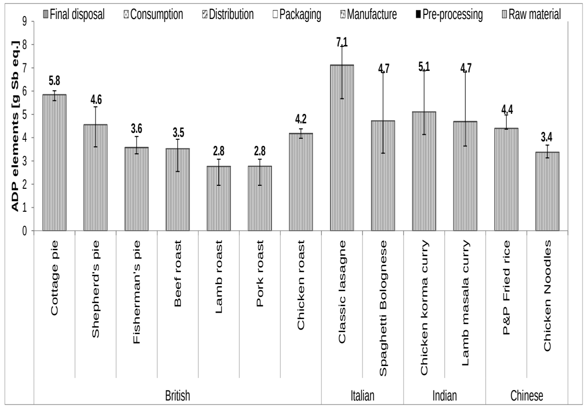
The lowest TETP is found in the Chinese cuisine with 52.6 g DCB eq., followed by Italian and Indian cuisines with 62 g and 64.5g DCB eq. respectively. The worst are the British recipes with 135.9 g DCB eq.

Summary

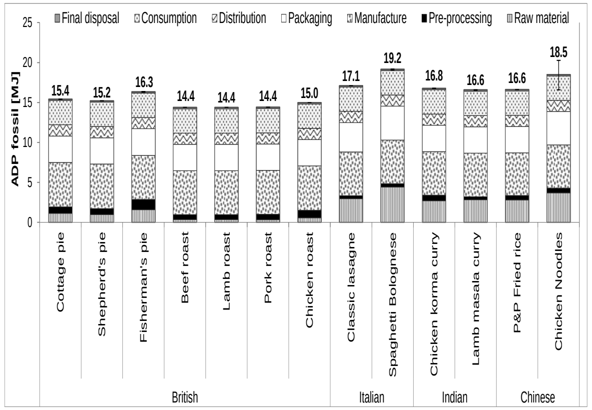
Figure 30a presents a quality summary of the environmental impact assessment explained previously; the 'heat map' represent with the black blocks representing the worst options (higher impacts) and the white representing the best options (lower impacts). When all the impacts are weighted equally, the most environmentally efficient meals are the roast dinners, in particular the pork roast dinner presenting the lowest values in impacts as GWP, AP, HTP and POCP, among others. On the other hand, the least environmentally efficient are the Italian meals (Spaghetti and Lasagne), Lamb masala curry and Cottage pie. On average, the worst option is the Spaghetti with almost the highest values in all toxicity impacts (HTP, MAETP and TETP) and POCP.



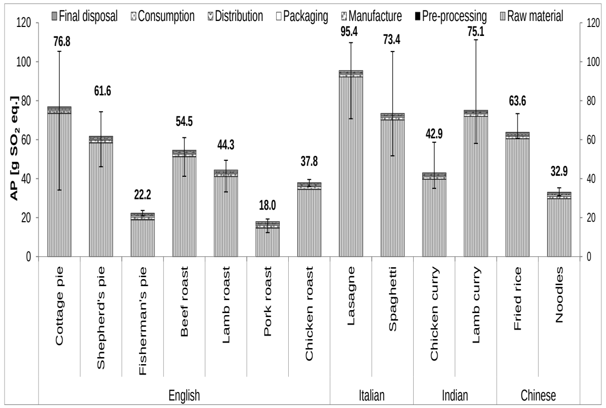
a) Global warming potential (GWP)



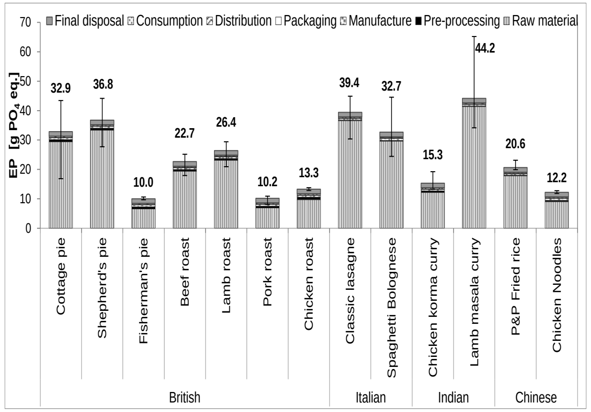
b) Abiotic depletion potential (ADP $_{elements}$)



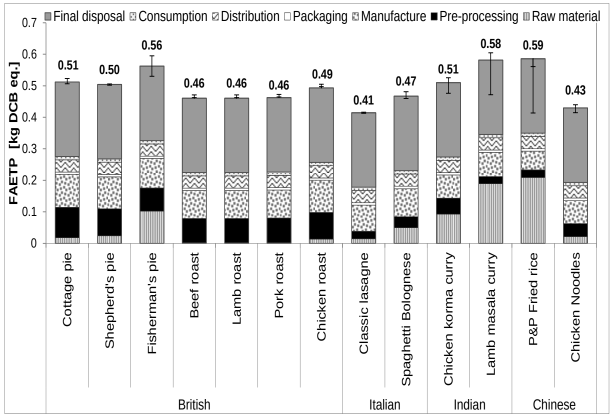
c) Abiotic depletion potential (ADP $_{fossil}$)



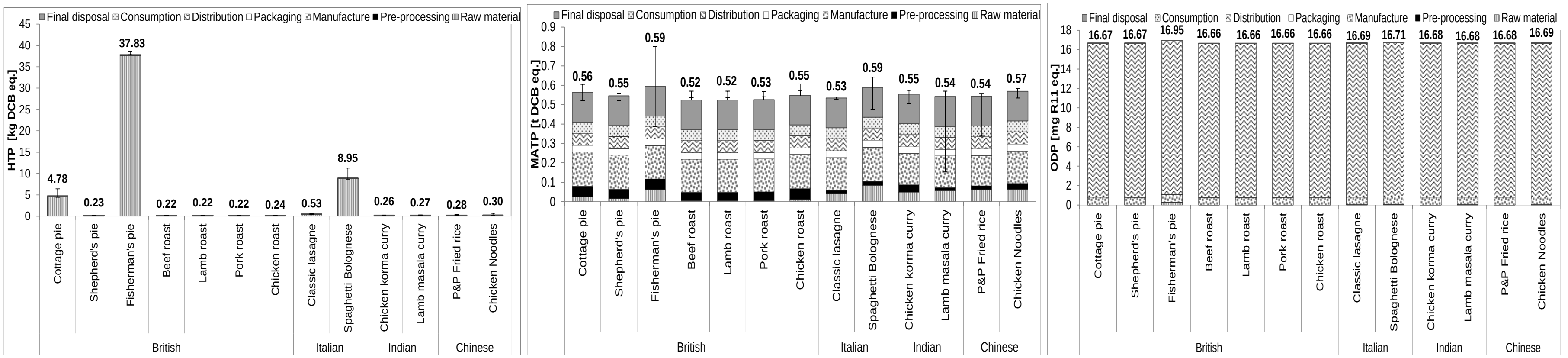
d) Acidification potential (AP)



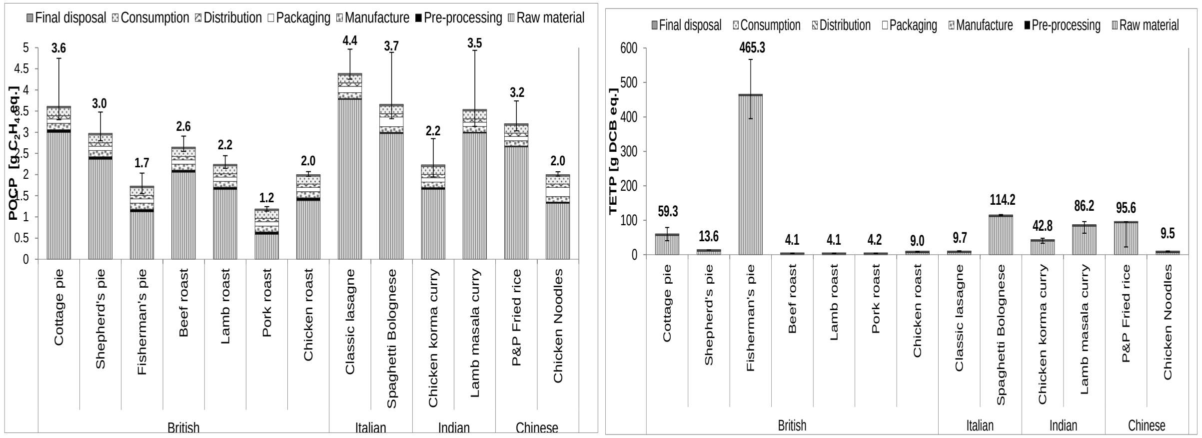
e) Eutrophication potential (EP)



f) Fresh aquatic ecotoxicity potential (FAETP)



g) Human toxicity potential (HTP) **h) Marine aquatic toxicity potential (MAETP)** **i) Ozone depletion potential (ODP)**



j) Photochemical ozone creation potential (POCP) **k) Terrestrial ecotoxicity potential (TETP)**

Figure 27 Environmental impacts of the ready-made meals

3.2 Meat replacements

Due to the high importance of the meat composition in the environmental impacts analysed, this section presents the analysis of possible environmental improvements substituting a proportion of meat with similar meat replacement options. The study analyses the integration of tofu, granule soy and seitan when possible in to the British, Italian Indian and Chinese recipes. The study tests the replacements of 10% and 30% (by mass) of the original recipes with vegetarian options. Only small proportions of the meat are replaced in order to maintain the taste and character of the meal. These values were selected as an exercise so that changes in recipe composition could be tested by the manufacturers and the consumers. The results are discussed by cuisines and shown in Figure 28 a-h.

Granule soy is also known as ‘textured soy’ and it is a product designed to provide proteins from vegetable sources (soy beans) with the texture of meat when it is consumed. Granule soy is well known in plant-based diets; however it is also commonly used in meat product such as meatballs, patties, and meat sauce, amongst others. In the food industry granule soy is used as a meat expander, which can replace up to 30% (FAO 1992).

Seitan or ‘wheat meat’ is a gluten-wheat based product with high levels of protein (20.33 g per 100 g of product) (Natursoy 2012). It is typically used in East and Southeast Asia, as well as Russia and in the Middle East (Baranova et al. 2008) but nowadays is presented in vegan and vegetarian diets. These products are rising in popularity, mainly due to its similarities with meat when it is cooked (Hackett 2012).

Tofu is the Japanese name for ‘bean curd’ foods, a traditional and ancient Chinese product. In the 70’s, the availability of tofu in the market started to grow, especially for the increment of vegetarian diets and replacement of tofu and meat (FAO 1992).

3.2.1 British cuisine

In the British cuisine, only cottage and shepherd’s pieces were modified, mainly because they use minced meat (beef or lamb), which is easier to replace without changing too significantly the aesthetic and taste of the original recipe. The meat replacements used are granule soy and seitan, and their results are shown in Figure 28 a&b.

When granule soy and seitan replace beef and lamb, six impacts remain without changes: ADP $_{fossil}$, FAETP, HTP, MAETP, ODP and TETP. This is because in those impacts, the main contributors are the manufacturing, distribution and waste disposal stages, which remain almost without any change in the variations analysed. The other impacts present overall reductions from 5% to 26%.

In the case of cottage pie, GWP is reduced from 5% to 16% with replacements of 10% and 30% respectively, decreasing to 3.60 kg CO_2 eq. per meal (for the 30% replacement); AP is reduced by 8 to 26%; EP is reduced by 9% to 23% respectively. Finally, ADP $_{element}$ decreases by 7% to 22% to 4.56 g Sb eq., while the POCP decreases by 7 to 22%, equivalent to 2.81 g C_2H_4 eq. (See Figure 28a&b)

Similar with cottage pie, the Shepherd’s pie made with meat replacements presents the largest reductions in AP and EP, decreasing to 45.9 g SO_2 eq. and 27.6 g PO_4 eq. (26% and 25% respectively). Moreover, GWP decreases by 5% to 16%, reaching 3.65 kg CO_2 eq. per meal. It is observed that POCP and ADP $_{elements}$ present similar reductions, from 7 % to 21%.

3.2.2 Italian cuisine

Similarly to British cuisine, the beef of classic lasagne and spaghetti Bolognese are replaced with granule soy and seitan. The results are presented in Figure 28 c&d. When the recipe is replaced with granule soy and seitan only five out of 11 impacts vary, reducing the impacts on average by 26% in the best scenario (30% of meat replacement) (see Figure 4c&d).

In the case of classic lasagne, the greatest reductions are found in AP, EP and POCP. For AP, the variations are from 9% to 26% with values down to 70.5 g SO_2 eq. per meal; EP and POCP reduce the impacts from 8% to 24% and 26% respectively, thus decreasing to 30 g PO4 eq. and 3.4 C_2H_4 eq. per meal. GWP decreases to 4.2 kg CO_2 eq. per meal.

Similar to classic lasagne, both replacements have similar influence in the environmental impacts of Bolognese in terms of amount and the type of impact. For instance, the highest improvements are found in the ADP elements and AP, with reduction of 27%. GWP is reduced by 16%, reaching 3.53 kg CO_2 eq. per meal. Finally EP and POCP present similar variations, with reduction of 23% and 22%, respectively.

3.2.3 Indian cuisine

In the case of both curries the meat (chicken and lamb) is replaced by tofu, in a range of 10% and 30%. For both meals, the ADP $_{fossil}$ and toxicities increase with the replacement of tofu due to the processing stage being highly energy intensive. The improvements previously described in sections 3.2.1 are based on the fact that rearing animals produces more emissions than growing soy beans, especially in the case of lamb. However, in the case of chicken replaced by tofu, the variations actually slightly increase the GWP.

Figure 28e shows that replacing chicken by tofu reduces four impacts and increases five impacts out of 11. Only two impacts remain with negligible changes, ODP and TETP. The greatest reductions are found in the ADP $_{element}$ and AP, decreasing by 22% and 20% respectively. Moreover, EP and POCP are also improved by 12 and 9%. However, for GWP, the replacement increased the impact from 2.9 kg to 2.96 kg CO_2 eq. per meal (~2%).

The highest variation is observed in MAETP, increasing the impact from 0.55 t to 0.73 t DCB eq. per meal (~32%). The remaining three largest increments are noticed in ADP $_{fossil}$, FAETP and HTP with an increment of around 21% on average. For instance, ADP $_{fossil}$ increases from 16.7 to 20.4 MJ, while FAETP and HTP increase from 0.51 kg to 0.63 kg DCB eq. and from 0.26 kg to 0.31 kg DCB eq. per meal.

The replacement of tofu for lamb in 10% and 30% affects nine out of 11 impacts (See Figure 4f). Just as the previous analysis, ODP and TETP remain without relevant changes (lower than 1%).

As can be observed, GWP is reduced by 14%, decreasing from 4.9 kg to 4.25 kg CO_2 eq. per meal. The greatest improvements are found in ADP $_{elements}$, AP and EP with reductions of 26% on average. POCP also presents significant improvements with a reduction of 19%. However, four impacts are increased. The highest increase is found in MAETP and ADP $_{fossil}$ with 20% and 25%; in the case of the HTP the variation is 12% while in the case of FAETP is only 5%.

3.2.4 Chinese cuisine

For the Chinese options, the chicken and pork are replaced by tofu. The variations consider a replacement of 10% and 30%. Figure 28g&h present the results for both meals.

In the P&P fried rice the greatest reductions are found in the ADP $_{elements}$, AP and EP, being between 8% to 23%, 7% to 20% and 6% to 18%, respectively. Moreover, GWP improves only by 2%, from 2.8 kg to 2.76 kg CO_2 eq. per meal. The POCP impact is decreased from 3.2 g to 2.76 g C_2H_4 eq. (14%).

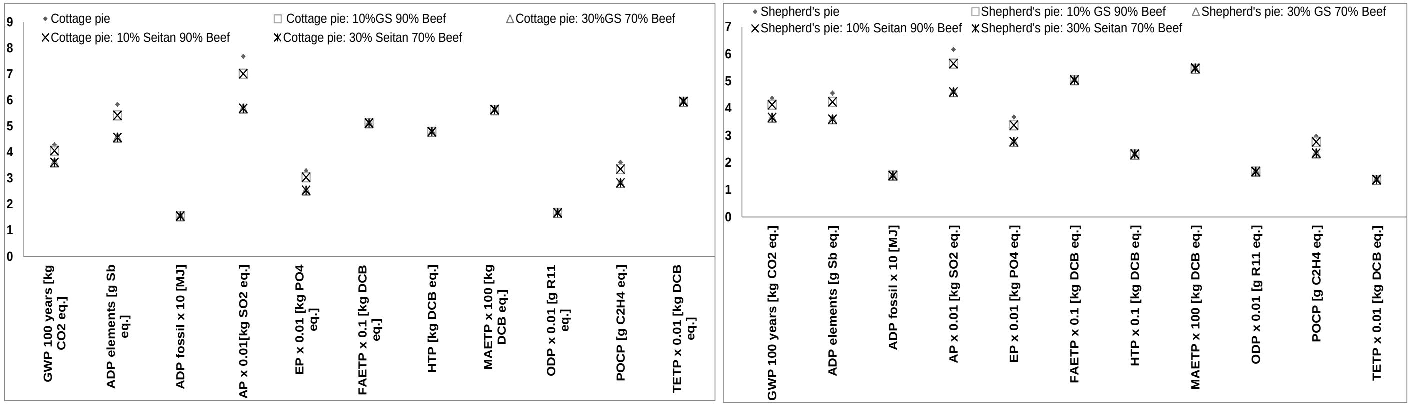
Four impacts increased as a result of the meat replacement: ADP $_{fossil}$, FAETP, HTP and MAETP. The ADP $_{fossil}$ and FAETP increase by 5% to 15% and by 1% to 4%, while HTP and MAETP increase by 3% to 9% and by 6% to 19%, respectively. The ODP and TETP remain without changes (See Figure 4g).

As was the case with P&P fried rice, for chicken noodles the replacement of tofu presents the greatest reductions in ADP $_{elements}$ and AP with 10% to 30% in the case of the former and 8% to

23% in the case of the latter (See Figure 4h). Only two other impacts are reduced: The EP decreases by 5% to 16% and the POCP by 4% to 11%. On the other hand, four impacts increase.

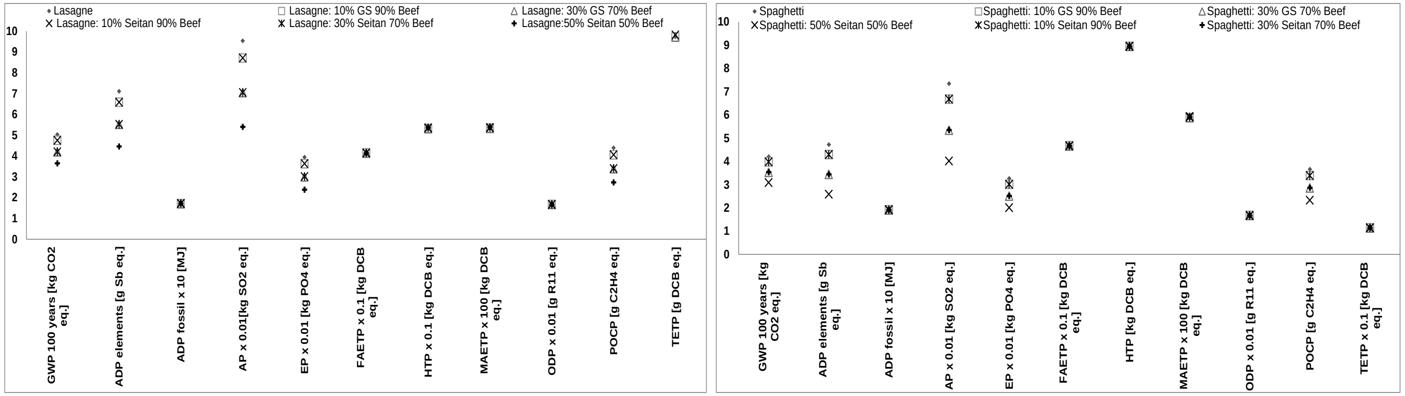
The greatest increases are found in the ADP $_{\text{fossil}}$ and in MAETP, with a variation of 5% to 16% and 7% to 21% respectively. The lowest variations are found in FAETP, HTP and TETP, with increases of 2% to 6% in the case of the former, and around 3% to 10% in the case of the last two.

Finally, GWP and ODP remain without relevant changes, due to tofu and pork having similar GWP and in the case of ODP, the main contributor is the distribution stage.



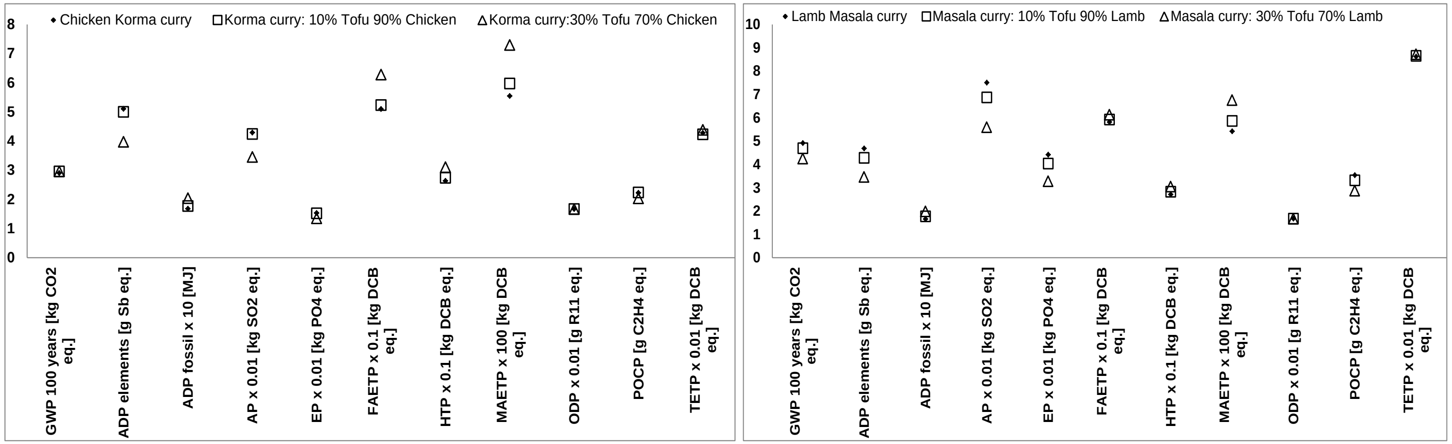
a) Cottage pie

b) Shepherd's pie

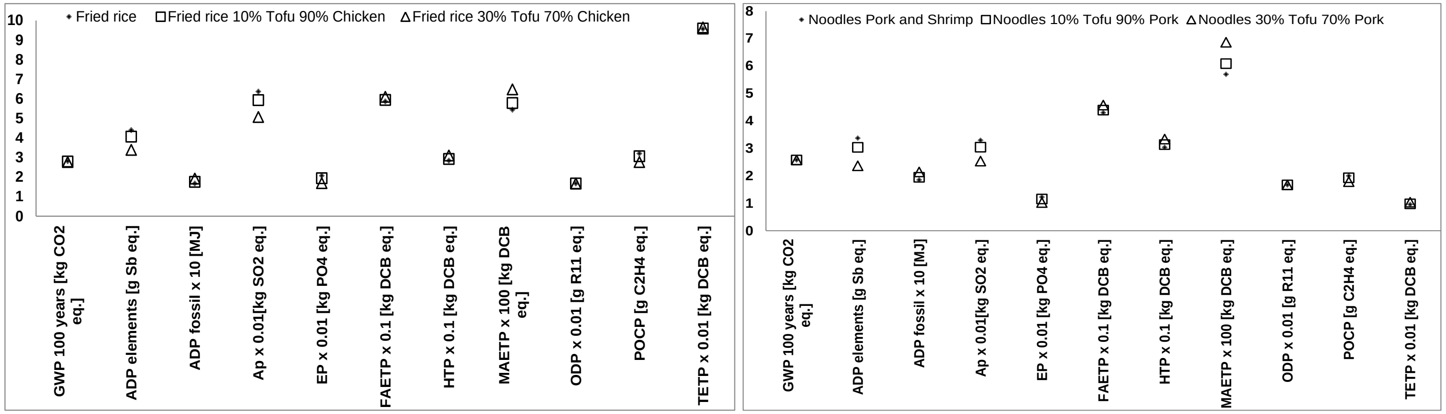


b) Clasicc lasagne

d) Spaghetti Bolognese



e) Chicken korma curry **f) Lamb masala curry**



g) Pork and prawns fried rice **h) Chicken noodles**

Figure 28 Environmental impacts variation of the ready-made meals using meat replacements

3.3 Sensitivity Analysis

In order to test the effect of different meat sources on the environmental performance of the meals, this section analyses the variation between different meat productions. In order to understand these variations, the four roast dinners were selected to assess the influence: beef, lamb, pork and chicken. Due to lack of available data, only three environmental impacts are analysed: global warming potential (GWP), acidification potential (AP) and eutrophication potential (EP).

The different meat productions considered for the case of beef were non-organic, organic, 100% suckler, low land and high upland (William et al. 2006). The effect of land use change (LUC) is also applied to 100% suckler, low land and non-organic (Nguyen T., et al. 2010). For lamb, the options are non-organic, organic and 'higher valuation of mutton' (William et al. 2006). The scenarios for pork are non-organic, organic, heavier finishing, indoor breeding and outdoor breeding (William et al. 2006). Finally, in the case of chicken, the options are conventional, organic and free range (William et al. 2006).

As can be seen in Figure 29, GWP presents the highest variation in the beef options with values up to 2.6 times higher than the study. In particular, the GWP ranges from 3.2 kg CO_2 eq. per meal to 8.47 kg CO_2 eq. These differences are mainly due to the integration of the land used change (LUC) into GWP. Opposite trend is found in Lamb roast dinner, the alternative studies decrease the GWP between 7% and ~20%, the highest being GWP 2.69 kg CO_2 eq. per meal. Moreover, the lowest variations are found in the Pork roast dinner, with increments up to 2%. Finally, the GWP of Chicken roast dinner varied from 2.47 gg CO_2 eq. per meal for the base scenario to 2.87 kg CO_2 eq. per meal in the case of the British organic chicken.

In terms of AP (see Figure 29), the variation in the Beef roast dinner is less than for GWP. The AP could be improved by 8% and increase by 45%, depending of the rearing type. The greatest variation is found in the Lamb roast dinner, with impacts 3.6 times higher than the meal studied. On the other hand, the impact could also be reduced around 10%. A similar trend is found for the Pork roast dinner, with AP reaching almost three times the impact of the base case. Finally, in the case of the Chicken roast dinner, the variations are much smaller than the ones described before, with AP increasing up to 23%.

For EP, the Beef roast dinner presents variations between 63% higher and 1% lower.. Moreover, the highest variation is found in the Lamb roast dinner, with values 2.3 times higher than the base scenario, the options also present a possible improvement of 9%. The pork roast dinner does not present possible improvements; however, the possible options can increase the impacts by up to 50%. Similar trend is seen in Chicken roast dinner, with only possible increments in the sources analysed.

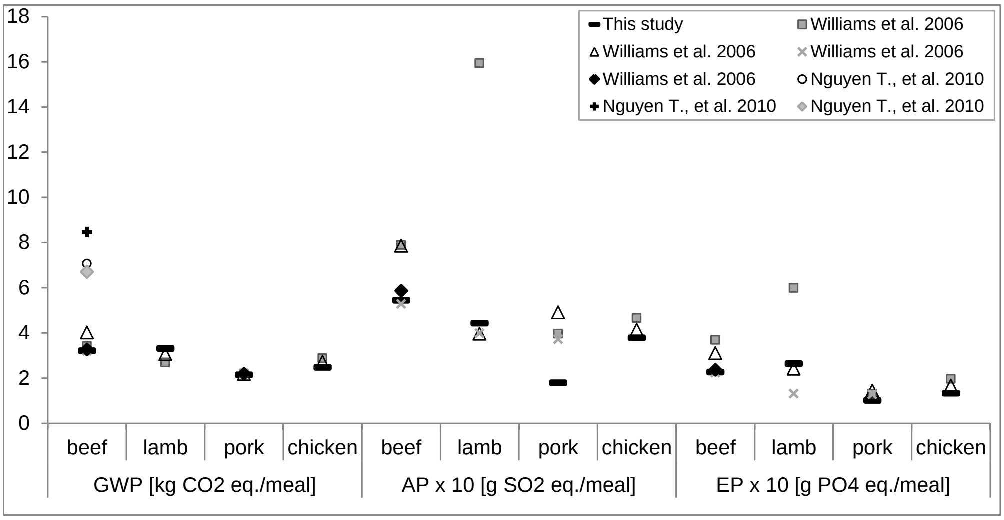
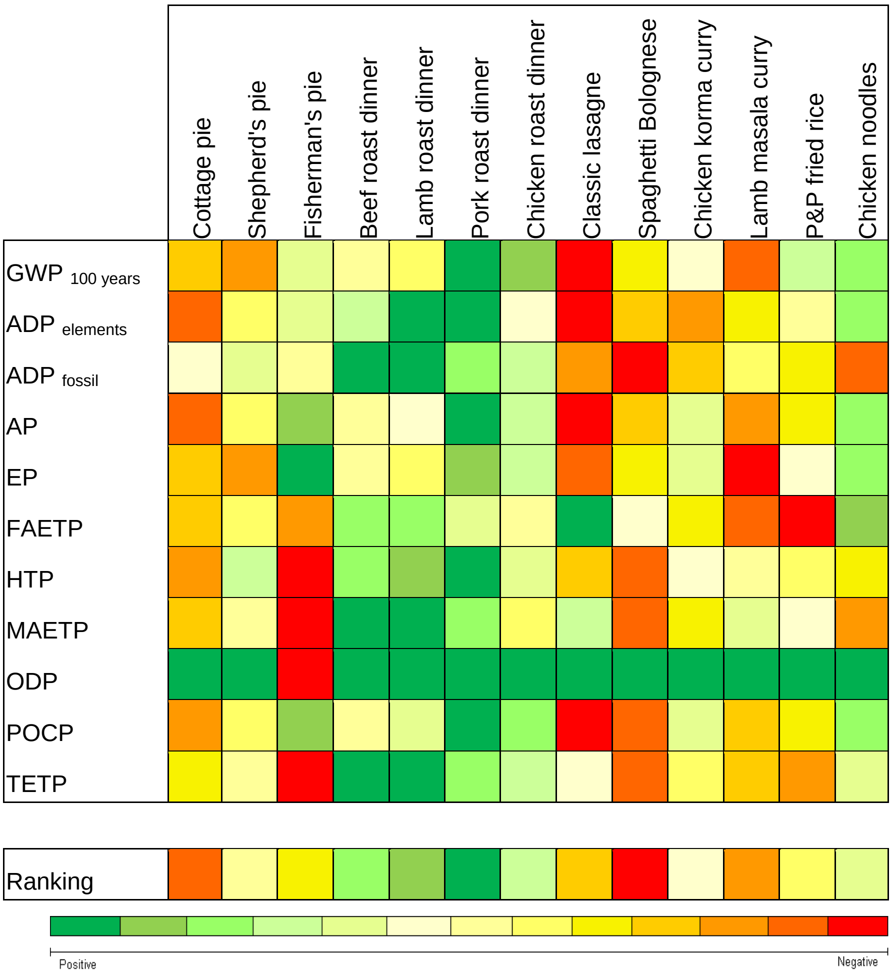
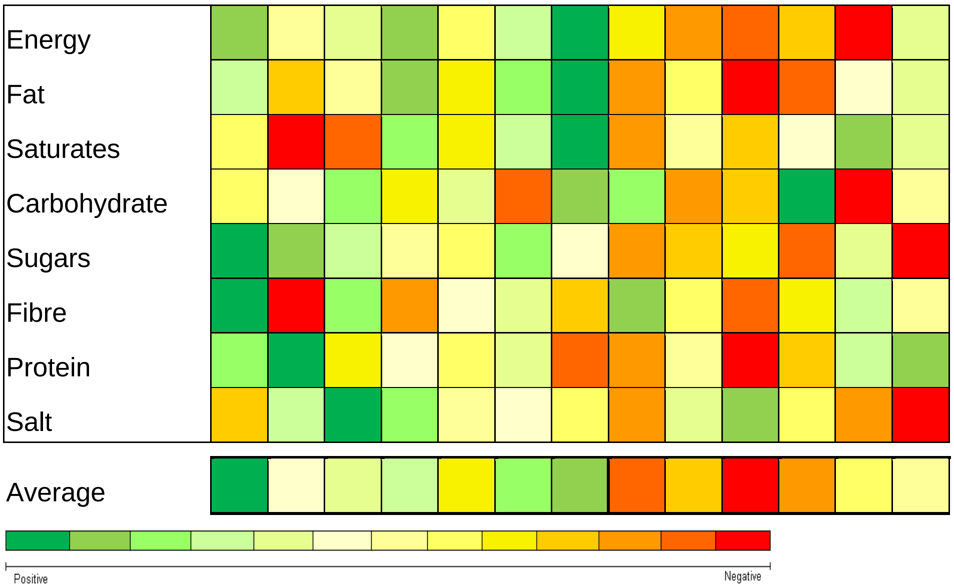


Figure 29 Sensitivity analyses of GWP, AP and EP for the four different meat options



a) Environmental impacts



b) Nutritional content

Figure 30 Graphic representation ('heat map') of the environmental impacts [a] and the nutritional content [b] of the thirteen ready-made meals analysed

3.3.1 Nutritional analysis

This section analyses the nutritional content of the different ready-made meals selected in this study and also the relationship between nutrition and three environmental impacts: GWP, AP and EP. The nutritional parameters considered in this study are energy content, fat and saturated fat, carbohydrates and sugar, protein, fibre and salt. The relationship between the nutritional content and the environmental impacts is assessed as the nutritional-environmental efficiency for each meal: the unit of nutrient per unit of impact. The results are shown in Figure 30b and Figure 31 a-c.

3.3.2 General Nutritional content of the thirteen ready-made meals

The nutritional information of the different meals is an average of each product selected for the study (see section 2). Figure 30b is a representation of the nutritional information of the chilled ready-made meals and the detailed values are presented in Table 11. It can be seen that the Italian and Indian cuisines have a higher energy content, except for the Chinese Pork & Prawns fried rice, which presents the highest energy content with 158 kcal per 100g of meal. Similarly, the fat and saturated fat content of the Indian and Italian cuisine tend to be greatest, as well as the British Shepherd's and Fisherman's pie. Moreover, the highest carbohydrates and sugar contents are noticed in the Chinese cuisine followed by the Italian and then Indian. A similar trend is found in the case of the Salt content.

For the proteins, the lowest content is found in cottage pie with 4.4 g. per meal, while the highest is found in the Indian meals, Lasagne and Chicken roast dinner with up to 8.9 g per meal. Similar trend exhibits the fibre content with only one difference, the lowest value is found in the Shepherd's pie.

It is important to observe that the quality diagram is based on a ranking of each meal from 1 (green) to 13 (red), with 1 being the lowest value and 13 the highest. Therefore, the health analysis does not take into consideration the scores, only the ranking. It should not be interpreted as a nutritional or healthy guideline, for example a high level of protein content is not necessarily a good or bad characteristic but dependent on the health requirements of each consumer.

Table 36 ***Nutritional content of the thirteen ready-made meals***

	Cottage pie	**Shepherd's pie**	**Fisherman's pie**	**Beef roast**	**Lamb roast**	**Pork roast**	**Chicken roast**	**Classic lasagne**	**Spaghetti Bolognese**	**Chicken korma curry**	**Lamb masala curry**	**P&P fried rice**	**Chicken noodles**
Energy (MJ)	436	503	489	436	512	475	402	530	555	641	547	664	489
Energy (kcal)	104	119	117	104	122	113	96	130	132	154	131	158	117
Fat (g)	4.0	5.6	5.2	2.7	5.5	3.4	2.2	5.9	5.4	7.0	6.6	4.6	4.1
of which saturates (g)	2.0	3.0	3.0	0.8	2.5	1.1	0.6	2.8	1.8	2.7	1.3	0.7	1.1
Carbohydrate (g)	11.1	10.7	9.7	11.4	10.6	13.2	9.3	9.7	13.1	12.4	6.0	22.8	10.9
of which sugars (g)	1.0	1.1	1.3	1.5	2.0	1.2	1.3	2.4	2.3	2.3	3.8	1.3	4.9
Fibre (g)	0.9	3.1	1.3	2.6	1.6	1.5	2.0	1.0	1.7	2.7	1.8	1.4	1.7
Protein (g)	5.6	4.4	7.2	6.9	7.1	6.7	8.7	8.3	7.0	8.9	8.0	5.6	5.3
Salt (g)	0.6	0.5	0.4	0.5	0.5	0.5	0.6	0.6	0.5	0.5	0.6	0.6	0.7

3.3.3 Nutritional content and environmental impacts

In this section the concept of efficiency is used in terms of the nutritional parameter analysed per unit of impact generated. The analysis is based on the assumption that consumers need all of the nutritional factors described above. Therefore, a more efficient product is one that delivers a high quantity of nutrition (e.g. protein) with a small quantity of associated environmental impact (e.g. GWP). It is important to note that these efficiency ratings do not demonstrate the healthiness of the meal, but instead the effectiveness in delivering nutritional content relative to the environmental impact.

3.3.3.1 Nutritional content and GWP

Figure 31a presents the results of the nutritional content against GWP. When the energy content of the meal is considered, the least efficient source is the cottage pie with 87.50 kcal per kg CO_2 eq.. Classic lasagne, lamb masala curry and Shepherd's pie present efficiencies lower than 100 kcal per kg CO_2 eq.. In the next range, from 100 kcal to 140 kcal per kg CO_2 eq. there are four meals: spaghetti Bolognese, beef, lamb and chicken roasts. Ranging from 141 to 180 kcal per kg CO_2 eq. are only two meals: fisherman's pie and chicken noodles. Finally, the most efficient source of energy in terms of GWP is the P&P fried rice with 203 kcal per kg CO_2 eq., followed by chicken curry and pork roast with 191 and 189 kcal per kg CO_2 eq., respectively. This is because pork has the highest energy content and one of the lowest GWP across the different meals. Moreover, processed ingredients such as cream and butter are also calorie intensive

In terms of fat and saturated fat content, there is a large range of efficiencies with respect to GWP, from 3 g to 8.7 g per kg CO_2 eq. The least efficient source of fat and saturated fat is the chicken roast dinner with 3.2 g (fat) and 0.87 g per kg of CO_2 eq. (saturated fat), whilst the most efficient is the chicken korma curry with 0.86 and 3.29 g per kg CO_2 eq. Cottage pie and beef roast dinner have very low fat-GWP efficiency with 3.3 g and 3 g per kg CO_2 eq. In the case of the saturated fat, the P&P fried rice is also one of the less efficient with 0.9 g per CO_2 eq., while fisherman's pie is the most efficient with 03.8 g per kg CO_2 eq.

When carbohydrate and sugar content is analysed, the least efficient is the lamb masala curry followed by classic lasagne and shepherd's pie with 4.4 g, 6.9 g and 8.8 g carbohydrates per kg CO_2 eq., while the most efficient is the P&P fried rice with 29.2 g per kg CO_2 eq.. In the case of sugar, the least efficient is the cottage pie with 0.23 g of sugar per kg of CO_2 eq.. The most efficient with respect to sugar is chicken noodles with 6.8 g per kg of CO_2 eq., followed by chicken and lamb curries with ~2.7 g per kg CO_2 eq.

Considering sources of protein, the most efficient meals are chicken roast dinner with 12.7 g per kg CO_2 eq. followed by pork roast dinner and chicken curry with 11.2 g and 11.1 g per kg CO_2 eq. The least efficient sources of protein are the British cottage and shepherd's pies with 4.7 g and 3.6 g of protein per kg CO_2 eq. In the case of fibre and salt, the least efficient sources are the same for both parameters; the cottage pie and the classic lasagne with ~0.7 g of fibre per kg CO_2 eq. and 0.44 g of salt per kg CO_2 eq. The most efficient sources of fibre are chicken korma curry with 0.94 g per kg CO_2 eq., followed by chicken and beef roast dinner with 3.37 g of fibre per kg CO_2 eq. In the case of salt, the worst option is chicken noodles with 0.9 g per kg CO_2 eq.

When the nutritional efficiency with respect to GWP is considered, the most efficient meal is the Indian chicken korma curry followed by British pork roast dinner with Chinese chicken noodles in third position, while the best options based on GWP alone (see Section 3.1.1) are the pork roast dinner followed by chicken roast dinner in second place and Chicken noodles in third one. The Chicken roast dinner performs much worse in terms of efficiency per kg CO_2 eq. produced compared to GWP per meal. The worst options based on the nutritional efficiency are the cottage pie followed by the classic lasagne and lamb masala curry. A similar trend was shown by the GWP impact assessment where the worse options were also Lasagne and Lamb curry but Shepherd's pie instead of the cottage pie. It is important to observe that because the recipes have several ingredients it is not easy to state all the relationships that influence the results. However it is clear that pork has one of the lowest GWP between the meats analysed, as well as the highest calorie content between the other meats. A similar trend is found for other nutrients as fat and saturated fat.

3.3.3.2 Nutritional content and AP

The results of the comparison of nutritional parameters and the acidification potential (AP) are presented in Figure 31b.

In terms of energy content, the most efficient sources are the pork roast dinner and the fisherman's pie with 22.6 kcal and 18.9 kcal per g SO_2 eq. The least efficient options are the cottage pie and classic lasagne with 4.88 kcal and 4.9 kcal per g SO_2 eq. Similarly to the energy content, the fisherman's pie is the most efficient meal in terms of fat and saturated fat, with 0.84 g and 0.48 g per g SO_2 eq., respectively. Other options with high efficiency rates for both parameters are chicken curry, and lamb and pork roast dinners. The least efficient option is the beef roast dinner for both parameters with 0.18 g (fat) and 0.06 g per g SO_2 eq. (saturated fat). The least efficient option for the saturated fat content is the P&P Fried rice with 0.04 g per g SO_2 eq.

In the case of the carbohydrate content, the most efficient source is the pork roast dinner with 2.6 g per g SO_2 eq. Fisherman's pie, chicken korma curry, P&P fried rice and chicken noodle present an efficiency range between 1.5 g to 1 g per g SO_2 eq. The least efficient meal is the lamb masala curry with 0.29 g of carbohydrates per g SO_2 eq. The British cottage and shepherd's pies and Italian classic lasagne and spaghetti present an efficiency range between 0.37 g to 0.7 g carbohydrates per g SO_2 eq. When the sugar content is considered, the most efficient meal is the chicken noodles with 0.53 g of sugar per g SO_2 eq. The worst options are the British cottage and shepherd's pie with 0.05 g and 0.07 g per g SO_2 eq.

The most efficient sources of protein are the pork roast dinner and the fisherman's pie with 1.34 g and 1.17 g per g SO_2 eq. The least efficient sources of protein are the cottage and the shepherd's pie with 0.26 g of protein per g SO_2 eq. Classic lasagne, spaghetti and P&P fried rice also have low efficiency with values ranging from 0.3 g to 0.35 g protein per g SO_2 eq.

The last two parameters, fibre and salt content, present the same best and worst option. The most efficient meals are the British pork roast ready-made meal with 0.29 g of fibre and 0.11 g of salt per g SO_2 eq., whilst the least efficient options are cottage pie and classic lasagne with 0.04 g of fibre and 0.03 g SO_2 eq.

In summary, when the nutritional and environmental efficiency is considered based on the SO_2 eq. produced (AP), the best options are found in the Pork roast dinner followed by Fisherman's pie and Chicken korma curry. Only the third position varies from the total Acidification Potential results where the third best meal is Chicken noodles; the chicken korma curry has the fifth position. The least nutritionally efficient meals based on AP are Cottage pie followed by Lasagne and Lamb masala curry. The environmental impact assessment presented the same worst meal but in different order: the worst option is Lasagne then the Cottage pie and finally the Lamb masala curry.

3.3.3.3 Nutritional content and EP

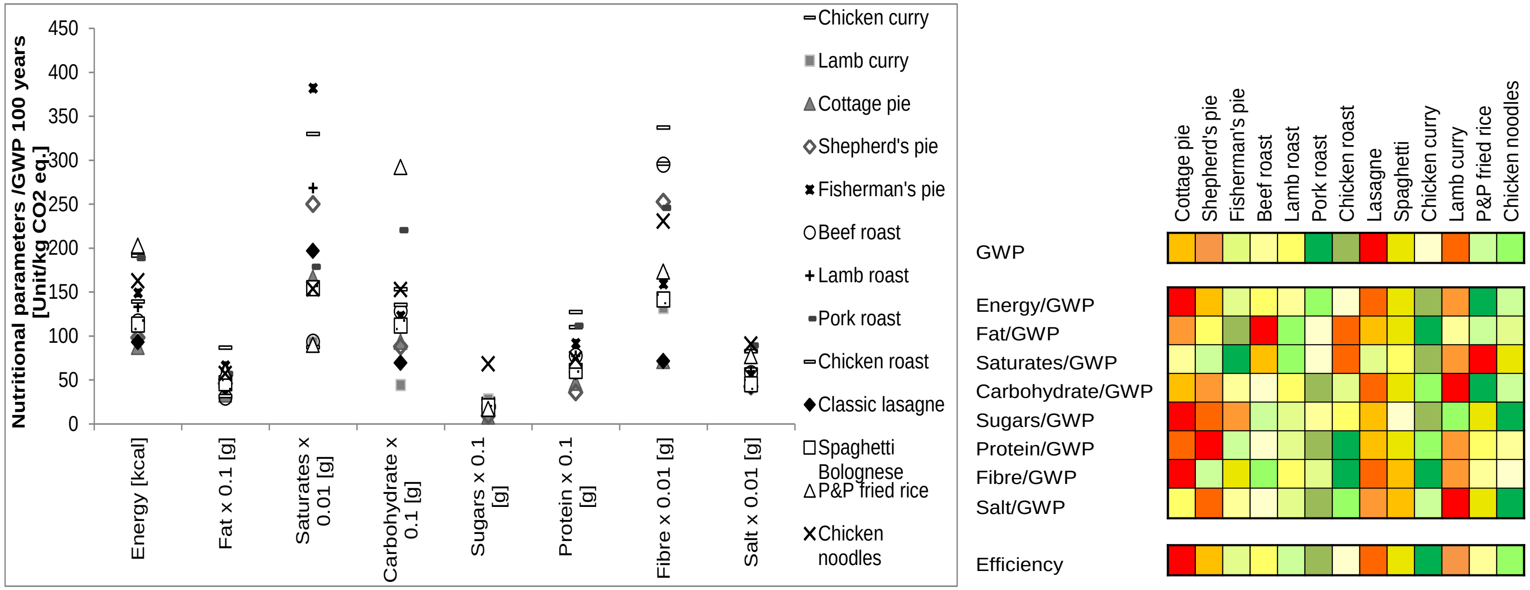
Figure 31c shows the results of the nutritional parameters against the eutrophication potential. In the case of the energy content, the most efficient meal is the fisherman's pie with 42 kcal per g PO_4 eq. The pork roast and chicken korma curry present values in the same range with an average value of 38 kcal per g PO4 eq. As with the 11.4 kcal per g PO_4 eq. efficiency, the least efficient options are the British cottage and shepherd's pie, lamb masala curry and classic lasagne. In the case of the fat and the saturated fat, the least efficient options are the lamb masala curry, cottage pie and the beef roast with an average of 0.0.43 g of fat and 0.11 g of saturated fat per g PO_4 eq. In the case of fat content, the most efficient is the fisherman's pie with 1.87 g per g PO_4 eq., whilst for saturated fat the most efficient is the chicken curry with 0.62 g per g PO_4 eq.

In the case of the carbohydrates, the most efficient option is the pork roast and P&P fried rice, with 0.47 g and 0.4 g per g PO_4 eq. The least efficient options are the lamb masala curry and the classic lasagne with 0.05 g and 0.089 g per g PO_4 eq. In the case of sugar, the least efficient meals are the cottage and shepherd's pie with 0.11 g per g PO_4 eq. The most efficient is the chicken korma curry with 0.54 g per g PO_4 eq.

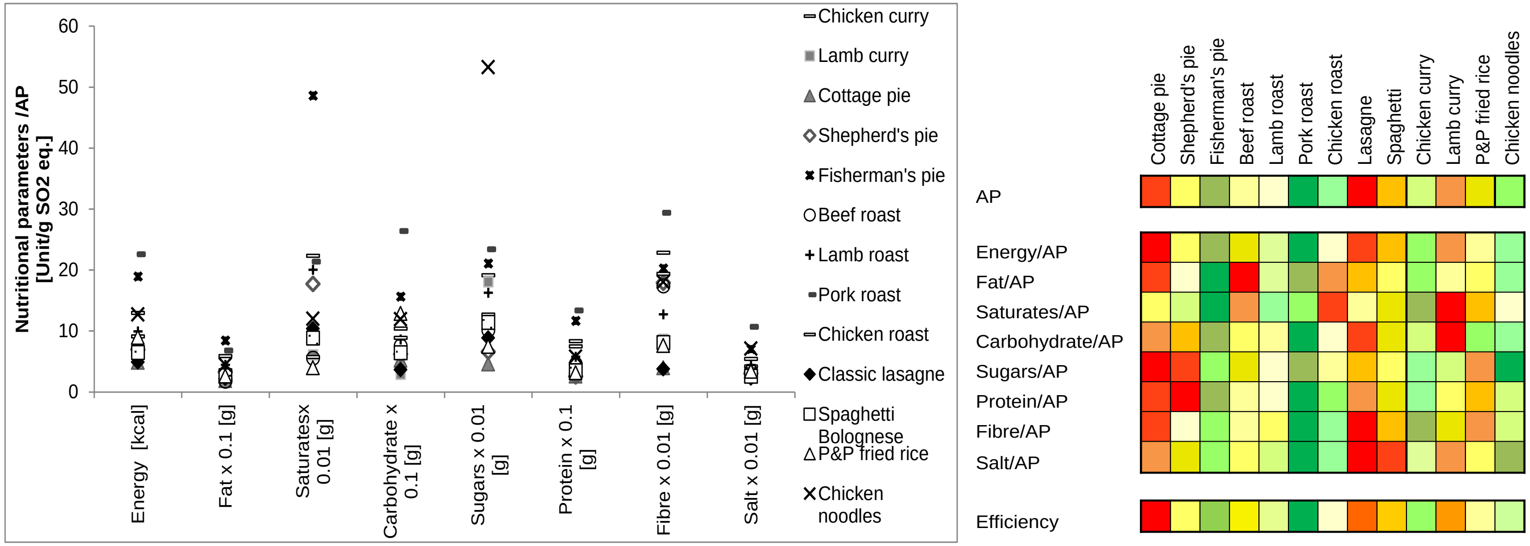
In terms of protein sources, the most environmentally efficient is the fisherman's pie with 2.59 g per g PO_4 eq., while the least is the shepherd's pie with 0.43 g per g PO_4 eq. Pork and chicken roast dinners also present good level of efficiency with values only 10% lower.

Finally in terms of fibre and salt, the least environmentally efficient meals are the same as carbohydrates, the lamb masala curry and classic lasagne. The best option in the case of the fibre content is the chicken korma curry with 0.54 g per g PO_4 eq., while in the case of the salt content; the best options are the pork roast and the chicken noodles with 0.19 g per g PO_4 eq.

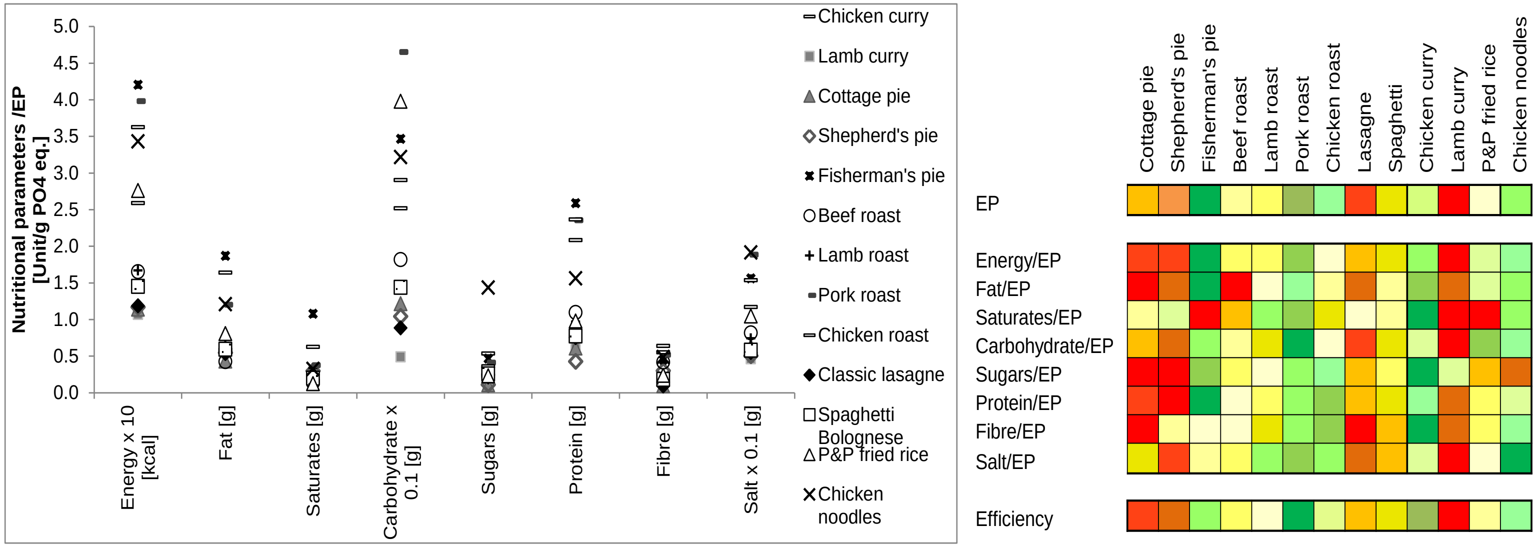
In summary, when the nutritional efficiency is incorporated with the analysis based on Eutrophication potential (EP) the best meal options are pork roast dinner followed by the chicken korma curry and Fisherman's pie. Similar trend is found when only the environmental impact is considered, however, the best meal here is the fisherman's pie followed by pork roast dinner, chicken noodles and chicken korma curry. The worst options are the lamb masala curry followed by the cottage and shepherd's pie. When only the environmental impact is considered the worst option is lamb masala curry followed by the lasagne and then shepherd's pie. Cottage pie holds the fourth worst position.



a) Nutritional parameters and GWP



b) Nutritional parameters and AP



c) **Nutritional parameters and EP**

Figure 31 Analysis of the Nutritional content in relation with GWP, AP and EP

4 Conclusion

This paper has assessed the environmental performance of thirteen ready-made meals available in the UK supermarkets; the meals are chosen from the most commonly consumed cuisine: British, Italian, Indian and Chinese, which represent around 85% of the preferences.

The results suggest that the most environmentally sustainable cuisine is the Chinese followed by the British. The worst cuisines are the Italian and Indian; only when the environmental impacts are considered.

Focusing on the meals, the most environmentally sustainable options are the roast dinners; in particular the pork and the chicken roast dinner. The worst options are the Italian classic lasagne, Indian lamb masala curry and the Italian spaghetti Bolognese followed by the British cottage and shepherd's pie.

The global warming potential (GWP) of the different meals ranges from 2.15 kg CO_2 eq. in the case of pork roast dinner to 5.03 kg CO_2 eq. in the case of the classic lasagne. Almost half of the recipes studied presents GWP in the lowest range (2 kg to 3 kg CO_2 eq. per meal) while around 39% show values in the highest range (4 kg to 5 kg CO_2 eq.). The rest of the meals present GWP in a range of 3 kg to 4 kg CO_2 eq.

The main hotspots are the raw materials, in particular beef and lamb, but also the distribution and manufacturing stages. However the contribution varies depending on the impact and the meal. For instance, the main hotspot for GWP is the raw materials stage; although the contribution in each meal varies between ~40 and 70%. Throughout all the recipes, the main contributor in the raw material stage is the animal sources (meat and dairy products), in particular beef and lamb. Moreover, the raw material stage is also the main hotspot for $ADP_{elements}$ (99%), acidification potential (~92%), eutrophication potential (~83%), human toxicity potential (~33%), photochemical ozone creation potential (75%) and Terrestrial ecotoxicity potential (65%).

The manufacturing and distribution stages have also a significant contribution due to the energy consumption and the refrigerants (production, usage and leakage); in particular the most affected impacts are ADP_{fossil} (~34% and ~9%), FAETP (~18% and ~8%), HTP (~13% and ~6%), MAETP (~31% and ~11%) and Ozone depletion potential (~4.6% and ~94.8%). In the case of GWP these stages are also important but with a lower contribution than the raw materials (~10% and 19%).

Additionally, the pre-processing and packaging stages have a significant contribution to ADP_{fossil} (~4% and ~22%), FAETP (~12% and ~2%), MAETP (~7% and ~6%). Finally, consumption and final disposal stages present the largest contribution to ADP_{fossil} (~19% and ~1%), FAETP (~2% and ~48%), HTP (~17% and ~13%), MAETP (~10% and ~28%) and EP (~1% and ~8%).

The analysis of recipe variations has found that the most affected impacts are the ones driven by the raw material stage. In particular, AP, POCP are the most influenced. In terms of recipes, British cottage and shepherd's pies, Italian spaghetti and Indian lamb masala curry are the most affected by the variations in the recipe composition, presenting the highest ranges.

The animal sourcing can also affect the environmental performance of the ready-made meals. The sensitivity analysis carried on shows that GWP, AP and EP can increase up to four times when the land use change (LUC) is considered. Therefore, the impacts of the meals can be greatly affected by the sources and the results of this study could change drastically, between the meals and the cuisines analysed.

The study has also investigated the potential reduction in environmental impacts associated with replacing the meat components with meat-replacement products. The study shows that granule soy and seitan improves five out of 11 impacts, with the other six remaining constant. These meat replacements improve GWP up to 17%; while the AP and EP are improved up to 27 % and 25%. The $ADP_{element}$ and POCP decreases by 27% and 22%.

In the case of tofu, the trend is different and more complex; only two impacts (ODP and TETP) remain constant while the other nine improve or deteriorate depending on the meal. For instance, for both curries the AP, EP, ADP $_{element}$ and POCP improve when tofu is incorporated. However, in the case of GWP, lamb masala curry improves up to 14% while chicken korma curry deteriorates by 2%. The other impacts also increase, with MAETP presenting the largest increment (~32% in chicken korma curry). This is due to the highly energy intensive of the tofu manufacturing, affecting the impacts driven by the energy consumption.

It can be seen that seitan and granule soy have proven to be possible alternative to reduce the environmental impacts of cottage and shepherd's pie, as well as classic lasagne and spaghetti Bolognese. In the case of tofu, the results are not conclusive because tofu improves the impacts dominated by the raw materials but also worsens ADP $_{fossil}$ and the toxicities due to the highly energy intensive manufacturing process. Moreover, the analysis does not show great differences between granule soy and seitan, mainly due to lack of data (granule soy uses allocated data while seitan uses an adaptation of a home-made recipe). If information from industry were available the results might change, in particular in the toxicity impacts. Furthermore, the authors are aware that other quality parameters such as texture, taste, nutritional content, among others, should be tested before integrating these ingredients in the ready-made meals.

Even though meat is one of the main factors in impacts such as GWP, AP, EP and POCP, there are not simple answers to reduce the environmental impacts associated to the meals. The study analysed alternative as replacing meat with meat replacements, however the study did not consider factors such as taste, nutrition and health, allergies, among many other important parameters for the industry and consumers when these products are producing and buying.

In terms of nutritional aspects, the study also analyses the nutritional content of the different meals and also the nutritional-environmental efficiency of them. The study finds that overall the ranking of meals based on the environmental performance is largely the same as the ranking based on nutritional efficiency. The worst options are British cottage pie, the Italian classic lasagne and the Indian Lamb masala curry. The best options are the British pork roast dinner, the Indian chicken korma curry and the British Fisherman pie.

Finally, there are several uncertainties within the study, in particular those related to the inventory of the raw materials. As was explained, the recipes had to be simplified due to the absence of available life cycle inventories or environmental impact assessments. Additionally, the assumptions used such as the meal selections, recipes and manufacturing processes within the study maybe highly uncertain due to the lack of information from industry. However the results are seen as a good baseline for future studies as well as a basis of information for decision making in particular for the consumers.

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Chapter 5: Life Cycle Costs and Environmental Assessment of Common British Ready-made Meals

This paper is currently being prepared for submission to a peer reviewed journal and the possible options are the Journal of Cleaner Production and the International Journal of Life Cycle Assessment.

The research, consisting of an economic analysis and the environmental impact assessment of common ready-made meals consumed in the UK, was designed, executed and written by the author of this thesis. Co-authors Azapagic A. supervised the research and edited the paper.

Life Cycle Costs and Environmental Assessment of Common British Ready-made Meals

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Abstract

Purpose: This study aims to estimate the life cycle costs of common British ready-made meals and integrate the environmental impacts to find the most sustainable meal options. Based on surveys, the study considers 13 recipes from the four major cuisines: British, Italian, Indian and Chinese.

Method: The study conducts economic and environmental analyses of these ready-meals based on life cycle costing (LCC) and life cycle assessment (LCA) methodologies. The study is from ‘cradle to grave’, considering the raw materials, packaging production, pre-processing, manufacturing, distribution, consumption and final disposal stages. The functional unit is 360 g of an individual chilled/frozen packed meal consumed at home.

Results and discussion: The LCC of the chilled British ready-meals studied ranges from £1.17 in the case of the Chinese chicken noodles to £2.66 in the case of the British fisherman’s pie. Half of the meals’ LCC are lower than £1.5 and third of the meals have LCCs lower than £2.0. The frozen options show on average just 1% higher LCC than the chilled options. The hot spots are the raw materials and the consumption stages. In particular seafood, fish and meat, and also processed ingredients are the ones with greatest contribution (higher costs). The commercial value added, that is the difference between cost of production and the retail price, was also estimated for each meal. The greatest added value is found in the chilled meals, specifically in recipes such as British roast dinners and Chinese chicken noodle, while the lowest is found in the fisherman’s pie. When the environmental impacts are included, the trend is different: the frozen meals present lower impacts than the chilled options, especially in the case of the GWP and ODP.

Conclusion: The analysis of the LCC of common British ready-made meals shows that the raw materials and the consumption stage are the key factors in the LCC of these products. Also, the study shows that the frozen options have an LCC only 1% higher and the value added could go from almost 90% to 3%, depending of the recipe and the meal option (chilled or frozen). Also, the study concludes that when the environmental and economic analysis are analysed the best ready-made meal options are the Chinese chicken noodles and the British roast dinners, in particular the pork based one.

1 Introduction

The food and drink sector (FDS) is one of the most important sectors in the UK economy, not only due to its economic contribution but also because it is one of the most resilient sectors: being one of only a few sectors that kept growing during the time of economic crises (FDF 2011;Key Note 2013). Moreover, the FDS is the largest sub-sector within the manufacturing sector. In 2009, the FDS had a gross value added (GVA) of £19.7 billion, a turnover of £72.7bn and £70.8bn on exports, and it provides more than 377,000 jobs (FDF 2014). Additionally, in the face of low consumer confidence and volatility in the raw material prices (Key Note 2013), the sector has experienced steady growth of 10% between 1994 and 2009 (BIS 2011).

However, the FDS has been recently facing new complex challenges with respect to consumer lifestyle and dietary changes (FDF 2014). Convenience and time saving are some of the main drivers of contemporary society and a specific market within the FDS has emerged: the ready meal market. In fact, the ready meal market was valued at £1.97 bn by 2013, and is expected to grow by 15.4% to £2.34 bn by 2018 (Key Note 2014); overall, the prepared meal market has been experiencing an annual growth of 4.5% since 2009 and it is expected to grow 2.9% annually in the next 10 years (IBIS World 2014).

The ready meals market is divided into two main sub-sectors, the chilled and frozen markets. The chilled market has grown by 47% since 2009, from £1bn in 2009 to £1.38bn in 2013 (Key Note 2014). In March 2013, around 28.1% of adults said they consume chilled ready meals at least once a week. The frozen ready-made meals were valued at £692m in 2013 and it represented 12% of the total frozen food market (BFFF 2014).

Despite the bright economic performance of the ready-made meal sector and the overall food sector, there are some negative social issues directly linked with it, relating to health, affordability, accessibility and even food poverty.

Food affordability is a concept that relates to the cost of food items, the living area and the consumer income (Islington Council 2014), and it can be measured using different indicators and indexes. For instance, the affordability index shows that the UK is ranked 13th in the world with a score of 87.8 points (The Economist Group 2014;Oxfam 2014). Some of the indicators evaluated are the food consumption as a share of the household expenditure, proportion of population under the poverty line, GDP per capita, agriculture import tariff, food safety programmes and access to financial help for farmers. The affordability concept is so complex, that even though good indexes do not reflect affordable food prices; for instance, in the UK food prices keep rising annually and a clear example is the Consumer Price Index (CPI), which measures how prices of different items are behaving; in the case of the UK, it has risen by 1.9% compared with the same period last year, being the highest increase since October 2012 (Office for National Statistics 2014). The food and non-alcoholic beverage group is one of the three main contributors, alongside fuel and transport (Office for National Statistics 2014).

In recent years the rise in food prices has been due to factors such as a reduction in crop yield, weather conditions and political issues. For instance, in 2012 the analyses of key factors of food price changes were based on three main issues: the global agricultural commodity prices, exchange rates and fluctuations in oil prices (Emma Downing and Harker 2012). This is also exacerbated with the constant growing demand of food, especially because of cultural food changes: people all over the world are eating more meat and manufactured products than before (Hoffman 2014;WHO 2003).

Worldwide, the most affected by increasing prices are always developing countries, however in developed countries such as the UK, the food affordability issues are reflected in the increase in the number of people using food banks (UK 2014). In 2012, the demand for UK food banks doubled from the previous year (2011). The rising prices have affected the low income households who are reducing the consumption of fruit and vegetables and replacing it with cheaper food, usually low quality in terms of health (Emma Downing and Harker 2012). In fact, it is calculated that a healthy diet can cost over 50% more, chiefly due to the cost of fruits and vegetables (Islington

Council 2014). Therefore in the UK, food poverty is related to poor quality diets which could turn into chronic diet-related diseases (CDRD). For instance, four million British people could not afford a healthy diet in 2000 (Islington Council 2014). In 2007, 30% of low income families were worried about running out of money for food and 36% could not afford a healthy diet. Also the income distribution on food varies through social classes; low income families spent 26% of their incomes in food while high income household spent just 6% (Islington Council 2014). In particular, there are four groups in higher risk of suffering food poverty; unemployed people or living with low incomes; older people and people with disabilities; households with dependent children and finally, members of black and ethnic minority groups (Islington Council 2014).

Factors such as lack of confidence and skills related with shopping and cooking, increase the use of ready-made meals (Key Note 2013). Ready-made meals are consumed on average once a week by around a third of the UK population (Islington Council 2014).

As mentioned, several sustainability issues affect the ready-made meal sector; in the case of the environmental aspects, the increasing concern about climate change as well as water and land usage can be reflected in the growing number of environmental life cycle studies (LCA) on the subject (Head et al. 2014;Manfredi and Vignali 2014;Ebner et al. 2014;Hörtenhuber et al. 2014;Van Kernebeek et al. 2014); however, in economic terms, life cycle costing assessment (LCC) studies within the ready-made meal sector are still scarce (Mohamad et al. 2014;Utne 2009;Vinyes et al. 2013).

The consumption of ready-made meals has been driven by different factors such as increasing prices of food items, lack of time and cooking skills, which have a common characteristic: convenience; however the sustainability of this sense of convenience has not been well studied yet. Therefore, this research aims to estimate the life cycle costs of common ready-made meals in the UK and to integrate the environmental assessment of these products, in order to identify the most sustainable options.

2 Methodology

The economic analysis of the common British ready-made meals is based on the life cycle costing (LCC) methodology using the approaches suggested by Hunkeler et al. (2008) and Swarr et al. (2011). The LCC methodology was chosen in order to analyse the economic aspects under a life cycle perspective and also to be able to make further and fair comparisons with the environmental assessment, which follows the ISO Standards 14040-44 (ISO 2006a;ISO 2006b). The following section presents the methodological details of the study, as well as the data and assumptions used. The environmental analysis is based on the previous work, the details of which can be found in X. C. Schmidt Rivera and Azapagic (2014).

2.1 Goal and scope

The goals of the study are:

- to estimate the life cycle costs of common ready-made meals in the UK and determine the economic 'hot spots';
- to analyse and compare the influence of the different recipes and the product options (chilled and frozen) on the meal costs:
- to estimate the value added along the supply chain of the meals; and
- to compare the life cycle costs and the environmental impacts of common British ready-made meals and identify the most sustainable options.

For both studies, the calculation of the costs and environmental impacts are developed for 13 representative ready-made meals, including chilled and frozen options.

The scope of the study is from 'cradle to grave', considering the cultivation and production of raw materials, processing the ingredients, manufacturing of the meals, as well as the distribution and consumption.

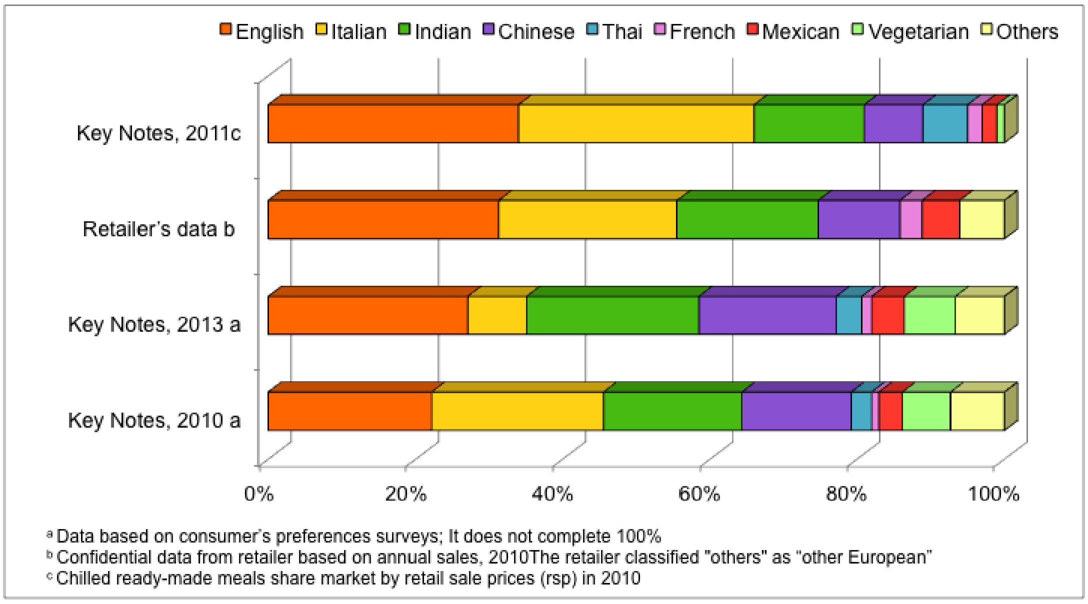
The waste management and the transportation are considered within the different stages. Figure 44 presents the system boundaries. The functional unit for the study is defined as 'a personal packed chilled/frozen meal of 360g, sold in supermarket and heated at home in the microwave'.

In total, 13 different ready meals recipes are selected for analysis, from four different cuisines (Table 37), investigating both frozen and chilled products, which represents around 85% of the market sales and the most preferred cuisines based on consumer's surveys (Figure 31). The recipes for the frozen option are the same as the chilled ready-made meal, as there is no detailed information about preferences or data for them. Also it is assumed that all recipes can be delivered either as a chilled or as frozen meal.

Table 37 Selection of the ready-made meals recipes per cuisine[a]. Note, for each meal, both a frozen and chilled product is analysed.

Cuisines			
British	***Italian***	**Indian**	**Chinese**
Cottage pie	Classic lasagne	Chicken korma curry	Chicken noodles
Shepherd's pie	Spaghetti Bolognese	Lamb masala curry	Pork and prawns egg fried rice
Fisherman's pie			
Beef roast			
Lamb roast			
Pork roast			
Chicken roast			

[a] The recipe selection was made through a screening in different supermarkets websites. The criteria were that the meals should be presented in almost all supermarkets, both chilled and frozen if possible.



[a] Data based on consumer's preferences surveys; It does not complete 100%
[b] Confidential data from retailer based on annual sales, 2010The retailer classified "others" as "other European"
[c] Chilled ready-made meals share market by retail sale prices (rsp) in 2010

Figure 32 The most consumed cuisines based on consumer preferences surveys and sales

To provide comparability with the environmental LCA results, this study uses the same scope, functional unit, recipe selection and composition as the LCA study shown in X. C. Schmidt Rivera and Azapagic (2014); therefore the details of each stage are not explained in this paper. Finally, it is important to note that the study does not consider the capital assets.

2.2 System definition

The system boundary is illustrated in Figure 2 and broadly consists of the agriculture and farming, pre-processing of ingredients, meal manufacture, distribution, consumption and disposal. After the agriculture and farming stage, all the ingredients besides the processed ones (straight to the manufacturing stage) are transported to the pre-processing stage, where the vegetables and animals are prepared (processing and slaughter house) and stored (regional distribution centre). After these activities, the products are transported to the manufacturing stage. In the factory, the ingredients are cooked, packed and transported to the regional distribution centre for products (RDC_p) and then delivered to the retailers where they are stored and then displayed. Finally, the consumers transport the meal home, where it is stored and then heated (microwave). The left overs and the packaging are disposed of to landfill (final disposal stage). Within each stage, the disposal and treatment of the waste and wastewater is included.

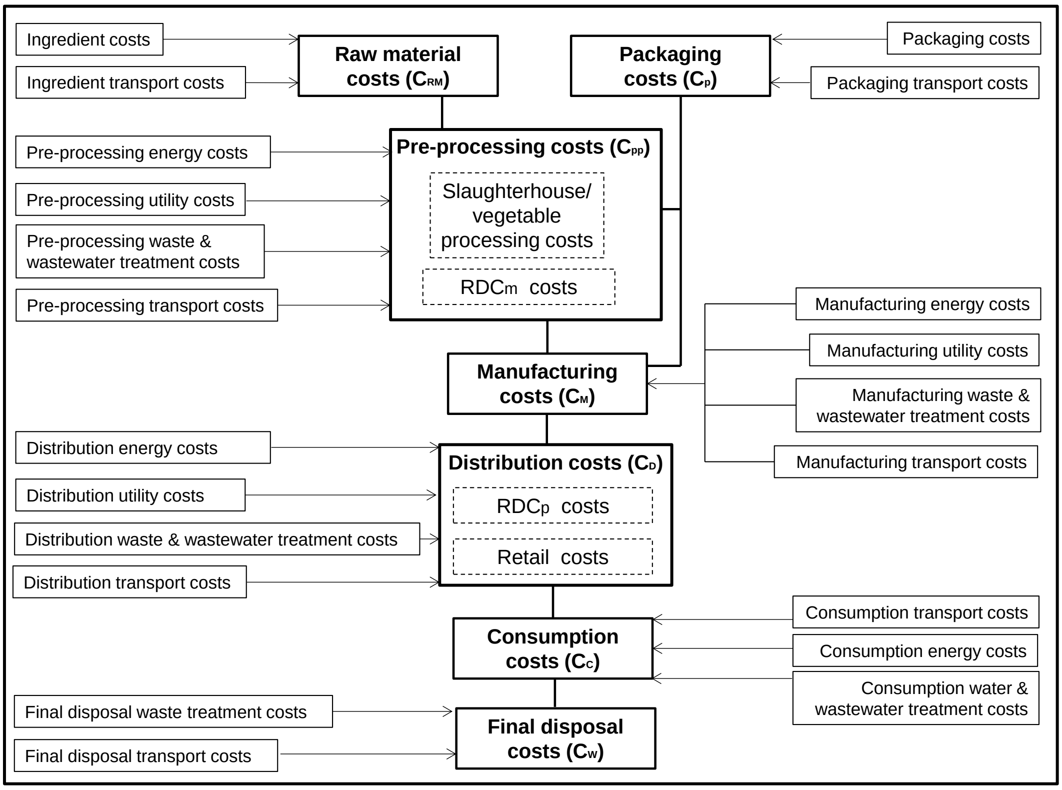


Figure 33 Ready-made meal system boundaries definition [RDC: Regional distribution centre; m: raw materials; p: final product]

2.3 Calculation of the life cycle costs

As described previously, the life cycle costing (LCC) of the ready-made meals considers the costs of each life cycle stage and is calculated as follows:

$$LCC = C_{RM} + C_{PP} + C_M + C_P + C_D + C_C + C_W \tag{1}$$

where:

LCC	life cycle cost of the meal
C_{RM}	costs of the raw material stage of the meal
C_{PP}	costs of the pre-processing stage of the meal

C_M	costs of the manufacturing stage of the meal
C_P	costs of the packaging stage of the meal
C_D	costs of the distribution stage of the meal
C_C	costs of the consumption stage of the meal
C_W	costs of the final disposal stage of the waste from the meal

Complementing the LCC, this study also estimates the value added of the ready-made meals. This parameter represents the total profit margin of the product; therefore it is calculated as the difference between the retail price of the product and the cost of production, which in terms of life cycle stages is up to the distribution stage. Equation 2 shows the calculation details.

$$VA = RP - LCC_{Cradle\ to\ distribution} \tag{2}$$

$$LCC_{Cradle\ to\ distribution} = LCC - C_C - C_W \tag{3}$$

where:

VA	value added from 'cradle to distribution'
RP	retail price of the meal (ready-made) or raw materials (home-made meal)
$LCC_{Cradle\ to\ distribution}$	life cycle cost from 'cradle to distribution'

The details of the data and the costs of each stage are presented below.

2.4 Data and Assumptions

Several sources are used for the cost calculation and the details are shown in the following sections. It is important to note that all the results are presented in British pounds (£).

2.4.1 Raw materials

The raw material stage considers the costs of the ingredients, which are accounted for by the market value at farm gate based on various data sources (indicated in Table 38). In the case of processed ingredients, the raw materials and the utilities required to manufacture them are included. Table 38 presents the ingredient composition of each recipe and the data, while the summary of the utilities for the processed ingredients are showed in Table 40. The study also considers the variation in the recipe composition across different manufacturers and Table 39 shows the different ranges for each meal.

Table 38 Ingredients, costs and quantity used for the ready-made meal recipes

		Weight (g)													
Ingredients	**Cost (£/kg)**	Chicken korma curry	Lamb masala curry	Cottage pie	Shepherd's pie	Lasagne	Spaghetti	Fisherman's pie	Chicken roast	Beef roast	Lamb roast	Pork roast	Fried rice	Chicken Noodles	**References**
Rice	0.26	134	134	-	-	-	-	-	-	-	-	-	197	-	IndexMundi (2012)
Pasta/noodles	0.22	-	-	-	-	47	119	-	-	-	-	-	-	112	Calculated
Mashed potatoes:		-	-	180	180	-	-	164	-	-	-	-	-	-	
Potatoes	0.15	-	-	167	167	-	-	153	-	-	-	-	-	-	UK Government and Defra (2013)
Milk	0.34	-	-	7	7	-	-	7	-	-	-	-	-	-	UK Government and Defra (2013)
Butter	19.8	-	-	5	5	-	-	5	-	-	-	-	-	-	Calculated
Meat:															
Beef	1.83	-	-	58	-	72	58	-	-	41	41	41	-	-	UK Government and Defra (2013)
Lamb	2.59	-	74	-	58	-	-	-	-	-	-	-	-	-	UK Government and Defra (2013))
Pork	1.22	-	-	-	-	-	-	-	-	-	-	-	57.6	-	UK Government and Defra (2013)
Chicken	0.87	74	-	-	-	-	-	-	76	-	-	-	-	65.9	UK Government and Defra (2013)
Fish	4.65	-	-	-	-	-	-	59	-	-	-	-	-	-	UK Government and Defra (2013)
Prawns	23.1	-	-	-	-	-	-	18	-	-	-	-	9	-	IndexMundi (2012)
Vegetables and Sauce:															
Potatoes	0.15	-	-	-	-	-	-	-	94	94	94	94	-	-	UK Government and Defra (2013)
Carrots	0.41	-	-	-	6	14	19	-	44	44	44	44	-	45	UK Government and Defra (2013)
Peas	1.05	-	-	-	11	-	-	17	43	43	43	43	25.6	-	UK Government and Defra (2013)
Onions	0.43	113	35	59	15	23	49	-	13	-	-	-	18.9	45	UK Government and Defra (2013)

		Weight (g)													
Ingredients	**Cost (£/kg)**	Chicken korma curry	Lamb masala curry	Cottage pie	Shepherd's pie	Lasagne	Spaghetti	Fisherman's pie	Chicken roast	Beef roast	Lamb roast	Pork roast	Fried rice	Chicken Noodles	**References**
Tomatoes	0.44	-	87	-	15	94	76	-	-	-	-	-	-	-	FAO (2008)
Tomato paste	3.04	-	3	3	-	-	-	-	-	-	-	-	-	-	Calculated
Cream	8.48	20	9	-	-		-	-	-	-	-	-	-	-	Calculated
Flour	0.31	2	-	1	-	9	-	4	4	11	11	11	-	-	Calculated
Sugar	0.41	7	-	-	-		-	-	-	-	-	-	-	-	UK Government and Defra (2013)
Wine	2.02	-	-	15	-		27	-	-	-	-	-	-	-	FAO (2008)
Beef stock (water)	1.6 x10^{-3}	-	-	39	73		-	-	76	106	106	106	-	-	United Utilities (2014)
Milk	0.34					88	-	87	-	13	13	13	-	-	UK Government and Defra (2013)
Butter	19.87					9	-	9	-	-	-	-	-	-	Calculated
Bread	4.01	-	-	-	-	-	-	-	5.2	-	-	-	-	-	Calculated
Eggs	0.92	-	-	-	-	-	-	-	3.4	7.1	7.1	7.1	20.4	-	UK Government and Defra (2013)
Soy sauce	9x10^{-3}	-	-	-	-	-	-	-	-	-	-	-	12.8	92.5	Calculated
Oil (vegetable/olive)	0.68; 2.17	8	17	5	2	3	11	-	0.9	-	-	-	18.9	-	IndexMundi (2012); FAO FAO (2008)
Salt	0.05	2	1	1	1	1	1	1	1	1	1	1	-	-	IndexMundi (2012)

***Table 39 Ranges of the recipe composition due to the variations of the ingredients used across different manufacturers of the chosen ready-made meals*[a]**

	Shepherd's pie		**Cottage pie**		**Fisherman 's pie**		**Chicken dinner**		**Beef/Lam/ Pork dinner**		**Classic lasagne**		**Spaghetti Bolognese**		**Chicken korma curry**		**Lamb masala curry**		**P&P fried rice**		**Chicken noodles**	
	Max	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**
Rice/ Mashed potatoes/ Pasta [%]	50	50	60	47	48	41	50.3	57	50.3	57	13	13	37	23	41	36	41	36	85	81	37	25
Meat and sauce [%]	50	50	40	53	52	59	-	-	-	-	87	87	63	77	59	64	59	64	-	-	-	-
Meat [%]	40	*23*	44	*14*	29	14	22	20	13	9	27	16	31	17	50	26	50	26	15	19	20	17
Sauce [%]	60	*77*	56	86	23	45	27.7	23	36.7	34	73	84	69	83	50	74	50	74	-	-	55	46

[a] The recipes are based on a market screening, which was done looking for the common ready-made meals in the British supermarkets (online and presently): Asda (2014), Sainsbury's (2014); Tesco (2014); Morrisons (2014);Iceland (2014);Lidl (2014)

Table 40 ***Summary of the cost and the utilities used for manufacturing processed ingredients***[a]

Utilities (amount per kg of final product)	**Costs (£/unit)**	**Flour**	**Bread**	**Butter**	**Cream**	**Pasta**	**Semolina**	**References**
Electricity (MJ)	$2.7\text{x}10^{-2}$	0.36	0.41	0.51	3.16	0.58	3.07	DECC (2014)
Natural gas (MJ)	$3\ \text{x}10^{-2}$	0.45		-		1.01	0.11	DECC (2014)
Heat (MJ)	0.48		5.71	0.68	7.06	0.14		DECC (2014)
Water (l)	$1.6\text{x}10^{-3}$	0.13	10.86	2.3	22.06	0.31	0.22	United Utilities (2014)
Fuel oil (kg)[b]	0.045			-		0.02		DECC (2014)
Waste (kg)	$93\ \text{x}10^{-3}$	0.01		-		0.01	0.01	Eunomia Reaserach & Consulting Ltd (2013)
Raw materials								
Wheat (kg)	0.18	1.25					1.32	UK Government and Defra (2013)
Soy beans (kg)	0.3							IndexMundi (2012)
Cream (kg)				2.3				UK Government and Defra (2013)
Milk (l)					14.71			UK Government and Defra (2013)
Flour (kg)			4					UK Government and Defra (2013)
Semolina (kg)						1.01		IndexMundi (2012)

[a] The cost of the processed ingredients are presented in Table 38

[b] The original cost is £0.045 per kwh (DECC 2014)

2.4.2 Pre-processing stage

Table 41 presents the utilities required for the pre-processing and storage (RDC_m) of the ready-made meals, whilst Table 42 shows the utilities for pre-processing of meat, fish and seafood. A detailed description of this stage is presented in X.C. Schmidt Rivera and Azapagic A. (2014).

Finally, due to a lack of data, the costs associated with ‘animal waste’ at the pre-processing stage are not included. However the potential impact of this is accounted for within the sensitivity analysis.

2.4.3 Manufacturing stage

Table 43 details the cost of the utility requirements and associated costs for the manufacturing stage of each recipe.

2.4.4 Distribution

This stage is divided in two sub-stages where first the meal is stored in the regional distribution centre (for products, RDC_p), and then it is transported to the retailer, where the ready-made meal is also stored and then displayed; chilled food is displayed in open cabinets while frozen food in closed ones. Table 41 presents the utilities and costs of this stage. The details of the stage are described in X. C. Schmidt Rivera and Azapagic A. (2014).

Table 41 Summary of the utility costs in the pre-processing and distribution stages

Utilities (£ per kg)	**Pre-processing**	**Distribution**		**References**
		Chilled	**Frozen**	
Storage time (hr)	12	60	278	
Electricity	1.58 x10^{-3}	1.42 x10^{-2}	3.70 x10^{-2}	DECC (2014)
Water	5.01 x10^{-3}	0.67	-	United Utilities (2014)
Steam	2.85 x10^{-5}	-	-	Spirax Sarco Limited (2014)
Refrigerant (ammonia) charge	1.68 x10^{-4}	1.68 x10^{-4}	2.93 x10^{-4}	Technicold Service Inc. (2003)
Refrigerant (R134a) charge	-	5.36 x10^{-3}	1.70 x10^{-3}	Stoody Industrial & Welding Supply Inc. (2006)

Table 42 Summary of the utility costs of the pre-processing of meat, fish and seafood (Nielsen PH et al. 2003)

Utilities (£ per kg)	**Cattle**	**Pigs**	**Chicken**	**Fish**	**Shrimps**	**Costs references**
Electricity	3.78 x10^{-3}	1.11 x10^{-2}	2.67 x10^{-2}	2.65 x10^{-2}	7.72 x10^{-2}	DECC (2014)
Natural gas	-	-	-	6.6 x10^{-3}	0.31	DECC (2014)
Heat	8.16 x10^{-2}	0.3	0.24	-	-	DECC (2014)
Water	3.2 x10^{-3}	4.3 x10^{-3}	1.98 x10^{-2}	8.48 x10^{-3}	-	United Utilities (2014)
Ammonia	-	-	-	0.04	-	Technicold Service Inc. (2003)
Waste	6.05 x10^{-2}	3.26 x10^{-2}	3.44 x10^{-2}	1.58 x10^{-2}	0.18	Eunomia Reaserach & Consulting Ltd (2013)

Table 43 *Summary with the manufacturing costs allocated to the different meal recipes based on the functional unit (360g)*

Cuisine	**Recipes**	**Energy Consumption**[a] **(£/MJ)**	**Electricity**[b] **(£)**	**Fuel oil**[c] **(£)**
British	Cottage pie	1.9	3.49 x10^{-2}	2.12 x10^{-2}
	Shepherd's pie	1.9	3.49 x10^{-2}	2.12 x10^{-2}
	Fisherman's pie	1.9	3.49 x10^{-2}	2.12 x10^{-2}
	Beef roast dinner	2.38	4.27 x10^{-2}	2.65 x10^{-2}
	Lamb roast dinner	2.38	4.27 x10^{-2}	2.65 x10^{-2}
	Pork roast dinner	2.84	5.14 x10^{-2}	3.18 x10-^{2}
	Chicken roast dinner	2.52	4.56 x10^{-2}	3.18 x10^{-2}
Italian	Classic lasagne	2.1	3.78 x10^{-2}	2.65 x10^{-2}
	Bolognese spaghetti	1	1.75 x10^{-2}	1.06 x10^{-2}
Indian	Chicken korma curry	1.7	3.10 x10^{-2}	2.12 x10^{-2}
	Lamb masala curry	1.7	3.10 x10^{-2}	2.12 x10^{-2}
Chinese	P&P fried rice	1	1.84 x10^{-2}	1.06 x10-^{2}
	Chicken noodles	1	1.84 x10^{-2}	1.06 x10^{-2}

[a] The energy consumption is calculated using the cooking time of the correspondent home-made recipes and it was used to calculated the electricity and fuel used per each meal; detailed description and explanation refer to X. C. Schmidt Rivera and Azapagic A. (2014).

[b] The electricity consumption rate is £9.7x10^{-2} per kwh (DECC 2014)

[c] The fuel oil rate is £0.53 per litre (DECC 2014)

2.4.5 Consumption

The consumption stage considered the meal transportation to consumer's home as well as the storage of the meal in the required conditions (chilled or frozen). Then the meal is warmed up in microwave and served. The left over as well as the packaging are sent to the next stage. The utilities required are presented in Table 44 and the detailed assumptions are described in X. C. Schmidt Rivera and Azapagic A. (2014).

The average fuel consumption is 7.79 l/100 km and it is based on the average car size selected using data for the best-selling cars in the UK in 2013 (Lee Boyce 2013;Car Buyer 2014;Matt Bird 2013), the average distance is 7.5 km (Pretty et al. 2005) and the fuel price is £1.32 per litre based on (DECC 2014)

Table 44 Summary of the costs of energy and water usage of the consumption stage

Activity	Ready-made meals Chilled (£)	Ready-made meals Frozen (£)
Storage: electricity consumption [a]	$3.09x10^{-4}$	$2.78x10^{-3}$
Warm-up: electricity consumption [a]	$1.21x10^{-2}$	$6.05x10^{-2}$
Wash-up: water consumption [b]	$1.59x10^{-3}$	$1.59x10^{-3}$
Waste water	$1.14x10^{-3}$	$1.14x10^{-3}$
Transport	0.776	0.776

[a] The electricity consumption rate is £0.155 per kWh (DECC 2014)

[b] The water consumption rate is £1.6 $x10^{-3}$ per litre (United Utilities 2014)

2.4.6 Final disposal

This stage considers the cost of the waste management of the consumer's waste. Therefore, this stage includes the costs of transporting and landfilling the meal leftover (24% of the meal (WRAP 2009)) and the packaging of the meal. The details are presented in Table 45.

Table 45 Summary of the final disposal costs of the waste generated in the stage

Activity	Cost[a] (£)
Food landfilling	0.00804
Plastic bag landfilling	0.00093
Plastic RM landfilling	0.00326
Cardboard landfilling	0.00140
Transport to landfill	0.00011

[a] The cost are calculated based on landfilling fees: 93 £/tonne (Eunomia Reaserach & Consulting Ltd 2013)

2.4.7 Packaging

This section accounts for the details of the costs of packaging used during the life cycle of the ready-made meal. The study includes the production of the materials but does not include the manufacturing of each packaging. The details of the materials costs are presented in Table 46.

Table 46 Summary of the packaging cost of the ready-made meal life cycle

Material	Cost (£/kg)	Reference
Wood (pallets)	0.25	IndexMundi (2012)
Cardboard (boxes and RM packaging)	0.14	LetsRecycle (2014)
PP (crates)	1.69	Plastics Informat (2012)
Poly PP (RM packaging)	1.37	Plastics Informat (2012)
LDPE (film RM packaging and bag)	1.57	Plastics Informat (2012)

2.4.8 Retail prices

Table 47 shows the retail prices obtained from the market research performed to for this study.

Retail prices of the recipes analysed in the study per kg of product

Table 47 Retail prices of the chilled and frozen ready-meals [a]

		Average retail price (£)		Maximum retail price (£)		Minimum retail price (£)	
Cuisines	**Meals**	**Chilled**	**Frozen**	**Chilled**	**Frozen**	**Chilled**	**Frozen**
British	*Shepherd's pie*	5.34	2.96	9	3.75	2.67	2.50
	Cottage pie	5.616	3.03	9.23	5.32	2.37	2.14
	Fisherman's pie	5.34	3.66	9.03	6.25	2.37	2.50
	Beef roast	8.15	4.60	9	6.25	6.7	3.90
	Lamb roast	8.75	4.38	8.75	4.38	8.75	4.38
	Pork roast	8.75	4.00	8.75	4.00	8.75	4.00
	Chicken roast	6.76	4.55	9.21	6.25	2.38	3.75
Italian	*Classic lasagne*	5.4	3.85	12.5	6.67	1.99	2.14
	Spaghetti Bolognese	5.17	3.85	9	5.47	2.37	2.50
Indian	*Chicken korma curry*	6.58	3.69	10	5.32	3.33	2.50
	Lamb masala curry	7.21	3.39	9.15	4.00	5.68	2.78
Chinese	*P&P fried rice*	6.15	4.00	8	4.00	4	4.00
	Chicken noodles	7.1	3.80	8.34	4.00	4.44	3.64

[a] The retail prices are based on popular products found in British supermarkets: Asda (2014), Sainsbury's (2014); Tesco (2014); Morrisons (2014);Iceland (2014);Lidl (2014)

3 Results and Discussions

This section presents the results and discussions of the life cycle costing (LCC) and environmental analyses (LCA) of common British ready-made meals. First in section 3.1, the life cycle costing results are presented, including the analysis of the chilled and frozen options. The results of the value added are shown in section 3.2 and finally, in section 3.3, the integrated analysis of the environmental and economic assessments of the ready-made meals is discussed.

3.1 Life cycle costing of the ready-made meals

The results and discussion for the ready-made meals are presented first for the chilled ready-made meals (3.1.1), then for the frozen alternatives (3.1.2) and lastly the sensitivity analysis is discussed (3.1.3).

3.1.1 Life cycle costs of the chilled ready-made meals

As shown in Figure 34, the total life cycle cost of each chilled meal ranges from £1.17 (for Chinese chicken noodles) to £2.66 (for British Fisherman's pie). Around half of the studied meals (46%) exhibit life cycle costs between £1.2 and £1.4; these are the four options of British roast dinners: beef (£1.27), lamb (£1.32), pork (£1.21) and chicken (£1.27). The Italian spaghetti Bolognese and the Indian chicken korma curry present similar life cycle costs with only one pence difference i.e. £1.39 and £1.40 per meal respectively. Moreover, 38% of the products present life cycle costs in the band of £1.41 to £ 1.6, in particular the British cottage and shepherd's pies with £1.46 and £1.52 per meal respectively, the Italian classic lasagne with £1.59 per meal, the Indian lamb masala curry with £1.56 per meal and the Chinese pork and prawns (P&P) fried rice with £1.60 per meal.

In terms of the contribution from each stage (see Figure 34 and Figure 35a&b), the main contributors are the raw materials and the consumption stages with ~30% and ~55% on average across all the meals analysed. The manufacturing and packaging stages contribute 5% each. The pre-processing stage contributes 2% while the other stages less than 1%. Overall, all the stages present variations in the contribution depending on the recipe but the highest are found in the raw materials and consumption stages

In the case of the raw material stage, the contribution varies significantly across the recipes, from £0.19 (17% of total LCC) for Chinese chicken noodles and British pork roast, to £1.57 for British fisherman's pie (60% of total LCC). This large difference between the meals is due to large variation in cost for a number of key ingredients. Meals containing a large proportion of fish and seafood as well as lamb and some processed ingredients such as butter and cream are on the higher end of the scale, whereas lower cost meals tend to contain more vegetables, rice and pasta.

For instance, in the Chinese chicken noodles and the British pork roast dinner, the raw materials stage contributes ~17%. The quantity of chicken and pork in each meal contributes 51% and 41% to this stage respectively (see Figure 35a&b). As can be observed in Table 2, these recipes contain relatively inexpensive ingredients.

As mentioned, the meal with the highest contributing raw material stage is the British fisherman's pie with almost 60%; this is largely due to the prawns, contributing almost a half (49%) of this stage, following by the fish and butter with 25% and 20% (see Figure 35). In the case of prawns and fish, the prices are based on trading-prices (Table 38) while for butter; the high cost is related to calculations based on the costs inputs for manufacturing. For instance, Figure 36 shows the differences between the market costs of butter and other processed ingredients, and the calculated manufacturing costs. In the case of the butter, the calculated cost is seven times the market price. The value calculated for cream is also high (six times the market value). Similar trend is found in the case of bread and tomato paste, where the calculated price is 2.8 and 4.6 times the market value, respectively. The reasons for these differences are likely due to the quality and availability of data, which is adapted from a Danish database (Nielsen PH et al. 2003). This data is from 2003 and may not necessarily be up to date. Additionally, there may also be significant variation across regional markets in particular for dairy products.

For flour, soy sauce and pasta however, the estimated costs are far below the market price (see Figure 36). The market price of flour is 3.7 times lower than the farm gate costs, while the soy sauce is 9.1 times lower. Finally, the calculated cost of pasta is around 6.3 times lower than the whole sale costs. In particular for soy sauce, the large difference may be due to the lack of data in the manufacturing process of the sauce: the data used only contains some of the ingredients (soy beans, water, flour and salt). Neither the utilities nor any associated waste are accounted for.

For the case of the shepherd's pie the raw materials contribute 36% of the total LCC; lamb represents almost 60% of this and butter 27%; potatoes are the third contributor with 7% while the other ingredients contribute less than 1%. The British cottage pie presents a 33% raw material contribution; beef contributes 45% to this and butter 30%; the third highest contributors are the onions and potatoes with a contribution of 7%. The other ingredients have a negligible contribution with less than 2%.

Between the roast dinners, the contribution of the ingredients is similar: 25% of the total LCC for lamb; 22% for beef; 20% for chicken and 17% for pork. These small differences are largely due to the different costs of the meats. For the beef roast, the contributors to this stage are beef (54%), peas (23%), carrots (9%) and potatoes (7%), whilst the other ingredients contribute with less than 2%. A similar trend is found in lamb roast (25% raw material contribution), where lamb contributes 65% of raw material cost, following by peas with 17%. Carrots and potatoes contribute with 8% and 5%, respectively. The other ingredients contribute with less than 2%. In the case of the pork roast dinner, pork contributes with 41% and peas with 27%. Carrots and potatoes have a similar contribution with 13% and 9%. Finally eggs contribute with 4%, while the other ingredients contribute with less than 2%. In the chicken roast recipe, the raw material stage contributes with 20%. The chicken is the major contributor with 45% and peas contributes with 22%. Carrots, bread and potatoes have a similar contribution with 10%, 9% and 7%, respectively. Onions and eggs contribute with 3% and 2%, while the other ingredients have a contribution lower than 1%.

For the Italian cuisine the main contributor in the raw materials stage is the meat. In the case of the classic lasagne, the beef contributes 45%, the butter with ~30% and the tomatoes with 10%. The milk accounts for 5% while the onions and pasta with 2% each. The other ingredients account for less than 1%. Similar, the major contributor in the spaghetti Bolognese is the beef with 50%. The second and third contributors are the tomatoes and red wine with 11% and 14% respectively. Onions add 7%, while olive oil and pasta accounts for 6% each. The other ingredients contribute with lower than 2%.

In the Indian cuisine, lamb masala curry presents a similar trend as the others: the raw materials stage contributes 39% to the total LCC, the lamb contributing the most with 64%. The second largest contributor is the cream with 13%. Tomatoes and rice also have a considerable contribution with 9% and 6%, respectively. Onions contribute 4% while the oil contributes 2%. The other ingredients contribute less than 1%. Opposite trend is found in the chicken korma curry where the raw materials stage has a contribution of 29% and the main contributor is the cream with 43%. Chicken contributes 27% and the onions 17%. The rice contributes only 9%. The other ingredients account for less than 1%.

In the case of the Chinese cuisine, the contribution of the raw materials stage in the total life cycle costs is 40% for the pork and prawns (P&P) fried rice and 16% for the chicken noodles. The main contributor in the P&P fried rice meal is the prawns with around 60%. The second largest is the pork with 18%. Rice and peas contribute 8% and 6%. The eggs contribute 4% while the other ingredients contribute less than 2%. Chicken noodle has the chicken as the main contributor, with ~50%. The second largest contributors are carrots and onions, both with 14%. The noodles contribute 12% and the transport with 4%. It is important to notice that the only meal where the transport contributes considerable is in this recipe.

Although the consumption stage, in absolute value, is the same (£ 0.79) for each ready-made meal, the contribution of the consumption stage to the whole life cycle costs presents variations through the different recipes due to the influence of the raw material stage; in this case, as expected, the highest contribution is found in the Chinese chicken noodles and in the British pork roast dinner with ~66%. The lowest contribution is seen in the British fisherman’s pie with 30%. The main cost for this stage is the consumer’s transport, with a contribution of ~98%. Activities as cooking, storage and water usages account for less than 2%.

In the case of the manufacturing and the packaging stages, the contribution varies from 3% to ~8%, while in the case of the pre-processing stage, the variation ranges from 1% to 5%. Finally, the distribution and the final disposal present a constant contribution of 1% through all the recipes.

It is important to note that the distribution and final disposal stages are the same for all recipes, because the final product is equally treated, without special consideration attached to the recipe.

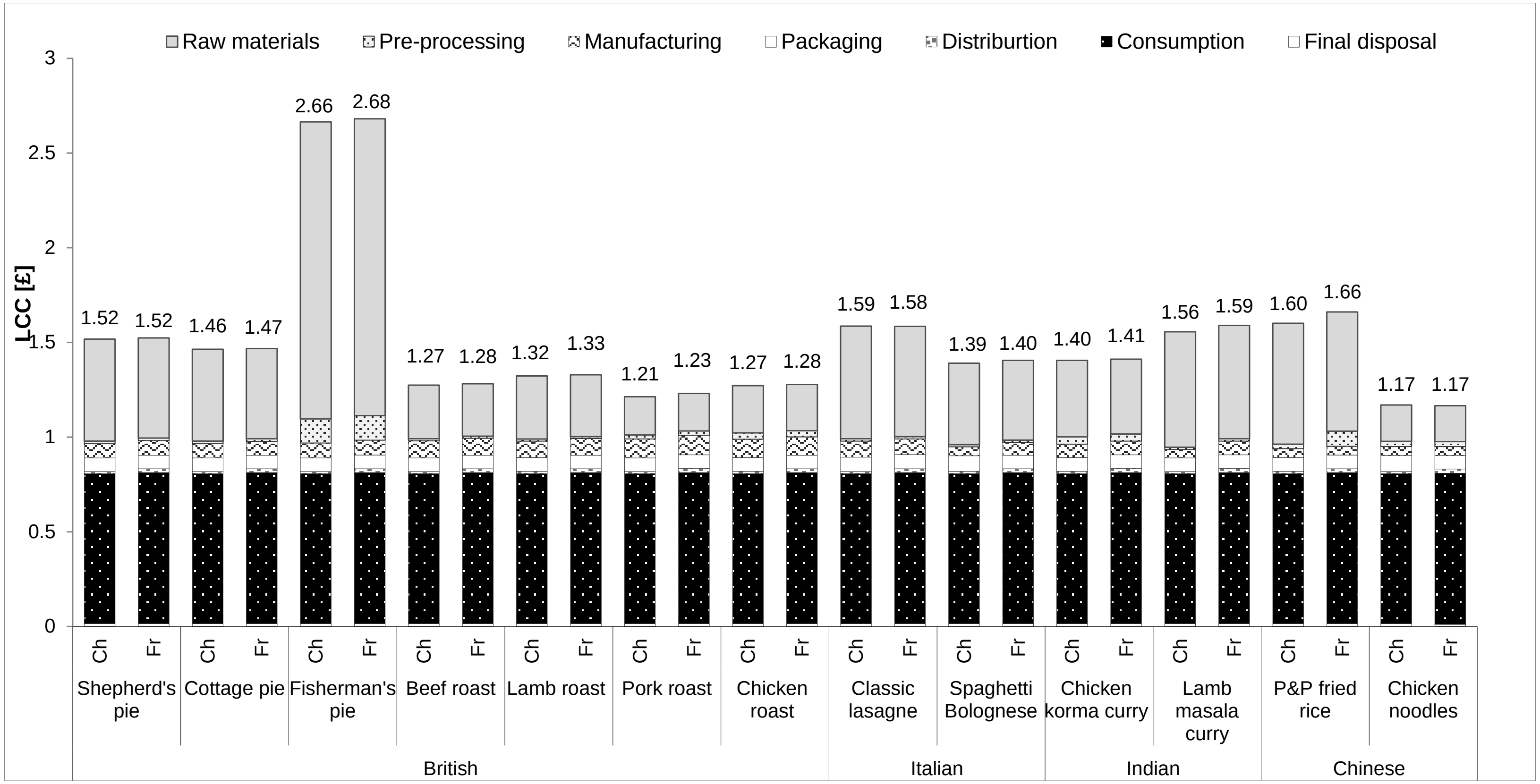
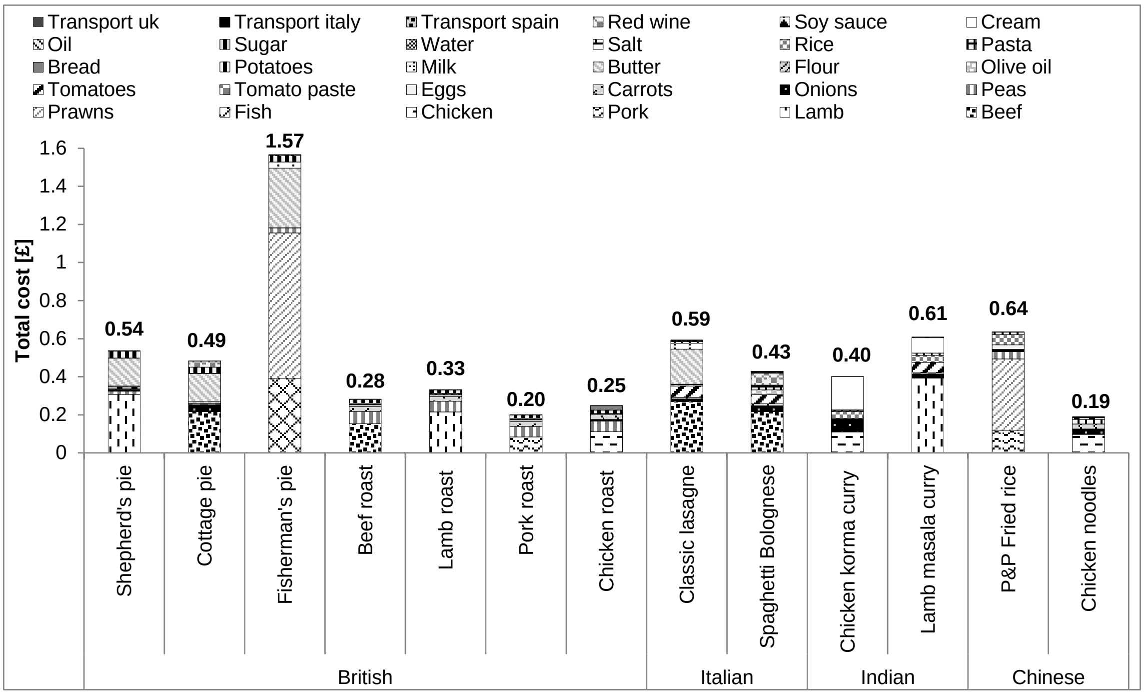
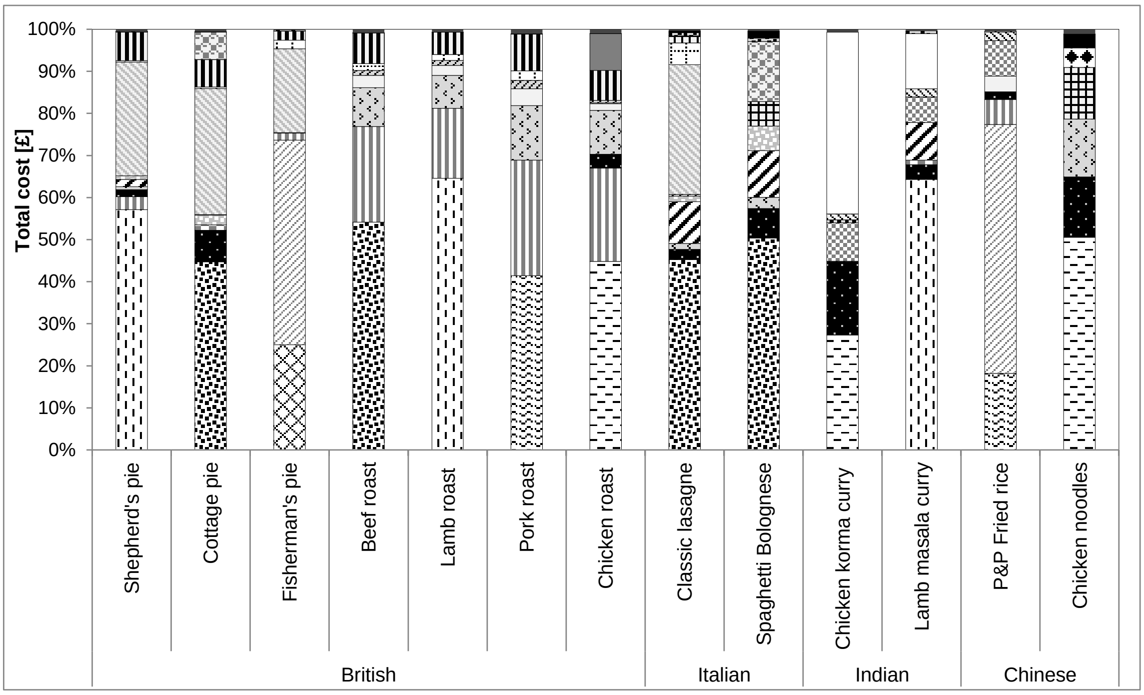


Figure 34 Life cycle costs (LCC) of common British ready-made meals in their chilled and frozen options



a) Raw material stage contribution



b) Ingredient contribution to the raw material stage

Figure 35 Contribution of the different ingredients in each meal and in the raw material stage

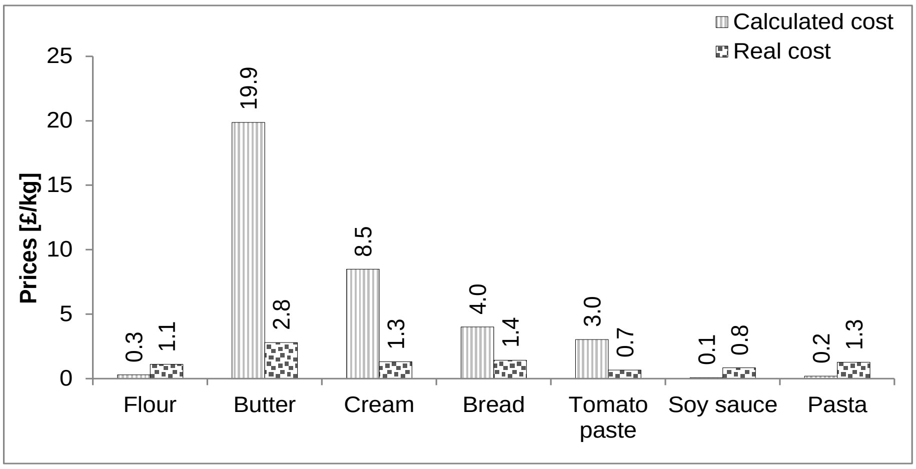


Figure 36 Market value and life cycle cost of processed ingredients

3.1.2 Comparison of the life cycle costs of the chilled and frozen ready-made meal options

As can be seen in Figure 34, the variations between the life cycle costs of the chilled and frozen options are small; the costs of the frozen options are on average 1% higher than the chilled, with a variation between 0.5% and 4%. The greatest effect is found in the Chinese P&P fried rice with the frozen option ~4% higher than chilled. Only two meals, the Italian classic lasagne and the Chinese chicken noodles present lower costs in their frozen options, this is mainly due to the reduction in the packaging usage when the meal is frozen. The lower losses (waste) rate in the frozen supply chain affects not only the disposal (waste treatment) but also the raw materials stage; frozen ready-made meal has on average 2% lower cost than the chilled products in this stage. However, the greatest differences come from the manufacturing and distribution stage. The former presents on average 9% higher cost than the chilled alternative while the latest highest almost 70%.

When the four cuisines are analysed, in both options (chilled and frozen) the highest LCC is found in the British cuisines with on average £1.73 and £1.74 per meal. The lowest LCC is found in the Chinese cuisines with £1.38 and £1.41. In the case of the Italian and Indian, they are very similar between the two options. For the chilled ready-made meals, the Indian cuisine presents lower LCC with overall £1.48 per meal, while the Italian exhibits an average LCC of £1.49 per meal. Opposite trend is found in the frozen options, where the Italian cuisine has lower LCC with £1.49 per meal and the Indian cuisine an average of £1.5 per meal.

3.1.3 Sensitivity analysis

In order to test the impact of the assumptions made within the LCC estimation, this section analyses possible variations in the ready-made meal costs. Therefore, this section examined the following parameters:

i) variation in the prices of fish and shrimps, key ingredients in the fisherman's pie; and
ii) credits for the rendering in the slaughter house (pre-processing stage).

3.1.3.1 Influence of fish and prawn prices

The base scenario uses fish at £4.65 per kg. and prawns at £23.1 per kg (see details in Table 38), which contribute £0.39 and £0.76 respectively, to the fisherman's pie ready-made meal. For the sensitivity analysis, the study considers four different types of fish: salmon (£ 4.48 per kg), mackerel (£1.28 per kg), pollock (£3.14 per kg) and haddock (£2.22 per kg) (Seafish 2013). For prawns, the study replaces with a shrimp (prawns) at £5.34 per kg (Seafish 2013).

In Figure 37a the results on the costs of fisherman's pies are presented. As can be seen, the variations of the fish prices are not as large when compared with the prawns. The meal costs range from £2.64 for the fisherman's pie made with salmon to £2.37 for the meal made with Mackerel; these represent reductions on the ready-made meal's LCC between 1% and 11% comparing with the base scenario.

A greater reduction is found in the case of the prawns, with 22% lower total life cycle cost comparing with the base scenario (see Figure 37 a); this is due to the shrimps (prawns) price being around four times lower than the one used in the study.

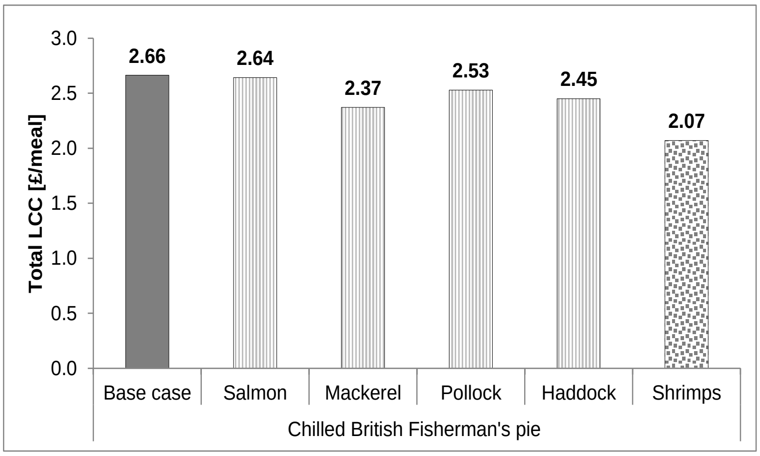
Although the sensitivity analyses exhibit a high reduction in the LCC of the Fisherman's pie, the LCC is still the highest of the 13 meals analysed even when the cheapest ingredients are used.

3.1.3.2 Influence of the rendering[4] costs

The influence of the rendering cost is tested in the British roast dinners. The costs of rendering are £1.13 per kg offal cattle, £1.12 per kg offal sheep, £0.69 per kg offal pig and £0.57 per kg of offal chicken; these values are based on FAO (2008). The rendering is assumed as the waste generated in the slaughterhouses.

When the system is credited with the rendering costs (see Figure 37b), the LCC is reduced by between 1% (pork roasts) and 3% (beef and lamb). The major reductions are found in the beef and lamb due to the higher prices of the beef and lamb offal (£1.13 and £1.12 per kg), and the higher rate of animal waste (carcase rate) which is ~40% for cattle and lamb, while the pork is 26% and the chicken is ~27%.

Although the variations are small, adding the rendering credits to the LCC reduces the beef roast dinner cost to the level of the chicken options, being the second lowest cost amongst the roasts. The best and the worst position remain the same, with the pork roast dinner being the most affordable while the lamb the most expensive.



a) Variations in the cost of the fisherman's pie key ingredients: fish and shrimps

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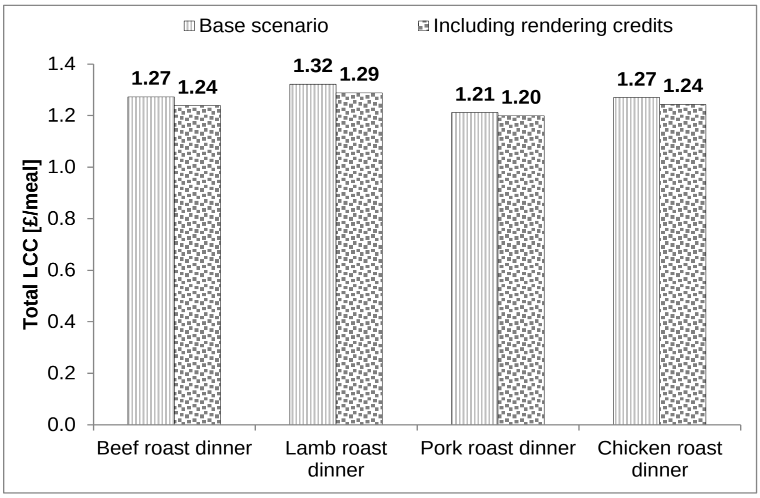
[4] Rendering refers to the conversion of animal processing waste into valuable materials.



b) Variations of the LCC's roast dinner with the rendering credits

Figure 37 Sensitivity analyses of the ready-made meals

3.2 Value added analysis of the chilled and frozen ready-made meals

This section analyses the value added, the retail price variation and the variation of the recipe composition in the ready-made meals. First, the chilled ready-made meal options are analysed (3.2.1), and then the correspondent frozen options (3.2.2).

3.2.1 Chilled ready-made meals

Figure 38 shows the analysis of the value added in the chilled ready-made meals. The results are presented in cost per kg of meal, due to the different portion sizes for different brands. The average value added (VA) within the chilled ready-made meals analysed is £4.73 per kg, the highest being £7.62 per kg in the case of the British pork roast and the lowest being the British fisherman's pie with £0.14 per kg.

The British roast dinners have on average the greatest VA, at ~84% of the retail prices; in particular the pork roast dinner, where the value added is 87%. The Chinese chicken noodle also has a high value added with £6.01 per kg, representing 86% of the meal retail price.

In a lower range between 80% and 60%, there are seven meals: the Indian chicken korma curry and the lamb masala curry present VA of 75% and 71% of each meal's retail price. The Italian meals, lasagne and spaghetti, present lower added value with 60% and 69% of the market value.

Similar to the Italian dishes, the British shepherd's and cottage pies show a value added of 63% and 68% respectively. Finally, the fisherman's pie represents the lowest added value with only 3% of the retail price.

The study also considered the variation in recipe (Table 39) and retail price. In the case of the former, the highest life cycle cost variations are found in the British fisherman's pie and in the Chinese P&P fried rice; these two meals are greatly affected by the variation in the composition of the high-cost ingredients (prawns and fish).

In the case of the retail price, the greatest variations are found in both Italian dishes, especially the classic lasagne, and also in the British pies. For instance, the classic lasagne has retail prices almost 2.3 times its average price and lower retail prices as 30% of the average price. In the case of the British pies, the lowest retail prices are 50% lower than the average retail price of these meals while the higher prices are 1.7 times. The Italian spaghetti Bolognese presents similar values as the pies.

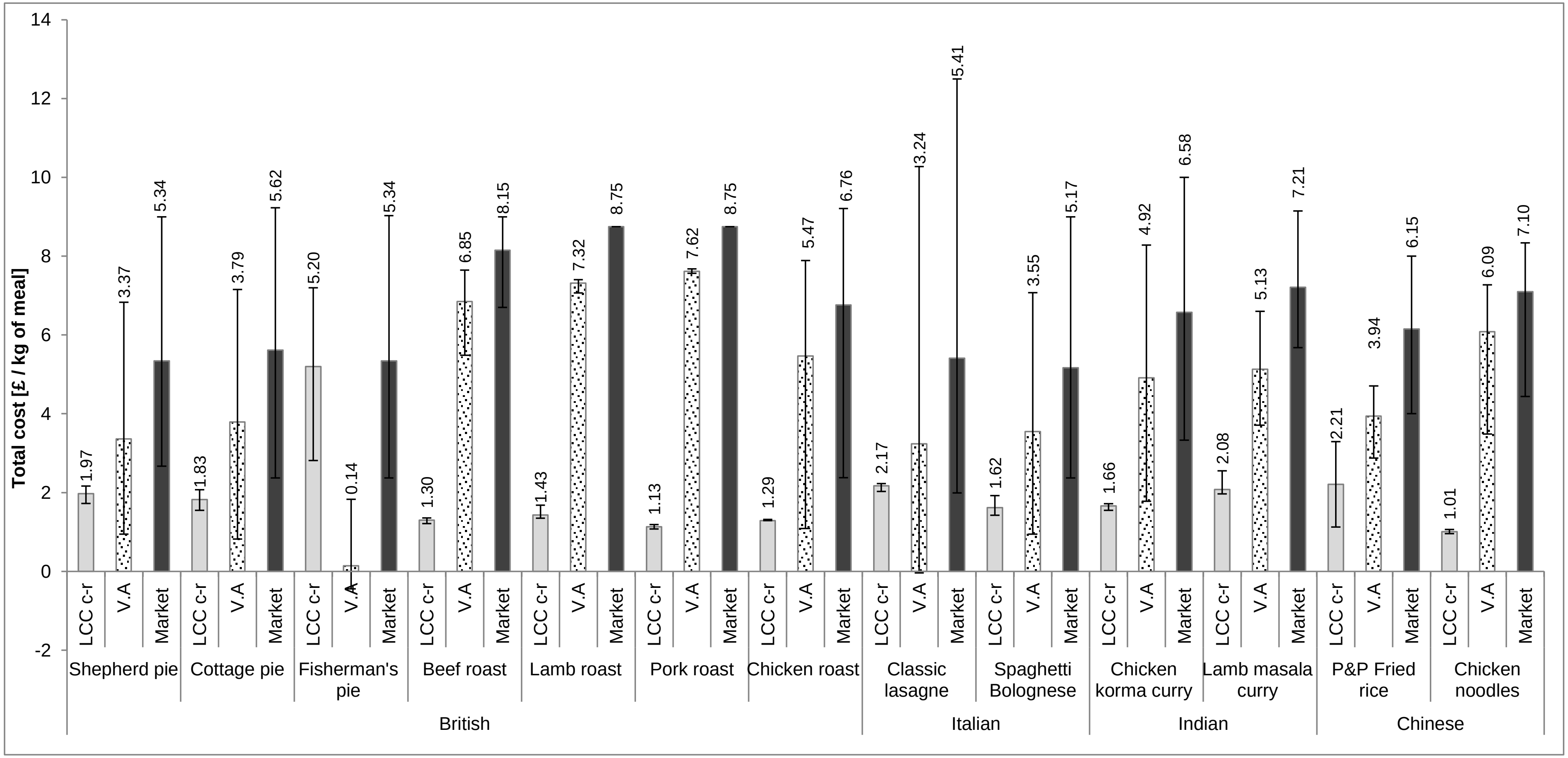


Figure 38 Value added analysis of the chilled ready-made meals

[RP: retail price; LCCc-d: life cycle costs from cradle to distribution (to the retailer). Error bars represent minimum and maximum costs related to the variation in the retail price and recipe composition of ready-made meals]

3.2.2 Frozen ready-made meals

Figure 39 shows the value added results for the frozen ready-made meals. In this case, the average VA is £1.9 per kg. The greatest VA is found in the British beef roast dinner with £3.30 per kg of meal, while the lowest is in fact a value lost, is found in the British fisherman's pie with £1.53.

Similar to the chilled options, the lowest value added is found in the British shepherd's pie, but this time with 33% of the market value. There are only three other meals with a value added lower than 50%: British cottage pie with 40%, Indian lamb masala curry with 36% and the Chinese P&P fried rice with 41%. There are four meals in the range of 50% to 70%; the Indian chicken korma curry with an added value of 55%, the Italian spaghetti with 57% and the Lamb roast dinner with 67%. Finally, there are four meals with a value added greater than 70%: the British beef, pork and chicken roast dinner with on average 72% and the Chinese chicken noodle with 74%. Finally, as mentioned, the Fisherman's pie presents a 'value lost', with retail prices lower than the calculated life cycle cost; in this meal, the retail price is 70% of the calculated LCC. This is due to the high prices of the fish and prawns.

Due to the recipes being the same for both chilled and frozen meals, the influence of recipe variation is the same for frozen meals as with chilled meals, with the fisherman's pie and the P&P fried rice being the most affected. In the case of the retail prices, the highest differences are found in the British cottage and fisherman's pies and in the Italian classic lasagne, all of them with retail prices around 1.7 times the average retail price of the meal and around 35% lower prices.

Summarising, from the results it can be inferred that the chilled ready-made meals offer greatest margin to the supply chain, with values added over 60% in almost all the meals analysed, except for the Fisherman pie. However, from the consumer's perspective, these meal options clearly represent a lower value for money. The frozen meals still generate a significant marginal value, ranging from 30% to 70%, but with more affordable prices for the consumers. The only exception for both meals is the Fisherman's pie

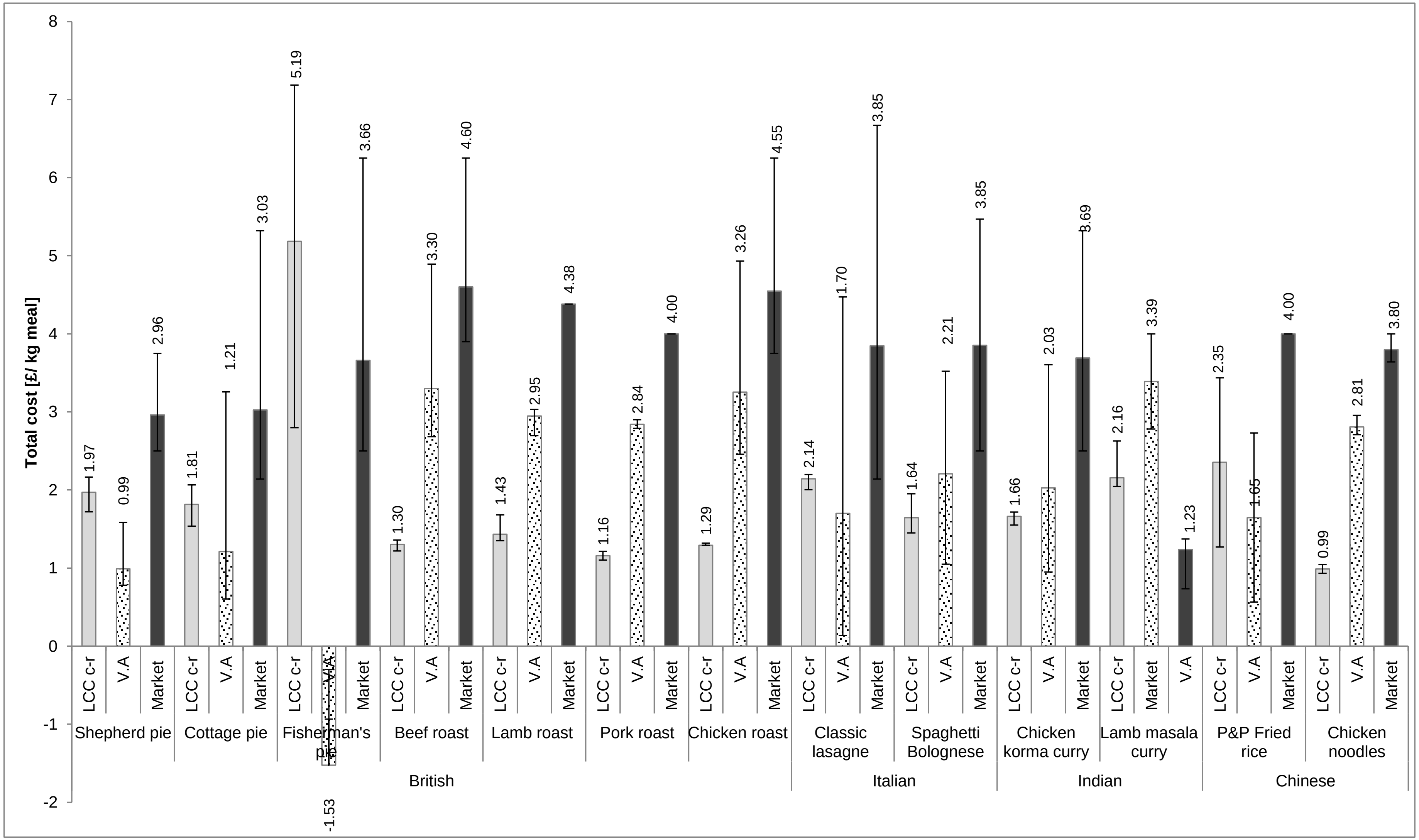


Figure 39 Value added analysis of the frozen ready-made meals

[RP: retail price; LCCc-d: life cycle costs from cradle to distribution (to the retailer). Error bars represent minimum and maximum costs related to the variation in the retail price and recipe composition of ready-made meals]

3.3 Comparison of the life cycle cost and the environmental impacts

Figure 39 and Figure 40 present the economic and environmental impacts analyses of the chilled and frozen ready-made meals, respectively. This section uses a qualitative approach to identify the best meal options for both the economic and environmental results. The figures were built by ranking the meals in order of descending values and assuming equal importance for all the impacts considered, with white boxes indicating the lowest costs and impacts and the black the highest. This so-called 'heat map' helps to visualise the differences between the options and to identify the best and worst meal scenarios.

As discussed, the LCC of the frozen meals is higher than the corresponding alternative chilled options due to the higher energy consumption. However, when they are compared under the environmental perspective, a different trend is found; the frozen ready-made meals present lower impacts than the similar chilled options in nine out of 11 impacts. This trend is particularly evident in impacts such as GWP and ODP. In the case of the former, this is due to the fact that the chilled products usually have higher waste rates and in the case of the distribution stage, the impacts of the refrigerant uses and leakages are higher because the chilled products are displayed in open cabinets. There are only two impacts where the frozen options present higher values, those are the ADP $_{\text{fossil}}$ and the MAETP; due to the higher energy uses in the frozen processes.

Throughout the 13 meal recipes analysed, similar trends are noticed between the economic and environmental analyses. The lowest LCC are found in the Chinese chicken noodles and the British roast dinners. Similar trend is seen in the environmental impacts assessment where the lowest impacts are exhibited by the British roast dinners in particular pork and chicken based and in the Chinese chicken noodles. Only one meal, the British fisherman's pie shows dissimilar tendency. This meal presents the highest LCC but presents the lowest environmental results, with respect to AP, EP, GWP and POCP. The only exception is HTP and TETP where it shows the worst performance; however, the data acquisition plays an important role in the reliability of these impacts.

Overall, the LCC and LCA share the raw material stage as one of the hotspots. However, as was previously mentioned, the main contributor in the LCC is the consumption stage. In the case of the LCA, consumption stage is relatively small across all the impacts. Additionally, the manufacturing and distribution stages contribute significantly to the LCA results, due to the high energy consumption as well as the refrigerant uses.

Considering all the recipes, the most sustainable options appear to be the Chinese chicken noodle and the British roast dinner, especially the pork-based dinner, whilst the least are the Italian ready-made meals, the Indian lamb masala curry and the British cottage and shepherd's pies.

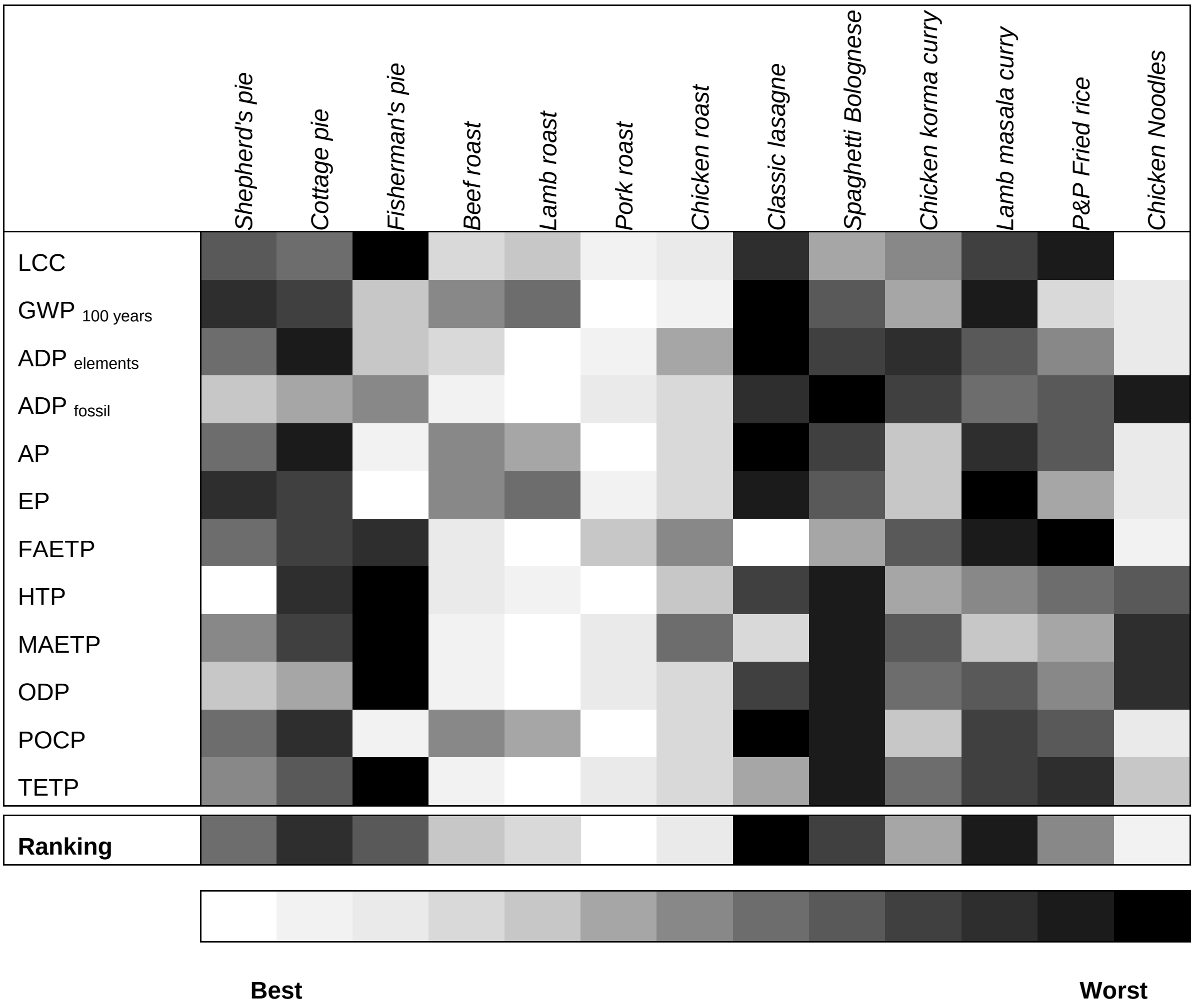


Figure 40 Economic and environmental assessment of common British chilled ready-made meals

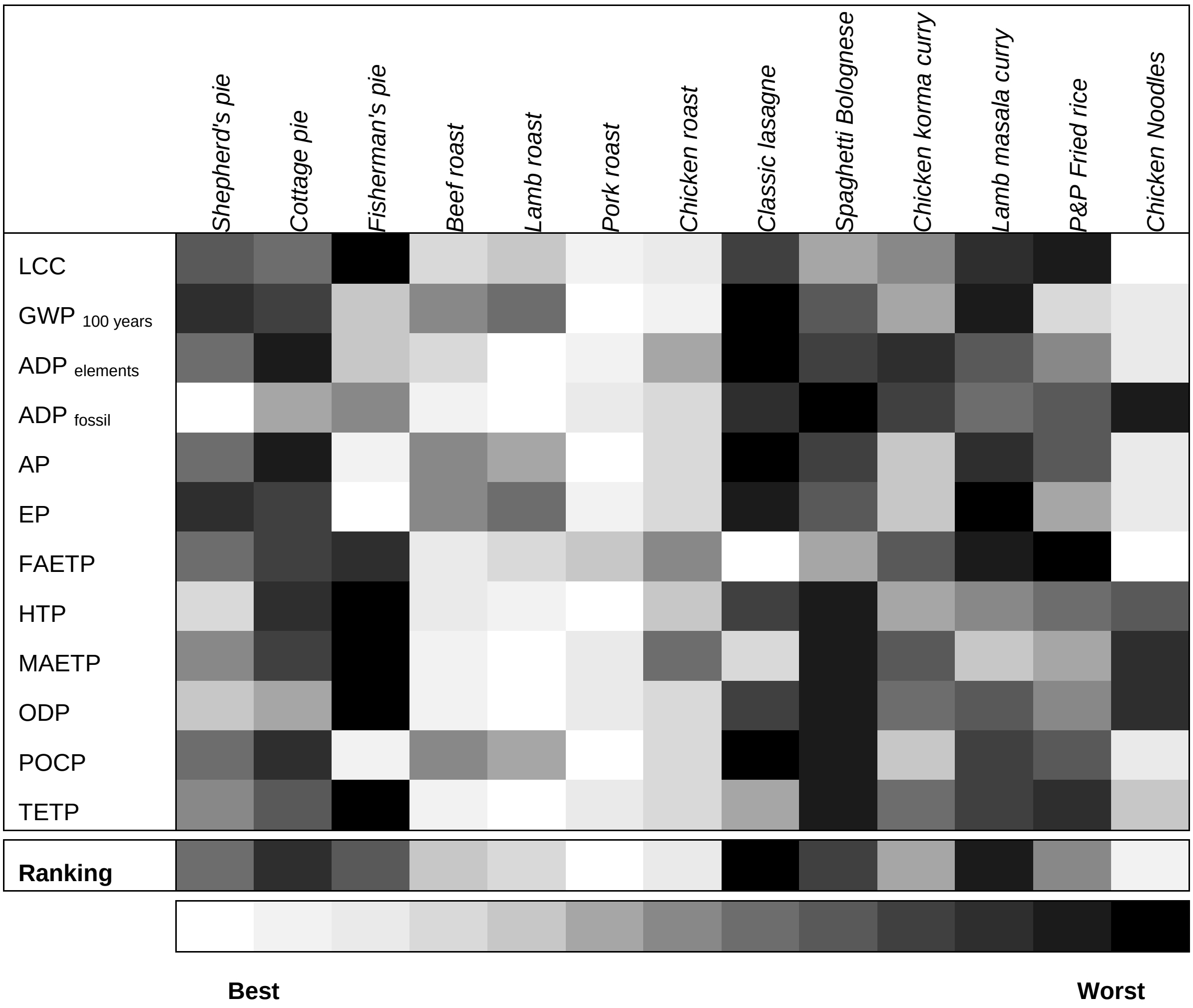


Figure 41 Economic and environmental assessments of common frozen British ready-made meals

4 Conclusions

The total life cycle costs of the chilled ready-made meals range from £1.17 to £2.66 per meal. The lowest LCC is found in the Chinese chicken noodles while the highest is found in the British fisherman’s pie. Half of the meals present a LCC lower than £1.50 per meal, while only a third present a LCC in the range of £1.51 to £2.00 per meal.

The hot spot analysis shows that the raw materials and the consumption stages are the critical stages in the LCC. In the case of the former, the ingredient contribution is the most relevant and is the biggest differentiator across recipes. The consumption stage contributes an average of 55% to the LCC, which is almost entirely due to the transport of the meal post-purchase. This stage would be of much higher relevance if the energy and fuel prices increased further. It is important to note that consumers do not always take into account this stage, as it is not easy to account for, as the ready-made meal purchase is normally part of an overall shopping trip, as it was calculated in this study. Therefore, if the shopping trip includes purchasing a number of items, the contribution could change significantly, being lower if it is a big shopping list.

In terms of absolute value, the distribution, consumption and final disposal stages are almost exactly the same for all the recipes. Therefore the contribution varies mostly due to the changes in the raw materials stage.

The recipes with higher amount of meat, fish and seafood as well as higher amount of processed ingredients tend to exhibit the greatest LCC. The highest contribution (60%) is found in the British fisherman's pie due to the high cost of ingredients such as prawns and fish, responsible for around 75%. The lowest contribution is found in the British pork roast dinner and in the Chinese chicken noodles with a stage contribution lower than 20%.

Overall the meat, fish and seafood in the recipes are the main contributors to the raw material stage, with more than 40%. The only exception is the Indian chicken korma curry where the chicken contribution is lower than 30%. This finding is particularly relevant due to the constant increasing costs of the raw materials and fuels, making it more difficult to eradicate food issues such as food affordability and food poverty, as well as diet-related chronic diseases. In particular, food items as fish, meat, vegetables and fruits are the most affected, driving to consumers to increase the purchase of processed food, usually with lower health and quality characteristics, affecting consumer's health.

Particular interest is found in the processed ingredients due to the high differences between the market prices and the calculated cost. For instance, the life cycle cost of the butter is seven times the wholesale market price while cream is around six times. One possible reason for this could be the process characteristics, in particular the efficiency and waste rates, the allocation methods, and the market behaviours.

The comparison between the chilled and the frozen options show that there are minimal cost differences: the frozen options are on average 1% higher than the chilled. This is due to the fact that the contributions of the manufacturing and distribution stages are small (~5% and ~1%) and the energy usage in the consumption stage is almost negligible compared with the transport. However when the market values are compared, the chilled options are far more expensive than the frozen options. Consequently, the value added is higher for the chilled meal, meaning that the supply chain received more profits with those products than the alternative frozen one.

The higher retail prices of the chilled ready-made meals can be due to several reasons; for instance the chilled ready-made meal market is better positioned; also the chilled ready-made meals have more variety in terms of recipes but also in terms prices, having premium lines (expensive products) and also value meals (lower prices). Finally, the consumer's image of the chilled food is attached to healthier and better quality options than the frozen meal, and this trend was endorsed by the 'horsegate' scandal, which mainly affected frozen ready-made meals.

The sensitivity analyses present different results. In the case of variations in fish and prawn prices, the alternative options reduced the LCC of the fisherman's pie up to 22% when prawn source is changed; despite the change however, the fisherman's pies still have the highest LLC. In the case of the rendering credits, the reductions are relatively modest, with the highest being only 3% for the beef and lamb roast dinner, positioning the beef roast as the same level of the chicken roast.

Overall, the economic and the environmental assessments show similar results of the meals analysed. The British roast dinners, in particular pork, and the Chinese chicken noodles are the most sustainable options, while the Italian classic lasagne, the Indian lamb masala curry and the Shepherd's pie are the worst options.

The study was performed based on several assumptions that due to the absence of available data cannot be either confirmed or denied; for instance the shares of the different types of meals are based on confidential data, supported by surveys; the meals and recipes were selected after a market study (screening of available meals in supermarkets) and due to lack of detailed descriptions, those were completed by home-made recipes. Also, the costs of the ingredients and the processes definitions are based on free-data sources, which do not always represent the reality of the factories. Therefore the results of the study will change if more detailed information from the sector and from the supply chain, in particular manufacturers, is available.

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Chapter 6: Sustainability Assessment in the UK Ready-made Meal Sector

This paper is currently being prepared for submission to a peer reviewed journal and the possible options are the Journal of Cleaner Production and the International Journal of Life Cycle Assessment.

The research, consisting of the environmental, economic and social assessment in the UK ready-made meal sector, using a bottom-up approach extrapolating the results of previous studies, was designed, executed and written by the author of this thesis. Co-authors Azapagic A. supervised the research and edited the paper.

Sustainability Assessment in the UK Ready-made Meal Sector

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Abstract

This paper aims to carry out a sustainability assessment in the UK ready-made meal sector. A range of most popular ready-made meals across different cuisines are considered, with the annual production of 483.5 kt, representing 85% of the total sales in the sector. Taking a life cycle approach, the assessment of environmental sustainability is carried out using life cycle assessment; life cycle costing is used for the economic evaluation and social indicators for the social assessment. The results shows that the global warming potential (GWP) in the ready-made meal sector is 4.94 Mt of CO_2 eq. per year with the chilled ready-made meal market being the main contributor at 3.49 Mt of CO_2 eq. The ready-made meals sector contributes 1% to the UK GHG emissions and 4% to the GWP of the whole food and drinks sector.

The total life cycle costs of the meals considered are £2.1 billion per year with the chilled meals market contributing £1.42 billion and the frozen remaining £0.68 billion. The value added is estimated at £958 million per year. With respect to different cuisines, the British and Italian cuisines are the largest contributors to the environmental impacts with the former having the highest impacts for seven out of 11 impacts analysed and being responsible for 40% of the total life cycle costs. The Italian meals have the highest values for three environmental impacts (acidification, eutrophication and photochemical smog) and contribute 27% to the total life cycle costs in the sector. The meals in the Chinese cuisine have the lowest environmental impacts, followed by the Indian cuisine, together representing 30% of the total life cycle costs. This is because the former meals have higher-impacts and cost, and also because of the higher volume share. For the social sustainability, wages and forced labour were found to be critical in the agriculture due to the conditions of this activity while workers injuries and fatalities are found to be significant issues in the manufacture of the meals, having the greatest figures in the sector. Food security and poverty line are important from the consumer point of view.

1 Introduction

There has been an increasing interest in the food sector over the past few decades due to many reasons, including nutritional, affordability and environmental issues. For instance, national and international environmental engagements such as the climate change acts have been developed by organizations such as United Nations (UN) and also throughout local governments (UNEP 2013;The Scottish Government 2014;Welsh Government 2011;CCC 2014); although all these initiatives have been implemented, the environmental problems still exist.

The search for more sustainable solutions within the food industry has led to numerous environmental studies; therefore, it is not difficult to find environmental assessments, carbon footprint and LCA studies of food items (Schmidt Rivera et al. 2014;Romero-Gámez et al. 2014;Cederberg et al. 2011) and also within the food industry (Andersson 2000;Basset-Mens et al. 2009;Curtin 2009).

Moreover, the concern about the environmental impacts of the consumption of food has been growing too; in particular due to the strong connection between social issues such as nutrition and health. This growing concern is reflected in numerous studies about environmental impacts of diets, which are trying to relate different diet options and the environmental impacts generated, especially GWP (González et al. 2011;Carlsson-Kanyama 1998;Baroni et al. 2007;Marianne Leuenberger et al. 2010;Tukker et al. 2009;Van Kernebeek et al. 2014). Most studies find that the higher the content of meat, specially beef and lamb, the higher the impacts. However, there are no easy solutions to this as diets depend on consumer needs and choices which are based on different factors, including nutritional content, physical requirements and taste, and differ depending on the gender, age and cultural background (Van Kernebeek et al. 2014;Cerutti et al. 2014;Saxe et al. 2013;Martindale et al. 2012). There are also several publications related to the impacts of food/diet options in human health; specifically these studies analyse the relationship between different diets and food items with specific diseases as asthma or with healthy parameters as life expectancy (Orlich Mj and et al. 2013;Rosenkranz et al. 2012;Clonan et al. 2012;Friend of the Earth 2012;Baroni et al. 2007).

However, sustainability assessments of specific sectors within the food industry are scant. As far as the authors are aware, there is only one study considering the environmental, economic and social impacts, focused on the UK beverage sector (Amienyo 2012). Therefore, this study seeks to analyse, as a first attempt, the sustainability in another important sector within the UK food industry: the ready-made meal sector.

The ready-made meals have been labelled as an essential part of British life, with the British sector occupying the top in the European ready-made meals market (Winterman 2013). The UK ready-made meal sector was valued at £1.97 bn in 2013; the latest figures estimate that the value of the market by 2014 is £2.04 bn (Key Note 2013;CFA 2014a;Key Note 2014), and it is expected to grow by a further 15.4% by 2018 (Key Note 2014). This continuous growth is reflected in the increasing number of new companies in the sector; in 2011 there were 75 companies producing ready-made meals, which increased to 80 in the following year. Moreover, 62% of the companies had a turnover over £1 m (Key Note 2013).

With regard to employment, the food and drinks sector (FDS) is characterised as having a high level of permanent and stable jobs, with 94% being full time jobs in 2009 and with surveys showing that workers remain in their jobs for around nine years on average (University of Cambridge 2010). In terms of the gender split, male workers dominate the sector with on average 67%. Regarding the age of employees, 30% are over 45 year old (University of Cambridge 2010).

As an important part of the FDS, the ready-made meal sector has had a controversial role in the population's health with its products being considered unhealthy, in particular, frozen options. However, although there are several studies related to health effects of consumption of ready-made meals, the results are still not clear. Some studies state that ready-made meals have higher levels of fat, calories and sodium than the home-made options (Shore 2013;Benson

2013;Daneshkhu 2014) while others affirm that these products are much better options than a similar home-made version, based on the nutritional analysis of recipes (White 2012;Maples 2014).

The UK ready-made meal sector is divided into two main markets: chilled and frozen. The chilled market has grown by 47% since 2009, from £1 bn in 2009 to £1.48 bn in 2013; also being the fourth most important sub-sector in the chilled food market with 12% (CFA, 2014). The chilled ready-made meal market represented 68% of the market value of the whole ready-made meals sector in 2012. The frozen ready-made meal market was valued at £692 m in 2013, also representing 12% of the total frozen food market. In terms of volume, this sector represents 9% of the total frozen food market with 182 kt. (BFFF 2014a). Own labels (supermarket brands) lead in both markets with a broad range of quality (value to premium meals) and also with a big variety suitable for all kinds of diet. The market is mostly shared by 10 companies, with the largest being Bakkavör Foods Ltd[5]., Greencore Group PLC[1], 2 Sisters Food Group Ltd.[1], HJ Heinz Manufacturing UK Ltd. with turnovers over £800 m (Key Note 2014;Key Note 2013).

The popularity of these products is undisputed; for instance there are more than 12,000 different chilled products with a population spending in 2013 around 15% of the total food purchased, totalling £12,671 million. Overall, around 30% of UK adults buy ready-made meals (CFA 2014c).

The increasing awareness and demand for better environmental products based on consumers surveys (products labelled as environmentally friendly, animal welfare, produced sustainable, food miles, fair trade, and so on (Defra 2014;Defra 2012;Key Note 2014)) and standards are a cross-industrial challenge for the sector. The UK Food and Drink Sector (FDS) is the largest single contributor to the GHG emissions with 61 mt CO_2 eq. (only considering the net trade)[6]; specifically, the manufacturing sub-sector contributes 13 mt CO_2 eq., the retail 11% while the catering and households account for 20% (Defra 2014). Moreover, food manufacturing uses 5.2 mt oil eq., representing 15% of the agri-food sector. The food manufacturing sector also generates 3.2 tonnes of waste a year while retail produces 0.4 and households 7.2 tonnes a year; 17% of the overall food purchased is wasted annually (Defra 2014).

The food manufacturing sector has been reducing its CO_2 emissions over the past year; by 2013, they were reduced by 32% from 1990 baseline. The amount of waste has also gone down by 7.4% (FDF 2013).To reduce the water stress, the FDS created the Federation House Commitment, which is a voluntary initiative to reduce 20% of water usage by the sector by 2020 (FHC 2014). The industries involved have already decreased 16% of their water consumption, representing 4.4 million m^3 between 2007 and 2012. The Courtauld commitment represents another initiative between the food sector, WRAP and local authorities in order to reduce food and packaging waste (WRAP 2014).

In an attempt to address the healthy issues and in particular the increment in diet related chronic diseases (DRCD), the food industry has been engaged in the voluntary public health responsibility deal (PHRD). Since 2011, the sector has committed to improve the public health through actions such as the product labelling and food nutrient content. Moreover, in 2013 a complementary new agreement was announced, this time related to saturated fat content, reviewing portion sizes and providing information about healthier options (Department of Health 2014). However, there is still no evidence that the sector is actually changing the way food is manufactured to address the health issues more directly. Moreover, due to the voluntarily conditions, there are no strict regulations or control pathways from the government or organisations as NGO to control the actual changes and the commitment targets.

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[5] These companies produce ready-made meals for supermarkets

[6] It excludes the food packaging, food waste, land use change, transportation in the manufacturing stage and utility uses in the consumption stage. Also, the net trade considers the emission from food imports emission less the ones from food exports.

Another important issue closely related with health and wellbeing is food security which involves food affordability, food access and food use (WHO 2014). It is a complex concept but it can be said that food security is achieved "when all people at all times have access to sufficient, safe and nutritious food to maintain a healthy and active life" (FAO 1996).

Analysing the UK food system, in terms of affordability*,* the country is ranked 16th on the overall food index and 13th in the specific affordability index among 125 countries*,* based on the "Food affordability index" (The Economist Group 2014;Oxfam 2014a); this is despite the UK being the 6th richest country (Dugan 2014). However, the analysis of these and other similar indices (e.g. household disposable income, food prices, etc.) is not an easy task. For example, the UK household disposable income spent on food decreased by 2% between 1999 and 2007 and some analysts interpret this as a reduction in food prices. By contrast, others claim that even if the prices have not changed, the quality of the food has diminished, implicating that the overall spending has decreased too. Statistics confirm that the prices have risen while the purchases have decreased; for instance in 2012 people spent 17% more in food compared to 2007 purchases, but buying 4.7% less food than in 2007 (Cooper et al. 2014). Consequently, the health and wellbeing of the population, in particular those on lower incomes, have been deteriorating. Clear examples are the increase in the obese and overweight population during the period between 1999 and 2007, especially in the lowest social segments (Cassidy 2014). The increasing number of 'food bank' users in the UK is another example of food affordability issues: during 2013 around a million of Britons used food banks (Milligan 2014).

The food index has three categories a part from the food affordability, which are: enough to eat, food quality and health. The main issues across these categories are the volatility of food prices, undernourishment, quality and affordability of food and water, and overall health. The UK's worst performance is found in the health category (28th position), followed by the food affordability (13th/14th position) and then the food quality (20th/8th) (The Economist Group 2014;Oxfam 2014a). One of the main challenges is the volatility of food prices; since 2007, there has been an increase of 22% in the food prices, which is almost double (12%), compared to EU countries (Defra 2014). In 2011, the relative affordability for lower-income households was 16.6% compared with 11.3% for all UK households. Moreover, ready-made meals and specially the processed food group have increased their prices by 28% since 2007.

The higher prices have also affected the food quality of the household food purchases; for instance in 2011 lower income families reduced their consumption of carcase meat by 18%, fruits by 15% and vegetables and fish by 12%, compared with purchases made in 2007 (Defra 2014). These items have been replaced by increasing the consumption of flour by 20%, non-carcase meat and meat products by 14%, cheese and confectionary products by 7% and 5%, respectively. Therefore, 90% of shoppers state that the prices are the top five drivers for shopping, with the price being the most important for 39% of people. On the other hand, healthy options were the most important purchasing factor for only 9% of the shoppers (Defra 2014).

Related to food security, food independency as part of the full access to food, are further important issues. In the UK only 53% of the food is produced domestically, with 24 countries contributing to around 90% of the UK supply chain[7] (Defra 2014). This fact could affect the development of the sector but also the health and dietary patterns of the population, due to several goods are not produced at national levels, therefore economic and political changes and even weather condition could affect the UK population health.

Focusing on food quality, several studies have shown that the quality of food consumed in the UK is mediocre and the government together with the NHS and the FDS are aware of this issue (Department of Health 2014). As a result the government, NHS, and FDS are trying to help through campaigns as "5 a day", "Eat well plate", food labelling (traffic light and nutritional guidelines), and also through information to educate the population (NHS 2014;NHS 2012).

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[7] Percentage based on the unprocessed food at farm-gate value

Some studies also suggest that dietary risk factors and physical inactivity are responsible for 10% of a global deteriorating of health (Lim et al. 2012). The main dietary risks are the low consumption of vegetables and fruits and also high consumption of sodium (Lim et al. 2012). Between 2007 and 2012, the consumption of fruit and vegetables reduced by 14% with the lowest-income families consuming on average 2.9 portions per person per day (Defra 2014).

Furthermore, the ready-made meal sector was also affected by another food quality issue, the ‘horsegate’ or ‘horsemeat scandal’. In 2013, in the UK and Europe, ready-made meals were found to contain horsemeat and even pork meat without being labelled. As a result, regulation and food quality become an important issue for consumers and by implication, for the sector. Since then, there has been more emphasis on tracking the provenance of food (Key Note 2013;Key Note 2014) to reduce the possibility of future incidences of food contamination.

Ready-made meals are considered to be ‘convenience’ food saving time and sometimes even money (e.g. Candel 2001; Costa, Dekker et al. 2001; Brunner, van der Horst et al. 2010). Candel (2001) explains that these as well as lack of culinary skills are directly related with consumer decisions to purchase ready-made meals. Lately, other drivers for their consumption have also emerged. According to Freedman (2007), the food market has been experiencing changes: consumers are avoiding to eat at home not only to save time or due to lack of cooking skills, but also to try new food and new ingredients. For instance, between 1985 and 2005, in UK the expenditure in the restaurant and catering market rose by 33%. In terms of home budgets, the expenditure on food was 22% in 2004 with people spending on average a third of their food budget on eating out. However, during the economic crisis between 2007 and 2013 these figures dropped drastically as people could not afford to eat out more than often anymore. Consequently, ready-made meals came as an affordable alternative to try new dishes from different cuisines at a much more affordable cost (Key Note 2013). However, another study found that, while convenience and saving time is important, for some consumers factors such as food freshness and enjoyment in the meal preparation are also important and drive decisions against ready-made meal consumption (Buckley et al., 2007).

Another important driver is the changes in the family composition and structure, particularly such as the increasing number of single-person households (around 20% of the British population), the growing number of women working and the larger proportion of senior citizens in the population (Michael Freedman 2007; Millstone and Lang 2008). Surveys show that people who are eating ready-made meals, in particular frozen, more than twice or three times a week are usually not working because they are retired, with illness or/and with disabilities. In these cases, the meals are usually provided by the healthcare system (Worldpanel 2011).

Therefore, as discussed above, a range of sustainability issues affect the production and consumption of ready-made meals. This study attempts to analyse and quantify some of these with the aim of evaluating the sustainability in the UK ready-made meal sector. For these purposes, the environmental, economic and social assessment has been carried out taking a life cycle approach as described in following section.

2 Methodology

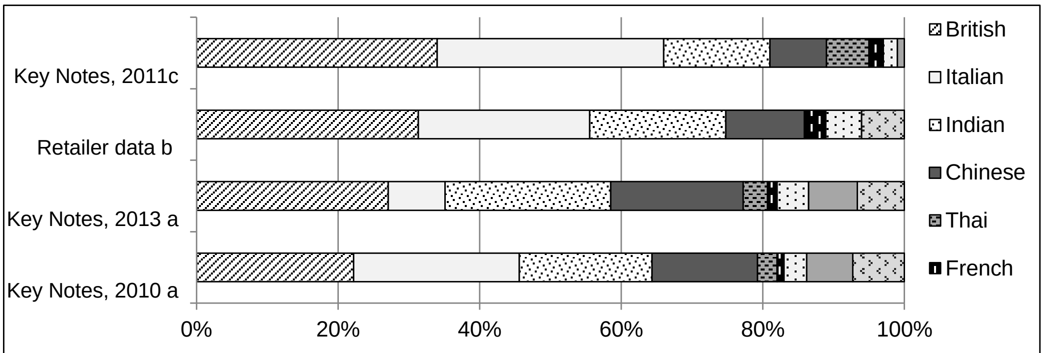
The sustainability assessment integrates the environmental, economic and social aspects relevant to the ready-made meals sector. Life cycle environmental assessment (LCA) and life cycle costing (LCC) have been used to quantify the environmental impacts and costs in the sector. The LCA study follows the methodology in the ISO Standards 14040/44 (ISO 2006a;ISO 2006b) and LCC follows the approach proposed by Hunkeler et al. (2008) and Swarr et al. (2011). The social sustainability assessment uses a range of social indicators (following the approach developed by the UNEP/SETAC (Andrews et al. 2009;Benoît et al. 2010;Benoît-Norris et al. 2011).

2.1 Goal and scope

The goal of the study is to assess the sustainability in the UK ready-made meal sector on a life cycle basis. For these purposes, thirteen most popular meals in the UK representing more than 80% of the market sales by value are considered across different cuisines (Figure 42 and Figure 43). For each cuisine two representative[8] recipes have been chosen for consideration, except for the British cuisine where seven types of meal are considered as they occupy the majority of the market (see Figure 42).

To estimate the environmental impacts and economic costs, first LCA and LCC have been carried out for these meals for both chilled and frozen options (as detailed in X. C. Schmidt Rivera and Azapagic (2014b);X. C. Schmidt Rivera and Azapagic (2014a)). Then, each impact has been averaged for each cuisine weighted for the contribution of each cuisine to the market, based on data in Figure 43. The results have then been extrapolated to the ready-made meals sector taking into account the annual production of chilled and frozen meals. For instance, chilled options dominate the market with around two thirds (68%) of the market sales (Key Note 2013). The frozen meals production by the end of 2013 was 182 kt (BFFD 2014).

For the social sustainability assessment, social indicators are used to assess the social sustainability at the sectoral level.



[a] Data based on consumer's preferences surveys; It does not complete 100%
[b] Confidential data from retailer based on annual sales, 2010. The retailer classified "others" as "other European"
[c] Chilled ready-made meals share market by retail sale prices (rsp) in 2010

Figure 42 The most consumed meals for the most popular cuisines based on consumer preferences surveys and sales

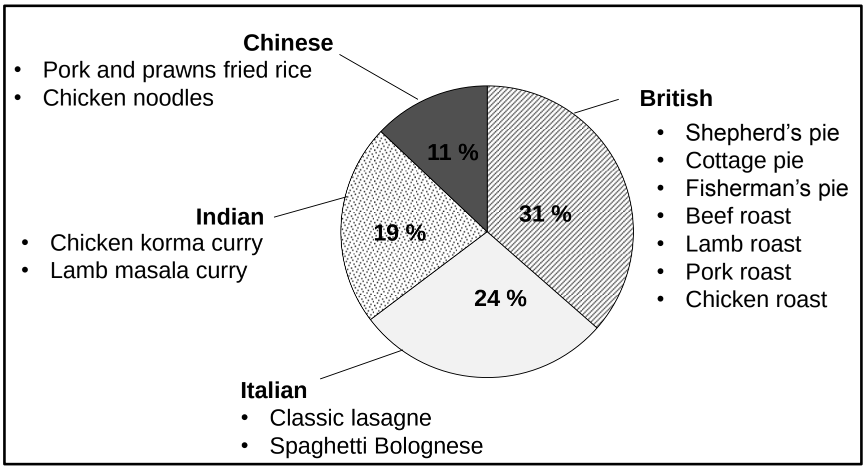


Figure 43 Cuisine market share and selected ready-made meals recipes per cuisine [Retailer confidential information, 2013]

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[8] The recipe selection was made through a screening in different supermarkets websites. The criteria were that the meals should be presented in almost all supermarkets, both chilled and frozen if possible.

As indicated in Figure 44, the *scope* of the study is from ‘cradle to grave’, considering the cultivation and production of raw materials, their processing, their manufacture, distribution and consumption of the meals.

The functional unit is defined as the total amount of each type of meal produced in 2013, i.e. 182 kt for the frozen meals 386.8 kt for the chilled meals[9]. A summary of the life cycle of the meals is provided in the next section; for details, see X. C. Schmidt Rivera and Azapagic (2014b);X. C. Schmidt Rivera and Azapagic (2014a).

2.2 System definition

Figure 44 shows the system boundaries of the ready-made meals considered in the study. As mentioned, the ready-made meal sector is divided in chilled and frozen ready-made meals. Based on statistics and confidential information, the study considers fours cuisines: British, Italian, Chinese and Indian. In the case of the former, seven recipes are considered: cottage, shepherd’s and fisherman’s pie, and four roast dinners (beef, lamb, pork and chicken). In the case of the Italian, the meals are classic lasagne and spaghetti Bolognese. The Chinese cuisine includes the pork & prawns fried rice and chicken noodles. Finally, the Indian cuisine considers two curries: chicken korma and lamb masala.

The system considers the production of the raw materials and packaging, the pre-processing of them and the production of the ready-made meal. The distribution stage is also included as well as the consumption of the meal and the final disposal of it. Detailed description of the system is presented in X. C. Schmidt Rivera and Azapagic (2014b) and X. C. Schmidt Rivera and Azapagic (2014a).

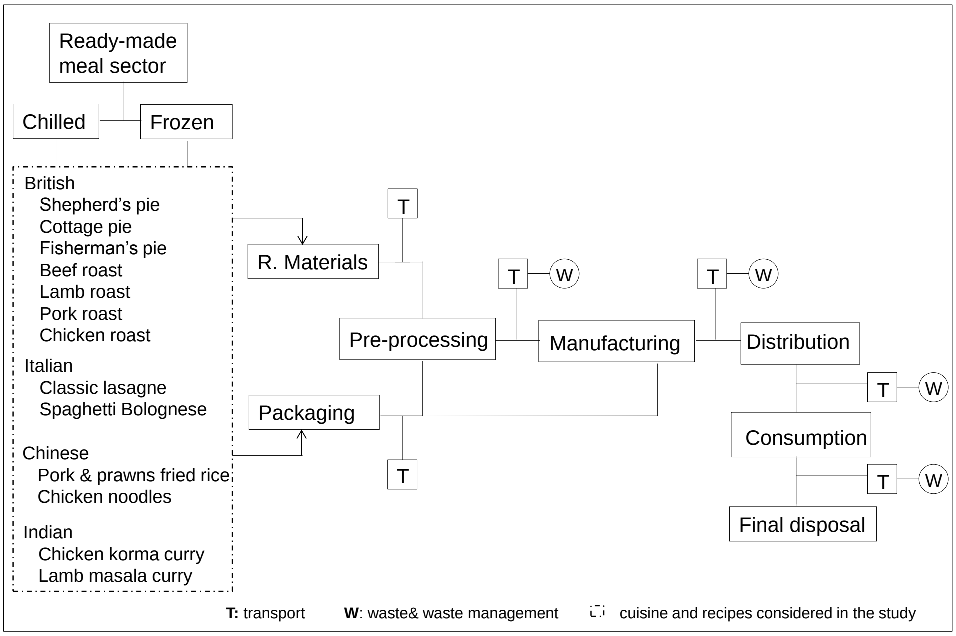

Figure 44 System boundaries for the sustainability assessment in the ready-made meal sector

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[9] The volume of the frozen ready-made meal is based on BFFF 2013; due to lack of information of the chilled ready-made meal volume, it was assumed the market share, which is 32% for the frozen chilled market and 68%. Therefore, if the 32% of the market is assumed to be 182 kt, the 68% is 386.8 kt. Source: BFFF. (2014a). *Retail statistics December 2013* [Online]. Available: http://bfff.co.uk/wp-content/uploads/2014/07/Retail-Stats-Dec-2013.pdf [Accessed March 10th 2015].

2.3 Calculation of life cycle costs

The life cycle costing (LCC) assessment of the ready-made meals is based on the calculation of the costs of each life cycle stage; therefore the cost of the raw materials, the pre-processing, manufacturing, packaging, distribution, and consumption and final disposal stages (See Figure 45). Summarising, the LCC is estimated as follows:

$$\boldsymbol{LCC = C_{RM} + C_{PP} + C_{M} + C_{P} + C_{D} + C_{C} + C_{W}} \qquad \textbf{(1)}$$

where:

LCC	total life cycle cost of the ready-meal
C_{RM}	costs of the raw material (meal ingredients)
C_{PP}	costs of the pre-processing of raw materials
C_{M}	costs of meal manufacturing
C_{P}	costs of packaging of raw materials and ready-made meal
C_{D}	costs of the distribution of the ready- meal
C_{C}	costs of the meal consumption (meal preparation)
C_{W}	costs of the disposal of waste from the meal

The details of the data and the costs for each stage are presented below.

Moreover, the study analyses the value added (VA) of the ready-made meal sector. Below, the summary of the calculation is presented.

$$\boldsymbol{VA = RP - LCC_{Cradle\ to\ distribution}} \qquad \textbf{(2)}$$

where:

VA	value added from 'cradle to distribution'
RP	retail price of the ready-made meals
$LCC_{\text{Cradle to distribution}}$	life cycle cost from 'cradle to distribution'

Details of the calculations are shown in X. C. Schmidt Rivera and Azapagic (2014a).

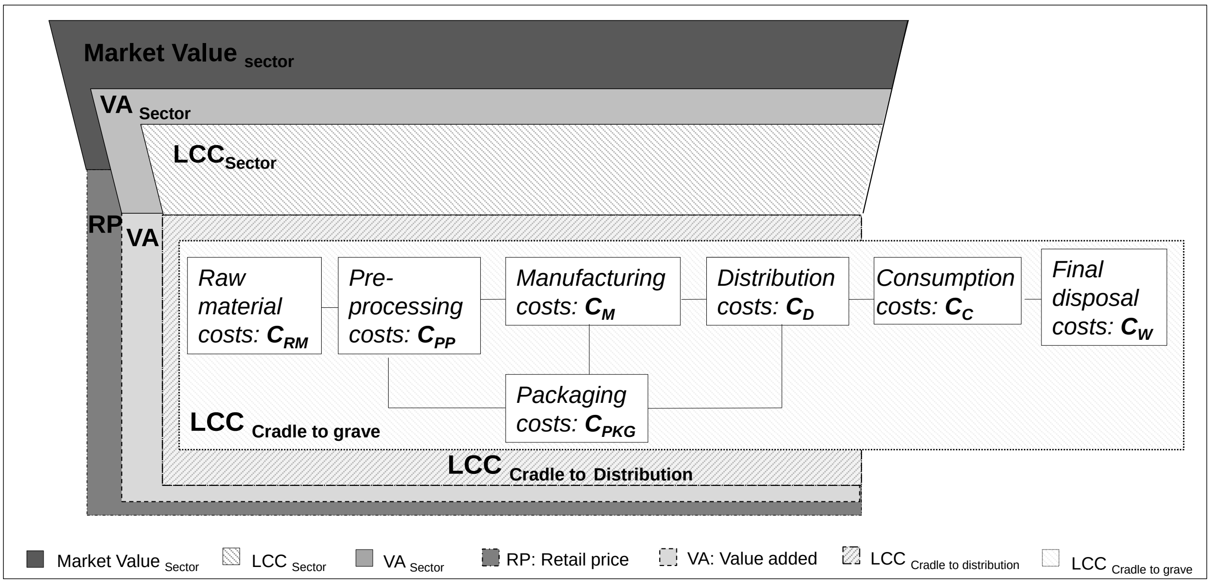

Figure 45 Life cycle stages considered in the calculation of the total life cycle costs of the sector and the value added

2.4 Social indicators

As mentioned earlier, the social analysis is based on the guidelines described by Andrews et al. (2009), Benoît-Norris et al. (2011), Benoît et al. (2010), UNEP/SETAC (2009). These authors propose several social indicators, which in this study are selected based on the relevance within the country and sector as well as the data availability. Due to the study uses as much as possible British ingredients, the assessment of the country of origin was not considered, however, the assessment within the supply chain is done instead. Table 48 summarises the indicators selected for the social analysis of the ready-made meal sector and the British food sector. These indicators complement the social issues discussed before, therefore there are some quantitative and qualitative indicators.

Table 48 Summary of social indicators

Categories and Indicator	**Definition** [a]	**Criteria** [b]
Employees:		
Employment	Description of the employment characteristics of the sector as well as the contribution to the UK economy.	N/A
Freedom of association	Every worker has the right to join and belong to the organization that they like without being discriminated and/or obliged; to be able to defend and promote their rights, negotiate salaries and benefits, among others.	▪ Low risk <1.5 ▪ Medium risk <2.5 ▪ High risk <3.5 ▪ Very high risk >3.5 (the laws are not enforced)
Collective bargaining	Every worker has the right to be part of an organization and together be able to negotiate their salaries, complementing benefits, etc.	▪ Low risk <1.5 ▪ Medium risk <2.5 ▪ High risk <3.5 ▪ Very high risk >3.5 (the laws are not enforced)
Child labour	The work that deprives children of their childhood, their potential and their dignity, and it is harmful for their physical and mental development.	▪ Low <4% ▪ Medium >4-10% ▪ High >10-20% ▪ Very high >20%
Wages	The salary received for a working period, which should meet at least the minimum wage established by law, collective bargaining or industrial standard.	▪ Low <2% ▪ Medium 2-10% ▪ High 10-50% ▪ Very high >50%
Fair salary	The measure of the wages and the baseline based on the activity and/or the sector. There are three aspects that this indicator considers: • Minimum wage required by law, which is based on the country; • Local prevailing industry wage, in this case it could be exactly the same as the minimum wage or different, it is dependent on the sector and the country;	▪ Low <2%; ▪ Medium 2-10%; ▪ High 10-50%; and ▪ Very high >50%.

	• Living wage also known as “non-poverty wage” or “floor wage”; this standard is generally higher than the minimum wage and it is developed for different organizations with the aim of establishing a wage that allows to fulfil the basics human needs as food, water, shelter, clothing, health care, education and transport and incomes for other activities.	
Working hours	Number of hours a week that an employee works in a country and in a specific industry. There are international minimum standards as working maximum 48 hours a week and at least rest one day during 7 days of work. In the UK, overtime is allowed only if it is voluntary and not exceeds 12 hours per week, it is not required in a regular basic and it is paid at least as a minimum rate.	▪ Low <10% ▪ Medium 10-25% ▪ High (25-50% ▪ Very high (>50%)
Forced labour	This indicator refers to the right of the workers to do an activity without their own will; being forced due to possible penalties or even threatens. Although these jobs can be paid, the facts that are not voluntary make them be considered labour forced.	▪ Unknown: no data found. ▪ Low: minimal evidence from available sources. ▪ Medium: forced labour is indicated in one of the main sources. ▪ High: forced labour is indicated in two or more of the main sources.
Equal opportunities/discrimination	Based on several international standards, in particular those defined by the International commitment of human rights. The right to be treated as equal without being discriminated due to physical characteristics, background, ages, gender, and so on.	▪ Low <1.3 ▪ Medium 1.3 – 2.3 ▪ High 2.3 – 3.3 ▪ Very high >3.3
Health and safety	This indicator refers to the health of the workers in the working places. In this case, the indicator is measure in terms of the number of injuries presented by the industry/sector.	▪ Low <4% ▪ Medium >4-10% ▪ High >10-20% ▪ Very high >20%
Local community and consumers		
Community and consumer engagement	Description of the issues and examples how the industry and sector is approaching them	N/A

Consumers health	Description of the health issues associated to the sector	N/A

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[a] Definitions from social assessment guidelines proposed by Benoît-Norris et al. (2011);Andrews et al. (2009);Fontes (2014) and adapted from United Nations, ILO and several NGO.

[b] Criteria are proposed by SHDB (2010)

2.5 Inventory data

This section presents the data and assumptions used in different life cycle stage.

2.5.1 Raw materials

The raw material stage considers the agriculture and farming operations required for growing the vegetables and animals. Figure 44 presents the system boundaries and the recipes considered for each cuisine; complementary, the inventories of the cost and the environmental data for the ingredients are presented Table 49. The detailed description of the stage and the data can be found in X. C. Schmidt Rivera and Azapagic (2014b) and in X. C. Schmidt Rivera and Azapagic (2014a).

Table 49 Summary of the LCC and LCA data of the ingredients of each recipe

Ingredients [a] [g]	**Cottage pie**	**Shepherd's pie**	**Fisherman's pie**	**Beef roast**	**Lamb roast**	**Pork roast**	**Chicken roast**	**Classic lasagne**	**Spaghetti Bolognese**	**Chicken Korma curry**	**Lamb Masala curry**	**P&P Fried rice**	**Chicken noodles**	**Costs [£/kg]**	**LCC data**	**LCA data**
Rice	-	-	-	-	-	-	-	-	-	134	134	196.8	-	0.26	IndexMundi (2012)	Ecoinve (2009)
Pasta/noodles	-	-	-	-	-	-	-	47	119	-	-	-	111.6	0.2	calculated	Bevilac et al. (2
Beef	58	-	-	41	41	41	-	72	58	-	-	-	-	1.83	UK Government and Defra (2013)	Williams al. (200
Lamb	-	58	-	-	-	-	-	-	-	-	74	-	-	2.59	UK Government and Defra (2013)	Williams Audsley al. (200
Pork	-	-	-	-	-	-	-	-	-	-	-	57.6	-	1.22	UK Government and Defra (2013)	Williams Audsley al. (200
Chicken	-	-	-	-	-	-	75.6	-	-	74	-	-	65.9	0.87	UK Government and Defra (2013)	Williams Audsley al. (200
Fish	-	-	59	-	-	-	-	-	-	-	-	-	-	4.65	IndexMundi (2012)	Vázque Rowe e (2010)
Prawns	-	-	18	-	-	-	-	-	-	-	-	9	-		IndexMundi (2012)	Nielsen et al. (2
Potatoes	167	167	153	93.6	93.6	93.6	93.6	-	-	-	-	-	-		UK Government and Defra (2013)	Williams Audsley al. (200
Carrots	-	6	-	44.3	44.3	44.3	44.3	14	19	-	-	-	45		UK Government and Defra (2013)	Nielsen et al. (2
Peas	-	11	17	43.2	43.2	43.2	43.2	-	-	-	-	25.6	-	1.05	UK Government and Defra (2013)	Canals al. (200
Onions	59	15	-	-	-	-	13.2	23	49	113	35	18.9	45	0.43	UK Government and Defra (2013)	Nielsen et al. (2
Tomatoes	-	15	-	-	-	-	-	94	76	-	87	-	-	0.44	FAO (2008)	Williams Audsley al. (200 (Antón

																2005)
Tomato paste	3	-	-	-	-	-	-	-	-	-	3	-	-	3.04	Calculated	EC (200 FAO (2
Cream	-	-	-	-	-	-	-		-	20	9	-	-	8.49	Calculated	Nielsen et al. (2
Flour	1	-	4	10.9	10.9	10.9	4	9	-	2	-	-	-	0.31	Calculated	Nielsen et al. (2
Sugar	-	-	-	-	-	-	-		-	7	-	-	-	0.41	IndexMundi (2012)	Ecoinve (2009)
Wine	15	-	-	-	-	-	-		27	-	-	-	-	2.02	IndexMundi (2012)	Amieny (2012)
Beef stock (water)	39	73	-	106	106	106	75.6		-	-	-	-	-	1.59 x10^{-3}	Utilities (2014)	Ecoinve (2009),
Milk	7	7	94	12.9	12.9	12.9	-	88	-			-	-	0.34	Government and Defra (2013)	William Audsley al. (200
Butter	5	5	14	-	-	-	-	9	-			-	-	19.87	Calculated	Nielsen et al. (2
Bread	-	-	-	-	-	-	5.2	-	-	-	-	-	-	4.01	UK Government and Defra (2013)	Nielsen et al. (2
Eggs	-	-	-	7.1	7.1	7.1	3.4	-	-	-	-	20.4	-	0.92	UK Government and Defra (2013)	William Audsley al. (200
Soy sauce [a]	-	-	-	-	-	-	-	-	-	-	-	12.8	92.5	9.3x10-2	IndexMundi (2012);UK Government and Defra (2013)	Ecoinve (2009
Oil (vegetable/olive)	5	2	-	-	-	-	0.9	3	11	8	17	18.9	-	0.67/2.17	IndexMundi (2012); FaoStat (2009)	Ecoinve (2009), mone a Ioppolo (2012)
Salt	1	1	1	1	1	1	1	1	1	2	1	-	-	5.33x10^{-2}	IndexMundi (2012)	Ecoinve (2009)
Total	360	360	360	360	360	360	360	360	360	360	360	360	360			

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[a] Component of soy sauce, adapted from Forte (2014)

2.5.2 Pre-processing and manufacturing

This section shows the inventory of the utilities and resources included in the pre-processing and manufacturing stages (see Figure 3). Table 3 shows the inventory of the cost and the utilities requires in each stage for processing ingredients and for producing ready-made meals. For detailed information of the stages see X. C. Schmidt Rivera and Azapagic (2014b) and X. C. Schmidt Rivera and Azapagic (2014a).

Table 50 Summary of the LCA and LCC data of the utilities of pre-processing and manufacturing stages

Utilities per meal	**Pre-Processing** [a,b]	**Manufacturing** [c,d]	**Costs (£/unit)**	**LCC references**
Electricity (Wh)	5.88	326	9.70×10^{-5}	DECC (2014)
Fuel oil (l)	-	3.97×10^{-2}	0.53	DECC (2014)
Water (l)	1.13	4.29	1.59×10^{-3}	United Utilities (2014)
Steam (Wh)	0.3	-	3.41×10^{-5}	Spirax Sarco Limited (2014)
Refrigerant charge (mg)[e]:				
Ammonia	180.5	-	3.35×10^{-4}	(Technicold Service Inc. 2003)
Refrigerant leakage (mg) [e]:				
Ammonia [b]	27.1	-	-	-
R22	-	11.4	-	-
Storage time (h)	12	12	-	-
Waste [b,d,f] (%)	15	16.65	9.3×10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)

[a] Data source: European Commission (2006) and Defra and Brunel University (2008).

[b] Detail data for the sub-stages in the pre-processing stage are available in (X. C. Schmidt Rivera and Azapagic 2014b)and (X. C. Schmidt Rivera and Azapagic 2014a)

[c] Data source: meal manufacturer

[d] Detail data for every meal is presented in X. C. Schmidt Rivera and Azapagic 2014b

[e] Assuming walk-in chillers/freezers in RDC_m, refrigerant leakage rate is 15%: Defra and Brunel University (2008).

[f] Data source: Canals et al. (2008) and BIS (2011)

2.5.3 Distribution

The distribution stage is divided in two sub-stages: RDC_p or regional distribution centre (for products) and retail. Table 51 details the inventory of the costs and the considerations of the stage. Detailed description of the stage, assumptions and data can be found in X. C. Schmidt Rivera and Azapagic (2014b) and in X. C. Schmidt Rivera and Azapagic (2014a).

Table 51 Summary of the LCA and LCC data of the distribution stage per ready-made meal

Utilities per meal	**RDCp**[a]		**Retail**[b]		**Costs (£/unit)**	**LCC references**
	Chilled	**Frozen**	**Chilled**	**Frozen**		
Electricity (Wh)	4.63x10^{-2}	0.61	52.85	136.8	9.70x10^{-5}	DECC (2014)
Refrigerant charge (mg):						
R134a	-		150.7	47.76	12.80	Stoody Industrial & Welding Supply Inc. (2006)
Ammonia	180.8	314.5	-	-	0.34	Technicold Service Inc. (2003)
Refrigerant leakage (mg):						
R134a	-	-	22.6	7.16		
Ammonia	27.1	47.2	-	-		
Storage time (h)	12	158	48	120		
Waste (%)	2	1	2	1	9.3x10^{-2} [c]	Eunomia Reaserach & Consulting Ltd 2013

[a] Data source: Defra and Brunel University (2008)

[b] Medium-size supermarket (floor area 1400 m2); includes consumption of energy for chilled and frozen storage, lighting and heating, ventilation and air conditioning. Data source: Defra and Brunel University (2008)

[c] Values per kg. of waste

2.5.4 Consumption

The consumption stage considers the meal transportation to consumer's home, storage and warm up of the meal, and water for washing up. The inventory of the utilities used and the cost are presented in Table 52. Detailed description of the stage and assumptions are available in X. C. Schmidt Rivera and Azapagic (2014b) and in X. C. Schmidt Rivera and Azapagic (2014a).

Table 52 Summary of the data used in the consumption stage per ready-made meal [a]

		Chilled			**Frozen**			
Utilities [a]	**Storage** [b]	**Warm-up** [c]	**Wash-up** [d]	**Storage**	**Warm-up**[c]	**Wash-up**[d]	**Costs [£/unit]**	**LCC references**
Electricity (Wh)	2	78.6	-	18	391.5	-	9.70 x 10^{-5}	DECC (2014)
Water (l)	-	-	1	-	-	1	1.59 x10^{-3}	Utilities (2014)

[a] Data per ready-made meal of 360 g.

[b] Estimated based on Nielsen PH et al. (2003), assuming the volume of the product of 750 cm3 and half empty fridge or freezer.

[c] Time based on manufacturer instructions and estimated based on average electricity consumption by microwaves of 0.0435 MJ/min (Jungbluth 1997).

[d] Assumptions based on Defra (2008)

2.5.5 Final disposal

The final disposal stage considers the meal leftover, meal packaging and the plastic bag. In Table 6 the cost and data of the waste and waste management details are presented. Moreover, in X. C. Schmidt Rivera and Azapagic (2014b) and in X. C. Schmidt Rivera and Azapagic (2014a), detailed descriptions of the assumptions and data can be found.

Table 53 Summary of the LCA and LCC data of the final disposal stage

Waste	Waste management	Quantity [g]	Costs [£/unit]	LCC references	LCA references
Food (ready-made left over)	landfill	8.64 x10^{-2}	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)	Ecoinvent (2009)
Cardboard packaging	landfill	1.50x10^{-2}	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)	Ecoinvent (2009)
Plastic packaging	landfill	4.5x10^{-2}	9.3x10^{-2}	Eunomia Reaserach & Consulting Ltd (2013)	Ecoinvent (2009)

3 Results and Discussion

3.1 Environmental Impacts

The environmental analysis of the sector is divided in two sections. First, the results for the chilled and frozen ready-made meals markets are discussed (sections 3.1.1 and 3.1.2) followed by impacts in the sector (section 3.1.3).

In order to estimate the impacts of each market (chilled and frozen), the market share is considered as follows: 68% for chilled meals and 32% for frozen meals (Key Note 2013); the volume sales for the frozen ready-made meal market is equal to 182 kt/yr. Volume sales data for the chilled ready-made meal sector were not available so that its market share of 68% was used to calculate the annual production volume of 386.8 kt.

For the contribution of different cuisines to the total market, the information obtained from a major UK retailer was used to obtain the values in Table 54.

Table 54 Summary of the cuisine share and volume sales by 2013 of the chilled and frozen ready-made meal market

	British	Italian	Indian	Chinese	Total
Distribution [a]	31%	24%	19%	11%	85%
Chilled share (kt) [b]	119.8	92.7	73.4	42.5	328.5
Frozen share (kt) [b]	56.4	43.6	34.6	20	154.6

[a] Share corresponds to 85% of the ready-made meal market and it is based on confidential retailer information
[b] Volume calculated based on the market share and on the cuisine share

3.1.1 Impacts in the chilled ready-made meals market

The environmental impacts in the chilled ready-made meal market and the contribution of each cuisine to the impacts are displayed in Figure 46. For example, the GWP is estimated at 3.49 Mt CO_2 eq. per year. The main contributors are the British and Italian cuisines with the equal share of 34%, emitting 1.19 Mt CO_2 eq. annually. The Indian cuisine adds 797 kt CO_2 eq. a year (23%) and the Chinese cuisine around 320 kt CO_2 eq. a year representing a contribution of 9%. This is due to the raw material stage which is the major contributor, and in particular for the recipes that contain meat and dairy products; therefore, the cuisines/recipes with higher content of those ingredients have a higher GWP. Similar trend is found for ADP $_{elements}$, with the British and Italian meals contributing 67% (33% and 34% respectively), Indian 23% and Chinese 10%. The total ADP $_{element}$ is 4,418 t Sb eq.

In the case of ADP $_{fossil}$, the chilled ready-made meal sector contributes 15,259 TJ; this impact also follows the previous impacts trend: the main contributor is the British cuisine with 34%, followed by the Italian with 31% and the Indian with 22%. The Chinese contributes with 14%.

This impact is influenced by energy and fuel consumption, therefore the cuisines/recipes which require more processing present higher impacts. It is important to note that in the case of these impacts, the differences between the recipes is not too high due to the stages with the highest contribution are the same or very similar for all recipes (manufacturing, distribution and consumption); however the contribution of the British and Italian cuisine is higher than the Indian and the Chinese.

In terms of cuisine contribution, FAETP, MAETP and ODP present the same distribution. In the three impacts, British cuisine is the main contributor with 37% and the Italian contributes around 26%. The Indian and Chinese contribute 23% and 13%, respectively. These three impacts contribute 455 kt DCB eq., 508 Mt DCB eq., and 15.2 t R11 eq. annually. Similar to the last impact, the variation between the absolute values within cuisine's impacts are not too great, but the share distribution escalates the differences.

The contribution to the chilled sector by HTP and TETP are 4,892 and 80.5 kt DCB eq., respectively. For these impacts the highest contributor by far is the British cuisine, with 73% and 56%; the Italian cuisine has a similar contribution in both cuisines with 25 and 20%, while the Indian and Chinese vary from 1% each in the case of HTP to 16% and 8%, respectively, in the case of TETP. In this case, the main reason for the negative performance of the British cuisine is due to fisherman's pie, which has the greatest HTP and TETP, around 30 times greater in the case of the former and around 100 times for the latest, relative to the average throughout the other recipes/cuisines.

In terms of cuisine share, a different trend is found in AP, EP and POCP. In these impacts the main contributor is the Italian cuisine with around 38%; the second largest contributor is the British cuisine with 31%. The Indian and Chinese cuisines have the lowest contributions with around 22% and 9%, respectively. The AP and EP of the chilled ready-made meals market is 56.1 kt SO_2 eq. and 25 kt PO_4 eq. per year. Finally, POCP presents 2.8 kt C_2H_4 eq. per year. In this case the influence of the raw materials in much greater than in the case of the GWP, over 90%, therefore even though the market share, the Italian cuisine present the highest contribution.

3.1.2 Impacts in the frozen ready-made meals market

As expected, the contribution of the cuisines is similar to the one found in the chilled ready-made meal. This is due to the fact that the same cuisine share was used for both markets. However, the impacts are different and there are, even though small, some variations.

As seen in Figure 46, the GWP of the frozen ready-made meal market accounts for 1,450 kt CO_2 eq. per year. The largest contributors are the British and Italian cuisines with 34% and 35%, respectively. The Indian is the third largest contributor with 23% and Chinese contributes only with 9%.

Similar trend is found in ADP $_{elements}$, were the main contributors are the British and Italian cuisines with 33% and 34%. The Indian and Chinese cuisines present similar shares as in the previous impact (23% and 10% respectively). The ADP $_{element}$ of the frozen RM market is 2,037 t Sb eq.

ADP $_{fossil}$ is 7,527 TJ, and the shares are as followed: 34% for the British cuisine, 30% for the Italian, 22% for the Indian and 14% for the Chinese.

A different trend is found in AP and EP where the main contributor is the Italian cuisine with around 38%. However, the British cuisine also has a considerable contribution with 31%. The Indian and Chinese shares are 22% and 9% respectively. Overall, the AP of the frozen ready-made meal market is 25.9 kt SO_2 eq. annually while the EP is 11.7 kt PO_4 eq. a year. Moreover, POCP is 1,289 t C_2H_4 eq. per year, and the cuisine contribution is similar as AP and EP: the Italian and British cuisines contribute with 37% and 31% while the Indian and Chinese with 21% and 11%.

FAETP, MAETP and ODP present 205.4 kt DCB eq. per year, 249.8 Mt DCB eq. per year, and 635.3 kg R11 eq. per year, respectively. Although the values are different for these three impacts, the contribution of the cuisines is the same overall; the British cuisine contributes with 37%, while the Italian and Indian contribute with around 27% and 23%. Finally, the Chinese cuisine adds the rest, 13%.

The HTP and TETP for the frozen ready-made meal market are 2.26 and 37.2 kt DCB eq. per year, respectively. The main contributor for both impacts is the English cuisine with 73% and 56% respectively. The Italian cuisine contributes with 25% and 20% for each impact. Finally, the Indian and Chinese cuisines present similar contribution for each impact: both contribute with 1% for the HTP, 16% and 8% for the TETP.

As can be seen, due to the assumption the cuisine share is same with the frozen ready-made meal market, the contribution of the cuisine is almost exactly the same as the chilled ready-made meal market.

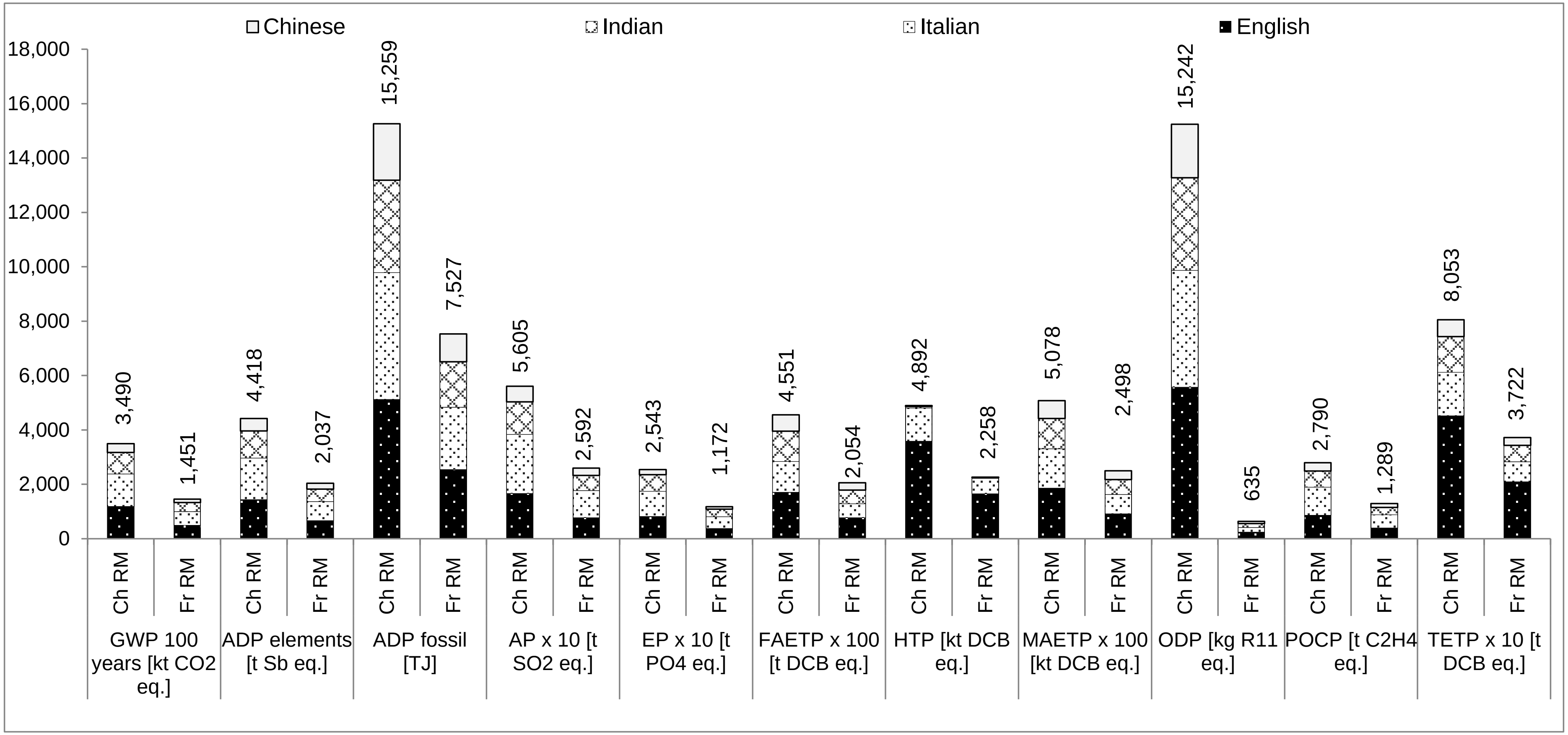

Figure 46 Environmental impacts and cuisine contribution of the chilled and frozen ready-made meal markets.

3.1.3 Environmental impacts in the ready-made meal market

This section discusses the total environmental impacts in the ready-made meal sector, based on the results presented in the previous two sections. Due to increasing focus on climate change, the study also analyses the contribution of this market to the GHG emissions from the UK food and drink sector (FDS) as well as total UK emissions.

Figure 47 presents the environmental impacts in the UK ready-made meal sector. As can be seen the GWP is estimated at 4.94 Mt CO_2 eq. per year, and the contribution of the chilled and frozen markets is 71% and 29%, respectively.

Similar to the GWP, only four other impacts show, even though small, a different pattern in terms to their contribution to the impacts, compared to the market share. For instance, ADP $_{fossil}$ is 22,786 TJ per year and MAETP is 757.6 Mt DCB eq. per year with both having the same contribution from the chilled (67%) and frozen (33%) markets. Moreover, FAETP is 661 Mt DCB eq. per year and the share of the markets is 69% for the chilled and 31% for the frozen. The largest difference in the contribution is found in ODP, where the chilled ready-made meal market is almost the only contributor with 96%; this impact is 15.9 kt R11 eq. a year and this is due to the higher contribution of the refrigerant used in chilled options; the chilled options use R314a while the frozen uses ammonia.

Finally, the following impacts present the same contribution as the market share (68% for the chilled and 32% for the frozen market): ADP $_{element}$ with 6.5 kt Sb eq. per year, AP and EP with 8.2 kt SO_2 eq. and 3.7 kt PO_4 eq. per year. HTP and TETP are 7.15 and 118 Mt DCB eq. per year, respectively. Finally POCP is 4.08 kt C_2H_4 eq. per year.

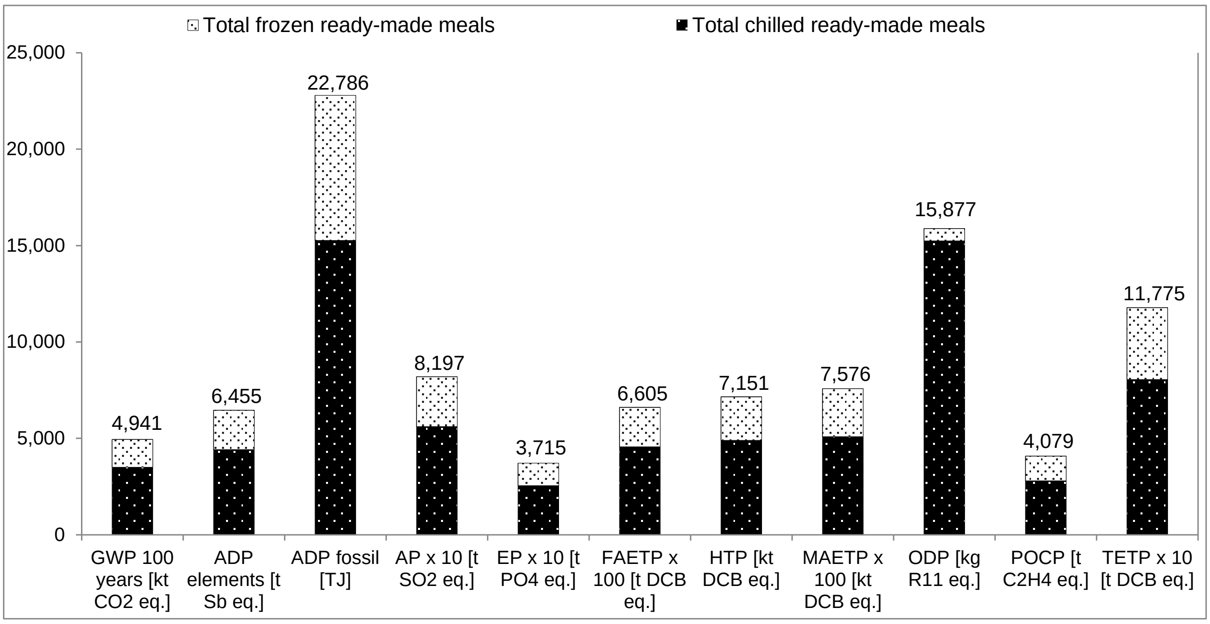

Figure 47 Environmental impacts and market contribution of the UK ready-made meal market

In order to assess the contribution of the ready-made meal sector to the FDS and the national GHG emissions, the scope of study has to change from ‘cradle to grave’ to ‘cradle to retailer’, excluding the consumption and final disposal stages due to those stages are not considered at the sector level. For instance, the FDS accounts for the agriculture, the processing and manufacturing of goods and the distribution and storage of them. As can be seen in Figure 48 the variation between the life cycle assessments considering ‘cradle to grave’ and ‘cradle to retail’ depends on the impacts.

For instance, the highest variations are found in the FAETP and MAETP with 59% and 45%, due to the final disposal stage playing an important role. In the case of the former, the final disposal stage contributes around 50% while in the latest it contributes around 30%. This is due to both impacts, the emissions from the waste management option for food waste and plastic packaging (landfill).

Moreover, ADP $_{\text{fossil}}$ decreases by 23%; due to the consumption stage contributes overall by 19% mainly for the energy used by the home's appliances. Other important variations are found in the GWP and POCP with reductions of 10% due to the consumption and final disposal stages contribute between 8% and 1% because of the emission from the electricity consumption and the waste management options. Similar situation is found in EP where the reduction is 7%. Again, the main stage responsible is the final disposal stage which contributes on average 8%.

Small variations lower than 2% are found in AP, TETP and HTP. In the case of the AP these stages contribute with less than 2% while in the case of TETP the consumption stage contributes with 7% and the final disposal stage contributes with 2%. HTP shows a particular behaviour even though these stages contributes with an average of 15% each, the superlative influence of the raw material stages in meals from the British and Italian cuisines, makes than the variations are really small.

Finally, in the case of the ADP $_{\text{elements}}$ and ODP, there are no variations; this is due to two different reasons. The main contributor in the ADP $_{\text{element}}$ is the raw materials, when the consumption and final disposal stages are not considered the impact is not affected. In the case of the ODP, the main contributor is the distribution stage, in particular the retailer. Therefore, as it was mentioned, further variation in the consumption and final disposal stages are not going to affect it.

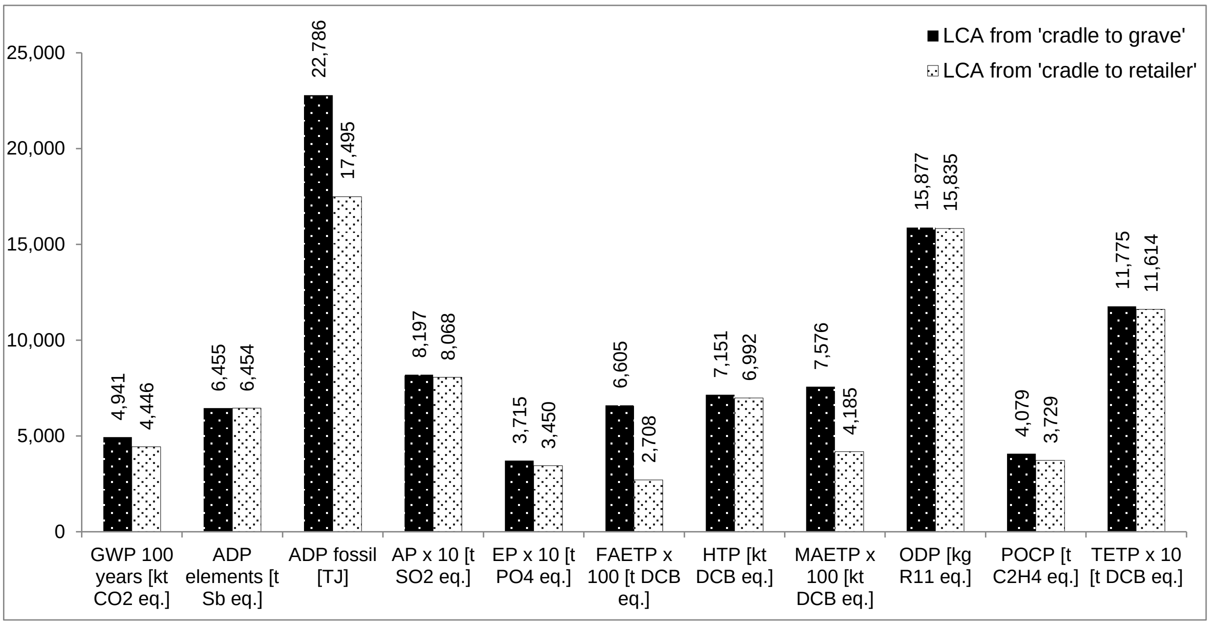

Figure 48 Comparison of the life cycle impacts of the UK ready-made meals sector considering from 'cradle to grave' (full life cycle) and from 'cradle to retail' (from raw materials to distribution).

When the GWP obtained is analysed from a sector and national perspective, the contribution of the ready-made meal market is ~1% (0.78%) of the UK CO_2 eq. emission (568.3 Mt CO_2 eq.(DECC and National Statistics 2015)). Moreover, when the consumption and final disposal stages are not considered, the total GWP is reduced to 4.45 Mt CO_2 eq., corresponding to ~4% of the food and drink sector (FDS) emissions (115 Mt CO_2 eq. (Defra 2013))(imports are not considered). Figure 48 and Figure 49 shows the results.

This result contributes to the environmental targets stated by FDF, which in terms of GHG emissions is the reduction of 35% of the CO_2 emission based on 1990 baseline by 2020. So far the FDF has achieved 27% of the reductions, representing around 1.8 Mt CO_2 eq.

Moreover, the sector has also defined targets related to the reduction of energy and water uses as well as waste generated. Therefore, knowing the contribution of the ready-made meal market, especially the hotspots, will help to set the targets of this specific sector within the FDF and contribute to the national ones.

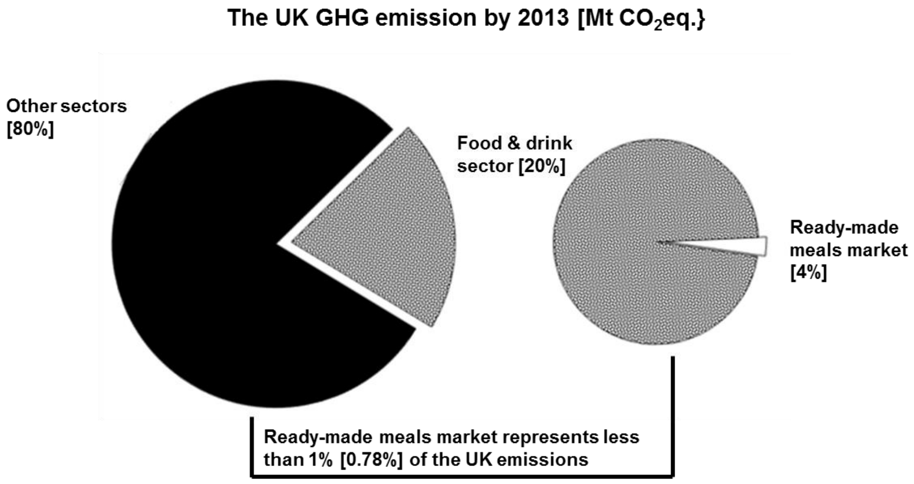

Figure 49 Contribution of the ready-made meal market to the food and drink sector (FDS) and to the UK emissions.

3.2 Life cycle costs of ready-made meals

This section shows the results of the total life cycle cost in the ready-made meal sector for the meals considered in the study. First, the life cycle costs of the chilled and frozen ready-made meal market are analysed, followed by the discussion of the total life cycle cost at the sectoral level. Finally, the value added of the ready-made meals is estimated. Figure 9 summarises the results.

The life cycle costs of the chilled ready-made meal market are estimated at £1,424 million, based on the total production of 328.7 kt (85% of the market) and the average LCC of the meals of £1.52 per meal (X. C. Schmidt Rivera and Azapagic 2014a). The contribution of the costs of the four cuisines is different from the cuisine share distribution considered. For instance, British cuisine contributes 40% or £575.4 million while the Italian cuisine contributes 27%, or £383.5 million. The Indian and Chinese cuisines are responsible for the remaining £465.6 million (21% and 11% respectively). This trend is due to the British and Italian cuisines using more expensive ingredients, such as more meat, fish and in particular processed ingredients (cream, flour, butter, etc.). It is important to notice that the processed ingredients are also calculated on a life cycle basis; therefore the calculated costs are different, higher or lower than the prices based on statistic (see X. C. Schmidt Rivera and Azapagic A. (2014b). for the detailed analysis).

The total life cycle cost of the products in the frozen ready-made meal market is estimated at £676 million. Similar to the chilled market, the major contribution is from the British cuisine with £272 million, representing 40%. The Italian cuisine adds £181 million or 27% to the total. As in the chilled market, the Indian and Chinese represent the 30%, with £222 million. Even though the costs of frozen ready-made meals are slightly higher than the chilled options, the share is smaller so the contribution to the whole market is too.

The total life cycle cost of the two sub-sectors is £2.1 bn; however when the consumption and final disposal are not considered (‘cradle to retail’) the life cycle cost of the ready-made meal market is £1.02 bn. When this value is compared with the real market value, it represents 51%, therefore it can be inferred that the value added of the market represents around £958 million (49%).

In particular, it can be seen that the chilled market value is £ 1.38 bn which is two times the life cycle cost of this market (from 'cradle to retail'). Consequently, the value added of the chilled ready-made meals is around £ 692 million.

Similar to the chilled market, the market value of the frozen market is 1.8 times of calculated value, being £593 million. In this case, the value added is £266 million.

As described in equation 2, the value added is calculated as the differences between the market value based in the retail sales prices and the life cycle cost until the retail or distribution stage ('cradle to retail'). The consumption and disposal stage are not accounted, due to the market value is calculated based on the volume of sales and the retail price of the products.

It is important to highlight that the values calculated represent only the 85% of the total ready-made meals sector.

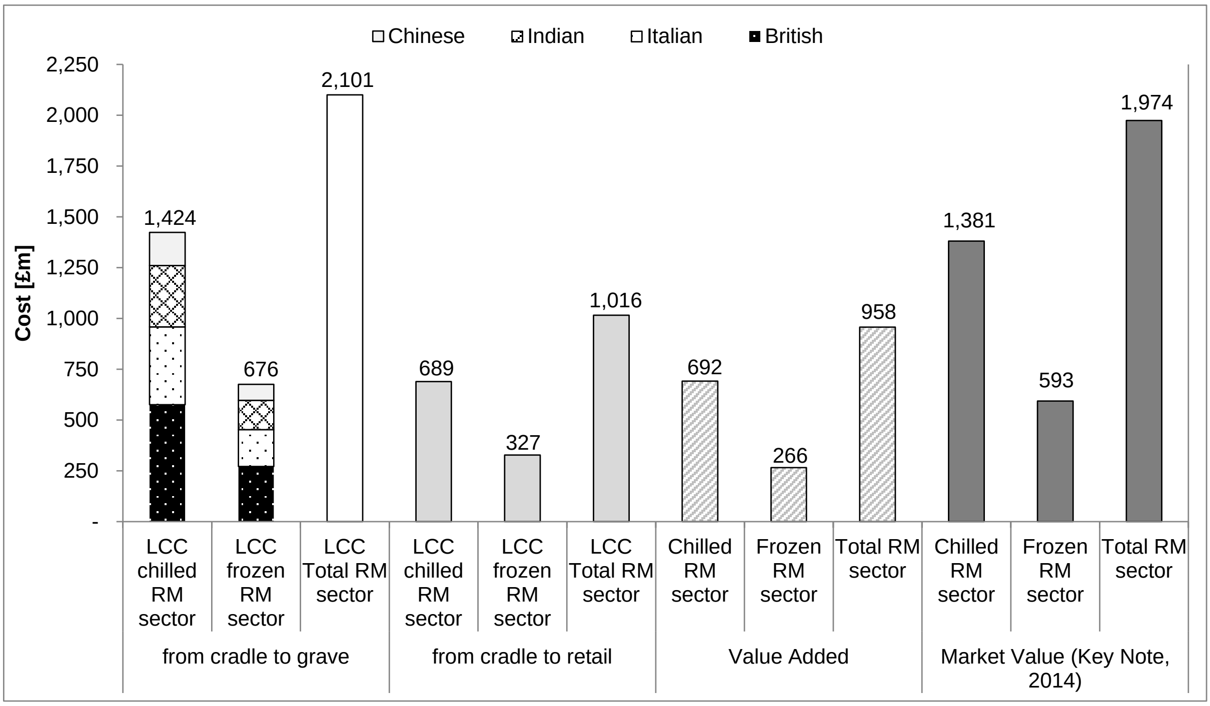

Figure 50 Comparison of the life cycle cost (LCC) of the ready-made meal sector from 'cradle to grave', 'cradle to retail' with the market value

3.3 <u>Social sustainability</u>

This part of the assessment is based on the social sustainability indicators developed in this research, as summarised in Table 48. They are divided into two main categories with respect to the main stakeholders: employees; and local communities and consumers. Where possible, the assessment is based on the ready-made meal sector but where data were not available; the analysis is based on the food and drink sector, manufacturing industry and/or the UK as a country.

3.3.1 Employees

This category presents social indicators related to the work conditions and workers right established by different national and international organizations.

3.3.1.1 Employment

The ready-made meal sector has 80 companies which provide employment to 6,190[10] people (Key Note 2013). This compares to the total manufacturing sectors which employs 362,000 people (Key Note 2013). Around 30% of companies have more than 100 employees but a quarter is small businesses, employing less than five people. Almost 20% of the companies are located in greater London with a similar percentage located in the North of England and a quarter in the South; there are no ready-made meal companies in Scotland (Key Note 2013). Between 2011 and 2012, five new companies with over 250 employees joined the ready-made meal sector (Key Note 2013). There are no latest figure related to new companies joining the market, however there are announcements of new investments in the sector; for instance there is a new investment in a ready-made meal factory in Carlisle that will provide up to 90 new jobs (Glotz 2014). Related to the market growth, there are contradictory expectations about the future. On one hand, the forecast for the following four years is positive despite the contraction experienced in 2013 (‘horsegate’), expecting to increase to £2.34 bn in 2018 (Key Note 2014). On the other hand, several important companies have declared that they are still recovering from the setback in 2013, which also opens options for closing some factories, especially manufacturers of frozen ready-made meals (Key Note 2013).

3.3.1.2 Freedom of Association

The UK and the food and drink sector are ranked as medium risk based on data from the Social hotspot data base (2010) and a study by Amienyo (2012), with an estimated score lower than 2.5. This is also supported by the data from the International human rank indicator (IHRRI) where in the category of “right to freedom of assembly”, “right to freedom of expression” and “right to acceptable job conditions” the UK scores around 70%, which can be interpreted as medium risk (Global Network for Rights and Development 2014). These results are interpreted as the execution of this right within the country and also considering the violation of it (cases registered).

For example, between 1999 and 2008, the number of strikes and lockout has decreased by 30% across all British economic sectors, with 205 in 1999 and 144 in 2008. In the same period, the manufacturing sector saw a reduction of 95%, with only two cases in 2008. From these facts, it can be inferred that either the work conditions have been stable or even improving, or these particular rights have been oppressed but there are no data to support either assertion. By comparison, during the same period, there was an increase of strikes and lockouts in the sectors such as education, real estate and renting businesses, retail and wholesale, but almost no variation in others such as public administration and defence, hotel and restaurants. However, it is important to note that the data refer to the period just before the economic crisis, thus the numbers might have changed.

3.3.1.3 Collective bargaining

Similar to the previous indicator, the UK score for collective bargaining is below 2.5 points (Amienyo 2012;SHDB 2010) on a scale from 0 to over 3.5 (see details in Table 8); therefore, it is considered a medium risk country. For the related aspect “right of acceptable work conditions”, the UK scores 68% confirming the medium risk category (Global Network for Rights and Development 2014).The latest in the overall framework for the internationally recognized worker rights supported by the International Labour Organization (ILO). Therefore, this parameter helps to understand the condition of the workers under the standard set by organizations.

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[10] Estimated figure from Key Note (2013). Market Report Plus 2013: Ready Meals. *In:* Edition, t. (ed.). Teddington, UK: Key Note.

3.3.1.4 Child labour

Based on the SHDB (2010) and a previous study developed by Amienyo (2012), the UK is classified as low risk. However, UN considers the UK as medium risk in particular due to issues of people trafficking and smuggling. However, this is an indicator which is applicable at the national rather than sectoral level and does not necessarily mean that the child labour is specific to the ready-made meals sector.

Nevertheless, worldwide, agriculture has a high rate of child labour with around 59%, following by services with 25% (ILO 2014b;ILO 2013). Therefore, since the agriculture plays a big part in the FDS, the possibilities of finding victims of child labour in the sector are high, particularly for the parts of supply chain outside the UK.

3.3.1.5 Wages

Based on SHDB (2010) and Amienyo (2012), the UK scores as low risk due to the minimum wage is higher than the minimum international standard of $2/day. If now the analysis is done within the industry and based on the countries parameters (minimum wage and average sector wage); it can be seen that the manufacturing sector has an average hourly wage for a full time worker in 2008 was £12.32, around 48% higher than in 1999. In the FDS, the average wage in 2007 was £11.49 per hour, or 2% lower than the average in manufacturing. However, when the minimum wage is compared, in the manufacturing sector was £9.3 per hour and in the FDS £9.7 (University of Cambridge 2010). Therefore, the manufacturing sector and the FDS have salaries above the minimum and, therefore represent a low risk country.

3.3.1.6 Fair salary

The UK is classified as a low risk country with respect to fair salary (Amienyo 2012;SHDB 2010). Additionally, considering the “right to adequate standard of living”, the UK scores 74%, supporting the category of low risk.

Furthermore, the minimum wage in the UK is £6.5 per hour (UK Government 2014b) for workers over 21 years. By contrast, the “living wage” calculated based on the basic costs of living (2014) is £7.65 across the UK and £8.80 in London. Therefore, the minimum wage is around 15% lower than the living wage, which can be catalogued as a high risk (score between 10% and 50%) using the criteria of the previous indicator (see criteria in Table 1). These results support the concern related to food security, especially in the affordability aspects, due to their earning are not enough to meet their basic needs.

Another relevant sub-indicator within the fair salary category is the “poverty line”, in the UK is based on the results of the surveys of household incomes called the Household below average income (HBAI) and it sets the poverty line at 60% of the median UK household income (Child Poverty Action Group 2010); this is also the norm for the EU countries and some other countries (Poverty and Social Exclusion 2014). The poverty line can be calculated considering the housing cost or before housing cost (BHC) or after housing costs (AHC); usually the first option is the commonly use, however it is the least fair. It is also adjusted according to family composition. For instance, in the period 2009/2010, the poverty line for a couple with one child under 14 years was £257/week and for a single parent with a child under 14 years was £167/week (Child Poverty Action Group 2010). Considering the minimum wage of £6.5 per hour, the poverty line is difficult to reach for a single parent with one child if the parent works maximum hours a week (48 hr/week) as the salary would be £312 a week, therefore the poverty line using BHS is £187.2 above the poverty line, but much lower if the AHS criteria is considered (Oxfam 2014c;JRF 2014). However, once the housing expenses are taken into account, the country, and by implication the sector, can be classified as medium-high risk.

3.3.1.7 Working hours

In the UK 48 hours is recognised as the maximum working hours a week (UK Government 2014a). For this indicator, the UK is rated as high risk with people working more than the maximum (Auling 2014;Amienyo 2012;SHDB 2010).

For the FDS, the statistics shows that between 1999 and 2006 the average number of paid hours a week was on average 42, reducing to 41.6 or 2% in 2007. Compared with the manufacturing sector, the average working hours for the FDS was 2% higher, making it the sector with the highest number of hours worked per week (ILO 2014a). Despite that, the working hours in the sector are still in the range, so that it is classified as a low risk.

3.3.1.8 Forced labour

For the UK, there is a medium-high risk of force labour, in particular due to human trafficking and sexual slavery. Around 3,000 to 5,000 people have experienced different grades of forced labour (Skrivankova 2014). To address this issue, a new Modern Slavery Bill is being discussed in the Parliament (May and Office 2014).

As stated by Allain et al. (2013), there are several patterns associated with forced labour and certain types of industries, and in the particular case of the food sector important characteristic are seasonality and informality in the labour market. Workers consider these jobs as temporal or as a transition; therefore they are willing to assume the poor working condition for a short period of time (Lalani and Metcalf 2012). Moreover the employment structure promotes this kind of practices, due to the labour is provided by third parties, usually labour providers and temporary work agency, who supply the workers for specific task while they arrange the contracts, work permits, wages and so on. These characteristics are clearly stated in the subcontracting practices, which are characterised for short term contract and lower salaries, comparing with the permanent workers with contracts from the company (Lalani and Metcalf 2012).

Overall, the forced labour vulnerability in the UK is based on four major characteristics: lack of enforcement of business regulations, making the workers weaker and with limited rights; inadequate supervision of labour standards; higher self-regulation of the business; and finally strict immigration and work permission policies, which in reality promote forced labour (Allain et al. 2013). Workers experiencing forced labour can be illegal immigrants but also EU immigrants and British citizens, which are probably working in low-skills manual and low-paid usually temporary jobs.

The labour regulation and standard are supervised by agencies as Her Majesty’s Revenue and Customs (HMRC), the Employment Agency Standards Inspectorate (EAS), Gangmaster Licensing Authority (GLA) and the Health and Safety Executive. These agencies aim to regulate and promote best practices in the labour market (Lalani and Metcalf 2012). However there are several regulations that due to the lack of specification allow the development of malpractices. For instance, the agencies which provide third party temporary worker can change their names and keep working as agencies until there are found working under the standards. Moreover the agencies do not work together, having different roles which are not coordinated. Finally, these malpractices are not easy to find, especially due to the workers are not always aware and if there are not unions, the information about workers’ rights is not always easy to find.

In 2012 there were 1,186 potential victims of forced labour and human trafficking, as estimated by the United Kingdom Human Trafficking Centre (UKHTC); however, screening of more than 2770 media articles revealed that there were only 263 reported victims (Dugan 2013). All these statistics lead to analyse the industry characteristics and promote changes in the practices that create spaces for the development of these malpractices. Moreover, awareness within the industry and the society should be promoted, in particular thinking in the worldwide position of the UK in terms of economic development and political relevance.

Due to the characteristics of the food sector and the issues explained above, it would appear that force labour is also found in the industry. For instance, in 2012 Scott et al. (2012) interviewed 62 migrant workers in five different places in the UK and the results showed that 14 were working under forced labour conditions in the food sector (Sam Scott (University of Exeter) et al. 2012). Some of the practices include indiscriminate wage deductions and charges, overwork, absence of contract, passport retention, threats and bulling (Sam Scott (University of Exeter) et al. 2012).

3.3.1.9 Equal opportunities/discrimination

The UK is classified as low risk for discrimination (SHDB 2010, Amienyo 2012). However, based on the global gender gap, the UK is ranked only 18th behind Lesotho (14th), Latvia (15th), South Africa (16th) and Nicaragua (9th); the top three countries are Iceland, Finland and Norway. For the UK, this ranking represents deterioration since 2006, when it was the 9th best country in the world with respect to gender equality (Ricardo Hausmann et al. 2012).

There are 14 different indicators considered in the global gender gap index, including number of women in the Parliament, wage equality for similar work and political empowerment. The UK has the worst score for the latter, being ranked 93rd; the second worst is the economic participation and opportunities, for which it occupies the 33rd place (Ricardo Hausmann et al. 2012).

According to other methodologies for equal opportunities, the UK is considered to pose medium risk. For instance, IHRRI scores the UK for two related human rights categories as follows: 72% for the “right to freedom from discrimination” and 70% for the “rights of foreigners” (Global Network for Rights and Development 2014).

These results means that from a fully execution of these rights (100%) the UK should still work on reducing the discrimination in aspects as wage differences between male and female, discrimination of minorities, and so on. Similar to the foreigners, which there are several nationalities encounter difficulties in situations as application for working and student visas, work opportunities, etc.

In the FDF, 26% of women were in forced labour in 2008, the figure that remained constant over the previous 10 years (ILO 2014a). The latest estimates show that today, this percentage has increased to around 33% (University of Cambridge 2010).

In terms of migrant population, in 2002 only 3% of the work force in the manufacturing sector was migrants; overall, almost all economic sectors in the UK have less than 5% of migrant population except of the hospitality and catering industry which has on average 14%.

3.3.1.10 Health and safety

In the period between 1999 and 2006, the total number of fatalities in the manufacturing sector was 337 with 307,654 workers sustaining non-fatal injuries. However, the injury rate has been decreasing over the period and in 2006 they reduced by 43%, with a total of 27,740 injured (ILO 2014a). Despite that, the food sector is still one with higher injury rates in manufacturing.

3.3.2 Hotspot analysis of the supply chain

The aim of this section is to complement the previous social analysis and examine the supply chain in more detail for each of the employee-related indicators discussed above. Therefore, some quantitative indicators are analysed for each actor of the supply chain (agriculture, manufacturers, wholesalers and retailers). The aim of this section is to compare the social performance of the actors within the supply chain and identify the social hotspot. The chosen indicators are employment, unemployment[11], wages, working hours, female participation in the workforce and per working hours and fatal injuries. The criteria are based in data availability. Note that the data are not specific to the ready-made meal sector in particular, but refer to the whole sectors involved in the supply chain. The results are summarised in Table 8 and discussed below.

The agricultural sector is a critical stage in the life cycle of ready-made meals for several indicators. For example, it has 11% higher working hours than the average in the whole UK economy and 30% lower salaries than the average (ILO 2014a). Moreover, this sector is responsible for 12% of the employment in the agro-food supply chain (0.42 million people), but only 1% of the national

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[11] It refers to the economic activity that the unemployed used to work or has experienced on ILO. (2014a). *Database on Labour Statistics: LABORSTA Internet* [Online]. Available: http://laborsta.ilo.org/ [Accessed 20th October 2014].

employment (Defra 2014). However, the sector has lowest unemployment (1% of the total unemployed people) and fatal injuries (7% of the total fatal injured occurred (ILO 2014a).

In the F&D sector, the best performance is found for the indicator 'wages', with salaries 5% higher than average UK wages (ILO 2014a). For employment, the sector also performs well, employing around 10%[12] of people working in the agri-food supply chain (Defra 2014) and contributing 12% to the overall economy with 3,600 thousand job positions (ILO 2014a). The working hours, however, are 4% higher than the average for all sectors. The worst performance is found for the fatal injuries, which are 18% higher than the total work-related fatal injuries in the UK (ILO 2014a).

The unemployment rate is also high in comparison with other sectors, with 11% of the unemployment related to this sector.

The analysis also suggests that the wholesaler and retailer sectors have 30% lower salaries and 15% higher working hours than the UK average. On the other hand, the retailer sector has the highest rate of employment, employing 30% of people working in the agri-food supply chain; the wholesale contributes 6%. In total, both sectors provide 15% of the employment in the whole UK economy. The working hours in these two sectors are 2% higher than the UK average and the fatal injuries 3% higher.

Finally, the transport and storage sector have 7% higher working hours and injuries than other economic sectors. At the same time, it contributes 7% of the total UK employment; the wages are 1% lower than UK average.

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[12] Specific data for the food and drink manufacturer sector

Table 55 Summary of the social indicators of the sector and the 'hotspot' analysis of the supply chain

High	Medium high	Medium low	Low
■	▓	▒	░

Social indicators	**UK, FDS & RMS**[13]	**Agriculture**	**Manufacturing**	**Wholesale** [d]	**Retailing** [d]	**Transport & storage**
Contribution to the employment of the sector (Thousand)[a,b]	3,100	420 (12%)	370 (10%)	230 (6%)	1,130 (32%)	
Contribution to the country Employment (Thousand)[c]	29,475	418 (1%)	3,547 (12%)	4,316 (15%)	4,316 (15%)	1,963 (7%)
Unemployment (Thousand)[a,b]	1,643	10 (1%)	183 (1%)	243 (15%)	243 (15%)	97 (6%)
Freedom of association	▓					
Collective bargaining	▓					
Child labour	▓	■				
Wages (£/h) [a,b]	11.77	8.18 (69%)	14.8 (105%)	7.98 (68%)	7.98 (68%)	11.6 (99%)
Fair salary:	░					
Living wage	■					
Poverty line	■					
Working hours (h)[a,b]	39.4	43.9 (11%)	40.9 (4%)	40.3 (2%)	40.3 (2%)	42.2 (7%)
Forced labour	■					
Equal opportunities	▓					
Female participation in the work force [b,c]			35%			
Female participation based on working hours [b]			31%			
Fatal injuries (number of persons)[a,b]	220	15 (7%)	39 (18%)	6 (3%)	6 (3%)	33 (15%)

[a] The percentages are related to the standard of the economic sectors of the UK.

[b] Data from ILO (2014a) based on the statistics of 2008.

[c] Data from Defra (2014) based on the agri-food supply chain[14]

[d] Wholesalers and retailers belong to the same economic sector; only when the figures are related to the agri-food sector they are divided.

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[13] FDS: food and drink sector; RMS: ready-made meal sector

[14] The Agri-food sector considers the agriculture and fishing, food and drinks manufacturing, food and drinks wholesaling, food and drink retailing and non-residential catering.

3.3.3 Local community and consumers

While the previous set of indicators was related to the work force, the indicators considered here examine how the food sector impacts on consumers and local communities through two indicators: community engagement and local employment.

3.3.3.1 Community and consumer engagement

This indicator refers to the level of participation of the sector in local communities, for example, by helping community development through financial or other support for specific projects, raising awareness related to food and health, etc. For instance, the UK Chilled Food Association (CFA), has a "healthy eating" initiative, aiming to reduce the content of fat, sugar and salt in their products and inform consumers on their content through proper labelling (CFA 2014b). The CFA also runs an educational programme called "chilled educational initiative", promoting job opportunities and potential career in the chilled food sector. The initiative has been developed in collaboration with teachers, schools bodies, students and food professionals in order to develop lessons, coursework and activities focused on topics such as the chilled food industry, product development, labelling and hygiene.

In the frozen food sector, the British Frozen Food Federation (BFFF), is committed to improving health and safety of their products through the "Health and Safety Pledge" (BFFF 2014c). Moreover, the BFFF has a commitment to promote the sustainability of their products, providing information on the environmental impacts as well as advice consumers on how to use their products in a more sustainable manner (BFFF 2014b).

A further example includes the campaign "Future in Food" in Scotland, developed by the Scottish FDF and aiming to increase the awareness of young people of the career opportunities provided by the food industry. A similar campaign called "Taste success - A future in food" is also run across the UK.

The FDF also has two specific campaigns focussing on nutrition and healthy-eating guidelines. One example is the guideline daily amounts (GDA) label, which helps consumers to compare the nutritional value of food products with the GDA. The other campaign is "the fresher for longer", which focuses on the packaging and food waste, trying to promote consumer awareness on how to preserve food for longer.

The FDF has also developed a campaign to promote the career in the food industry. The targets are students between 13 to 19 years old, who are being encouraged to pursue a career in the sector. Also the industry has been involved in a campaign called 'FDF's women into STEM' promoting the participation of women in science and engineering (STEM careers) as well as several other campaigns in social and digital media as 'Big Bang fair 2014' and 'Taste Success digital campaign' (FDF 2014a), which through different activities promote science and food industry careers to young people.

Another big commitment of the Federation is the promotion of apprenticeships and engineering studies in food. Although one of the biggest partners in terms of developments universities and research centres, the Federation has been working on initiatives related to other career pathways outside the academia, opening the spectrum to those not pursuing a university career (FDF 2014a;FDF 2014b)..

3.3.3.2 Consumer health

An important global challenge that has particularly affected the British population is the increasing rate of diseases, specifically diet-related chronic diseases (DRCD) of which the most studied and cause-proven food-related diseases include obesity and diabetes, cardiovascular diseases, hypertension, strokes, osteoporosis, dental diseases and certain types of cancer.

Between 2001 and 2003, the British average daily energy intake was 3,440 kcal per person; 42% of energy intake was derived from animal products, sugar and sweeteners (Millstone and Lang 2008). The average consumption of meat was 79.6 kg per person (Millstone and Lang 2008).

Although no percentage of undernourished population was registered, 204 cases of coronary heart diseases per 100,000 people were diagnosed in 2002. In 2008, 25% of the female adult population was obese and 32% overweight (The NHS Information Centre 2010); 24% of the male adult population is also obese and 42% are overweight (The NHS Information Centre 2010). In the case of children less than sixteen years old, 16.8% of the boys and 15.2% of girls were considered obese (The NHS Information Centre 2010). Latest figures have showed that in 2011 a quarter of the British adult population was obese and a third was overweight (Defra 2014).

The increase of DRCD is causing a rise in the national health costs because of treatments, information and prevention campaigns, and also disabilities support expenses (WHO 2003). For example, 7.4% of the UK's health budget - £5.8 billion a year - is spent by NHS on food-related illnesses (Scarborough et al. 2011).

Several factors have contributed to the rise of DRCD; examples are modern lifestyle, technological developments in processed food and high rates of consumption of junk food (McPherson 2014;Ng et al. 2013). For these reasons, it is expected that the DRCD will continue to rise and will more than double by 2020 (WHO 2003).

4 Conclusions

This paper has considered environmental, economic and social sustainability of the ready-made meals sector. The results suggest that the chilled ready-made meal market has the highest contribution to the environmental impacts due to its greater market share. For example, its global warming potential (GWP) is estimated at 3.49 Mt of CO_2 eq. while that of the frozen sector is 1.45 Mt of CO_2 eq. The sector contributes 3% to the GWP of the food and drink sector and 1% to total UK emissions.

The British cuisine meals are the greatest contributors to seven out of 11 impacts and the Italian to the remaining three, specifically acidification, eutrophication and photochemical smog. This is again largely due to their market share; for the same reason, Chinese and Indian meals have the lowest contribution. Similar trend is found when the meals are analysed, but with some exceptions. The greatest environmental impacts are found in both Italian dishes (classic lasagne and spaghetti Bolognese) and in the British cottage and Indian lamb masala curry; the lowest impacts are found in the British roast dinners, particularly pork and chicken based, and in both Chinese dishes (pork & prawns fried rice and Chicken noodles).

The total life cycle cost of the ready-made meal sector is estimated at £2.1 bn, with the chilled market costs being £1.42 bn and the frozen £676 million. Similar to the environmental assessment, the major contributor is the British cuisine (40%). The Italian cuisine contributes ~27% and the Indian and Chinese ~21% and ~12%, respectively. The market share and the ingredients play a critical role for the life cycle cost. The recipes with a higher amount of meat, fish and seafood, as well as those with greater quantities of processed ingredients have higher costs.

The value added estimated is £958 million. The life cycle cost of the ready-made meal sector is 51% lower when the boundaries are from cradle to retail (£1.02 bn).

It should be highlighted that the environmental and economic results of the sector are based only on four cuisines and thirteen specific recipes which due to lack of data were also simplified; therefore, these results should be considered as an initial analysis of the sector, aiming to provide a basis for further work.

From the social sustainability point of view, the sector has high risk with respect to indicators related to living wage, poverty line and forced labour, while a medium risk for freedom of association, collective bargaining, and equal opportunities. The best performance (low risk) is found for wages.

The agricultural sector has a high risk for wages and employment, the manufacturing for fatal injuries and the wholesaler and retailer sector for wages and employment.

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Chapter 7: Conclusions and Recommendations

Numerous sustainability issues associated with the ready-made meals, the complexity of the sector and the broad range of stakeholders were some of the drivers to perform this study, which is aiming to contribute towards sustainable development of the food industry. As far as the author is aware, this is the first study of its kind.

The results of the study are presented in five papers. The first two (Chapters 2 and 3) have compared, using a life cycle approach, the environmental and economic performance of two meal options: a ready-made meal and the correspondent home-made meal, both based on a recipe of a popular British meal (chicken roast dinner). The influence of various parameters associated with the production and consumption of the meal has also been considered, including sourcing of ingredients, cold vs frozen chain and appliances used for preparation of the meal by consumer. The next two papers (Chapters 4 and 5) have considered a range of the ready-made meals with the main purpose of evaluating the environmental and economic impacts of meals most-widely consumed in the UK. Four most popular cuisines have been considered, with at least two representative dishes (recipes) for both chilled and frozen meals. The research also assessed possible recipe improvements as well as the nutritional content of the meals.

The last paper (Chapter 6) has presented the sustainability assessment in the British ready-made meal sector, integrating the environmental, economic and social aspects, based on a life cycle approach. The study is based on the outcomes of the research presented in the previous four papers (Chapters 2-5), with the results escalated to the sectoral level using statistics and market analysis. Although the analysis does not cover the whole sector, the majority of the market (85%) is considered with the aim of providing a baseline the current situation and indicating opportunities for improvements.

The original research objectives specified in Chapter 1 have been achieved as follows:

- the main sustainability issues and the key stakeholders in the sector have been identified;
- the most popular types of ready-made meals have been identified and environmental and economic sustainability assessed on a life cycle basis;
- the hotspot and opportunities for improvements have been identified along the supply chains for the selected types of meal;
- the life cycle sustainability has been evaluated at the sectoral level, considering the majority of the market; and
- recommendations have been made to the key stakeholders for improvements in the production and consumption of British ready-made meals – these are summarised further below.

The main outcomes from this project are:

- the first life cycle environmental and economic assessment of different British ready-made meals; and
- the first attempt at the sustainability assessment in the British ready-made meal sector.

The main conclusions and recommendations are summarised in the rest of the chapter.

1 General conclusions

The following general conclusions can be drawn from this research:

- The British ready-made meal sector represents 1% of the total UK emissions and 3% of the food and drink sector, totalling 4.45 Mt of CO_2 eq./yr. When the full life cycle is considered (from ‘cradle to grave’), the total global warming is 4.94 Mt of CO_2 eq. Specifically:

  - The chilled ready-made meal market contributes 3.49 Mt of CO_2 eq.
  - The frozen ready-made meal market accounts for 1.45 Mt of CO_2 eq.
  - In terms of the cuisines, the British cuisine contributes 40%, the Italian 27%, the Indian 21% and Chinese 12%.
  - The greatest environmental impacts are found for the Italian and Indian meals, while the most environmentally sustainable meals are the Chinese followed by the British.

- The total life cycle costs of at the sectoral level, considering the meals assessed in this study, is £2.1 bn with the following contributions:
  - the chilled ready-made meal market accounts for £1.42 bn.
  - the frozen adds 676 million.

- The value added of the sector is estimated to be £958 million and the life cycle cost from cradle to retailer is £1.02 bn.

- The common environmental and cost hotspots for all the studies are raw materials. In particular, the meat, fish and seafood are the greatest contributors. For the environmental impacts, the manufacturing and distribution stages are also important contributors while for the costs, the consumption stage is the largest contributor owing to the high cost of energy and transport.

- The major social issues related to the food sector are the food-related health issues and food security, in particular the food affordability. In terms of the social indicators, the living wages and poverty line were found to have a high risk, while equal opportunities are classified as medium risk.
- When the supply chain is analysed, the agriculture, wholesale and retailers show high risk for the indicators such as wages and employment while the manufacturing presents high risk in fatal injuries.

- When the environmental and economic assessments are integrated for comparing a ready-made and a home-made meal, the most sustainable option is the home-made option. The best ready-made meal option is the frozen meal made from fresh ingredients and heated in the microwave, while the worst option is also the frozen ready-made meal but made from frozen ingredients and heated in the electric oven.

- For the common ready-made meals consumed in the UK, the economic and environmental analysis reveal that the most sustainable options are the Chinese chicken noodles and the British roast dinners, while the least sustainable are Italian lasagne, British cottage and shepherd’s pie and the Indian lamb masala curry.

- The study also shows that consumer choices play an important role for the economic and environmental impacts of both the ready-made or home-made meals, with cooking in microwaves leading to lower impacts and costs.

2 Specific Conclusions

This section highlights some of the specific conclusions draw in in each of the five papers.

2.1 Environmental and economic assessment of a ready- and home-made meal

The environmental and economic assessment of a ready- and home-made meal found that overall the latter is the most sustainable option (Chapters 2 and 3). The following two sections highlight the specific outcomes of that part of the study.

2.1.1 Environmental assessment

- The home-made meal option cooking the meal from scratch is the best option due to the absence of the manufacturing stage, lower use of chilled or frozen storage and a lower waste rate through the whole life cycle.

- For both types of meal, the raw materials are the main hotspot.
    - With respect to the ingredients sourcing, using Brazilian chicken and Spanish tomatoes reduces the environmental impacts, despite the long-distance transport.

- For the ready-made meal, the study found that:
    - The main hotspots are the raw materials (ingredients), the manufacturing and distributions stage.
    - Using the same appliance at home to heat the meal, the frozen meal has lower impacts than the chilled, due to the lower efficiency of the storage for the later because chilled products are stored in opened cabinets, consuming more energy and refrigerant than the frozen meal which is placed in closed display cabinets.
    - The worst appliance option is the electric oven, especially when the meal is frozen.
    - The refrigerant assumed in the study influences the results. In particular, R22 is the best option with lower global warming and ozone layer depletion; the only exception is marine ecotoxicity, which is greater for this option than for other refrigerants (R134a).
    - Even though the packaging stage is not a hotspot, it contributes to global warming, depletion of fossil fuels and human toxicity.
    - The pre-processing and waste management stages have a low contribution to most impacts.

2.1.2 Economic assessment

- The total life cycle costs (LCC) range from £1.41 to £2.54 per meal, depending on the scenario considered. For the home-made meals, from the costs are between £1.41 and £1.91 per meal.

- The consumption and raw materials stages are the main contributors to the LCC for both ready-made and home-made meals. In particular, the chicken and the tomato paste are the main contributors.

- The ready-made meal has 8% lower LCC than the home-made option; for the best home-made meal scenario, the LCC is 5% lower than the ready-made meal.

- The highest value added is found for the chilled meals, following by the frozen. Based on the supply chain perspective, the biggest value added is found for the ready-made meals, in particular, for the chilled option (£1.99bn). From the consumer perspective, the home-made meal is most cost effective.

- For the ready-made meals, the following specific conclusions apply:
    - The consumption stage has the highest contribution to the LCC (65%), especially when the electric oven is used.
    - The ingredients contribute between 17-30%. Of this, chicken meat and tomato paste account for 70%. The use of British conventional and organic tomatoes increases the LCC by up to 20%.
    - The contribution of the distribution stage is up to 20% for a frozen meal heated up in the electric oven.

2.2 Environmental and economic assessment of different ready-made meals consumed in the UK

This study considered 85% of the ready-made meals market, with the four most popular cuisines: British, Italian, Indian and Chinese (Chapters 4 and 5). The specific conclusions are as follows:

2.2.1 Environmental assessment

- The most environmentally sustainable cuisine is the Chinese, followed by the British. The worst options are the Italian and Indian respectively, based on the meal considered. Analysing the specific meals, the most environmentally sustainable options are the British roast dinners, in particular the pork and chicken based, with overall lower impacts.

- Additionally, the worst environmental options are the Italian lasagne and spaghetti, followed by the British cottage pie and Indian masala curry.

- In terms of specific environmental impacts, the outcomes are as follow:
    - The global warming ranges from 2.15 kg CO_2 eq. in the case of the British pork roast dinner, to 5.03 Kg CO_2 eq. in the case of the Italian classic lasagne. Around 40% of the recipes are in the range between 4 and 5 kg CO_2 eq., while around 50% in the range from 2 to 3 Kg CO_2 eq.
    - The main hotspots are the raw materials, distribution and manufacturing stages; in the case of the former, the most influential ingredients are beef and lamb. The contribution of the manufacturing and distribution stages is driven mainly by the energy uses and the refrigerants (production, usage and leakage).
    - The different ranges in the recipe composition mostly affect the impacts leaded by the raw materials stage, therefore the greatest ranges are found in global warming, acidification and photochemical smog.. In the case of the recipes, the biggest variations are found in the British cottage and shepherd's pies, the Italian spaghetti and the Indian lamb masala curry.

- The improvements proposed on the study have shown contradictory outcomes, which are:
    - The introduction of seitan and granule soy has proven to reduce five out of 11 impacts, remaining the other six constant; however, due to lack of complete inventories, the study could not reveal main differences between the two options. For instance, global warming is reduced up to 17%, while the acidification and eutrophication are improved up to 27% and 25%, respectively.
    - The inclusion of tofu to the meals has shown contradictory results depending on the recipes; however overall the ozone depletion and terrestrial toxicity remain constant through all of them.

- In terms of nutritional aspects, the results present a similar trend between the environmental impacts and the nutritional efficiency. Therefore, combining these two parameters, the worst options are the British cottage pie, the Italian classic lasagne and the Indian lamb masala curry. On the other hand, the best nutritional and environmentally sustainable options are the British pork roast dinner, the Indian chicken korma curry and the British fisherman's pie.

2.2.2 Economic assessment

In the case of the LCC the following outcomes are highlighted:

- The chilled ready-made meals analysed present a total life cycle costing ranging from £1.17 for the Chinese chicken noodles to £2.66 for the British Fisherman's pie.

- Overall, half of the chilled ready-made meal presents a total LCC lower than £1.50 while a third has values between £1.51 and £2.0 per meal.

- The raw materials and the consumption stages are the main contributors; the former due to the ingredients while the latest because of the transportation of the meal back home.

- The ingredients play a crucial role, changing the contribution of the stage from 20% to 60%. Meat, fish and seafood are the most relevant ingredients, being responsible for more than 40% of the relative stage contribution. The only exception to this trend is in the Indian chicken korma curry, with a chicken contribution lower than 30%.

- The respective frozen options present 1% higher total LCC than the correspondent chilled ready-made meals. This is due to the variations are presented in the distribution and consumption stages.

- The value added of the chilled products is 20% higher than the frozen due to the chilled meals present much higher retail prices than the correspondent frozen option. There are several possible reasons, as the better market position and image of the chilled meals, the higher shelf life of the frozen products and the recently horse meat scandal associated to frozen products in this sector, among others.

2.3 Sustainability assessment in the ready-made meals sector

The specific conclusions from this study presented in Chapter 6 are detailed below.

2.3.1 Environmental assessment

- For both chilled and frozen meals, the greatest contribution to the impacts is from the British and Italian cuisines; the former has the highest contribution for seven out 11 impacts, including global warming, while the latter contributes mostly to acidification, eutrophication and photochemical smog. The Chinese cuisine is environmentally most sustainable, followed by the Indian. These results are highly affected by the market share.

- Overall, the contribution to the impacts follows the contribution of the meals to the market share, with 68% of impacts being from the chilled and 32% from the frozen meals. The only exception is ozone depletion, which is almost entirely due to the chilled ready-made meals (96%).

2.3.2 Economic assessment

- The total LCC at the sectoral level is estimated at £2.1 bn of which value added is almost half of that (£958 million).

- The LCC in the chilled ready-made meals sector is £1.42 bn and the value added is estimated at £692 million.

- The LCC in the frozen ready-made meals sector is £676 million, with the value added of £266 million.

2.3.3 Social sustainability assessment

- One of the biggest social sustainability issues is the food price, especially in parameters as food security and food affordability, where the country is positioned in an average position comparing with other European countries.

- The other biggest issues and closely related to the food prices, are the increment of diet related chronic diseases. The higher food prices have affected the quality of the food consumed, which adding to the changing in lifestyle has for example increased the overweight and obese population.

- In terms of the social indicators, the lowest risks are found in the wages and fairly salary, however when the poverty line and living wage are considered, the sector shows a high risk. Other high risk factors are found in forced labour, with reference of cases found in the food sector.

- Equal opportunities, collective bargaining and the freedom of association are classified as a medium risk.

- When the supply chain is analysed, the agriculture, wholesale and retail sector present the highest risk for wages and employment. This is due to the seasonal characteristics of the agricultural activities, and the high part-time contracts for both, creating instability and high rotation of workers. For the manufacturing sector, the main risk is the high number of fatal injuries, due to the mechanised characteristics of the sector.

3 Recommendations

3.1 Recommendations to the industry and government

3.1.1 General recommendations

The following general recommendations can be made for the ready-made meals industry and the government:

- To ensure a sustainable development of the ready-made meals sector, future policies and industrial initiatives should consider a range of relevant economic, environmental and social aspects taking a life cycle approach, instead of focusing on single issues such as costs and climate change.

- An appropriate communication strategy as well as educational programmes should be developed in collaboration between the industry, the government and consumer groups to help consumers make more sustainable food choices, particularly with respect to convenience food, and advising them how they can contribute to improving the sustainability of food.

- Government policy should encourage the food sector to improve the environmental and social sustainability of convenience food and the industry should promote sustainability of food through stakeholder engagement along the supply chain, including suppliers and the consumer.

- A national database of life cycle environmental and social impacts of different types of food, including convenience food, should be developed and made freely available in the public domain.

- New technologies, infrastructure and legislation should be developed to enable recycling of all types of food packaging. Alternatively, non-recyclable packaging should be phased out.

- Government's advice to the public to "buy British" should not be made indiscriminately as in some cases it is more environmentally sustainable to import certain food than use local produce, despite long-range transport. Therefore, advice must be made on a case-by-case basis, depending on the type of product, production process and the world region from where the food may be imported. Similarly, the implications for social sustainability of imported vs local food should be better understood before providing advice to the consumer.

- The proliferation of different food labels only serves to confuse the consumer so that the industry and the government should develop a single, easy-to-understand food labelling system to improve awareness and enable better consumer choices.

- The industry and the government should invest in food research in collaboration with academia to enable sustainable development of the sector in the long term.

3.1.2 Specific recommendations

Based on the results of the specific case studies considered in this work, the following specific recommendations can be made:

- Manufacturers should consider a range of life cycle environmental impacts to inform their ingredients sourcing and product development.

- Manufacturers, retailers and wholesalers should make stronger commitments to reduce the amount of waste and packaging along the supply chain.

- The refrigeration throughout the supply chain should be more energy efficient using closed cabinets for chilled products in the same way the frozen products are stored and displayed. Furthermore, environmentally benign refrigerants should be used replacing those with high ozone layer depletion and global warming potentials; refrigerant leakage rates should also be reduced or completely eliminated.

- To reduce the environmental impacts of ready-made meals, manufacturers should consider providing alternative recipes for their classic or most popular meals; for instance, reducing the amount of meat or replacing red meat with poultry, or using meat alternatives such as granule soy or seitan.

3.2 Recommendations to consumers

The following recommendations can be made to the consumer, following the findings of this research:

- Consumers should be more aware of the important role they play in the food supply chain, particularly with respect to food cooking options and waste, aiming to use microwave instead of electricity ovens where possible and reducing food waste.

- They should demand that manufactures provided simple and transparent information on health and environmental impacts of food products through labelling that would be the same across different manufacturers.

- Consumers should cook more often instead of consuming highly-processed convenience food, in order to reduce their own and the supply-chain environmental impacts.

- They should be aware of the environmental impacts of meat consumption aiming to eat less meat, in particular red meat, as well as considering meat replacement options.

- Consumers should also be aware of the environmental impacts of different cuisines, to be able to make more informed choices.

3.3 Recommendations for future work

The following suggestions for future work can be made:

- More detailed, sector-specific economic and social sustainability assessment using primary data from the industry.

- Sustainability assessment of the rest of the ready-made meals market not covered in this study, including different types of diet.

- Sustainability assessment of other types of convenience eating, including catering.

- Further studies to enable a better understanding of the trade-offs between the nutritional values, environmental, economic and health impacts of convenience food.