# Environmental sustainability in the UK food service sector

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

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# Contents

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## List of abbreviations

| Abbreviation | Meaning |
|---|---|
| ADP | Abiotic depletion potential |
| AP | Acidification potential |
| BOD | Biological oxygen demand |
| CHP | Combined heat and power |
| CML | Institute of Environmental Sciences, Leiden University |
| COP | Coefficient of performance |
| DEFRA | Department for Environment, Food and Rural Affairs |
| EP | Eutrophication potential |
| EU | European Union |
| FAETP | Freshwater aquatic ecotoxicity potential |
| FAO | Food and Agricultural Organisation of the United Nations |
| GDP | Gross Domestic Product |
| GHG | Greenhouse gas |
| GN | Gastronorm |
| GWP | Global warming potential |
| HTP | Human toxicity potential |
| LCA | Life Cycle Assessment |
| MAETP | Marine aquatic ecotoxicity potential |
| Ntot | Total nitrogen |
| ODP | Ozone depletion potential |
| POCP | Photochemical ozone creation potential |
| SDU | Sink-top disposal unit |
| SRA | The Sustainable Restaurant Association |
| TEQ | Toxic equivalent weight to 2,3,7,8-Tetrachlorodibenzo-p-dioxin |
| TETP | Terrestrial ecotoxicity potential |
| TOC | Total organic carbon |
| UK | United Kingdom |
| US | United States |
| WRAP | Waste & Resource Action Programme |
| WWF | World Wide Fund For Nature |

# Abstract

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Food sustainability is a vitally important topic, since the global food system is threatened on many fronts by the consequences of unsustainable practices. Food service, i.e. food prepared for consumption outside of the home, is a significant part of the food sector. This research considers the environmental sustainability of the food service sector in the UK. The study focuses on a canteen where the meal is kept warm for some time after preparation, assuming different recipes.

Life Cycle Assessment (LCA) has been used to quantify the environmental impacts in the supply chain of this meal. To the knowledge of the author, this is the first LCA study in the UK food service sector. Eleven environmental impacts have been estimated following the CML 2001 impact assessment method, plus net primary energy demand. The results show that for six CML impact categories, including global warming potential, the greatest contributor to environmental impacts is the agricultural stage. For the remaining categories, impacts are spread more evenly throughout the supply chain.

The results were compared with LCA results from literature for the equivalent ready-made or home-made meal. For nine out of eleven CML impact categories, the canteen meal had the lowest impact. This was mostly due to higher energy efficiency associated with cooking meals in large batches in the canteen and lower levels of food waste.

Several recommendations for canteen operators can be drawn from the study. Reducing levels of food waste can reduce all impacts (in this study, by an average of 22% between best and worst cases). Replacing British tomatoes grown in heated greenhouses with Spanish tomatoes grown in unheated greenhouses can reduce impacts by an average of 46% in the categories of $ADP_{elements}$, $ADP_{fossil}$, AP, EP and $GWP_{100}$, but the additional transport required increases impacts in FAETP, HTP, MAETP, ODP, POCP and TETP by 14% on average. In all categories for which agricultural data for meat is available ($ADP_{elements}$, $ADP_{fossil}$, AP, EP and $GWP_{100}$), the impacts per meal are highest for beef, pork and sheep meat, medium for chicken and lowest for faba beans and sunflower seeds (except for $ADP_{elements}$, where sheep meat outperforms chicken). On average in these five categories, choosing faba beans over beef can reduce impacts by 48%, implying that menu changes can contribute to environmental sustainability.

Suggestions for further work include adding further data to the current LCA, integrating a nutritional analysis into the study, performing LCA for different types of meal and for other food service subsectors and considering social and economic aspects of sustainability in the food service sector.

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# 1. Introduction

## 1.1 Background

The theme of sustainability is overwhelmingly important in today's world, in which a new geological epoch, the Anthropocene, has been proposed to mark the importance of human influence on the planet (Waters et al., 2016). The biosphere faces many interconnected threats, some potentially irreversible (Steffen et al., 2015), including mass extinction (Ceballos et al., 2015) and climate change (Intergovernmental Panel On Climate Change, 2014). Although human actions are at the root of many of these threats, we are also at risk from the consequences, which could include decreased food security (Food and Agricultural Organisation, 2008), rising sea levels (Bamber and Aspinall, 2013) and more frequent extreme weather events (Intergovernmental Panel On Climate Change, 2014). Despite humanity's high demands on the planet, poverty is still widespread and poorer people may be disproportionately affected by the consequences of environmental degradation (WWF, undated).

Sustainability has been defined in many ways. For example, according to the US Environmental Protection Agency (undated-c):

> *"Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations".*

The related term "sustainable development" can be thought of as a means of reaching the state of sustainability (UNESCO, 2015). The Brundtland Report (Brundtland, 1987) defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

The main components of sustainability are commonly described as the "three pillars" or the "triple bottom line": environmental, social and economic considerations (Pope et al., 2004). Some sources also consider culture to be an additional component (Sustainable Kingston Corporation, 2015; UNESCO, 2015).

Environmental sustainability, on which this thesis will focus, concerns protection of ecosystems. Ecosystems provide goods and services that allow humanity to survive and thrive (UK National Ecosystem Assessment, 2009). For example, fertile soils allow crops to grow, plants produce oxygen that we breathe, bees pollinate crops and rain provides fresh water to drink. If ecosystems are damaged, their ability to supply these goods and services in the long term is impaired, meaning that a damaged ecological support system will be left behind for future generations.

Social sustainability concerns people's quality of life both now and in the future. Examples of relevant factors include health and safety, equality, poverty, education and living conditions (Hutchins and Sutherland, 2008). These are important both in their own right (although the priority of the different factors will depend on one's personal ethical outlook) and because societies in which a large proportion of the population is dissatisfied may be unstable.

Economic sustainability refers to long-term financial feasibility, phrased as "the ability of an economy to support a defined level of economic production indefinitely" by Vancouver Valuation Accord (undated). This is not the same as conventional measures of economic success such as sustained growth in Gross Domestic Product (GDP). Rees (2001) argues that indefinite economic growth may be inherently in conflict with the physical limits of living on a single planet. On the other hand, economic growth may be sustainable if economic output can be decoupled from extraction of physical resources (United Nations Environment Programme, 2011). Poverty reduction up to a certain point (as distinct from indefinite economic growth) may be an effective way of reducing harm to the environment to some extent, because as people are freed from the immediate concerns of day-to-day survival, they are able to give attention to improving their surroundings (Arrow et al., 1995). From another point of view, improving environmental sustainability can, itself, contribute towards alleviating poverty (Rosenberg, undated).

In today's economic system, the damages arising from products and services sold on the market are often not factored into the price. The costs of these damages, known as "negative externalities", may be borne by a third party instead of the producer or consumer (Economics Online Ltd, 2016). For example, if packaging is dropped on the street as litter, it is the local council (and therefore everyone who pays council tax) that must pay for litter pickers, and it is future generations who must deal with landfill sites for decades to come. Patel (2009) claims that if the price of a hamburger made from beef raised on clear-felled forest reflected all of the social and environmental damage it caused, then that burger would cost US$200 rather than its typical current price of US$4. The producer benefits by not having to pay for the damages caused and the consumer benefits by being able to buy goods and services at lower prices than would be possible if the price reflected all of the damages. Hence, in some circumstances there is an economic incentive for environmental and social damage to continue.

One of the most essential commodities that the biosphere provides is food. Food production will become more important in the coming decades as the global population rises and consumption patterns change. The FAO estimates that food production will need to rise by 70% by 2050 (Food and Agricultural Organisation, 2009b). Even today, the food system does not adequately meet the needs of everyone: despite one and a half billion people being overweight, one billion people remain undernourished (Patel, 2007). Modern food production also causes huge numbers of animals to suffer; around 70 billion farmed animals are killed for food each year. Two thirds of these are "factory farmed", i.e. reared intensively indoors (Compassion in World Farming, 2013).

The global food system has a significant impact on the environment. For example, food production accounts for around one-third of anthropogenic greenhouse gas (GHG) emissions (Garnett, 2011), agriculture uses 38% of the world's land area (World Bank, 2016) and 29% of fish stocks are overfished with another 61% being fully exploited (WWF, 2015). At the same time, food production is vulnerable to risks caused by environmental damage, for example, increased extreme weather due to climate change, fishery collapse due to overfishing, plastic pollution and ocean acidification, soil erosion and loss of pollinators due to pesticide use (Food and Agricultural Organisation, 2009b; Pimentel and Burgess, 2013; The Economist Intelligence Unit Limited, 2016).

A significant part of the food sector is the food service sector, also known as catering, in which food is served for consumption outside of the home. In the UK, food service provides about 15% of meals eaten (SKM Enviros, 2010), so it is to be expected that the environmental impact of food service is considerable. The food service supply chain is structured differently to the food retail supply chain (described in more detail in section 2.1). Despite this, there is relatively little discussion in the literature of the environmental impacts of the UK food service sector and how they may differ from the impacts of the UK food sector as a whole.

There are many reasons for food service operators to consider their environmental impact. In the short term, improving resource efficiency may save money. Sometimes this can be achieved through behavioural changes such as switching off equipment when it is not in use. Investment in more efficient equipment may also save money over time (Carbon Trust, 2012).

Environmental credentials can also be used to improve reputation and attract customers. Corporate social responsibility has gained visibility in the last few years and consumers are increasingly concerned about the environment and supply chain traceability (Ernst & Young, 2013; WWF, 2016). Thanks to the internet, consumers can research and verify the environmental claims of businesses. Non-governmental organisations (NGOs) have also been active in urging businesses to disclose and improve their environmental impacts (Poret, 2014).

Furthermore, businesses that consider the resilience of their whole supply chain may find it easier to adapt in the face of changing global conditions. WWF (2016) suggests that specific measures in this area may include reducing reliance on meat and encouraging suppliers to produce food more sustainably.

Another reason for improving sustainability is to comply with legal requirements. Some existing regulations are discussed below in section 2.2.1. Future regulations are likely to be even more stringent, especially those concerning climate change. Since businesses are likely to be forced by regulation to adopt environmentally conscious practices in the long term, they could gain a competitive advantage by being early adopters of sustainability.

These pressures from various parties and on supply chains themselves mean that many food service operators are paying more attention to sustainability. This work aims to help inform them on how to become more environmentally sustainable, as outlined in the next section.

## 1.2 Research aims and novelty

The overall aim of this research is:

> *To investigate environmental sustainability in the UK food service sector and identify opportunities for improvement, using a study of a canteen meal.*

The specific objectives are:

1. to identify through a literature review the current state of environmental sustainability in the UK food service sector;

2. to quantify life cycle environmental impacts of various meal types prepared in the UK food service sector, specifically in a canteen where the meal is prepared from scratch on site and stored hot before being served (a “cook-hold” canteen); and

3. to give recommendations based on the results of the study on how the environmental sustainability of meals prepared in canteens can be improved.

This work is novel because it provides, to the knowledge of the author, the first LCA study in the UK food service sector. More precisely, it is the first study to calculate the environmental performance of the whole supply chain of a canteen meal in the UK using multiple impact categories. This provides valuable information on the magnitude of impacts and the location of hotspots in the supply chain. Since multiple impact categories are used, the study is able to illustrate some sustainability trade-offs between different meal types as opposed to ranking options on only one metric (such as global warming potential). Furthermore, the study compares and contrasts the impacts of the canteen meal with literature results for an equivalent ready-meal and home-made meal.

The rest of the thesis is structured as follows. A literature review is presented in Chapter 2, followed in Chapter 3 by an assessment of the environmental sustainability of a meal typically prepared in the UK food service sector. Finally, conclusions and recommendations for future work are summarised in Chapter 4.

# 2. Literature review

## 2.1 Overview of the food service sector

### 2.1.1 Definition of food service

Food service, also known as catering, refers to food which has been prepared for consumption outside of the home (The Institute of Grocery Distribution, 2005; US Department of Agriculture, 2014). This is distinct from food retail, where food is purchased to be eaten at home.

### 2.1.2 Global market size

It is difficult to measure the size of the global food service market because it is so extensive and varied. For example, street food stalls in developing countries are largely informal and their value is not measured (Gehlhar and Regmi, 2005). However, Schaefer (2014) estimates that the global food service market was worth $2.6 trillion in 2013. For comparison, the global food retail market (excluding food service) is estimated at around $5.6 billion in 2013 (Solanki, 2016). A different estimate is given by Johnson (2015) of $8.8 trillion for the global grocery market in 2015. For comparison, estimated 2013 Gross World Product is $74.3 trillion (Central Intelligence Agency, 2013). It follows that food service accounts for roughly one quarter to one third of the global food market and around 3% of the global economy.

### 2.1.3 UK market overview

Estimates of the UK food service market size vary considerably, ranging from £34 billion to £88 billion per year (see Table 1). The differences may be due to different sector definitions or measurement techniques. Given that the UK's GDP was £1.9 trillion in 2015 (International Monetary Fund, 2016), food service accounts for around 2% to 5% of the UK's economy.

Food service is a significant portion of the UK food sector: it accounts for around 15% of all meals consumed, around 11% of nutritional intake (SKM Enviros, 2010) and over one third of consumer spending on food and non-alcoholic drinks (DEFRA, 2016).

The UK food service market is growing and is predicted to grow further (M&C Allegra Foodservice, 2016; Mintel, 2015b; Ten Live Group, 2015), suggesting that it will become more important economically and environmentally over the next few years.

The UK catering workforce has been estimated at 1.42 million employees by Statista (2014) and 1.66 million by DEFRA (2016), approximately 5% of the UK workforce (Office for National Statistics, 2016). Small businesses dominate the food service sector, with Figure 1 showing that 82% of UK food service enterprises have fewer than 10 employees.

Table 1: Estimates of UK food service market size

| Source | UK food service market value | Year | Comments |
|---|---|---|---|
| Mintel (2015b) | £34 billion | 2014 | Excludes institutional catering |
| Ten Live Group (2015) | £47 billion | 2014 | - |
| DEFRA (2016) | £56 billion | 2014 | Catering excluding alcoholic drinks |
| Potato Council (2014) | £50 billion | 2013 | - |
| Euromonitor International (2016) | £59 billion | 2015 | Excludes institutional catering |
| M&C Allegra Foodservice (2016) | £85 billion | 2015 | - |
| DEFRA (2016) | £88 billion | 2014 | Catering including alcoholic drinks |

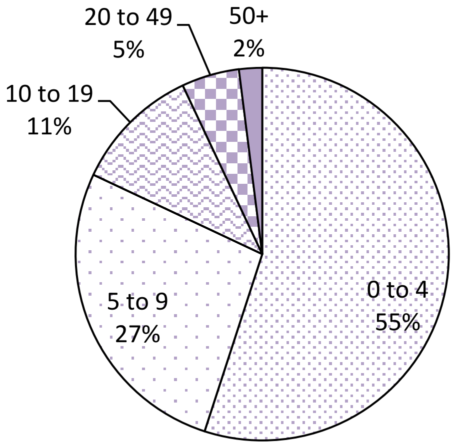


**Figure 1: UK food service enterprises by number of employees**

Source: Office for National Statistics (2013), Standard Industrial Classification codes 5610, 5621 and 5629. Percentages are on the basis of number of enterprises.

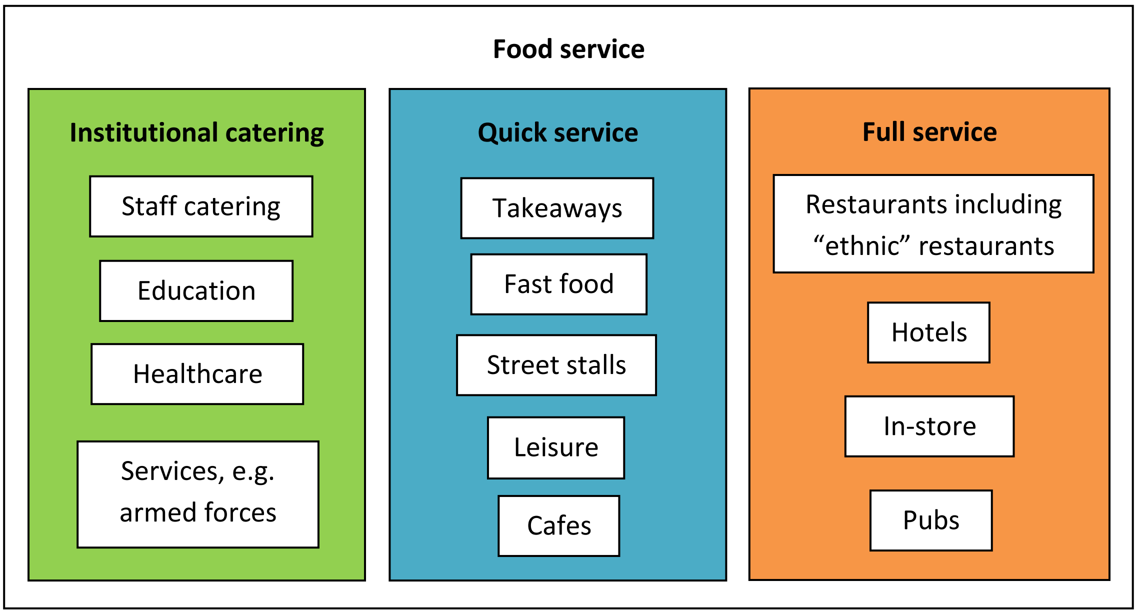


**Figure 2: Subsectors of the food service sector**

Based on SKM Enviros (2010), Oakdene Hollins (2013), AEA Technology Plc. (2012), Euromonitor International (2013) and Mintel (2014)

### 2.1.4 Subsectors

Food service outlets can be classified into many different subsectors, as shown in Figure 2. Definitions of subsectors vary by source and may overlap with each other. However, three rough categories can be distinguished:

- Institutional catering – e.g. workplaces, hospitals and places of education (Tsui, 2014).
- Quick service – these generally have no waiting staff and the customer normally pays before eating, e.g. fast food and takeaways (IBISWorld, 2016; Krishna, 2014).
- Full service – these usually have waiting staff and the customer often pays after eating, e.g. restaurants and hotels (Franchise Direct, 2010; Government of Canada, 2016).

Figure 3 shows that, in the UK, quick service restaurants are the largest single subsector on the basis of number of meals served, accounting for 24% of meals served, or 30% if leisure is also classed as "quick service". The subsectors classed under "full service" in Figure 2 together account for 29% of meals and the subsectors classed under "institutional catering" in Figure 2 together account for 41% of meals served. By market value, Figure 4, which excludes institutional catering, shows that subsectors classed as "full service" in Figure 2 account for over double the spending of "quick service".

Figure 5, which excludes institutional catering and uses different subsectors to Figure 3, confirms that, globally, "quick service", i.e. fast food, street stalls, takeaway and cafes, accounts for a large fraction of transactions. Full service restaurants account for a disproportionately large fraction of value of sales, because full service restaurant food is generally relatively expensive compared to other subsectors. It is unsurprising that the global percentages of subsectors differ from those in the UK, since different countries will have different customs and preferences regarding eating outside of the home. For example, street stalls are common in developing countries (Gehlhar and Regmi, 2005).

Another way to classify the food service sector is as cost sector (in which the main motivation is not profit, but rather the service is provided for the benefit of another organisation, e.g. school meals) or profit sector (in which making profit is the main purpose of the outlet, e.g. restaurants) (SKM Enviros, 2010; The Institute of Grocery Distribution, 2005). The food service sector can also be divided into in-house operators, which provide catering directly to diners, and contract caterers, which provide catering services to other organisations (The Institute of Grocery Distribution, 2005). The UK contract catering market was worth £3.8 billion in 2015 (Mintel, 2015a). Contract catering is not equivalent to institutional catering because institutions can provide food service in-house, but contract catering does provide services to many of the same subsectors, as shown in Figure 6.

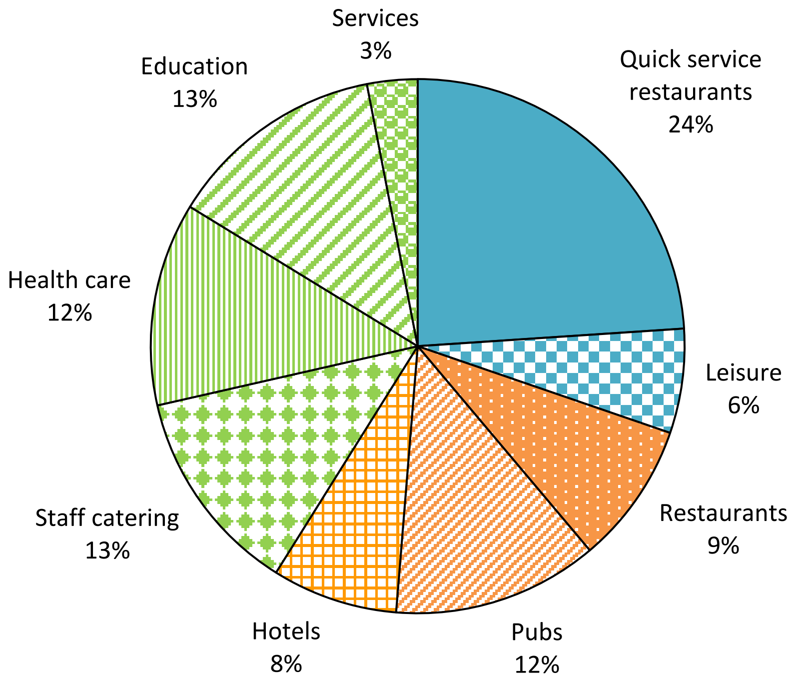


**Figure 3: Breakdown of UK food service subsectors by percentage of meals served in 2008**
Source: SKM Enviros (2010)

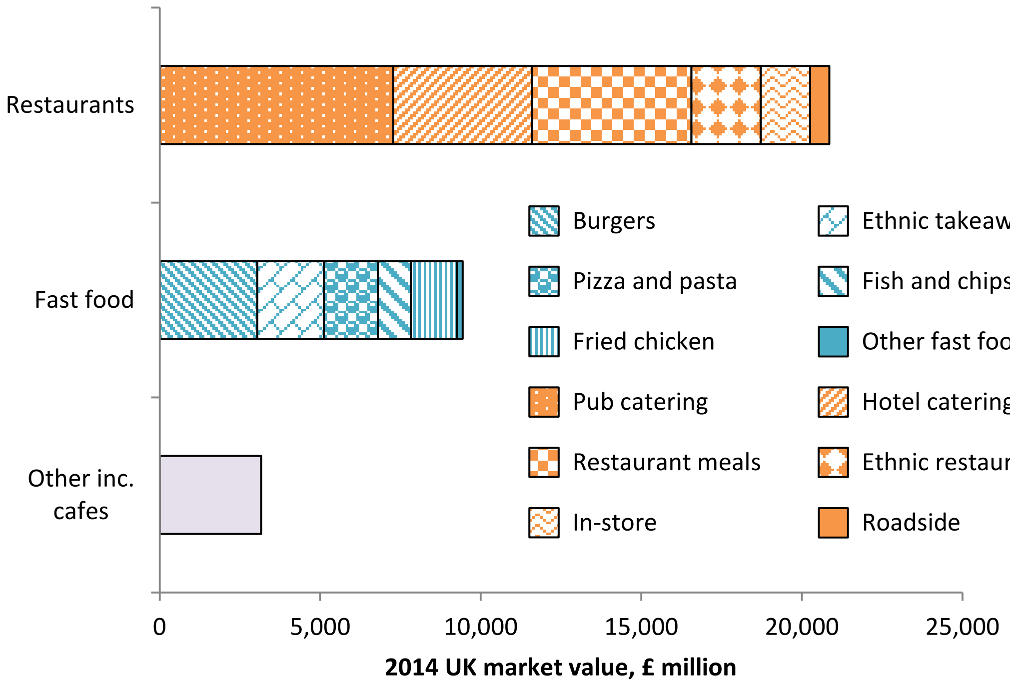


**Figure 4: UK food service market size by subsector, excluding institutional catering**
Source: Mintel (2015b)

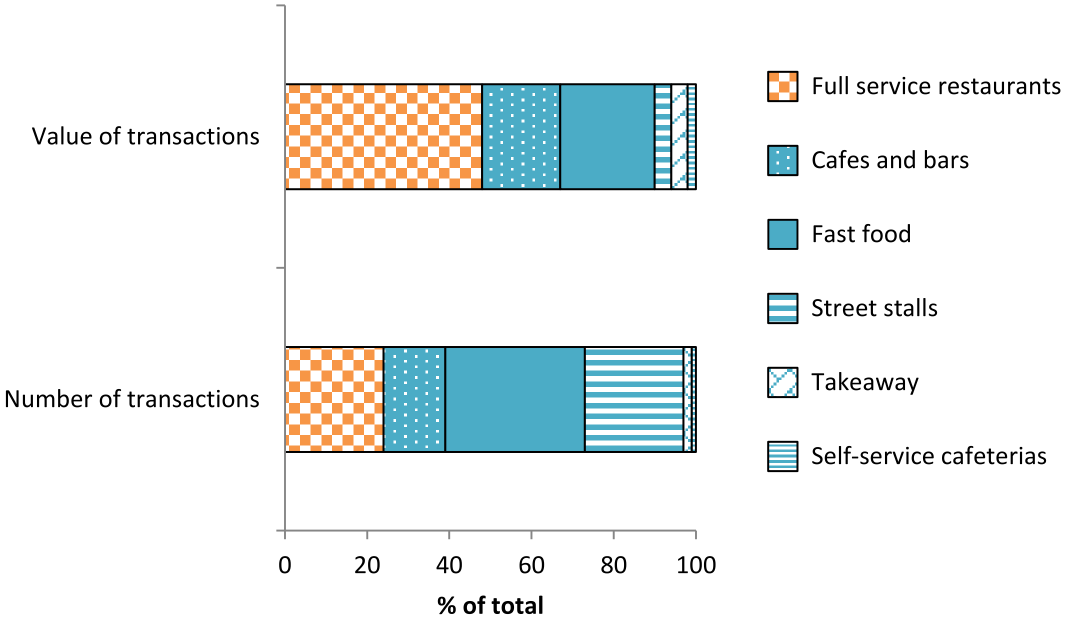


**Figure 5: Subsectors in global food service market, 2012 (excludes institutional catering)**
Source: Euromonitor International (2013)

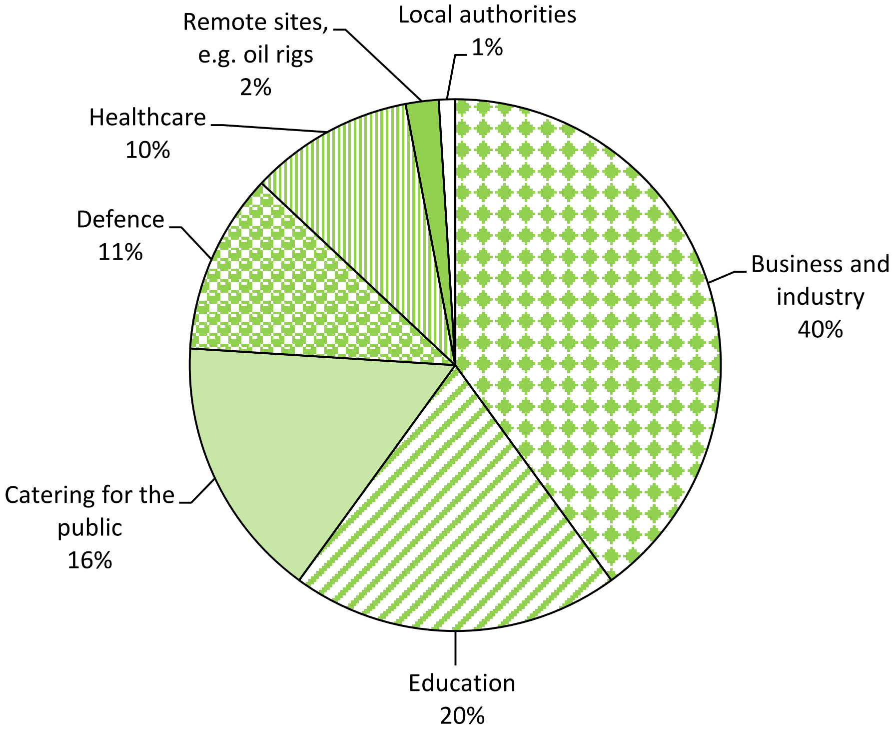


**Figure 6: Subsectors in UK contract catering sector, by percentage of meals served.**
Source: Mintel (2015a)

### 2.1.5 Supply chain configuration

In addition to food service operators there are other sorts of companies working in the food service supply chain. Farmers and food manufacturers provide food for both food retail and food service. There are also distributors (which deliver food to operators) and wholesalers (which sell food to distributors or operators). Distributors and wholesalers are often very large companies (despite being not well known to the public) because these types of business benefit from economies of scale and require high amounts of capital (Patel, 2007). They may offer a cash and carry service or deliver food directly to food service outlets. Figure 7 shows the supply chain routes available to operators and Figure 8 shows how most food service operators in the UK buy their food. Delivery wholesalers account for the majority of food service food purchases. In the UK, some leading delivered food service wholesalers are Brakes and Bidvest Foodservice. Some leading cash and carry operators are Booker, Bestway/Batleys and Costco (The Institute of Grocery Distribution, 2011).

Food service enterprises can operate on several different models (Fusi et al., 2015; Oakdene Hollins, 2013; University of Mississippi National Food Service Management Institute, 2002). The following divisions relate to the timing of the meal preparation in relation to the time of consumption:

- Cook-serve, in which food is served to the customer immediately after being prepared
- Cook-hold, in which there is a time delay between preparation and serving. This can be subdivided into:
    - Cook-warm (meals are kept hot until serving)
    - Cook-chill (meals are chilled and then reheated before serving)
    - Cook-freeze (meals are frozen and then reheated; this method is less common)

The cook-hold method can either be implemented on a single site or the meals can be prepared at one site (such as a centralised kitchen) and then transported to another site for serving.

## 2.2 Environmental sustainability schemes and guidelines for UK food service operators

### 2.2.1 Legislation and government guidelines

The UK government sets out buying standards that central government procurement must meet, either directly or through contractors. There is a standard specifically for food service (DEFRA, 2014a). It has both minimum mandatory standards and recommended best practice standards, covering traceability, animal welfare, nutrition, social impacts and environmental performance. There are also separate government procurement standards that specify efficiency standards for food service equipment such as ovens, dishwashers and refrigerators (DEFRA, 2012b).

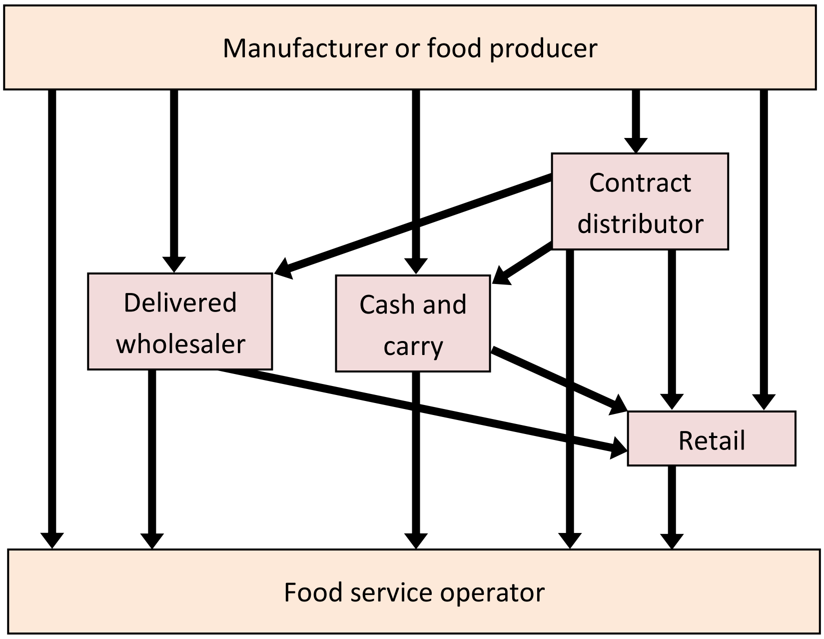


**Figure 7: Supply chain routes available to food service operators**
Source: The Institute of Grocery Distribution (2005)

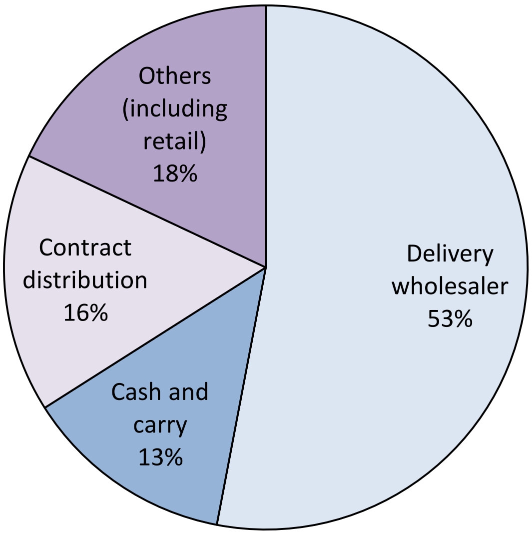


**Figure 8: Food service sector food purchases by route to market**
Source: The Institute of Grocery Distribution (2005)

The UK Government's Plan for Public Procurement (Bonfield, 2014) synthesises previous standards and guidance to create a "balanced scorecard" for public sector food service procurement. The scorecard is in line with European procurement law and is intended for voluntary use by contractors bidding for public sector contracts (DEFRA, 2014c). It covers many aspects including cost and quality. Aspects specifically relating to environmental sustainability are "environment" and "resource efficiency" with respect to energy, water and waste. For each aspect, both mandatory minimum specifications and descriptions of various levels of practice from "satisfactory" to "excellent" are given. Many of the specifications include adherence to existing standards such as the FAO Code of Conduct for Responsible Fisheries. Some of the specifications are qualitative and vague, such as the requirement to have an energy management policy without specifying what that policy must contain. The relative importance of each of the aspects is not yet given, although the government plans to provide weightings in the future.

Legislation does not have to be targeted at food service to affect food service outlets in both the public and private sectors. For example, landfill tax, at £84.40 per tonne in 2016 (HM Revenue & Customs, 2016), affects the waste management decisions of outlets (Oakdene Hollins, 2013). The Climate Change Levy is paid on the basis of commercial energy use (GOV.UK, 2016b). The Carbon Reduction Commitment Energy Efficiency Scheme requires large organisations to monitor their carbon dioxide emissions and purchase allowances (GOV.UK, 2016c). The scheme will be abolished in 2019, according to Carbon Trust (undated). Enhanced capital allowances to reduce tax are available when purchasing energy efficient equipment (GOV.UK, 2016a). Disposing of food waste down drains is already illegal in Scotland and will become illegal in the rest of the UK within two years (Enviro-Waste, undated).

### 2.2.2 Sustainability schemes specifically for food service

A number of schemes are available for food service operators in the UK to help them become more sustainable. Some of these are described below.

#### *2.2.2.1 The Sustainable Restaurant Association*

The Sustainable Restaurant Association (SRA) is a UK-based charity that helps "restaurants to become more sustainable and diners make more sustainable choices when dining out" (Sustainable Restaurant Association, 2010). It does this through a star rating system, as well as a separate scheme aimed specifically at university catering, by which restaurants can assess their sustainability in 14 key areas, shown in Table 2. Restaurants undertake the assessment voluntarily and in return are featured in the online Sustainable Restaurant Guide, which allows diners to search for nearby sustainable restaurants. The SRA also offers consultancy, food waste audits and energy audits.

**Table 2: Areas covered by SRA sustainability assessment, by category**

Data source: Sustainable Restaurant Association (2010)

| Sourcing | Environment | Society |
|---|---|---|
| • Environmentally positive farming<br>• Local and seasonal food<br>• Sustainable fish<br>• Ethical meat and dairy<br>• Fair trade | • Water saving<br>• Workplace resources<br>• Supply chain<br>• Waste management<br>• Energy efficiency | • Community engagement<br>• Treating people fairly<br>• Healthy eating<br>• Responsible marketing |

Caterers can receive a one, two or three star rating, depending on their scores in the different assessment areas. It is unclear how quantitative the assessment is and whether the ratings are a good indicator of the Life Cycle Assessment performance of a restaurant.

None of the categories address the issue of menu choice (e.g. vegetarian or vegan dishes) beyond the issues of seasonal food and animal welfare.

Restaurants are permitted to join the SRA as members without gaining a sustainability rating, but they must commit to take at least three new actions (related to some of the 14 assessed areas of sustainability) each year.

### *2.2.2.2 Food for Life Catering Mark*

The Food for Life Catering Mark is a voluntary standard, provided by the certification body of the Soil Association, which covers issues of health and animal welfare. Wider issues of sustainability, such as energy use and greenhouse gas emissions, are not covered. It applies to any sort of catering institution (Soil Association Certification, 2015). Factors covered include:

- Additives and trans fats
- Fresh food preparation from unprocessed ingredients
- Animal welfare standards
- Seasonal and local produce
- No genetically modified organisms
- Free drinking water
- No endangered fish species
- Food safety
- Health (including availability of vegetarian and vegan dishes)

### *2.2.2.3 The Carbon Trust Calculator*

The Carbon Trust have developed a carbon calculator that helps to reduce the energy use of food service operations (Carbon Trust, 2014). Factors considered by the calculator include menu choice, correct sizing of equipment, behavioural strategies, food delivery, storage and serving schedules.

#### *2.2.2.4 Waste & Resources Action Programme*

The charity WRAP has run multiple initiatives relevant to food service. The Hospitality and Food Service Agreement (WRAP, 2012; WRAP, 2014) was designed to reduce food and packaging waste and increase the proportion recycled, composted or anaerobically digested. Any size of business is able to join the agreement. By 2014, progress had been made (representing a saving of £3.6 million to businesses) but the original goals had not been reached. The Federation House Commitment (WRAP, 2015b) helped food and drink manufacturers to reduce their water use. The Business Waste and Recycling Commitment (WRAP, undated-a) supports local authorities to provide improved recycling services to businesses.

#### *2.2.2.5 Plate2Planet*

The supplier Bidvest Foodservice has set up the Plate2Planet website (Bidvest Foodservice, 2016) as a hub for foodservice organisations to share best practice on sustainability.

### 2.2.3 Sustainability schemes for the general food sector

Many other food sustainability schemes are available, covering a wide variety of aspects of sustainability. Not all of these are aimed specifically at foodservice outlets. There are too many to describe exhaustively, but some examples are given below.

The World Wide Fund for Nature (WWF) Livewell principles propose that a healthier and more environmentally sustainable diet can be achieved by eating more plants and less meat, eating a variety of foods, wasting less food, buying certified ingredients and eating less fat, salt and sugar (WWF, 2011).

Sustainable Food Cities (Sustainable Food Cities, 2015) is a network that encourages the public sector, businesses and NGOs to tackle a range of sustainability issues around food. Initiatives relating to catering and food procurement include food policies adopted by city councils and individual organisations, sourcing of local food and encouragement for organisations to achieve sustainability accreditation (for example, under the schemes mentioned above).

The Marine Stewardship Council provides certification for restaurants and food service firms who can show that they use certified sustainable seafood (Marine Stewardship Council, 2014).

The Good Egg Award promotes the use of free range eggs (Compassion in World Farming, 2014).

Meat Free Mondays, sometimes adopted by food service outlets, encourages people to reduce their meat consumption by cutting it out on one day of the week (Meat Free Monday, 2016).

The Roundtable on Sustainable Palm Oil provides certification of environmentally and socially sustainable production (Roundtable on Sustainable Palm Oil, 2016).

### 2.2.4 Discussion of sustainability schemes

The examples above show that sustainability standards and schemes vary widely in focus, with some standards covering only a single issue (e.g. free range eggs) and others claiming to measure sustainability more broadly. Such a wide variety may result in confusion amongst both operators and customers.

It is unclear to what extent adhering to any of these standards would affect the life cycle performance of the food served by caterers. There is a danger that, by focusing on the food service stage, some environmental burdens may be shifted to other stages of the food supply chain. For example, the Food for Life Catering Mark’s requirement that local food be chosen may be counterproductive if agriculture in another country has significantly lower impacts that outweigh the additional transport required.

Furthermore, only some of the standards consider menu choice as a means of improving the environmental performance of food served, for example reducing the amount of animal products. This is important because dietary choice can affect environmental impacts. For example, (Scarborough et al., 2014) find that, in the UK, daily food-related GHG emissions are 7.2 kg $CO_2$ eq. for diets rich in meat and only 2.9 kg $CO_2$ eq. for vegan diets. Moderate meat intake, pescetarian and vegetarian diets fall between these two extremes. Nijdam et al. (2012) show that GHG emissions per kg of protein for vegetal products (such as pulses), poultry, eggs and some types of seafood are relatively low, compared to moderate emissions for pork and dairy and high emissions for beef. It is therefore questionable how much improvement is possible by only focusing on welfare issues or direct energy use by the caterer.

WWF (2016) suggests that there is a lack of government incentives for many private sector outlets to prioritise health and sustainability. Strong market competition means that operators who do try to be more environmentally sustainable could be risking their economic sustainability. Some interviewees in the report state that only regulation, rather than voluntary commitments, can create a “level playing field”. Even if there is relatively little legislation affecting the private sector, public sector buying standards can influence the private sector: according to WWF (2016), some food service providers are using the public procurement standards for their private sector contracts.

One downside of relying on government guidance to incentivise sustainability is that guidance may change depending on the political climate. The recent turmoil over the UK’s membership of the European Union may create uncertainty over whether legislation regarding food sustainability will be consistent in the years to come, particularly where it is based on European laws (Sustainable Restaurant Association, 2015).

## 2.3 Environmental sustainability of the UK food service sector

### 2.3.1 Putting the environmental impacts of the UK food service sector into context

Estimates of the overall environmental impact of the food sector and food service sector vary widely due to different assumptions in calculations, but it is clear that food as a whole (both retail and food service) accounts for a substantial portion of global GHG emissions.

Tara Garnett (Garnett, 2011) estimates that the entire global food chain directly accounts for 30% of global GHG emissions, including the effects of land use change, i.e. conversion of natural ecosystems into farmland.

The majority of direct emissions from agriculture are methane and nitrous oxide (Garnett, 2011). Methane is emitted by animals' digestive systems (particularly ruminants such as cattle) and anaerobic decomposition of vegetation (e.g. in rice paddy fields). Nitrous oxide can be emitted from soils naturally, but the quantities produced may be increased by farming practices such as application of nitrogen-based fertilisers. It can also be given off by stored manure (Reay, undated; US Environmental Protection Agency, undated-b).

Goodland and Anhang (2009) put the impact of animal agriculture alone at 51% of global GHG emissions (excluding non-animal agriculture, and all other stages of the food chain) – much higher than the FAO's corresponding estimate of 18% (Food and Agricultural Organisation, 2006). The discrepancy between the two estimates is due to emissions said to be overlooked, undercounted or misallocated by the FAO (thus increasing the tally of global emissions), for example animal respiration, fish farming, photosynthesis foregone by deforestation and using the 20-year timeframe for methane global warming potential, rather than the more commonly used 100-year timeframe. The result has been disputed (Herrero et al., 2011).

A study by the European Commission estimates that "food and non-alcoholic beverages" account for around 29% of the European Union's total contribution to global warming, with "eating and drinking places" accounting for 8% (Huppes et al., 2006). These categories are separate rather than overlapping. Adding them together gives 37% of overall European global warming impact, but this still does not include, say, energy used in home cooking and so is likely to be an underestimate for the whole food chain. The study also gives estimates of the fraction of the contribution of these sectors towards other environmental impact categories, as shown in Table 3. The contribution of both categories together ranges from 27% to 70%, all of which are greater than the 25% share of spending that food accounts for. These estimates are produced by economic input-output modelling rather than direct emissions measurement and are based on data from 1992, so may be inaccurate or out of date.

**Table 3: Environmental impacts of and spending on food-related sectors as a percentage of total impact of the EU for each category**

Source: Huppes et al. (2006)

| Impact category | Food and non-alcoholic beverages | Eating and drinking places | Sum of both categories |
|---|---|---|---|
| Abiotic depletion | 21% | 6% | 27% |
| Global warming | 29% | 8% | 37% |
| Ozone layer depletion | 24% | 8% | 32% |
| Human toxicity | 24% | 7% | 31% |
| Ecotoxicity | 32% | 8% | 40% |
| Photochemical oxidation | 26% | 8% | 34% |
| Acidification | 30% | 8% | 38% |
| Eutrophication | 58% | 12% | 70% |
| Private and public expenditure | 17% | 8% | 25% |

**Table 4: Annual environmental impacts associated with a basket of food products**

Data source: Notarnicola et al. (2016)

| Impact category | Impact per average European citizen, per year |
|---|---|
| Climate change | 1,400 kg $CO_2$ eq. |
| Ozone depletion | 60 mg R-11 eq. |
| Human toxicity | 0.0021 comparative toxic units for human |
| Particulate matter | 0.85 kg $PM_{2.5}$ |
| Ionising radiation human health | 49 kBq $U^{235}$ eq. |
| Photochemical ozone formation | 2.8 kg NMVOC eq. |
| Acidification | 30 mol $H^+$ eq. |
| Terrestrial eutrophication | 130 mol N eq. |
| Freshwater eutrophication | 0.44 kg P eq. |
| Marine eutrophication | 12 kg N eq. |
| Freshwater ecotoxicity | 4400 comparative toxic units for ecotoxicity |
| Land use | 15 tonne carbon deficit |
| Water resource depletion | 44 $m^3$ water eq. |
| Resource depletion | 16 g Sb eq. |

**Table 5: UK food supply chain emissions and energy use**

Source: SKM Enviros (2010)

| Stage | Total GHGs Mt $CO_2$ eq. | % of total GHG emissions | Energy | $CH_4/N_2O$ | Refrigerants |
|---|---|---|---|---|---|
| | | | Mt $CO_2$ eq. | | |
| Pre-farm | 4 | 3% | 4 | | |
| Agriculture | 53 | 33% | 7 | 46 | * |
| Transport | 15 | 9% | 15 | | * |
| Manufacture | 13 | 8% | 12 | | 1 |
| Retail | 10 | 6% | 8 | | 2 |
| **Food Service** | **5** | **3%** | **5** | | * |
| Household | 21 | 13% | 21 | | * |
| Net trade | 39 | 24% | 28 | 11 | |
| Total | 160 | 100% | 100 | 57 | 3 |
| ** denotes limited data* | | % of total | 63% | 35% | 2% |

A more recent study performed Life Cycle Assessment on a representative basket of food products to estimate the food-related environmental impacts of the average European citizen (Notarnicola et al., 2016). The results are summarised in Table 4.

According to a study for DEFRA (SKM Enviros, 2010), emissions from the UK food chain are 160 Mt $CO_2$ eq. for energy, water and waste, including an allowance for food imported from overseas (it is unclear whether this also accounts for food exported from the UK). This is around 25% of total UK greenhouse gas emissions. Of this, food service operations have direct emissions of 5 Mtonne $CO_2$ eq. (3% of food chain emissions). However, when the proportion of the upstream emissions associated with the food produced for the food service sector is included, this rises to 24 Mtonne $CO_2$ eq. (15% of food chain emissions). For comparison, Garnett (2011) estimates that food service operations (not including their share of other stages) account for 6% of UK food chain GHG emissions.

Tassou et al. (2014) estimate that the UK food chain was responsible for 176 Mtonne $CO_2$ eq. emissions in 2013, which is a slight increase on the 2010 estimate from SKM Enviros (2010). DEFRA (2016) gives an estimate of 70 Mtonne $CO_2$ eq. per year for the UK food sector, but this excludes several important categories such as land use change, retail, domestic energy use and food import, so it is unsurprising that this estimate is much lower.

Table 5 shows that a mere 11% of emissions from energy use in the UK food chain are directly attributed to the agriculture and pre-farm stages. However, this does not include energy use in agriculture overseas. The majority of energy use is in the post-farm stages, showing that when examining energy use in the food chain, agriculture should not be the only focus point.

Garnett (2011) gives a different percentage breakdown, estimating that in the UK (excluding land use change) agriculture directly accounts for 40% of food chain emissions with fertiliser manufacture accounting for another 5%. This means that 55% of food-related GHG emissions come from post-farm stages of the supply chain, compared to 64% estimated by SKM Enviros (2010). The difference may be partly because SKM Enviros (2010) does not include overseas agriculture in the “agriculture” category. Both Garnett (2011) and SKM Enviros (2010) show that it is important to study the opportunities for environmental improvement in the post-farm stages as well as agriculture.

According to DEFRA’s Food Statistics Pocketbook, food service directly accounted for only 3 Mtonne $CO_2$ eq. in 2013 (DEFRA, 2016). However, this does not include an allocation for catering’s share of agricultural production. It is lower than, but comparable to, the 5 Mtonne $CO_2$ eq. estimate given in Table 5 for the direct impacts of food service. Tassou et al. (2014) give a slightly larger estimate of 6 Mtonne $CO_2$ eq. per year, but this includes hotels as well.

Tassou et al. (2014) estimate that the food chain (not just food service) accounts for 18% of primary energy use in the UK. The UK's food service sector's direct energy use has been estimated at 22 TWh/year (CIBSE, 2009) and 24 TWh/year (Tassou et al., 2014). The latter estimate is approximately 1% of the UK's total primary energy consumption in 2014 and therefore around 6% of the UK food chain's energy use (Department of Energy & Climate Change, 2015a).

According to DEFRA (2016), the UK food chain produced 15 Mtonne of waste in 2013 (more than one third of the total amount of food purchased). Of this, 0.92 Mtonne of waste was from "hospitality", i.e. food service. This does not include packaging waste. When packaging waste is included, the total for food service is 2.87 Mtonne (Oakdene Hollins, 2013).

The UK food and drink industry as a whole (excluding agriculture) was estimated to use 412 million $m^3$ of water in 2007, decreasing to approximately 360 million $m^3$ by 2010 (WRAP, 2013d). Within this, the proportion attributable to "hospitality and food service" increased from 41% in 2007 to around 44% in 2010. This was calculated using benchmarks rather than measured data. Although the category does include hotels, only water used for food preparation and by employees was included. Water use by customers, e.g. hotel showers, was excluded so this category can be roughly equated to food service. The other major user of water in the food and drink industry is the manufacturing stage, accounting for 56% in 2007 and 53% in 2010. The UK's overall water use in 2010 was 12.4 billion $m^3$ (including both mains water and direct abstraction), meaning that hospitality and food service together account for only 1.7% of overall water use.

### 2.3.2 Impacts of different food service subsectors

Some information exists on the environmental impacts of different subsectors of the UK food service industry.

Tassou et al. (2014) estimate that 30% of energy use in the UK food service sector is in commercial food service and 40% is in non-commercial catering such as schools, hospitals and defence. This corresponds to around 7 TWh per year for commercial and 10 TWh per year for non-commercial. Mudie et al. (2013b) estimate the energy use of the UK commercial catering sector at between 6.5 and 12.8 TWh/year. The upper estimate is extrapolated from data from a single chain of pub restaurants, which is unlikely to be representative of the whole sector.

The UK contract catering sector has been estimated to be directly responsible for 1.3 Mtonne $CO_2$ eq./year, based on data from four different sites extrapolated to the whole subsector. This is considerably higher than a previous estimate of 0.7 Mtonne $CO_2$ eq./year (AEA Technology Plc., 2012). If the new estimate is correct, the contract catering sector would account for 26% of direct UK food service emissions, based on the figures in Table 5.

Total waste produced by each subsector is shown in Figure 9, and Figure 10 shows the value of avoidable food waste per meal. It can be seen that restaurants are both the greatest absolute producers of waste and the most wasteful in terms of value of avoidable food waste per meal served. Staff catering is the least wasteful subsector, perhaps because they operate on a tighter budget.

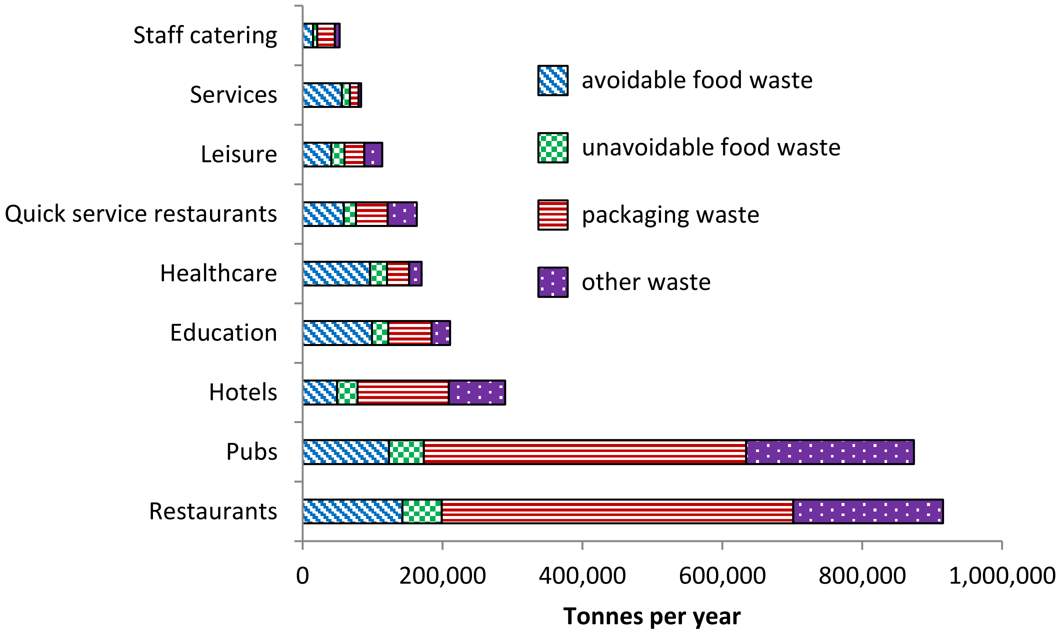


**Figure 9: UK food service waste by subsector and type of waste**
Source: Oakdene Hollins (2013)

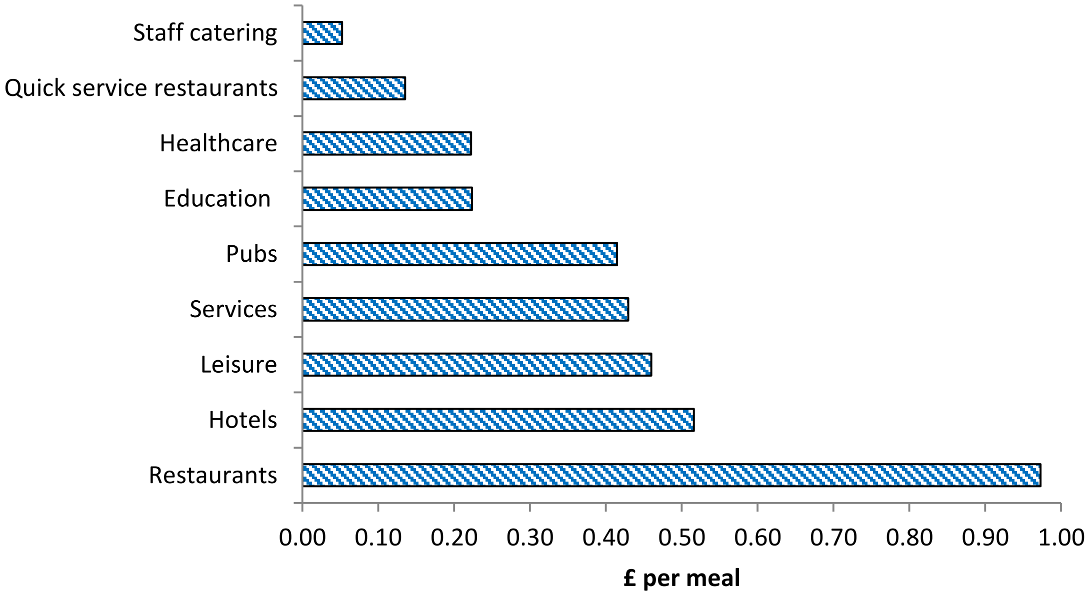


**Figure 10: Value of avoidable food waste in different UK subsectors**
Source: WRAP (2013c)

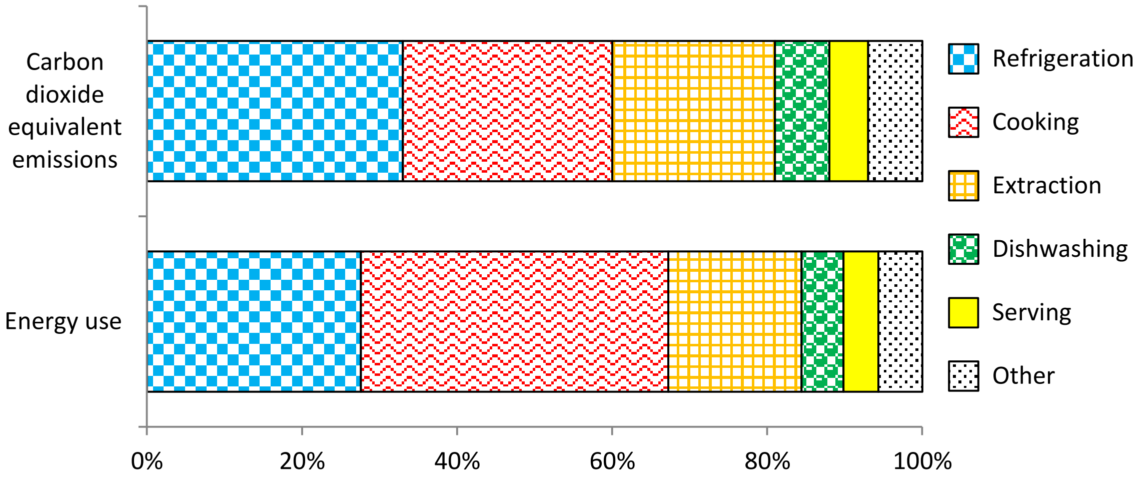


**Figure 11: Energy and greenhouse gas emissions in the UK contract catering sector, based on a sample of four sites**
Direct energy use only, with no allocation for the rest of the supply chain. Extraction refers to air conditioning and ventilation. Source: AEA Technology Plc. (2012).

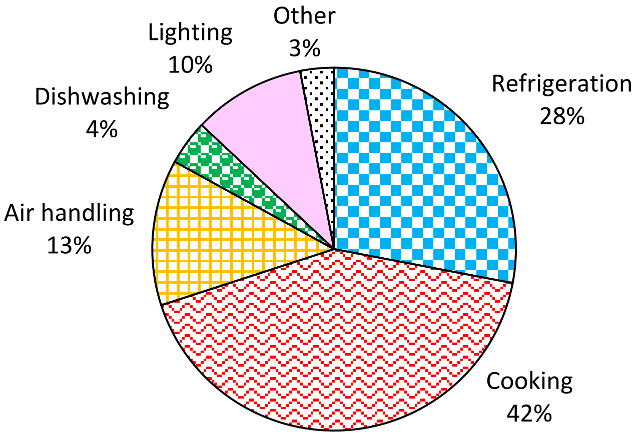


**Figure 12: Energy use (electricity and gas) in a sample of UK pub restaurants**
Air handling refers to air conditioning and ventilation. Source: Mudie et al. (2013a)

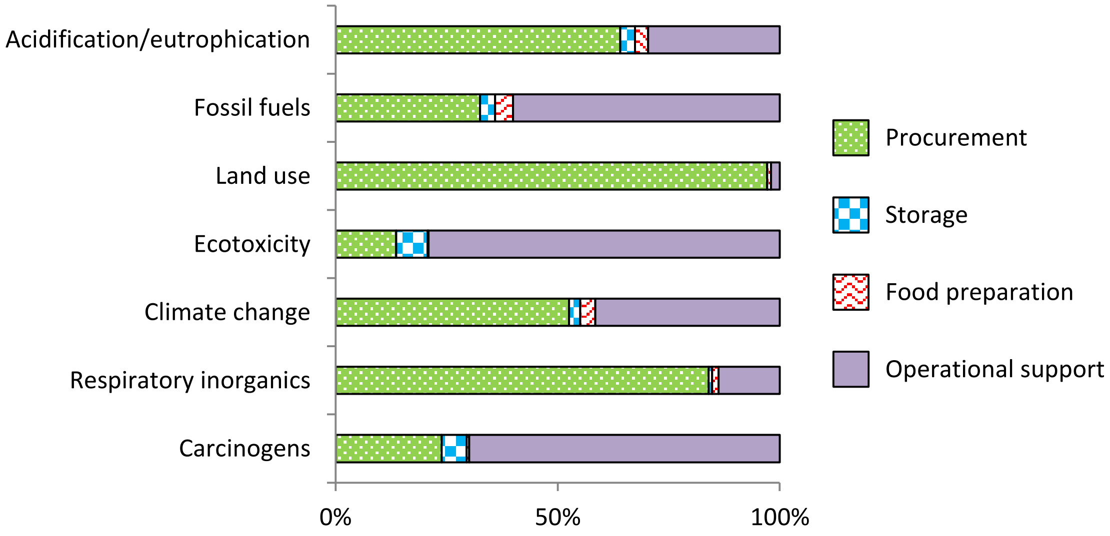


**Figure 13: LCA results of a sample of catering sites in the US as a percentage of each impact category**
Source: Baldwin et al. (2011)

### 2.3.3 Energy hotspots

Some studies examine what energy is used on directly within food service locations (see Figure 11 and Figure 12). Key uses include refrigeration, cooking and air handling (e.g. ventilation, air conditioning). As can be seen from the figures, the greenhouse gas emissions follow this pattern.

Mudie et al. (2013a) find that significant electricity savings could be made by behavioural changes and improved maintenance. Energy is found to be wasted by kitchen staff leaving equipment switched on even when it is not being used, refrigerators being located too close to heat sources and excessive use of hot-holding. In another example of this, Swain (2009) find that simply cleaning the condenser coil on a refrigerator in a university canteen reduces its energy use by 8%, and increasing the set point of a freezer by 5°C produces an 11% energy saving.

Tassou et al. (2014) estimate that only 26% of energy used in hotel and catering buildings is actually used on "catering processes" such as cooking and refrigeration. This suggests that other uses within the buildings, such as space heating and lighting, may have an important contribution.

### 2.3.4 Life Cycle Assessment Studies

Some Life Cycle Assessment (LCA) studies have been published relating specifically to the food service sector, although not specifically for the UK food service sector.

Baldwin et al. (2011) give an LCA of a sample of six different types of catering sites in the United States. The supply chain is divided into four categories: procurement (including all stages prior to food and beverages reaching the restaurant); storage; preparation and cooking; food service and operational support (lighting, heating, ventilation and air conditioning, water use and non-food supplies). The results, shown in Figure 13, are given as percentage contributions to each impact category rather than absolute values. On four of the seven impact categories, the procurement stage is dominant. Impacts from storage and preparation are minimal relative to the other stages, and operational support is the major contributor to carcinogens, ecotoxicity and fossil fuels. This suggests that focusing purely on the kitchen when looking at environmental improvements may not be effective – instead, perhaps caterers should focus on the type of food they buy and energy use outside of the kitchen.

A life cycle comparison (Ying and Freed, 2013) between US restaurant meals and home-cooked meals shows that a meal at a top-end restaurant produced 24.7 kg $CO_2$ eq./diner, compared to 8.5 kg $CO_2$ eq./diner for a mid-range restaurant and 7.5 kg $CO_2$ eq./diner for a home-cooked meal. In all cases, the ingredients contributed over 60% to the carbon footprint, with steak dominating. The meals in each location are different, so the study is not comparing like with like. One interesting point is that the home-cooked meal used two nitrous oxide cartridges to produce whipped cream. The impact of these alone is 8.7 kg $CO_2$ eq. They are therefore left out of the total for the home-cooked meal, given the ease of replacing them with a whisk. However, this information may be relevant to food service outlets where whipped cream is commonly used, such as coffee shops.

Jungbluth et al. (2016) perform LCA on the meals prepared by a Swiss operator of 240 canteens to calculate the impacts associated with farming, transporting and preparation. A typical meal is responsible for 4.1 kg $CO_2$ eq. – considerably less than the estimates for restaurant meals and a US home-cooked meal shown above. The breakdown of these emissions is shown in Figure 14. Agriculture accounts for 60% with direct canteen operation accounting for 25% and processing, packaging and transport together accounting for 15%. Other impacts are calculated using the ecological scarcity method. It is also shown how the impact of different production types varies throughout the year – for example, asparagus can be produced locally for very low impact during early summer, but for the rest of the year it is flown in from Peru with very high GHG emissions. An Excel tool was developed to help canteen operators calculate GHG emissions associated with their meals.

Manthey et al. (2011) calculate the carbon footprint of meals prepared in a German university canteen. This includes agriculture and transport, but not the canteen itself nor any waste produced. This may partially explain why the carbon footprint results – 2.8 kg $CO_2$ eq. for a meal containing meat and dairy, around 1.0 kg $CO_2$ eq. for a vegetarian meal and around 0.5 kg $CO_2$ eq. for a vegan meal – appear lower than the other estimates discussed above. This study is not useful for looking at the life cycle impacts of the meal, because it misses out key stages and only reports GHG emissions.

Similarly, Leuenberger et al. (2010) examine different meal types prepared in Swiss public canteens (e.g. hospitals, retirement homes) and find that meat-based meals on average produce 3.0 kg $CO_2$ eq., whereas vegetarian meals produce only 0.9 kg $CO_2$ eq. Electricity used in preparing the meals is estimated only roughly and energy used in storage is not accounted for – hence, these estimates are likely to be on the low side. Other impact categories are not considered.

Regarding fast food restaurants, Bengtsson and Seddon (2013) give an LCA of chicken products delivered to an Australian retailer or quick service restaurant, but do not include the quick service restaurant stage itself due to a lack of data. This suggests that more data are needed in the fast food subsector.

Kuo et al. (2005) study boxed food served to tourists in Taiwan. Impacts of three different types of packaging (cardboard, polystyrene and polypropylene) are considered in terms of "environmental cost", a monetary indicator based on emissions to the environment, with the polystyrene box having the lowest environmental cost.

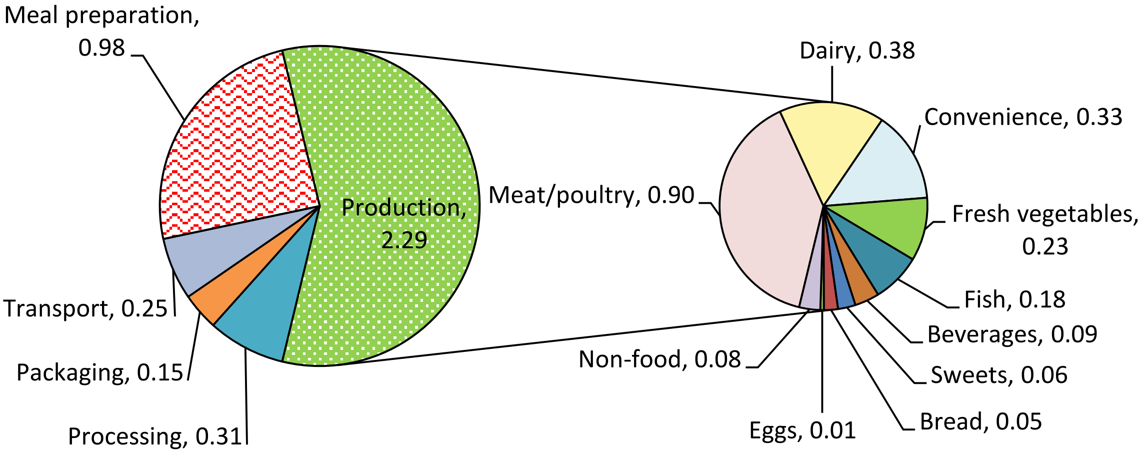


**Figure 14: Global warming potential of a Swiss canteen meal (kg $CO_2$ eq./meal)**

Source: Jungbluth et al. (2016)

Wang et al. (2013) consider Danish “professionally prepared meals” using both supply chain planning and Life Cycle Assessment. The supply chain considered is based on satellite kitchens, i.e. the centralised food service model discussed above. The effects of different refrigeration methods and packaging materials are investigated using a cradle to grave perspective. The raw material stage accounts for the majority of the impacts. A variety of impact categories are considered.

Dawe et al. (2004) perform ecological footprinting of a British college, including the food served in its canteen. The food is found to account for one quarter of the college’s environmental footprint (in terms of area of land and water required to produce goods and assimilate emissions). However, it is unclear which parts of the food supply chain are included or how many meals are served.

Fusi et al. (2015) examine the life cycle impacts of preparing pasta in the catering sector. Two types of supply chain (cook-warm and cook-chill) and two cooking methods (pasta cookers and range tops) were compared. The cook-chill chain was found to have generally higher environmental impacts than the cook-warm chain due to higher energy use and use of refrigerants. Pasta cookers were more efficient in terms of energy and water consumption and hence reduced environmental impacts.

## 2.4 Data gaps and areas for further research

Oakdene Hollins (2013) note a particular lack of data on small-to-medium enterprise engagement with sustainability initiatives. Data for other types of information, e.g. waste and water use, is patchy, varying highly between subsectors. As shown in Table 6, data coverage is particularly poor for restaurants, pubs, leisure catering and staff catering. However, data on energy use in gastro-pubs has recently become available thanks to Mudie et al. (2013a), who note a lack of prior research on energy consumption and reduction potential in commercial kitchens.

**Table 6: Data gaps identified for the hospitality and food service supply chain**

*** = excellent coverage; ** = good coverage; * = limited coverage; - = negligible coverage, as assessed qualitatively by Oakdene Hollins (2013)

| Sub-sectors | Sector profile | Waste data | Energy data | Water data | Technology | Bench-marking | Small and medium-sized enterprise engagement | Examples of good practice |
|---|---|---|---|---|---|---|---|---|
| Restaurants | *** | *** | * | - | - | - | - | * |
| Quick service restaurants | *** | *** | - | - | ** | * | - | ** |
| Pubs | *** | *** | - | - | - | - | - | * |
| Hotels | *** | *** | ** | ** | - | * | - | * |
| Leisure | ** | *** | - | - | - | - | - | - |
| Staff catering | ** | *** | - | - | - | * | - | * |
| Healthcare | *** | *** | ** | * | ** | - | - | ** |
| Education | *** | *** | ** | * | - | - | - | * |
| Services | *** | *** | - | - | ** | - | - | * |

SKM Enviros (2010) suggest that, amongst others, further research is needed into the variations between subsectors, supply chain models and methods of producing meals. This is consistent with Tara Garnett's comment (Garnett, 2008) that more research into the differences between food service operators according to size and according to public or private sector would be beneficial.

There appears to be a lack of studies of life cycle environmental impacts relating to the UK food service sector. Even for the food service sector in other countries, few of the studies mentioned above consider a range of impact categories from cradle to grave. Therefore, an LCA study of the UK food service sector would have value by helping stakeholders to quantify and understand the impacts of the supply chain and by indicating the most promising areas for improvement. In an attempt to contribute towards that goal the following chapter presents an LCA study of typical meals prepared in British canteens.

# 3. Life Cycle Assessment of a meal prepared in a British canteen

## 3.1 Introduction

The food service sector is highly varied, with subsectors ranging from fast food to pubs to restaurants. This study will focus on canteens. Canteens have been selected because they are used in staff catering, healthcare and education and therefore can be said to be ubiquitous throughout the economy. In all of the above settings, canteens tend to share the characteristic of meals being prepared in batches.

Canteens can use several different types of food service systems, including on-site preparation (where meals are assembled and cooked in the same location that they will be served at), centralised (where food is prepared in a centralised facility and transported to satellite kitchens) and ready-prepared (where meals are produced on site, then stored cold and reheated for serving). On-site food preparation from scratch has been assumed for this study because it is widespread (University of Mississippi National Food Service Management Institute, 2002). It is also assumed that food is kept warm for a period of time before being served. This method is known as “cook-warm” (a subdivision of “cook-hold”, which refers to any system where there is a time delay between cooking and serving), and is commonly used in food service (Light and Walker, 1990; Wilkinson et al., 1991). It has the advantage of allowing large batches of food to be prepared at the same time and reducing the time that customers have to wait.

The following sections describe the goal and scope of the analysis, the inventory data collection and the impact assessment of the LCA.

## 3.2 Goal and scope definition

The goal of this study is to assess life cycle environmental impacts of a meal prepared in a cook-hold canteen. The results will be compared and contrasted with the environmental impacts of the equivalent meal prepared as a ready-made meal and as a home-made meal, presented in Schmidt Rivera et al. (2014). The results will also be compared with LCA studies for the food service sector in other countries.

A roast chicken meal has been chosen for consideration in the baseline case. This matches the meal composition used by Schmidt Rivera et al. (2014). Furthermore, poultry is a commonly consumed type of meat when eating out in the UK (DEFRA, 2012a). Other types of meat and alternatives to meat are considered through a range of scenarios, as well as sourcing ingredients from different countries, using organic ingredients and different cooking methods. The scope of the study is from “cradle to grave”.

### 3.2.1 Functional unit

The functional unit is defined as "one meal served to a consumer in a cook-hold canteen in the UK food service sector". The composition of the meal used in the baseline scenario is shown in Table 7 and is based on the composition used by Schmidt Rivera et al. (2014) for ease of comparison. Note that the meal composition given by Schmidt Rivera et al. (2014) does not account for shrinkage of the ingredients during cooking. Weights for this meal are therefore chosen to match the weights that would have been given if shrinkage had been accounted for by Schmidt Rivera et al. (2014). The compositions of meals in alternative scenarios are discussed in section 3.2.3.

### 3.2.2 Description of system and system boundaries

The system considered in this study is outlined in Figure 15, with more details for each stage given in Table 8. As shown, the system includes cultivating vegetables and rearing chickens, their processing and packaging, storage in a wholesale depot, preparation of the meal and heated display in the kitchen before it is eaten and disposal of food and packaging waste generated in the canteen. Transport across the supply chain is also included as is the waste from each life cycle stage, in addition to the canteen waste. Refer to the fold-out diagram included at the back of this thesis for a more detailed diagram of the life cycle system in the baseline case (Case A as defined in Table 9). The fold-out diagram shows the main processes in each life cycle stage. It also illustrates how the main data sources have been put together.

The system does not include space heating and lighting in the canteen, human metabolism or the manufacture of equipment used in the kitchen or in processing (British Standards Institution (2008) recommends excluding capital goods). Biogenic carbon (i.e. carbon taken up by crops from the atmosphere) is not considered, since the carbon will return to the atmosphere within a short time period. Impacts from land use change (such as greenhouse gas emissions from deforestation) are only considered to the extent that the agricultural data sources include this effect. Brazilian chicken is the only product to have a notable deforestation component.

**Table 7: Composition of the meal in the baseline scenario**

Based on Schmidt Rivera et al. (2014)

| Ingredients | Cooked weight (g) | Raw weight (g) |
|---|---|---|
| Chicken | 68.6 | 98.0 |
| Potatoes | 85.8 | 87.5 |
| Carrots | 31.5 | 35.0 |
| Peas | 30.5 | 35.0 |
| Tomato sauce | 99.7 | 150.5 |
| *Tomatoes* | *66.2* | *112.2 (raw, deseeded)* |
| *Onions* | *23.5* | *28.3* |
| *Salt* | *1.0* | *1.0* |
| *Canola oil* | *9.0* | *9.0* |
| Total | 316.0 | 406.0 |

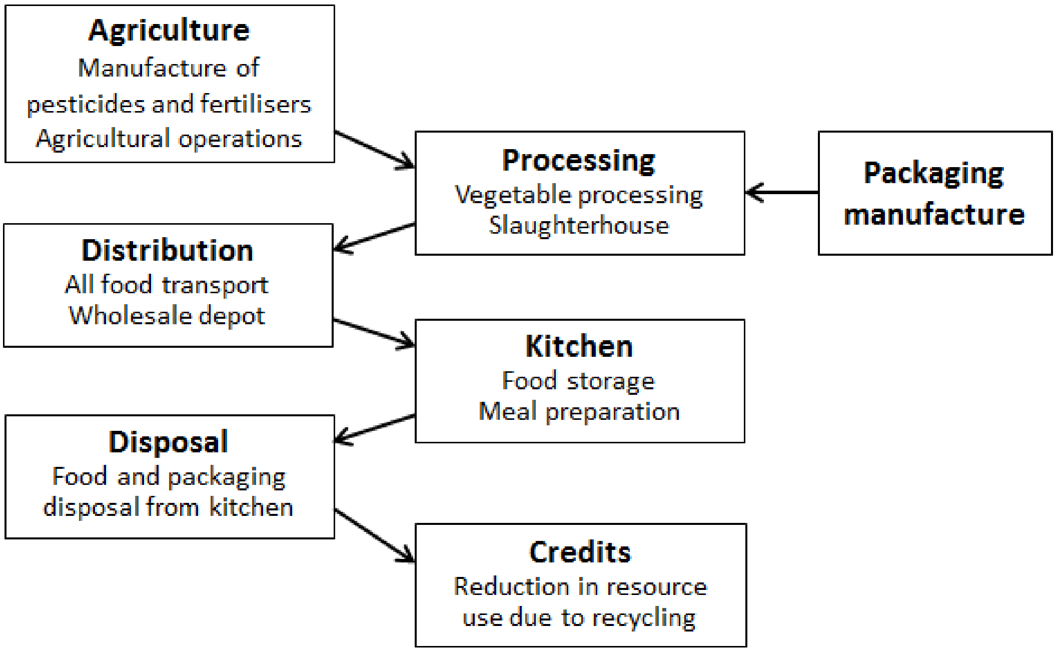


**Figure 15: Outline of life cycle of meal**

**Table 8: Description of each life cycle stage for the baseline scenario**

| **Life cycle stage** | **Description** |
|---|---|
| Agriculture | Vegetable agriculture (soil emissions, fuel used by tractors, heating of greenhouses, etc.)<br>Chicken rearing<br>Manufacture of fertilisers and pesticides<br>Transport of fertilisers and other materials to the farm |
| Processing | Chicken slaughter<br>Production of blood, meat and bone meal from chicken slaughter waste<br>Washing, chopping and chilling/freezing of vegetables<br>Disposal of food waste produced by processing<br>Waste water treatment<br>Transport of packaging from factory to processor |
| Packaging manufacture | Manufacture of all packaging used throughout the supply chain<br>*(This stage does not include any waste management)* |
| Distribution | Chilling of vegetables on farm<br>Transport of live chicken to slaughterhouse<br>Transport of vegetables to processor<br>Transport of ingredients from the processor to the wholesale depot<br>Chilled or frozen storage of ingredients at the wholesale depot<br>Transport of ingredients from the wholesale depot to the kitchen<br>Disposal of food and packaging wasted at the wholesale depot |
| Kitchen | Chilled or frozen storage in the kitchen<br>Cooking<br>Ventilation<br>Heated storage of meal between cooking and serving<br>Dish washing |
| Disposal | Disposal of food and packaging waste from the canteen<br>Treatment of waste water from the canteen |
| Credits | Reduction in resource use due to recycling of some waste |

Table 9: Scenarios considered in the study

| Name | Description |
|---|---|
| Case A (baseline) | Roast chicken meal of the composition shown in Table 7 prepared using non-organic ingredients all produced in the UK. Chicken, potatoes, carrots, onions and tomatoes are supplied chilled. Peas are supplied frozen. Canola oil and salt are supplied at ambient temperature. Chicken is cooked in an electric oven. Potatoes, carrots and peas are cooked in an electric steam oven. Sauce is prepared on a gas hob using fresh tomatoes. |
| Case B | As for Case A, but with chicken reared in Brazil and transported by ship to the UK. |
| Case C | As for Case A, but with tomatoes grown in Spain and transported by road to the UK. |
| Case D | As for Case A, but with the sauce prepared from tomato paste and water instead of fresh tomatoes. |
| Case E | As for Case D, but with the tomato paste made from Spanish tomatoes. |
| Case F | As for Case A, but with potatoes, carrots and peas boiled on a gas hob. |
| Case G | As for Case A, but with organic chicken and tomatoes. |
| Case H | As for Case A, but with British beef instead of British chicken |
| Case I | As for Case A, but with British pork instead of British chicken |
| Case J | As for Case A, but with British sheep meat instead of British chicken |
| Case K | As for Case A, but with French canned faba beans instead of British chicken. Beans are cooked with the tomato sauce. Faba beans are also known as fava beans or broad beans (they are usually harvested when mature, as opposed to younger broad beans commonly available in supermarkets). They are chosen because they can be grown in or near the UK, in contrast to some other pulse types such as chickpeas or soybeans. |
| Case L | As for Case A, but with French sunflower seeds instead of British chicken. Sunflower seeds are cooked with the tomato sauce. |
| Case M | As for Case K, but with Spanish fresh tomatoes. |
| Case N | As for Case L, but with Spanish fresh tomatoes. |

### 3.2.3 Scenarios

As indicated in Table 9, in addition to the baseline scenario (Case A), a further 13 scenarios are considered to explore the effects of different ingredients and different cooking methods. Since the different alternatives to chicken shrink to different degrees while cooking, equivalent weights are used at the point immediately prior to cooking in the kitchen.

## 3.3 Life cycle inventory

Most inventory data are based on literature. However, some qualitative guidance was given by David Shucksmith, the chef of a canteen on the University of Manchester campus (Shucksmith, 2015). The inventory data sources and assumptions are discussed below, by life cycle stage, with more detail on sources given in the appendices.

### 3.3.1 Agriculture

In the baseline scenario, all ingredients are assumed to be produced in the UK using non-organic agriculture. Other scenarios use ingredients produced organically in the UK and non-organically in Spain and Brazil. Where LCA data are available in the literature for the agricultural stage, these results have been used directly; for other ingredients, the agricultural stage is modelled in GaBi using inventory data from literature. Data sources are summarised in Table 10. The manufacture of materials used on the farm, such as pesticides and fertilisers, is included in this stage. Energy use on the farm (e.g. diesel for tractors) is also included. Some assumptions are made, such as the distance which materials are transported to the farm. More details are given in Appendix A.

**Table 10: Summary of data sources for agriculture**

| Ingredient | Country of origin | Weight per meal | Data source |
|---|---|---|---|
| Chicken | UK | 147 g live weight at farm gate | Williams et al. (2006) |
| | Brazil | 107 g dead weight at slaughterhouse gate | Da Silva et al. (2014) |
| Potato | UK | 100 g at farm gate | Williams et al. (2006) |
| Carrot | UK | 46 g at farm gate | Nielsen et al. (2003) |
| Pea | UK | 40 g at farm gate | Canals et al. (2008). Data for green beans are used as a proxy due to lack of information on pea agriculture. |
| Tomato | UK | 185 g at farm gate | Williams et al. (2006) |
| | Spain | | Torrellas et al. (2012) |
| Onion | UK | 35 g at farm gate | Nielsen et al. (2003) |
| Salt | UK | 1.1 g at plant gate | Ecoinvent Centre (2010) |
| Canola oil | UK | 9.9 g at oil mill gate | Ecoinvent Centre (2010) |
| Beef | UK | 177 g live weight at farm gate | Williams et al. (2006) |
| Pork | UK | 145 g live weight at farm gate | Williams et al. (2006) |
| Sheep meat | UK | 177 g live weight at farm gate | Williams et al. (2006). Note that lamb and mutton are considered as a single category by this data source. |
| Faba bean | France | 33 g dry weight at farm gate | French Environment and Energy Management Agency (2016). Note that beans expand significantly during cooking in the processing stage by absorbing water. |
| Sunflower seeds | France | 105 g at farm gate | French Environment and Energy Management Agency (2016) |

**Table 11: Summary of resource use in chicken processing, Case A**

Includes slaughterhouse and bone, blood and meat meal production. Data source: Nielsen et al. (2003).

| Resource | Amount per meal |
|---|---|
| Electricity | 117.8 kJ |
| Heat from natural gas | 86.4 kJ |
| Heat from light fuel oil | 42.6 kJ |
| Water | 1.36 l |

### 3.3.2 Harvest to processor

Live chickens are transported to the slaughterhouse by lorry. Reusable plastic crates are used to contain the chickens. Vegetables are chilled on the farm, using 202 MJ electricity per tonne of produce (Canals et al., 2008) before being transported to the processor by lorry. Chilling of potatoes is not modelled explicitly since the agricultural data source for potatoes already includes cooling. Vegetables are then transported, loose, in chilled lorries to the processor. More details are given in Appendices C and D.

### 3.3.3 Animal slaughter

Meat is processed and packed at the slaughterhouse. Waste body parts are turned into blood, bone and meat meal (Nielsen et al., 2003). In the UK, there are restrictions on using processed animal by-products as animal feed. However, it is legal to use them as fertiliser (DEFRA, 2014d), so the blood, bone and meat meal is credited to the system as a reduction in fertiliser use (see Section 4.3.10). Inventory data for the slaughterhouse and blood, bone and meat meal production are summarised in Table 11 and more details are given in Appendix B.

### 3.3.4 Vegetable processing

Resource use at the processor (summarised in Table 12 and Table 13) is calculated by adding together electricity, steam and water use for individual unit operations, obtained from European Commission (2006). Unit operations include sorting, transport on belts within the factory, washing, peeling, chopping, cooling and freezing. Waste vegetable parts are disposed of according to national statistics on waste management (WRAP, 2013a). More details are given in Appendices B and F.

### 3.3.5 Packaging

Packaging is used at various stages throughout the supply chain, summarised in Table 14. Primary packaging is the packaging that directly contacts the product (WRAP, undated-b). Primary packaging is applied at the processor. It is assumed that the primary packaging has been transported 100 km by road from its place of manufacture to the processor, remains on the food until the kitchen stage and is disposed of at the kitchen. The types of packaging are based on Shucksmith (2015).

Tertiary packaging is the outermost packaging used in distribution, e.g. pallets and stretch wrap (WRAP, undated-b). At the processor, food is stacked on Euro pallets and stabilised using polyethylene stretch wrap. The food is assumed to stay on the pallet until it leaves the wholesale depot. It is assumed that pallets are re-used 1000 times. Different weights of each product can be stacked onto one Euro pallet. These values affect the calculations for transport, refrigeration and tertiary packaging.

For delivery from the wholesaler to the kitchen, smaller plastic crates are used (since kitchens are unlikely to require a whole pallet of an ingredient). Re-usable plastic crates are also used to transport live chicken to the slaughterhouse.

Since secondary packaging (used to group individual units together) is used mainly for display purposes in retail, it is not considered in this study.

Details of the packaging calculations are given in Appendix C.

**Table 12: Summary of resource use in vegetable processing, Case A**

Includes potato, carrot, onion, fresh tomato and pea processing. Data source: European Commission (2006).

| Resource | Amount per meal |
|---|---|
| Electricity | 49.1 kJ |
| Steam | 0.15 kg |
| Water | 1.43 l |

**Table 13: Summary of resource use in tomato processing, Case D**

Data sources: European Commission (2006) and Food and Agricultural Organisation (2009a).

| Resource | Amount per meal |
|---|---|
| Electricity | 18.7 kJ |
| Steam | 0.12 kg |
| Water | 7.48 l |

**Table 14: Types of packaging used throughout the supply chain**

| Ingredient | Packaging category | Description |
|---|---|---|
| Live chicken | For live transport | High density polyethylene crate |
| Meat, potatoes, onions, carrots, peas, sunflower seeds | Primary | Polyethylene bag |
| Fresh tomatoes | Primary | Cardboard box |
| Tomato paste, faba beans | Primary | Tin-plate steel can |
| Salt | Primary | Polypropylene tub |
| Canola oil | Primary | Tin-plate steel can |
| All | Tertiary | Wooden Euro pallet |
| All | Tertiary | Linear low density polyethylene stretch wrap |

**Table 15: Weight of packaging used in Case A.**

Data sources: Shucksmith (2015), Tassou et al. (2008) and many others (see Appendix C).

| Single use packaging | Amount per meal, g |
|---|---|
| Polyethylene film | 6.21 |
| Cardboard | 3.28 |
| Tin-plate steel | 0.39 |
| Polypropylene | 0.04 |
| Linear low density polyethylene stretch wrap | 0.39 |
| **Packaging reused 1000 times** | |
| Wooden pallet | 15.1 |
| Polypropylene | 116.4 |
| High density polyethylene | 31.4 |

### 3.3.6 Transport

Transport assumptions are summarised in Table 16. Materials such as plastic packaging and fertilisers are also transported from their place of manufacture to the point of use. Some of the transport is temperature-controlled. The weight of the pallets and packaging, empty return journeys and refrigerant leakage are accounted for when calculating the transport capacity required, where relevant. All vehicles are assumed to have Euro 5 efficiency rating. No food waste is considered during the transport stages. The life cycle inventory data are from Tassou et al. (2008).

**Table 16: Transport assumptions**

| Transport stage | Distance | Mode | Comments |
|---|---|---|---|
| British ingredients from farm to processor or slaughterhouse | 200 km | Large articulated lorry | Chilled for all vegetables; ambient for live chicken. This stage does not apply to salt and canola oil. |
| Tomatoes, Spain to the UK | 1300 km | Large articulated lorry | Chilled. Transport across the English Channel (commonly by shuttle train through the Eurotunnel (Eurotunnel, 2016)) has not been included due to the relatively short distance. |
| Faba beans and sunflower seeds, France to UK | 800 km | Large articulated lorry | |
| Chicken, Brazilian slaughterhouse to Brazilian port, and UK port to wholesale depot | 800 km | Large articulated lorry | Chilled. |
| Chicken, Brazil to the UK | 10,000 km | Transoceanic freight ship | No return journey accounted for because the ship is unlikely to travel empty. |
| Ingredients from processor or slaughterhouse to wholesale depot | 100 km | Large articulated lorry | Chilled for chicken and vegetables, except for peas, which are frozen. |
| Ingredients from wholesale depot to kitchen | 100 km | Medium rigid lorry | |
| Fertilisers and pesticides from factory to farm | 100 km | Small lorry | Ambient. |
| Packaging from factory to point of use | | | |

**Table 17: Resource use at the wholesale depot, Case A**

Data source: Tassou et al. (2008).

| Resource | Amount per meal |
|---|---|
| Electricity | 0.788 kJ |
| Ammonia leakage | 0.737 μg |

**Table 18: Cooking methods used in the baseline scenario**

| Ingredient | Cooking method in baseline scenario |
|---|---|
| Chicken | Roasted in electric oven |
| Potatoes, carrots and peas | Steamed in electric steam oven |
| Tomato sauce | Onions are fried in canola oil on gas hob.<br>Fresh tomatoes are deseeded.<br>Onions and tomatoes are stewed together on the gas hob until the sauce has been reduced to the desired consistency.<br>Salt is added after cooking. |

**Figure 16: Summary of resources used at the kitchen stage, Case A**

| Resource | Amount per meal | Data sources |
|---|---|---|
| Electricity | 0.708 MJ | Shucksmith (2015), Tassou et al. (2008), Delphis Eco (2011), Bognár (2002) and many others (see Appendix E). |
| Natural gas | 0.571 MJ | |
| Water | 1.36 l | |
| R404a refrigerant | 368 µg | |
| Detergent | 2.9 g | |

### 3.3.7 Wholesale storage

Chilled food ingredients are stored in refrigerated or frozen warehouses, as appropriate. Some food is wasted at this stage, e.g. due to spills or passing the use-by date. The waste food and packaging are disposed of according to national statistics. Table 17 summarises the resources used and more details are given in Appendices D and F.

### 3.3.8 Kitchen

#### *3.3.8.1 Cold storage*

Chicken, potatoes, tomatoes, carrots and onions are stored in a walk-in refrigerator in the kitchen. Peas are stored in a walk-in freezer, and salt, canola oil, tomato paste, faba beans and sunflower seeds are stored at ambient room temperature. The use of walk-in refrigerators and freezers is based on information from Shucksmith (2015).

#### *3.3.8.2 Cooking*

The cooking methods assumed in the baseline scenario, based on Shucksmith (2015), are summarised in Table 18. See Appendix E for details of energy use, water use and emissions from the gas hob.

#### *3.3.8.3 Ventilation*

It is a legal requirement for ventilation to be used in workspaces, including commercial kitchens. Ventilation removes cooking fumes and keeps the working environment at a comfortable temperature. Where gas-fired appliances are used, ventilation also prevents the accumulation of carbon monoxide (Health and Safety Executive, 2012). The electricity use of an extractor hood is estimated based on the equipment used in the kitchen, assuming a running time of two hours. See Appendix E for details.

#### *3.3.8.4 Hot holding*

Since meals are cooked in large batches but not served all at once, they must be kept warm before being served to the customer. A mixture of enclosed hot cupboards and open display units, both powered by mains electricity, is assumed to be used. See Appendix E for details.

#### *3.3.8.5 Dishwashing*

Plates, pans and utensils are assumed to be washed in a dishwashing machine. See Appendix E for details.

### 3.3.9 Disposal

This stage covers disposal of food and packaging waste from the canteen. Disposal of waste from other stages is considered within those stages.

#### *3.3.9.1 Food waste levels*

Two types of food waste are considered at the canteen stage: preparation and spoilage waste produced in the kitchen (e.g. vegetable trimmings, food that has passed its use-by date), and plate waste (food that has been served to a customer but not eaten). Different food service subsectors produce different levels of food waste, which have been well documented by WRAP (2013b). For the baseline scenario, waste levels typical of the education subsector have been used. Waste levels typical of the restaurant and staff catering subsectors have been considered as part of the sensitivity analysis. Food waste levels throughout the supply chain are summarised in Table 19.

**Table 19: Summary of food waste, Case A**

| Stage | Proportion of food wasted | Data source |
|---|---|---|
| Chicken slaughterhouse | 27% of live weight | Nielsen et al. (2003) |
| Potato processing | 4% of processed weight | European Commission (2006) |
| Carrot processing | 20% of processed weight | |
| Onion processing | 13% of processed weight | |
| Fresh tomato processing | 13% of processed weight | |
| Pea processing | 4% of processed weight | |
| Wholesale depot | 2% of food entering depot | Tassou et al. (2008) |
| Deseeding tomatoes in kitchen | 25% of whole weight | Pick Your Own (2009) |
| Other preparation and spoilage waste in kitchen | 7% of cooked meal weight | WRAP (2013b) |
| Post-consumer plate waste | 12% of cooked meal weight | |

#### *3.3.9.2 Disposal of food waste from the kitchen*

Food waste disposal is divided between treatment methods according to national statistics based on food service subsector. As well as landfill, incineration and composting, some food is disposed of using a sink-top disposal unit (SDU). The SDU is installed above a sink in the kitchen, grinds up waste food into fine particles and flushes it down the drain with tap water.

#### *3.3.9.3 Waste water treatment*

As for vegetable processing, waste water is treated according to its composition when the waste food from the SDU is accounted for. See Appendix F for more details.

#### *3.3.9.4 Packaging waste*

Packaging waste is disposed of or recycled according to national statistics. Recycled materials are credited to the system as a reduction in the amount of virgin materials required. See Appendix F for more details.

The inventory data sources for recycling processes are summarised in Table 20.

### 3.3.10 System credits

Packaging which is recycled is credited to the system as a reduction in the amount of virgin materials required. Some food waste is converted to compost or blood, meat and bone meal, which is credited to the system as a reduction in the amount of fertiliser required at the agricultural stage. See Appendix F for more details.

**Table 20: Data sources for recycling processes**

| **Material** | **Data source** |
|---|---|
| Incineration and landfill for all materials | Ecoinvent Centre (2010) |
| Plastic recycling | CPM Chalmers University of Technology (2015) |
| Steel recycling | Ecoinvent Centre (2010), using a recycling process for reinforcement steel since it is the nearest available option. |
| Cardboard recycling | Ecoinvent Centre (2010), using a recycling process for paper since it is the nearest available option. |
| Composting | CPM Chalmers University of Technology (2002) |
| Conversion of slaughterhouse waste to blood, meat and bone meal | Nielsen et al. (2003) |

## 3.4 Impact assessment

The system has been modelled in GaBi 6 software (version 6.5.1.8) (Thinkstep, 2015). The impacts have been estimated following the CML 2001 (April 2013 update) method (Leiden University Department of Industrial Ecology, 2016). The following impacts are considered:

- Abiotic depletion potential, elements
- Abiotic depletion potential, fossil
- Acidification potential
- Eutrophication potential
- Global warming potential, 100 year time horizon
- Freshwater aquatic ecotoxicity potential, infinite time horizon
- Human toxicity potential, infinite time horizon
- Marine aquatic ecotoxicity potential, infinite time horizon
- Terrestrial ecotoxicity potential, infinite time horizon
- Ozone depletion potential, steady state
- Photochemical ozone creation potential
- Primary energy demand (not itself a CML impact category)

Graphs for each impact category show the contributions from each life cycle stage, including credits. Credits are subtracted from the sum of the other life cycle stages to give the overall total, which is labelled as a number on the graph. Hence, it is possible that one case, although appearing at first glance to have a higher graph total than another case, actually has a lower total due to the credits.

### 3.4.1 Abiotic depletion potential, elements ($ADP_{elements}$)

$ADP_{elements}$ refers to the use of non-renewable non-fuel resources such as metal ores and minerals. The impact per meal ranges from 0.4 g Sb eq. (Cases M and N) to 43.8 g Sb eq. (Case G), as shown in Figure 17. The main contributor to $ADP_{elements}$ in all cases is tomato agriculture, particularly British tomatoes since they are grown in heated greenhouses. Rearing animals for meat is also a notable contributor. The lowest impacts are achieved by combining sunflower seeds or faba beans as a protein source with Spanish tomatoes, since all three ingredients have very low $ADP_{elements}$. The highest impact comes from using organic British tomatoes and chicken, which have lower agricultural yields than the corresponding non-organic products.

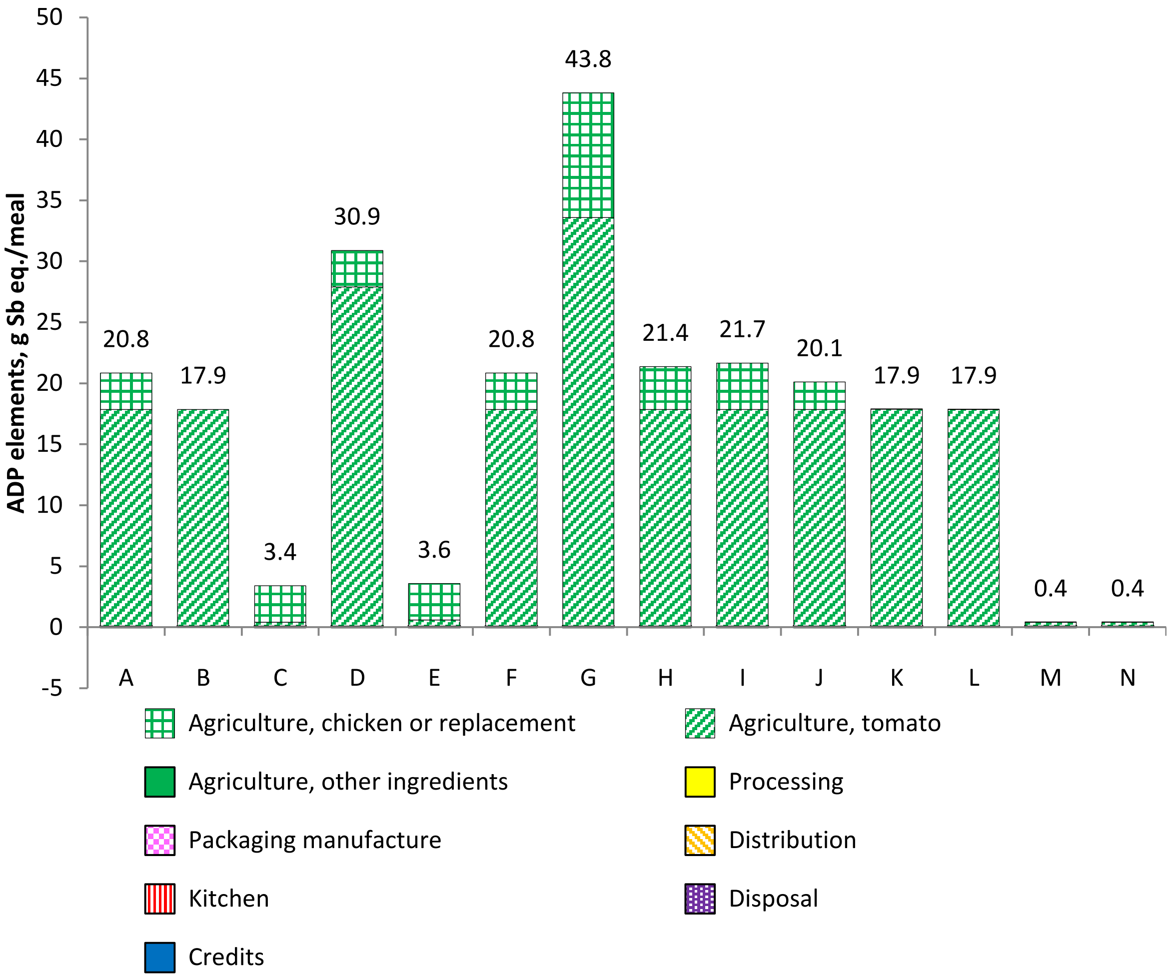


**Figure 17: Impact assessment results, abiotic depletion potential (elements)**

In more detail, the total ADP$_{elements}$ for Cases A and F (both using all British ingredients) is 20.8 g Sb eq. per meal served. This comes almost exclusively from the agricultural stage, with British tomato agriculture accounting for 17.8 g Sb eq. and British chicken agriculture accounting for 3.0 g Sb eq.

British tomato agriculture uses heated greenhouses to extend the growing season. Data for this are based on work by Williams et al. (2006), which suggests that when CHP (combined heat and power generation) is used to heat the greenhouse, 77% of abiotic resource use is due to heating and lighting, 26% comes from the construction of the greenhouse (including glass, aluminium frame, a concrete base and pipes for heating) and a credit of -6% is due to export of electricity from the CHP unit. Only one quarter of tomatoes grown in the UK use CHP. Commercial sensitivity means that not all of the inventory data used by Williams et al. (2006) are publicly available, so it is not possible to trace the hotspots in the case of non-CHP agriculture. However, the work by Williams et al. (2006) shows a non-linear relationship between the proportion of CHP uses and abiotic resource use. Specifically, abiotic resource use would fall relative to the current situation both in the case of no greenhouses using CHP (by about 9% per tonne of tomato) and in the case of all greenhouses using CHP (by about half, due to the exported electricity). The current proportion of CHP use results in higher abiotic resource use than either extreme.

The data taken from Williams et al. (2006) for British poultry production cannot be sufficiently disaggregated to identify hotspots for $ADP_{elements}$. Some possible sources are manufacture of the machinery for cultivating the feed crops and construction of buildings to house the poultry.

For Case B (Brazilian chicken), impact data for Brazilian chicken agriculture is taken from Da Silva et al. (2014) , which does not give a value for $ADP_{elements}$ because this category was not chosen to be relevant to the system. It is likely that the actual value is non-zero, for example, due to materials used in growing the feed crops, transporting feed and housing the chickens. Hence, the lower $ADP_{elements}$ shown for Case B (relative to Case A) may be misleading.

Cases C and E use Spanish tomatoes instead of British tomatoes. $ADP_{elements}$ for Spanish tomato agriculture is much lower than for British tomato agriculture. The Spanish greenhouses are unheated, and since heating and lighting accounted for the majority of $ADP_{elements}$ for British tomato agriculture, it makes sense that the Spanish value is much lower. The data source used for Spanish tomato agriculture (Torrellas et al., 2012) shows that the hotspots for abiotic depletion are the greenhouse structure (46%), auxiliary equipment (37%) and fertiliser production (12%). The impacts from the greenhouse manufacture are mainly from plastics and steel (note that the British greenhouse is assumed to be built from glass and aluminium instead).

Tomato agriculture has a greater impact in Case D (sauce prepared from British tomato paste) than in Cases A, B and F because a higher quantity of British tomatoes are required. The quantity of tomatoes required depends on the assumptions made about the thickness of the paste and sauce (see the sensitivity analysis section). Likewise, Case E has a greater impact than Case C due to the use of tomato paste. The quantity of tomatoes used also affects the total for Cases C and E in other impact categories.

Case G (organic British chicken and tomatoes) shows greater $ADP_{elements}$ for both chicken and tomato agriculture. Organic tomato yields are lower than for non-organic tomatoes. For organic poultry, poultry is less efficient at converting feed into edible meat (Williams et al., 2006).

Cases H, I and J show that $ADP_{elements}$ for British beef and pork agriculture are, respectively, 17% and 27% greater than for British chicken, whereas $ADP_{elements}$ for British sheep meat is 25% lower than for British chicken. The data source, Williams et al. (2006), shows that most of the $ADP_{elements}$ for beef agriculture comes from producing feed for the cattle (72% for concentrates and 25% for grass). It is not possible to identify hotspots for pork and sheep meat from Williams et al. (2006).

The agricultural stage of French canned faba beans and French sunflower seeds has negligible $ADP_{elements}$ compared to the British meat options. The lowest total $ADP_{elements}$ can be achieved by combining Spanish tomatoes with French faba beans or sunflower seeds, as shown in Cases M and N, which both have a total $ADP_{elements}$ of only 2% of Case A.

### 3.4.2 Abiotic depletion potential, fossil ($ADP_{fossil}$)

$ADP_{fossil}$ refers to the use of non-renewable fuel resources such as coal, oil and gas. The impact ranges from 6.6 MJ/meal (Case N) to 48.5 MJ/meal (Case G), as shown in Figure 18. The most significant determinant of $ADP_{fossil}$ is whether tomatoes grown in a heated greenhouse are used.

In Case A, $ADP_{fossil}$ is 28.3 MJ per meal. The majority of this (80%) comes from British tomato agriculture. As discussed above, British tomatoes are assumed to be grown in heated greenhouses. The heat source is usually natural gas (Williams et al., 2006).

For Case B, British tomato agriculture still accounts for the majority of $ADP_{fossil}$ but the amount attributed to chicken agriculture is increased by 74%. The functional unit for Brazilian chicken agriculture also includes the slaughterhouse (whereas the functional unit for British chicken does not), which contributes 7% of the $ADP_{fossil}$ for Brazilian chicken (Da Silva et al., 2014). The energy used at the slaughterhouse comes mainly from wood, which is not counted towards $ADP_{fossil}$. The production of chicken feed (maize and soybean) accounts for around 73% of $ADP_{fossil}$ for Brazilian chicken agriculture.

For Case B, the contribution to $ADP_{fossil}$ from the distribution stage increases by 48% compared to Case A because of the increased distance that the chicken is transported. However, distribution is still not a major contributor, at less than 5% of the total for Case B. The packing manufacture and processing stages are lower than for Case A because the slaughterhouse and packaging are instead included in the functional unit for Brazilian chicken agriculture.

For Case C, $ADP_{fossil}$ for Spanish tomatoes is a mere 3% of the value for British tomatoes, because the Spanish greenhouses are unheated. The reduction in $ADP_{fossil}$ at the greenhouse stage far outweighs the increase at the transport stage due to the extra distance that the tomatoes must be transported.

For Cases D and E, the increase in $ADP_{fossil}$ compared to Cases A and C, respectively, is due to the greater quantity of tomatoes required when using tomato paste.

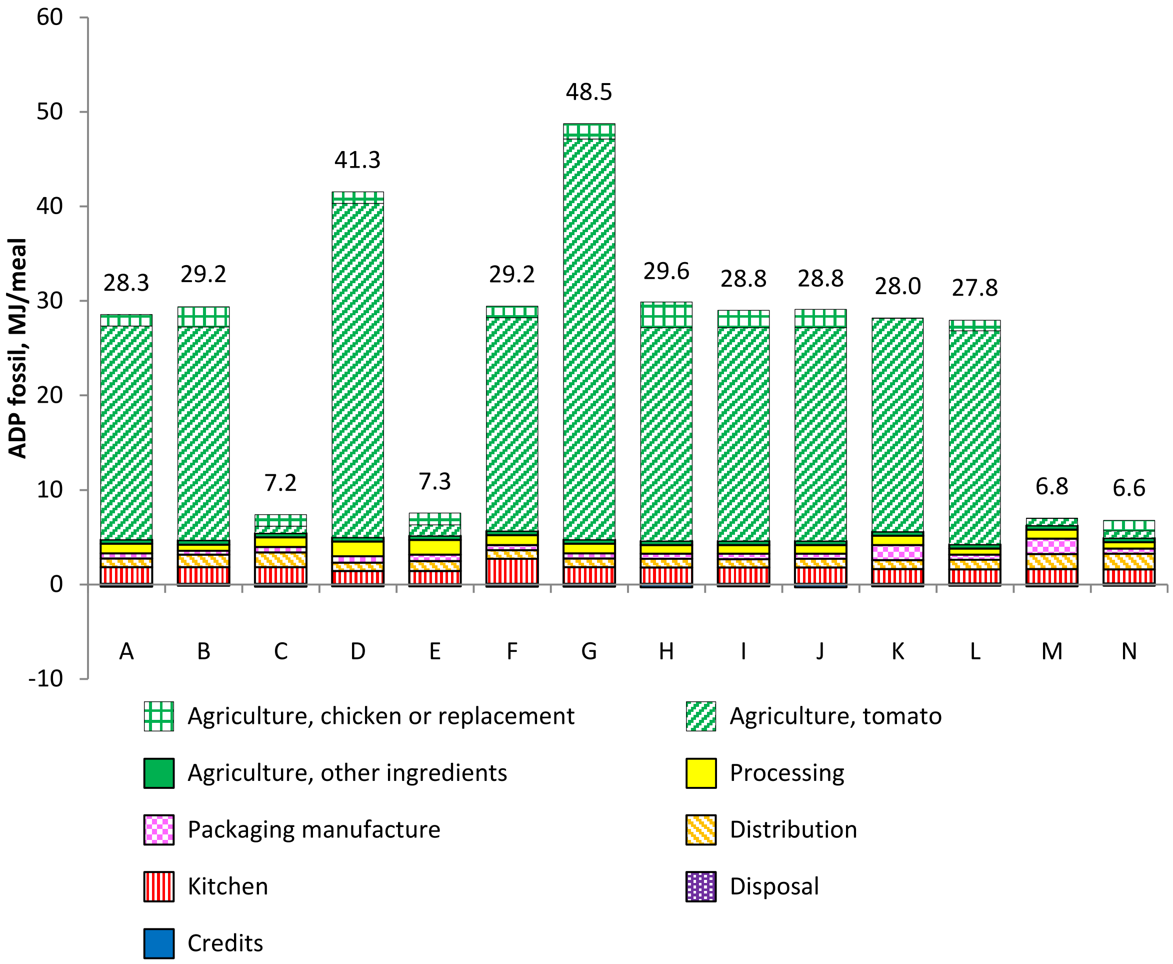


Figure 18: Impact assessment results, abiotic depletion potential (fossil)

For Case F, boiling the vegetables on a gas hob instead of in an electric steam oven increases the $ADP_{fossil}$ for the kitchen stage by 51% compared to Case A. This is because the water for boiling has to be heated up, as well as the vegetables themselves, which uses more energy than for the steam oven. Furthermore, gas hobs are assumed to be less energy efficient than steam ovens (33% as opposed to 65%).

Case G shows that $ADP_{fossil}$ for organic British chicken agriculture is 32% higher than for non-organic British chicken agriculture, and 88% higher for organic British tomato agriculture than non-organic. This is because organic tomato and chicken agriculture produces lower yields than non-organic agriculture.

$ADP_{fossil}$ for the agricultural stages of British beef, pork and sheep meat are, respectively, 119%, 47% and 55% higher than for British chicken. For beef, the hotspots in the agricultural stage are concentrates production (50%) and grass production (41%).

$ADP_{fossil}$ for the agricultural stages of French faba beans and sunflower seeds are 3% and 90%, respectively, of that of British chicken. Note that the sunflower seed data include processing of the seeds.

### 3.4.3 Acidification potential (AP)

AP refers to the ability of certain chemical species to deposit protons into the environment, for example as acid rain. The lowest AP per meal is 2.1 g $SO_2$/eq. (Case M) and the highest is 48.9 g $SO_2$ eq. (Case G). The main contributor in most cases is animal agriculture.

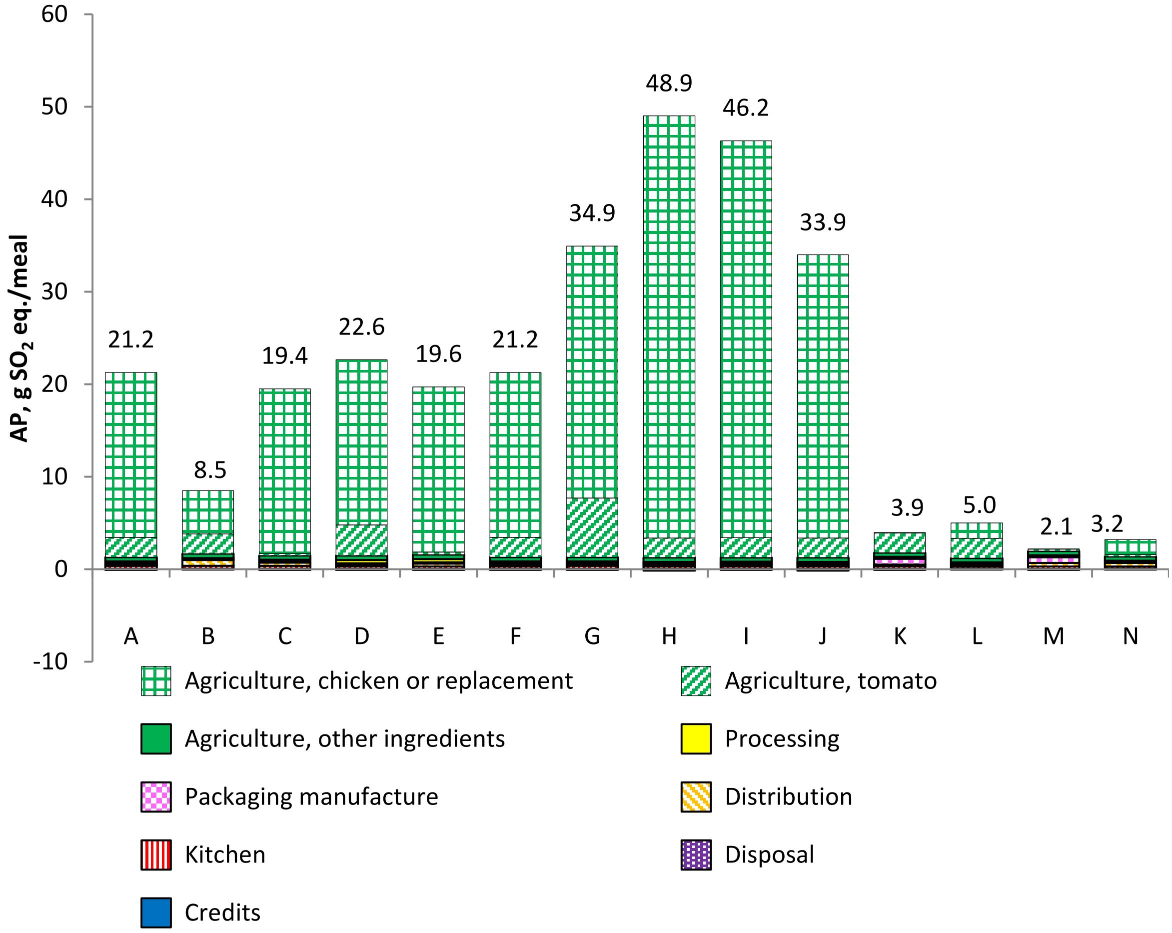


Figure 19: Impact assessment results, acidification potential

The acidification potential per meal served for Cases A and F is 21.2 g $SO_2$ eq. 84% of this comes from British chicken agriculture. The data source for British chicken (Williams et al., 2006) does not provide hotspots, but suggests that the main sources of AP from agriculture are ammonia emissions and $SO_2$ production from fossil fuel combustion. Ammonia emissions arise when nitrogen in animal excrement is converted during decomposition. If animals are fed protein surplus to their requirements, this can cause more nitrogen to be present in the excrement (Gay and Knowlton, 2009).

For Case B, the AP for Brazilian chicken agriculture is only 26% that for British chicken agriculture. The data source for Brazilian chicken (Da Silva et al. (2014), supplementary material) identifies the main sources as ammonia emissions from the chicken house (42%) and ammonia emissions from maize agriculture (38%). The ammonia emissions from maize agriculture are largely due to the use of urea fertiliser.

The AP of Spanish tomatoes in Case C is 9% of that of British tomatoes. Williams et al. (2006) show that the AP for British tomatoes comes largely from the heating and electricity use in the greenhouse (101% in the case of CHP being used, with a -15% credit for exported electricity). Torrellas et al. (2012) show that the AP for Spanish tomatoes comes mainly from auxiliary equipment (42%) and the greenhouse structure (39%). Auxiliary equipment includes irrigation, growth substrate (perlite) and electricity equipment. The Spanish greenhouses are unheated so there is no contribution from fuel for heating.

Case G, with organic chicken and tomato, shows that again, the organic chicken and tomatoes have a higher contribution than the non-organic equivalents due to lower yields.

AP for the agricultural stages of British beef, pork and sheep meat are 156%, 141% and 71% higher, respectively, than for British chicken agriculture. For beef agriculture, the main source of AP is manure (57%), followed by grass production (26%).

For the agricultural stages of French faba beans and sunflower seeds, AP is 0.3% and 9.3%, respectively, of that of British chicken agriculture. This is unsurprising because there is no animal excrement to produce ammonia emissions. Furthermore, the weight of feed that must be grown to feed animals is less than the weight of meat produced.

### 3.4.4 Eutrophication potential (EP)

EP refers to the potential of nutrients to cause excessive growth of biomass. This can deplete oxygen levels in waterways and alter the balance of species. EP per meal varies from 2.3 g $PO_4^{3-}$ (Case M) to 18.1 g $PO_4^{3-}$ (Case J). The main contributor in most cases is animal agriculture or sunflower seed agriculture.

For Case A, the eutrophication potential is 7.2 g phosphate eq. per meal. 70% of this comes from British chicken agriculture. The data source for chicken agriculture (Williams et al., 2006) does not give an exact breakdown of hotspots, but does state that the main sources of EP for agriculture in general are nitrate and phosphate leaching into water and ammonia being emitted to the air. As discussed in section 3.4.3, ammonia emissions can come from poultry excrement. Nitrate and phosphate can be present in poultry excrement. Nitrogen and phosphorus fertilisers used during feed production can also pollute water (Gerber et al., 2007).

In Case A, the disposal stage is also a notable contributor, accounting for 12% of EP. The majority of this (65%) comes from the treatment of food waste from the kitchen (almost entirely from the food sent to landfill), with 25% being from treatment of waste water from the kitchen (including food disposed of via a sink-top disposal unit) and 10% being from disposal of or recycling of packaging.

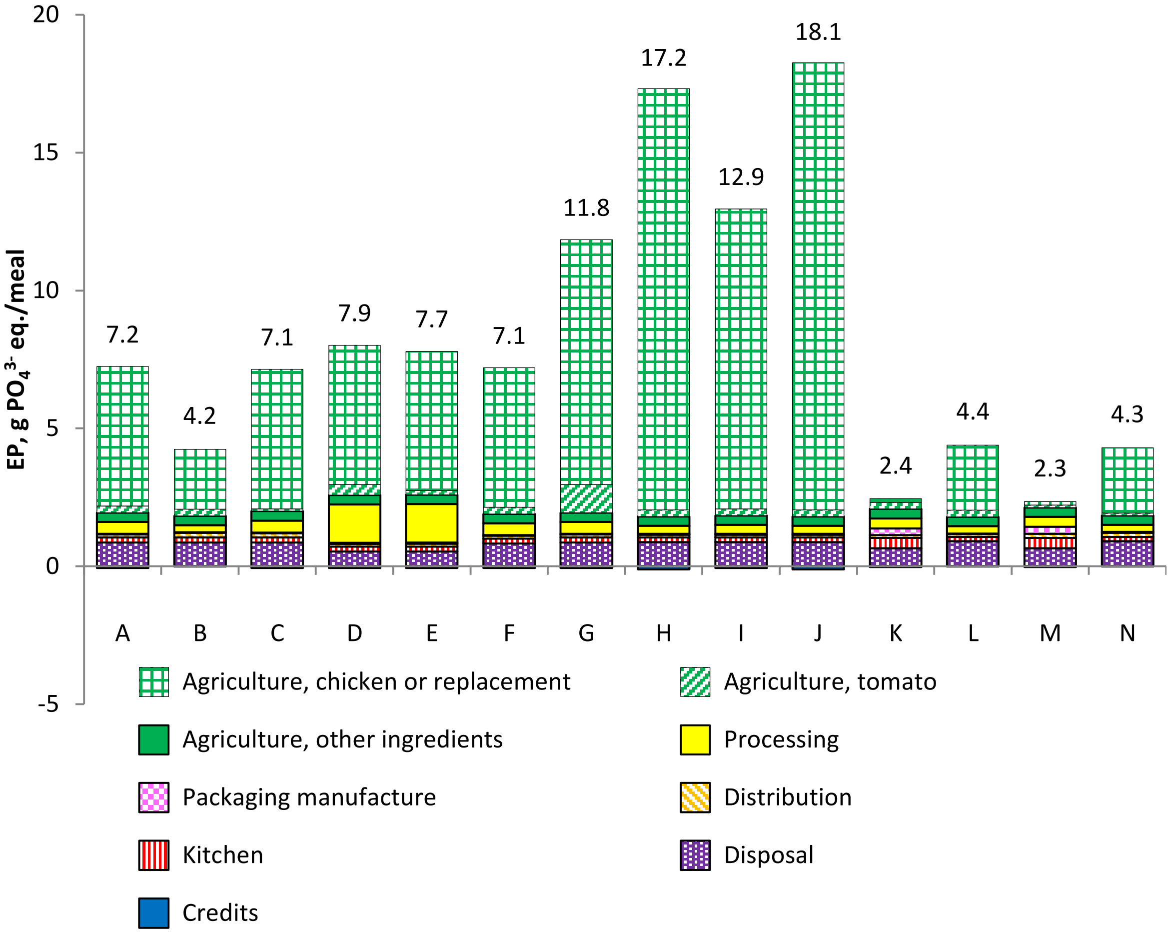


**Figure 20: Impact assessment results, eutrophication potential**

The EP for Brazilian chicken is 43% of that for British chicken, but is still the main contributor to EP for Case B. The hotspots of EP for Brazilian chicken are chicken feed production (70%) and emissions from the chicken housing (20%). It is unclear why the overall total for Brazilian chicken is lower than for British chicken, because Williams et al. (2006) do not give a breakdown of hotspots for British chicken.

The EP for Spanish tomato agriculture is 38% of that for British tomato agriculture, although neither are major contributors to the overall EP of a meal. For British tomatoes, the majority of EP comes from heating and electricity use in the greenhouse, so it makes sense that EP would be lower for Spanish tomatoes grown in unheated greenhouses. The main sources of EP for Spanish tomatoes are fertilisers (51%) and the greenhouse structure (31%).

In Cases D and E, using tomato paste, the processing stage has an EP over three times greater than when fresh tomatoes are used. This is because tomato paste processing produces more than 10 times as much waste water per kg of raw tomato as fresh tomato processing does, and a greater quantity of raw tomato is required per meal when using tomato paste.

In Case F, the kitchen stage's contribution to EP is 6% lower than for Case A. This makes sense even although the energy requirement in Case F is greater than in Case A (as seen in section 3.4.2) because the EP per MJ of energy from natural gas is much lower than for energy from mains electricity.

In Case G, the EP contribution of organic chicken and tomatoes is higher than for non-organic chicken and tomatoes, because, as discussed before, the yields for the organic agriculture are lower.

Cases H, I and J show that EP is significantly higher for British beef, pork and sheep agriculture than for British chicken agriculture (by over a factor of three for beef and sheep meat). The main sources of EP for beef agriculture are grass production (48%) and manure (36%).

EP for French agriculture of faba beans and sunflower seeds is significantly lower than for British chicken. However, French sunflower seed agriculture has slightly higher EP than Brazilian chicken.

### 3.4.5 Global warming potential, 100 year time horizon ($GWP_{100}$)

GWP refers to the contribution of emissions to climate change. Specifically, $GWP_{100}$ compares the radiative forcing impact of a gas to that of carbon dioxide over a time horizon of 100 years (the time horizon matters because some gases persist longer than others in the atmosphere). $GWP_{100}$ per meal varies from 0.6 kg $CO_2$ eq. (Cases M and N) to 4.3 kg $CO_2$ eq. (Case G).

For Case A, the $GWP_{100}$ per meal served is 2.6 kg $CO_2$ eq. The majority of this comes from the British tomato agriculture (66%) followed by British chicken agriculture (18%). For tomatoes, the heating and electricity use in the greenhouse is almost entirely responsible for the $GWP_{100}$. For chicken, the main contributor is $N_2O$ emissions, accounting for 41% of the $GWP_{100}$ of chicken agriculture (the breakdown of the remaining sources is not quantified by Williams et al. (2006)).

Of the remaining stages in Case A, the greatest contributor is the kitchen stage (5% of the total). The hotspots at the kitchen stage, shown in Figure 22, are electricity for cooking, gas for cooking, dishwashing and electricity for heated holding.

Brazilian chicken agriculture in Case B has a lower $GWP_{100}$ than British chicken agriculture. The main source is feed production (72%). Since Williams et al. (2006) do not give a more precise breakdown, the reason for the Brazilian chicken's lower $GWP_{100}$ cannot be identified.

In Case B, the distribution stage has a 49% higher $GWP_{100}$ than for Case A, because the chicken is transported a greater distance, including a portion of transport by freight ship. Nevertheless, distribution is still a minor contributor to $GWP_{100}$ (4% for Case B).

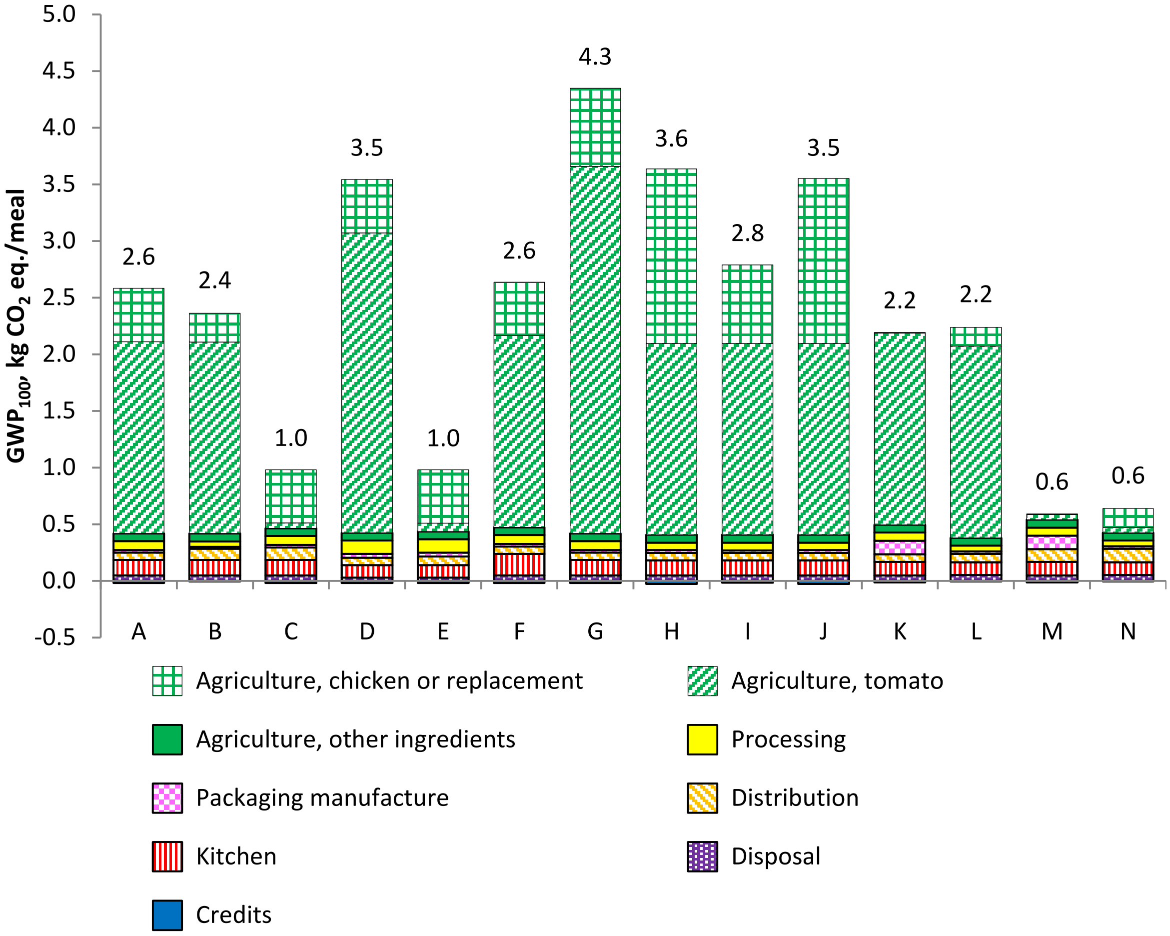


**Figure 21: Impact assessment results, global warming potential, 100 year**

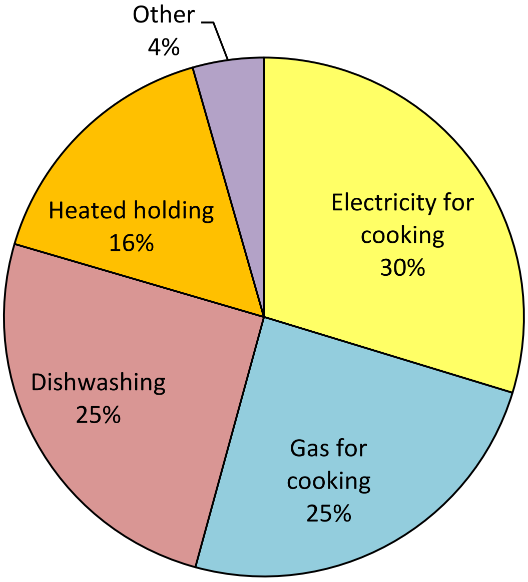


**Figure 22: Hotspots for $GWP_{100}$ from kitchen, Case A**

The $GWP_{100}$ for Spanish tomato agriculture in Case C is only 3% of that for British tomato agriculture, because the Spanish greenhouses are unheated.

The processing stage for Cases D and E has a 52% higher $GWP_{100}$ than for Case A, because tomato paste production uses more electricity per kg of raw tomatoes than fresh tomato processing. Tomato paste production also requires steam, whereas fresh tomato processing does not.

The kitchen stage for Case F has a 40% higher $GWP_{100}$ than for Case A, because, as mentioned in section 3.4.2, boiling the vegetables on the gas hob requires more energy than using the steam oven due to the extra mass of water to heat and lower efficiency of the gas hob. This outweighs the fact that some mains electricity is replaced by natural gas (mains electricity has greater $GWP_{100}$ per MJ than natural gas, since it includes more carbon-intensive sources of energy, such as coal).

In Case G, the $GWP_{100}$ contribution of organic chicken and tomatoes is higher than for non-organic chicken and tomatoes, because, as discussed before, the yields for the organic agriculture are lower.

$GWP_{100}$ of British beef, pork and sheep agriculture is 326%, 147% and 309% of that of British chicken agriculture. For beef, the main sources are concentrates production (27%), grass production (21%) and 46% "other", according to Williams et al. (2006). It is likely that "other" includes methane emissions from the cattle's digestion.

For French faba bean and sunflower seed agriculture, $GWP_{100}$ is 1% and 36%, respectively, of that of British chicken agriculture.

The lowest $GWP_{100}$ of the scenarios studied is achieved by combining faba beans with the use of Spanish tomatoes instead of British tomatoes (Case M, which has $GWP_{100}$ of 22% of that of Case A).

### 3.4.6 Freshwater aquatic ecotoxicity potential, infinite time horizon (FAETP)

FAETP refers to the toxic impacts on freshwater ecosystems such as lakes and rivers. The impact per meal ranges from 295 g DCB eq. (Case D) to 611 g DCB eq. (Case M), as shown in Figure 23. Significant contributors are disposal, canola oil agriculture and manufacture of steel packaging. However, since the data sources used for the agricultural stages did not provide information on, for example, pesticide release to the environment, it is possible that the true FAETP per meal is greater than shown here.

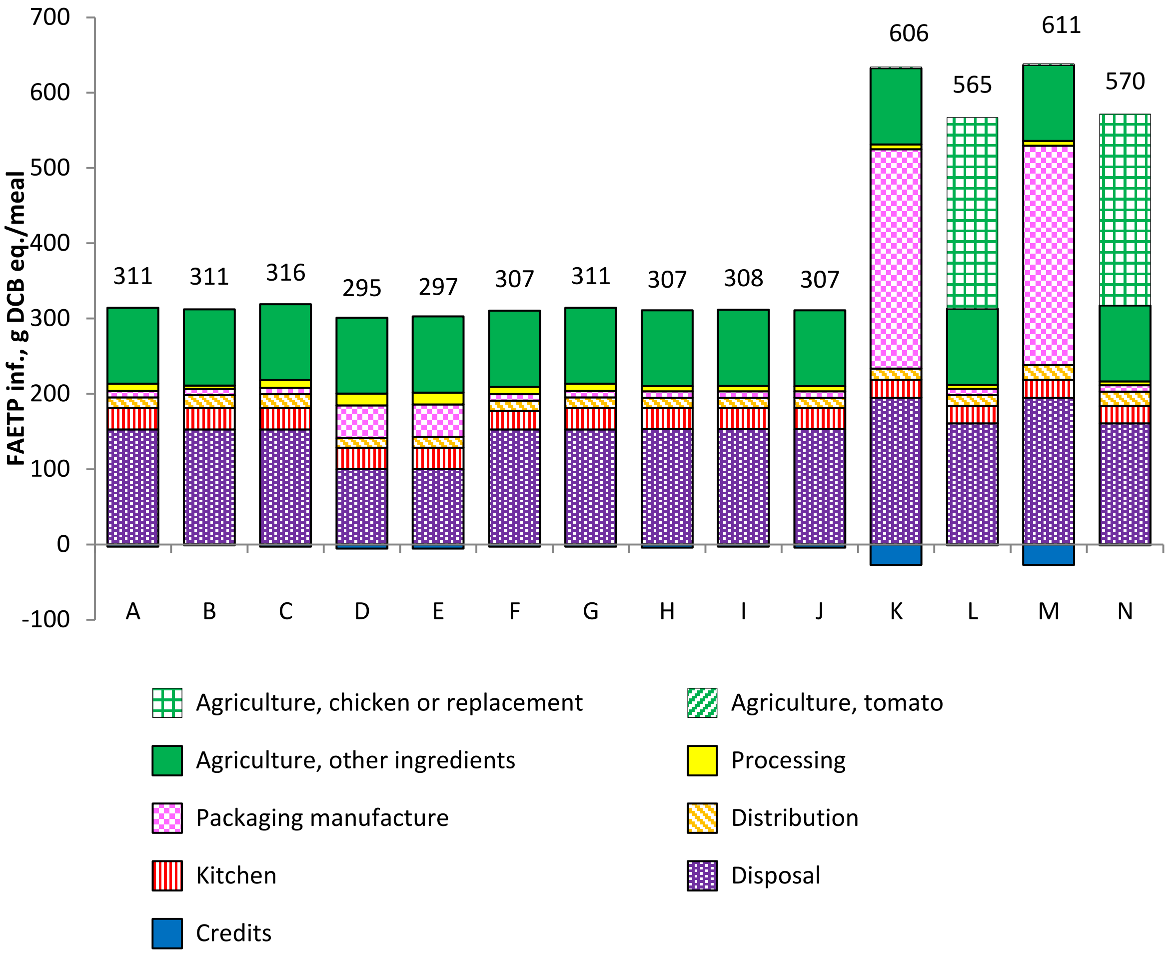


**Figure 23: Impact assessment results, freshwater aquatic ecotoxicity potential**

For Cases A and G, the total FAETP per meal served is 311 g DCB eq. The LCA results from literature for British chicken, tomato and potato agriculture did not include FAETP, so the true total may be higher. The main source of FAETP is the disposal stage (49%), the majority of which (94%) comes from landfill of food waste from the kitchen.

The second largest contributor (32%) is agriculture for ingredients other than chicken and tomato. Of this, the majority (99%) comes from canola oil agriculture. However, since the inventory data for carrot, pea and onion agriculture did not include release of pesticides (for example) into the environment, the actual FAETP for these ingredients may be higher.

For Case B, the FAETP of the processing stage is reduced compared to Case A because the slaughterhouse stage is included in the agricultural stage, not the processing stage, for Brazilian chicken. The FAETP of the distribution stage is increased because of the extra distance that the chicken is transported.

Likewise, in Case C, the FAETP of the distribution stage is 33% greater than for Case A because of the extra distance that the tomatoes are transported.

The FAETP of the disposal stage for Cases D and E is 34% lower than for Case A. This is due to the amount of food waste from the kitchen being lower, because there is no tomato seed waste. The processing stage in Cases D and E is 59% and 60%, respectively, higher than for Case A, because processing tomato paste requires more electricity and steam than processing fresh tomatoes. The distribution stage in Case D is 8% lower than for Case A because the weight of the concentrated tomato paste is less than the weight of the fresh tomatoes required to make the same amount of sauce.

For Case F, the FAETP of the kitchen stage is 14% lower than for Case A, because some electricity use is replaced with natural gas use, which has lower FAETP per MJ of energy production. The majority of FAETP from the UK mains electricity mix comes from coal.

FAETP data are not available in the data sources used for British beef, pork or sheep agriculture. However, the Agribalyse database (French Environment and Energy Management Agency, 2016) gives full data on the release of pesticides and other chemicals to water, so the relatively low FAETP for faba bean agriculture is based on the data as opposed to reflecting a lack of data. In Cases L and N, sunflower seed agriculture accounts for 45% of total FAETP. Although Cases K to N appear to have higher agricultural FAETP compared to the other scenarios, this may not be true in reality due to the lack of data on the agricultural stages of chicken and chicken alternatives.

In Cases K and M, FAETP for the packaging manufacture stage is more than 34 times as great as for Case A due to the extra steel used for faba bean packaging. Some of the steel packaging is recycled, contributing to the credits, which represent a reduction in total FAETP of 5% in Cases K and M.

### 3.4.7 Human toxicity potential, infinite time horizon (HTP)

HTP refers to potential toxic effects of released chemical species on people. HTP per meal ranges from 124 g DCB eq. (Cases H and J) to 1588 g DCB eq. (Case M). The main contributor in the case of large HTP is the manufacture of steel packaging.

For Cases A and G, the HTP per meal served is 134 g DCB eq., with the sources spread fairly evenly between the life cycle stages. Again, the LCA results from literature for the agricultural stage of British chicken and most other ingredients did not include HTP, so the actual total may be higher. The largest contributor is packaging manufacture (28%), followed by the kitchen stage (24%), processing (15%), disposal (15%), agriculture (14%), distribution (12%) and credits (-8%).

Within the kitchen, the hotspots are electricity for cooking (37%), dishwashing (38%) and electricity for hot holding (20%).

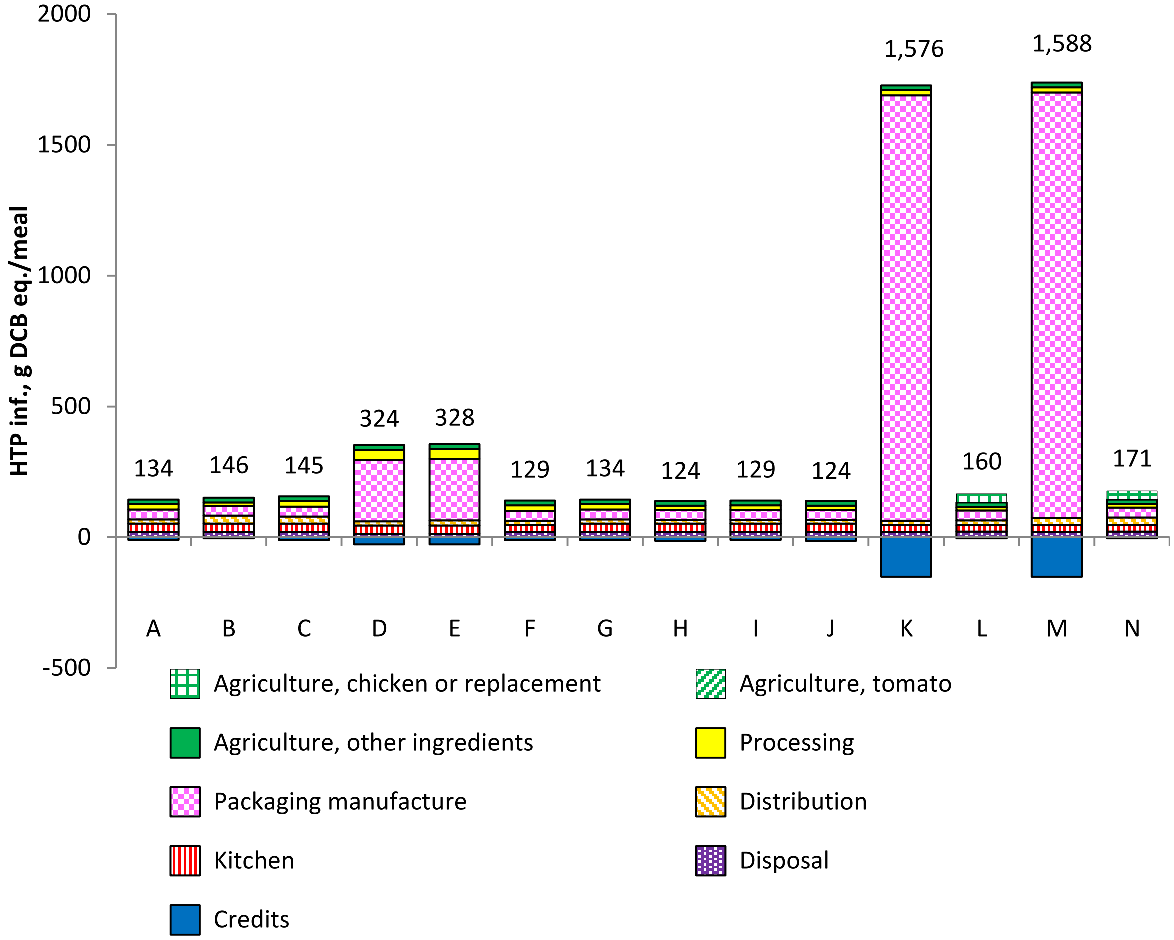


**Figure 24: Impact assessment results, human toxicity potential**

Within processing, the hotspots are steam production (42%), electricity (32%) and waste water treatment (17%).

Within the disposal stage, 73% of HTP comes from food waste treatment from the kitchen, almost entirely from the portion going to landfill.

The majority of credits for HTP come from blood, meat and bone meal being used to replace fertiliser (53%) and recycled steel displacing made from virgin materials (28%).

In Cases B, C and E, the HTP of the distribution phase is increased because of the extra distance travelled by the chicken or tomatoes.

In Case B, the credits are reduced compared to all other cases using meat because the slaughterhouse stage, which produces blood, meat and bone meal as a by-product in the UK, is already included in the functional unit for Brazilian chicken. This is also the reason that the HTP of the processing and packaging manufacture stages are lower for Case B than for the other cases using meat.

For Cases D and E, the HTP of the disposal stage is lower than for the other cases because there is no tomato seed waste, and therefore less food waste from the kitchen.

HTP for processing is 83% and 84%, respectively, greater for Cases D and E than for Case A, because the processing of tomato paste uses more steam and electricity than processing fresh tomatoes does.

For packaging manufacture, HTP is more than six times higher in Cases D and E than in Case A, mainly due to the extra steel used for packaging the tomato paste.

For the kitchen stage, HTP is 14% lower in Case F than in Case A because of the replacement by natural gas of some electricity, which has higher HTP per MJ than natural gas, mainly due to the inclusion of coal in the generating mix.

As for FAETP, the HTP of faba bean and sunflower seed agriculture is based on complete data of chemical release, whereas HTP data are not available for meat and tomato agriculture. Hence, it is clear that sunflower seed agriculture has greater HTP than faba bean agriculture, but it is unknown how it compares to the true total for Cases A to J.

In Cases K and M, HTP for packaging manufacture is an order of magnitude greater than for all other cases, due to the extra steel used to package the faba beans. This outweighs the smaller HTP for faba bean agriculture, leading to greater total HTP in Cases K and M than for Cases L and N.

### 3.4.8 Marine aquatic ecotoxicity potential, infinite time horizon (MAETP)

MAETP refers to toxic effects on ocean ecosystems. The range of impacts varies from 218 kg DCB eq./meal (Case F) to 525 kg DCB eq./meal (Case M). Disposal, the kitchen stage and steel packaging manufacture are major contributors.

For Cases A and G, the MAETP per meal served is 232 kg DCB eq. Again, since the literature sources for LCA results for the agricultural stage of most ingredients did not calculate MAETP, the actual total may be higher than shown. The main contributors are the kitchen stage (36%) and disposal (35%). Within the kitchen, the hotspots are electricity for cooking (40%), dishwashing (34%) and heated holding (22%). Within disposal, 87% of MAETP comes from food waste treatment, mostly from landfill.

For Case B, MAETP for processing is lower than for Case A because the slaughterhouse is not included, and MAETP for distribution is larger because of the extra distance the chicken is transported. For Case C, the distribution phase also has greater MAETP than for Case A because of the extra distance the chicken is transported.

For Cases D and E, the additional steam and electricity use in tomato paste production explain the higher MAETP for processing relative to Case A.

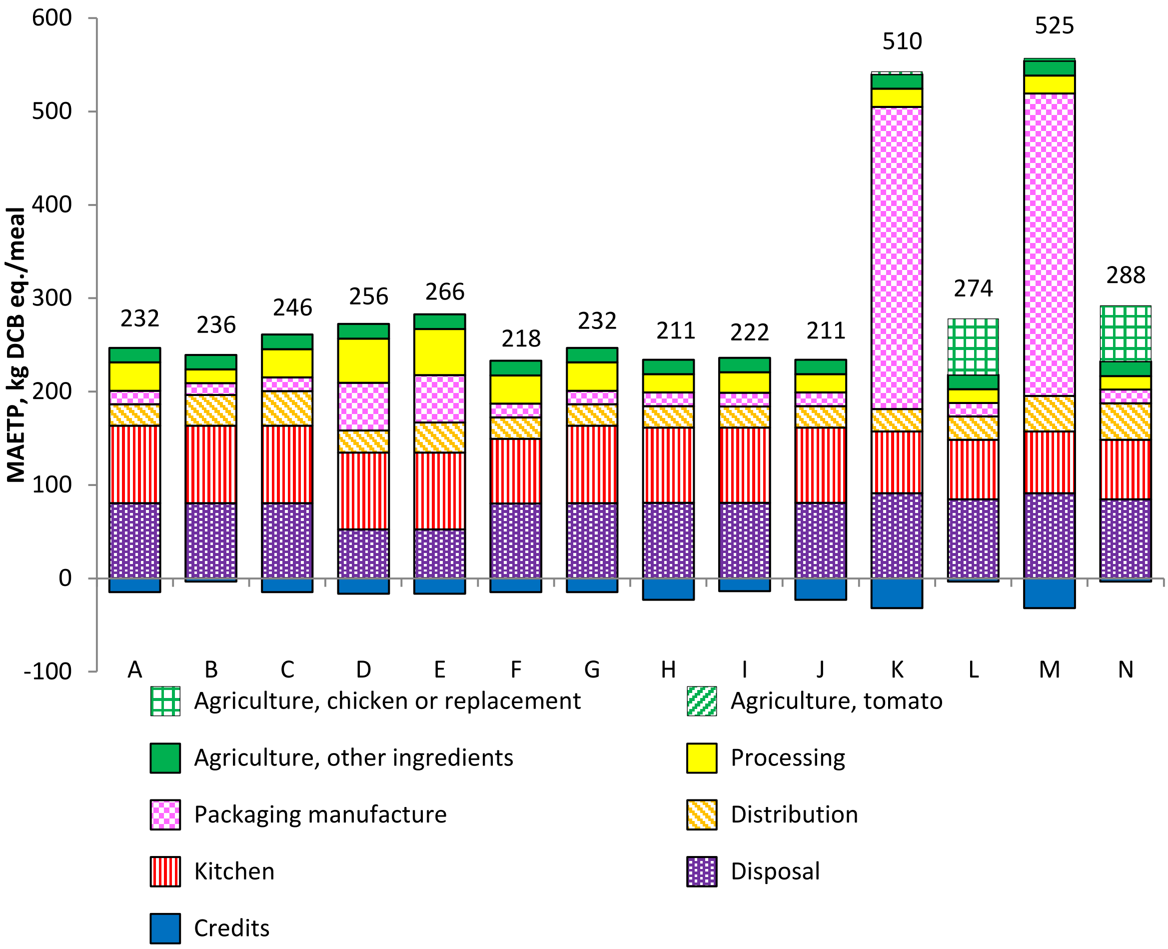


**Figure 25: Impact assessment results, marine aquatic ecotoxicity potential**

For Case F, the kitchen stage has 17% lower MAETP than for Case A due to the substitution of some mains electricity with natural gas.

For Cases H, I and J, the data sources for the relevant animal agriculture did not provide MAETP data. The credits portion is larger in Case H because a smaller fraction of the cattle carcass is turned into edible meat at the slaughterhouse stage (compared to chicken slaughter), and hence there is more waste to be turned into blood, meat and bone meal fertiliser. The same is true for Case J because the yield at the slaughterhouse is assumed to be the same for sheep as it is for cattle.

MAETP for sunflower seed agriculture is 22 times greater than for faba bean agriculture. However, the extra steel packaging for faba beans, means that the total MAETP for the faba bean cases is significantly higher than for the sunflower seed cases. The packaging manufacture stage for Cases K and M has an MAETP more than 22 times as great as for Case A.

### 3.4.9 Terrestrial ecotoxicity potential, infinite time horizon (TETP)

TETP refers to toxic impacts on land-based ecosystems. TETP per meal ranges from 49 g DCB eq. (half of the cases) to 117 g DCB eq. (Cases L and N).

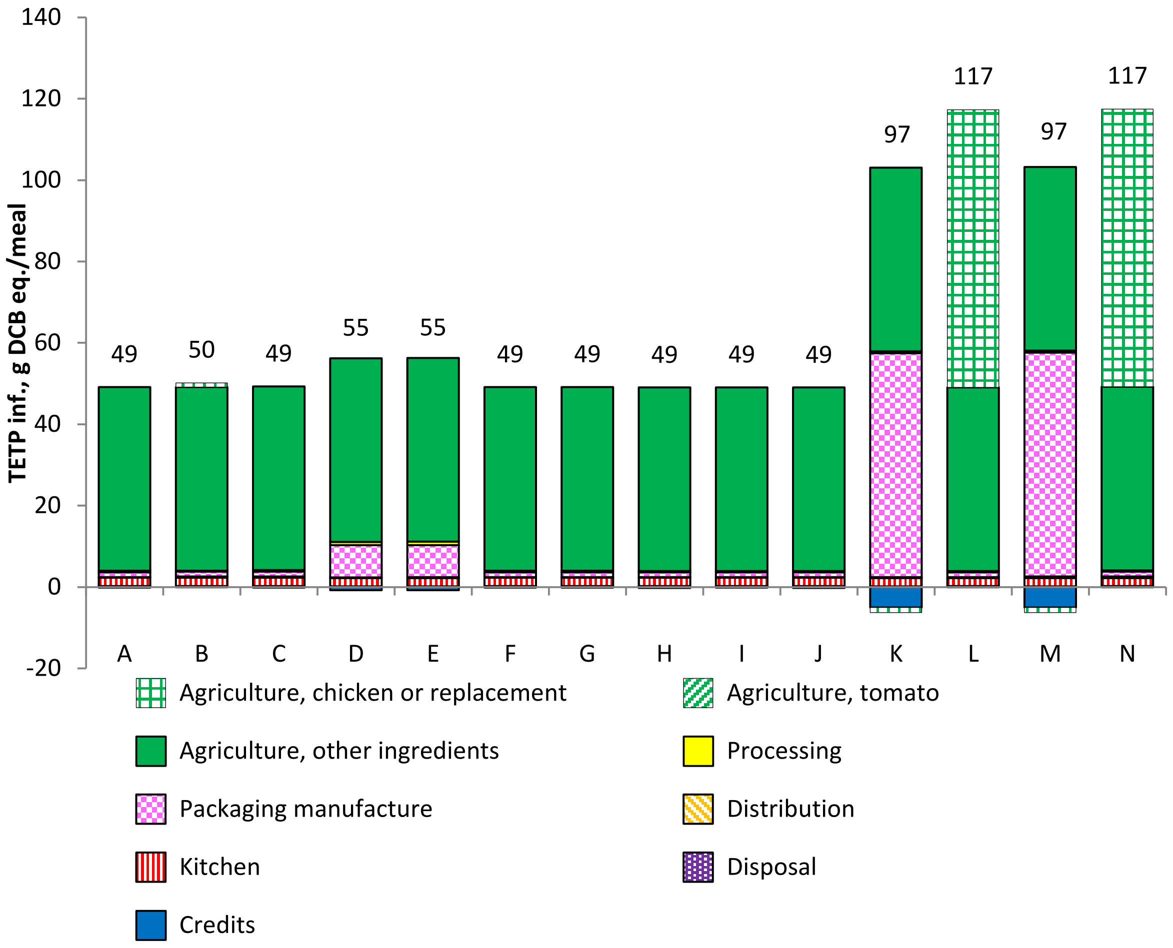


**Figure 26: Impact assessment results, terrestrial ecotoxicity potential**

For Cases A to J, the overwhelming majority of TETP comes from the farming of canola oil (92% in Case A). Again, since the literature sources for the agricultural stage of most ingredients did not include TETP, the true total may be greater than shown. However, the TETP for Brazilian chicken agriculture is known to be 1.4 g DCB eq. TETP for faba bean agriculture in Cases K and M is actually negative, at -1.2 g DCB eq. Although the data source on which faba bean agriculture is based does not fully explain the reason for this, it is probably due to the agricultural practices displacing a previously used process. In Cases K and M, the packaging stage accounts for 57% of the total TETP, mainly due to the extra steel required to package the faba beans. Some of the steel is recycled, contributing to the credits, which reduce overall TETP by 5% in Cases K and M. In Cases L and N, sunflower seed agriculture accounts for 58% of the TETP. Although Cases L and N appear to have the greatest TETP, this may not be true in reality due to a lack of TETP data for other ingredients.

### 3.4.10 Ozone depletion potential, steady state (ODP)

ODP refers to the destructive effect that some chemical species have on the ozone layer. ODP per meal ranges from 36.4 µg R-11 eq. (Cases H and J) to 59.2 µg R-11 eq. (Case N). The main contributor in most cases is distribution.

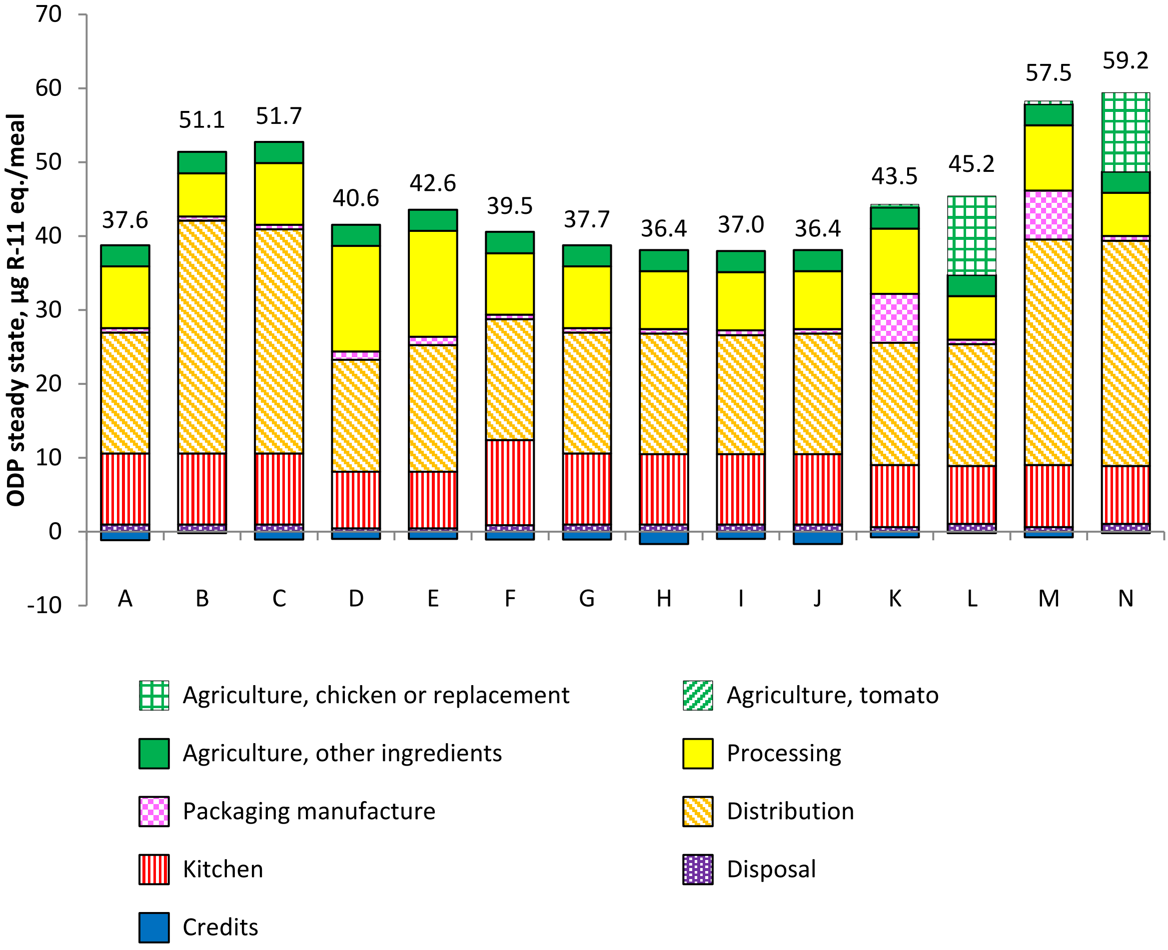


**Figure 27: Impact assessment results, ozone depletion potential**

For Case A, the ODP per meal served is 37.6 µg R11 eq. The main contributors are distribution (43%), kitchen (26%) and processing (22%).

Within distribution, the hotspots are transport (52%) and manufacture of R134a (45%). For transport, ODP comes from various sources including the production of diesel and construction of the road. Note that both ammonia and R134a, the only refrigerants used in the distribution category, have zero ODP so there is no contribution to ODP from refrigerant leakage.

Within the kitchen stage, the hotspots for ODP are refrigerant manufacture (40%), electricity for cooking (18%), dishwashing (17%) and natural gas use (13%). The refrigerant used is R404a, which has zero ODP, so there is no contribution from refrigerant leakage.

Within processing, the hotspots for ODP are steam production (61%), electricity (12%) and natural gas (11%).

In Cases B and C, the distribution stage has greater ODP than for Case A (by 93% and 86%, respectively) due to the extra distance travelled. In Cases D and E, the processing stage has a 72% greater ODP than for Case A because of the extra steam and electricity used in tomato paste processing. In Case F, the kitchen stage has 20% greater ODP due to the greater energy use.

Note that for chicken, tomato, potato, beef, pork and sheep agriculture, ODP data are not available. Hence, although it is clear that sunflower seed agriculture produces much greater ODP than faba bean agriculture, it is not clear what the true total ODP for any case is.

### 3.4.11 Photochemical ozone creation potential (POCP)

POCP refers to the promotion of the formation of ozone at ground level, which can be harmful to human health and to ecosystems. POCP per meal is between 126 mg ethene eq. (Cases H and J) and 236 mg ethene eq. (Case N). However, the literature data for several ingredients does not include POCP, so the true total POCP may be higher than shown for each case.

For Case A, the POCP per meal served is 132 mg ethene eq. The contributions from different stages in Case A are distribution (27%), kitchen (23%), agriculture (17%, of which 77% is due to the canola oil), packaging manufacture (15%), processing (14%), disposal (10%) and credits (-7%).

For Cases B and C, the POCP for distribution is 96% and 86%, respectively, greater than Case A due to the greater transport distances. In Cases C and E, the Spanish tomatoes contribute to POCP. It is likely that British tomatoes also contribute to POCP, but this is not included in the data source. In Case D , the processing stage has 72% greater POCP than for Case A due to the extra steam and electricity used in processing tomato paste. The POCP of the kitchen stage in Case F is only 7% greater than for Case A.

For Cases K and M, the POCP of the packaging manufacture stage is over three times as great as for Case A, due to the additional steel used in packaging the faba beans.

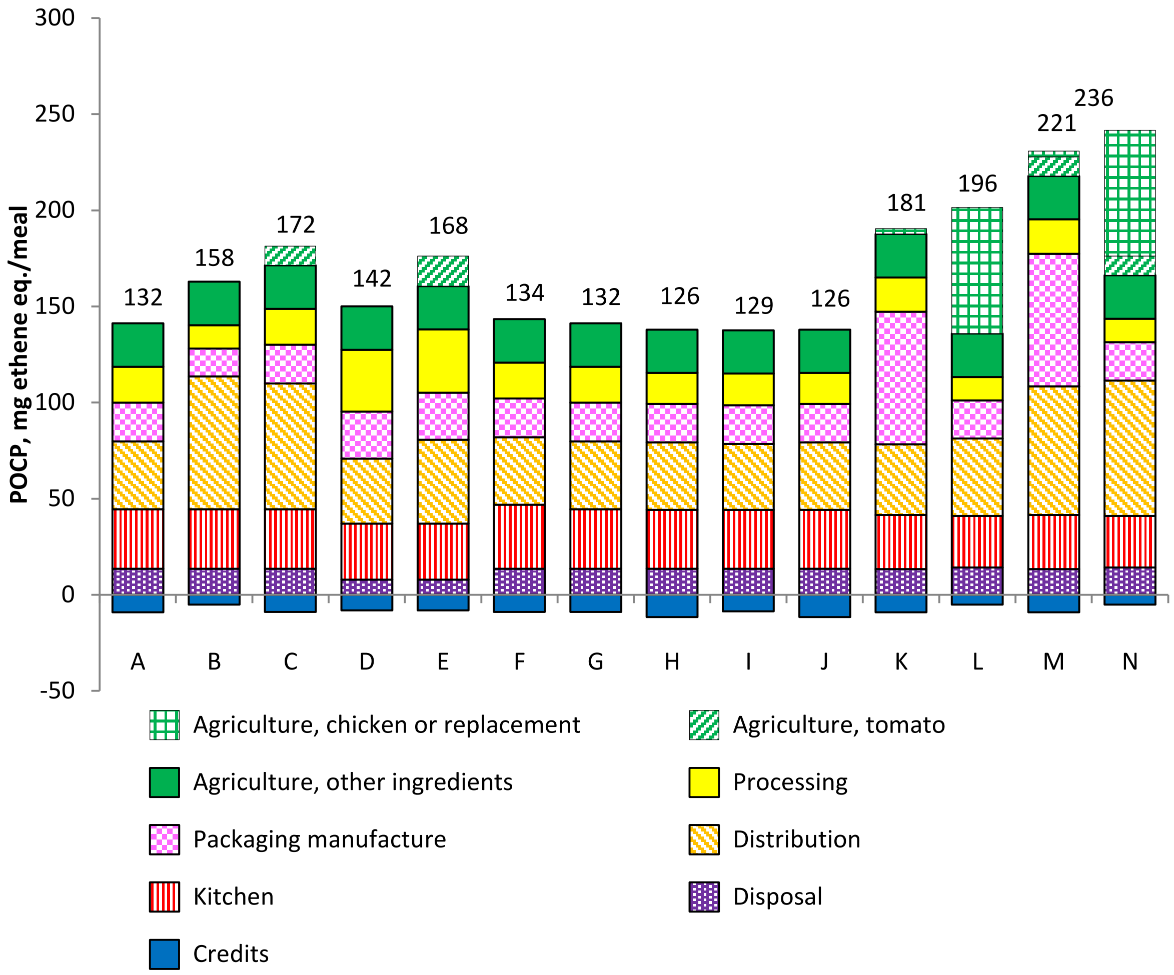


**Figure 28: Impact assessment results, photochemical ozone creation potential**

### 3.4.12 Net primary energy demand

In addition to the impact assessment results outlined above, net primary energy demand is calculated and shown in Figure 29. Net primary energy demand is smaller than gross primary energy demand because it accounts for energy used to evaporate water within the fuel (OECD, 2016). This is slightly larger than $ADP_{fossil}$ because some renewable energy is used (note that for some ingredients, $ADP_{fossil}$ for the agricultural stage is assumed to be equal to the primary energy demand because of a lack of information on the proportion of renewable energy used). For French faba bean agriculture, the primary energy demand appears to be much greater than its $ADP_{fossil}$. However, according to the figures calculated by the GaBi software, this is not due to the amount of renewable energy being used – the amount of non-renewable primary energy demand has itself been calculated to be much greater than $ADP_{fossil}$. The reason for this is unclear, but it could be due to the large fraction of nuclear energy in the French electricity mix. To put the primary energy demand figures into context, the calorific value of the roast chicken meal is estimated to be approximately 1.6 MJ (Condé Nast, 2014).

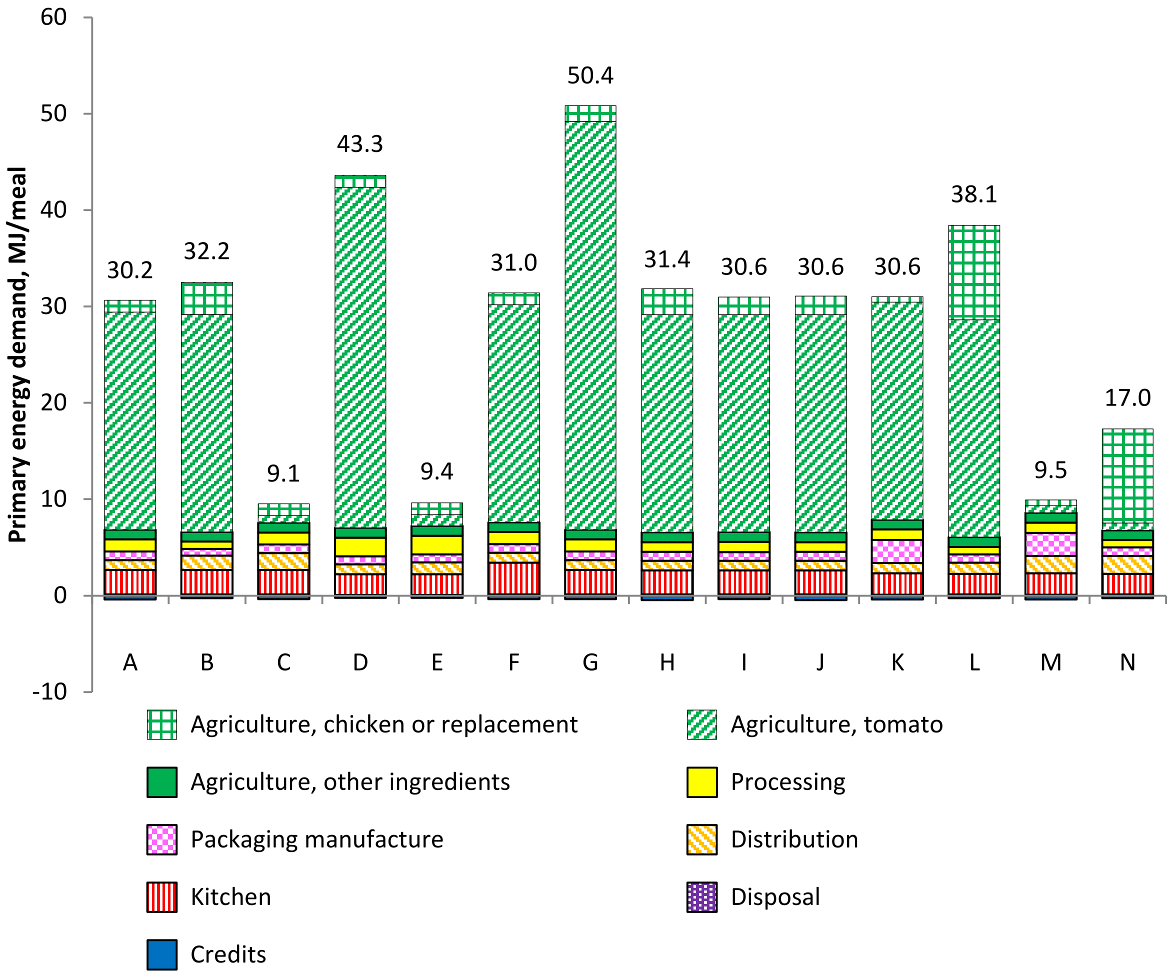


**Figure 29: Net primary energy demand**

## 3.5 Comparison with ready-made and home-cooked meal

Schmidt Rivera et al. (2014) considered the same roast chicken meal as in this study, but with the meal prepared as a ready-made and a home-cooked meal. The authors considered several different scenarios; here, Case E from this study is compared with scenarios “RM-2” (ready-made) and “HM-1” (home-made) of Schmidt Rivera et al. (2014), since all use Spanish tomato paste. In the home-made and ready-made meals, all ingredients are British and non-organic, except for the tomato paste, which is Spanish and non-organic. Chicken, vegetables and the whole ready-meal are provided fresh (i.e. chilled, not frozen). The ready-meal is cooked (i.e. reheated) in an electric oven. In the home-made meal, the chicken is roasted in an electric oven and the vegetables and tomato sauce are cooked on an electric hob.

Figure 30 compares Case E (canteen meal) with the equivalent ready-meal and home-made meal. Since Schmidt Rivera et al. (2014) used GaBi version 4, the results were recalculated by Schmidt Rivera in GaBi version 6 for consistency with this study. Due to some differences in the agricultural data between Schmidt Rivera et al. (2014) and this study, the agricultural impacts for the ready- and home-made meal have been recalculated with the data used by this study. This allows the comparison of the agricultural stage between all three scenarios to be fair. Note that the meal composition given by Schmidt Rivera et al. (2014) did not account for shrinkage of the ingredients due to the evaporation of water during cooking, i.e. the meal composition refers to the raw weights of the ingredients. Hence, the functional unit of this study uses amounts of ingredients which, when raw, correspond to the quantities used by Schmidt Rivera et al. (2014).

As indicated in Figure 30, there are slight differences in the contribution towards impacts from the agricultural stage in all three cases. These are due to the different amounts of food wasted in each supply chain. In particular, 17% by weight of the ready meal is assumed to be wasted at the manufacturing stage. 18% of vegetables and 8% of meat and tomato paste are assumed to be wasted during preparation of the home-made meal. In comparison to the canteen meal (where only 7% is wasted during preparation), this means that the home-made meal requires more food at the farm gate and the ready-meal requires still more. For example, the agricultural stage of the ready-meal has 13% higher $ADP_{elements}$ than that of the canteen meal, and that of the home-made meal is 4% higher than that of the canteen meal.

In all cases, the ready-meal has greater impacts from the packaging stage than the home-made meal since the ready-meal is individually packaged. For six impact categories, the contribution from canteen meal packaging is between that of the ready-meal and home-made meal. For $ADP_{fossil}$, $GWP_{100}$ and POCP, canteen meal packaging has the lowest contribution. For FAETP, HTP and TETP, the canteen meal has the greatest contribution from packaging. The contribution from these latter three categories is in Case E dominated by the impacts of tinplated steel production for the tomato paste cans. The ready-meal uses tomato paste which has been packaged in industrial-sized steel drums (holding 230 kg of paste each), so the amount of steel packaging per meal is 6 g. It is unclear whether the drums are reused. For the canteen meal, which uses wholesale-sized cans (holding 4.5 kg of paste each), each meal requires only around 2 g of tinplated steel. The home-made meal is assumed to require 8 g of tinplated steel due to using smaller cans of paste (holding 400 g each). According to Ecoinvent Centre (2010), tin plated chromium steel sheet has much higher impacts per kg than a typical steel product. It is therefore unsurprising that for categories in which Case E packaging is largely due to tinplated steel (FAETP, HTP, MAETP and TETP), the equivalent contribution from the ready-meal is (except for MAETP) lower than for Case E, despite the additional weight of steel used for the ready-meal. However, it would also be expected that for FAETP, HTP, MAETP and TETP, the equivalent contribution from the home-made meal would be around four times larger than for the canteen meal. This is not the case. One explanation is that the packaging impacts for the home-made meal could have been calculated using an Ecoinvent Centre (2010) process for steel as opposed to tinplated steel.

This exemplifies a general problem in LCA: even if two studies use broadly the same assumptions, differences in implementation can cause significant variations between the results. However, in this case the packaging stage only affects the ranking of the three scenarios in the HTP and TETP categories (i.e. if this stage were removed, then the rankings would only change for these categories).

For the distribution stage, the most dramatic difference can be seen in the ODP impact category. The ready meal has by far the greatest ODP, primarily due to the manufacture of the refrigerant R134a in the distribution phase, according to Schmidt Rivera et al. (2014). Most of the R134a in the ready-meal distribution is used at the retail stage. The home-made meal is assumed by Schmidt Rivera et al. (2014) to use only 24% of the R134a in retail that the ready-made meal does. Hence, it makes sense that ODP is lower for the home-made meal than the ready-meal, but it is not clear why the difference is so large (distribution ODP for the home-made meal is only 3% of that of the ready-meal). The canteen meal lacks the retail stage, since goods are transported directly from the wholesale depot to the canteen kitchen. Furthermore, the weight of manufactured refrigerant attributed to the ready meal and home-made meal is assumed by Schmidt Rivera et al. (2014) to be nearly seven times as great as the amount of refrigerant lost to leakage, whereas for the canteen meal the amount of manufactured refrigerant attributed to one meal is assumed to be equal to the amount lost to leakage. Hence, the canteen meal has an even lower ODP than the home-made meal.

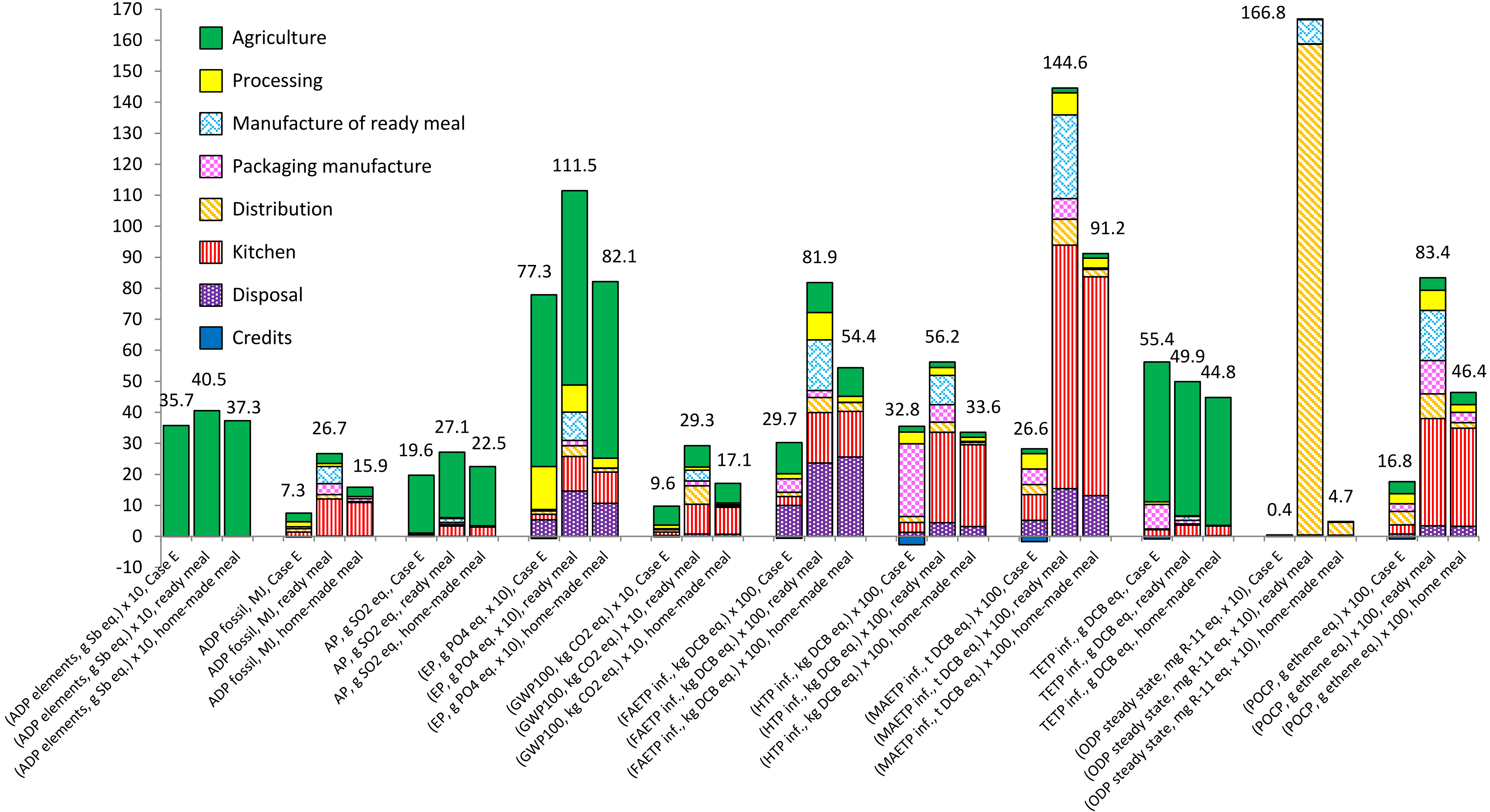


**Figure 30: Comparison of Case E (canteen meal, this study) with ready- and home-made meal**

Data source: Schmidt Rivera et al. (2014). To obtain the actual value, divide the value shown on the graph by the multiplier given in the axis label. For example, Case E has a $GWP_{100}$ of 0.96 kg $CO_2$ eq.

For all impact categories, the canteen meal has considerably lower impacts from the kitchen than the ready-meal and home-made meals have. For example, $GWP_{100}$ from the kitchen stage is 0.11 kg $CO_2$ eq. for Case E, 0.96 kg $CO_2$ eq. for the ready-meal and 0.87 kg $CO_2$ eq. for the home-made meal.

Energy consumption for cooking in each case is summarised in Table 21. It can be seen that the canteen meal uses approximately an order of magnitude less energy for cooking than the ready- and home-made meals. This is because the canteen meals are prepared in large batches and hence the cooking equipment is assumed to be operating at full capacity. In contrast, the whole ready meal and the chicken for the home-made meal are assumed to be cooked in an oven where only one meal is cooked at a time. This explains why the kitchen stage of the canteen has such as low contribution towards impacts. The extra energy used in cooking appears to outweigh the fact that only the canteen meal has a heated holding stage. The canteen meal may become less energy efficient to cook if equipment is not used at full capacity or if cooking equipment is left switched on while it is not being used. These factors are not considered in this study, but would be useful to consider in future work.

The ready-meal also includes a manufacturing step, whereas neither of the other cases do. This contributes to increasing the impacts of the ready-meal relative to the other cases in several impact categories (notably $ADP_{fossil}$, EP, $GWP_{100}$, FAETP, HTP, MAETP, ODP and POCP). Manufacturing includes the initial cooking of the ready meal, which uses less energy than reheating the meal at home because of efficiencies of scale. The whole manufacturing stage uses 1.17 MJ of electricity (see Table 5 of Schmidt Rivera et al. (2014)), compared to 4.57 MJ for reheating the meal at home.

In all categories, the impacts from the disposal stage are lowest for the canteen meal. For example, FAETP for disposal is 100 g DCB eq. per meal, compared to 236 g DCB eq. and 256 g DCB eq. for the ready-meal and home-made meal, respectively. This is largely because a lower amount of food is assumed to be wasted as post-consumer leftovers (12% for the canteen meal , compared to 24% for the ready-meal and home-made meal).

Overall, the canteen meal has the lowest impact out of the three scenarios for nine out of eleven impact categories. The main stages causing the canteen meal impacts to be lower are the kitchen (due to greater energy efficiency during cooking), disposal (due to less food being left on the consumer's plate) and agriculture (due to lower food waste). The exceptions are HTP and TETP, where the large contribution from steel packaging increases the canteen meal's impacts. For HTP, the canteen meal is worse than the home-made meal but better than the ready-meal, and for TETP, the canteen meal has the highest impact.

Table 21: Energy use for cooking for canteen, ready-meal and home-made meal

| Scenario | Energy used for cooking | Comment |
|---|---|---|
| Case E canteen meal | 0.43 MJ | Includes roasting chicken in electric oven, steaming vegetables in electric steam oven and preparing tomato sauce on gas hob. |
| Ready-made meal | 4.57 MJ | Based on Table 7 of Schmidt Rivera et al. (2014). Chilled ready-meal is reheated in electric oven. Value does not include initial cooking in the manufacturing stage. |
| Home-made meal | 4.10 MJ | Based on Table 8 of Schmidt Rivera et al. (2014). Chicken is roast in electric oven and sauce and vegetables are prepared on electric hob. |

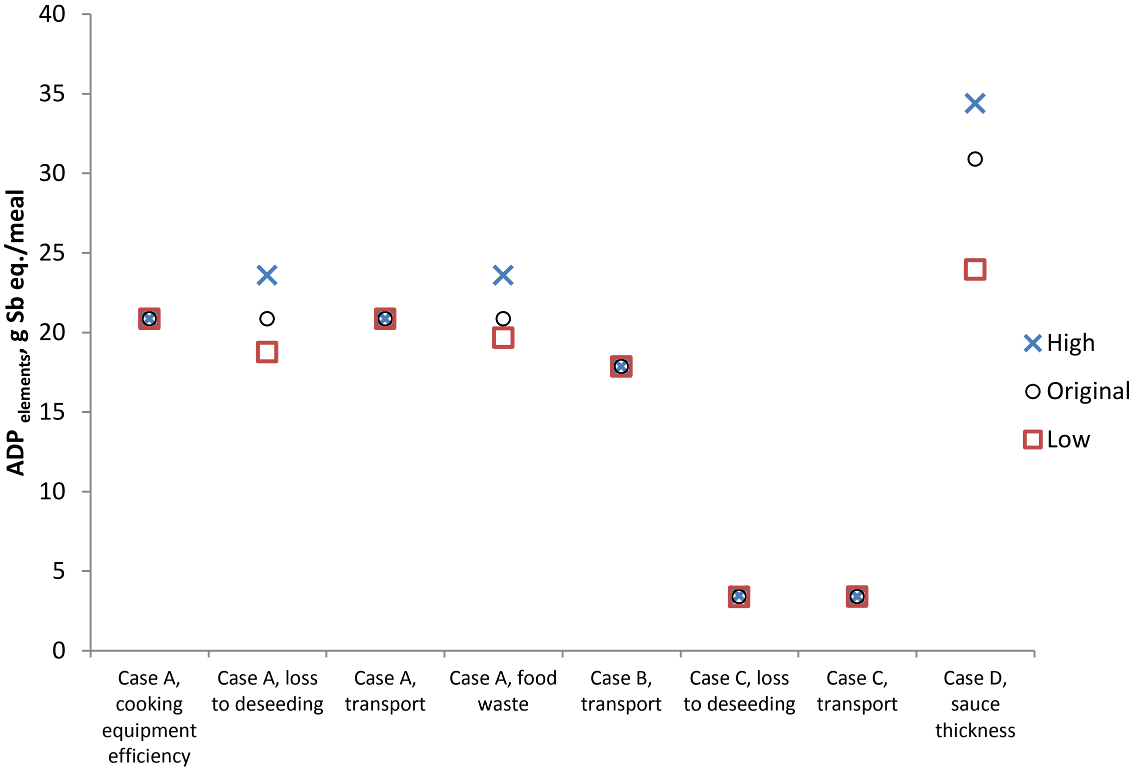
## 3.6 Sensitivity analysis

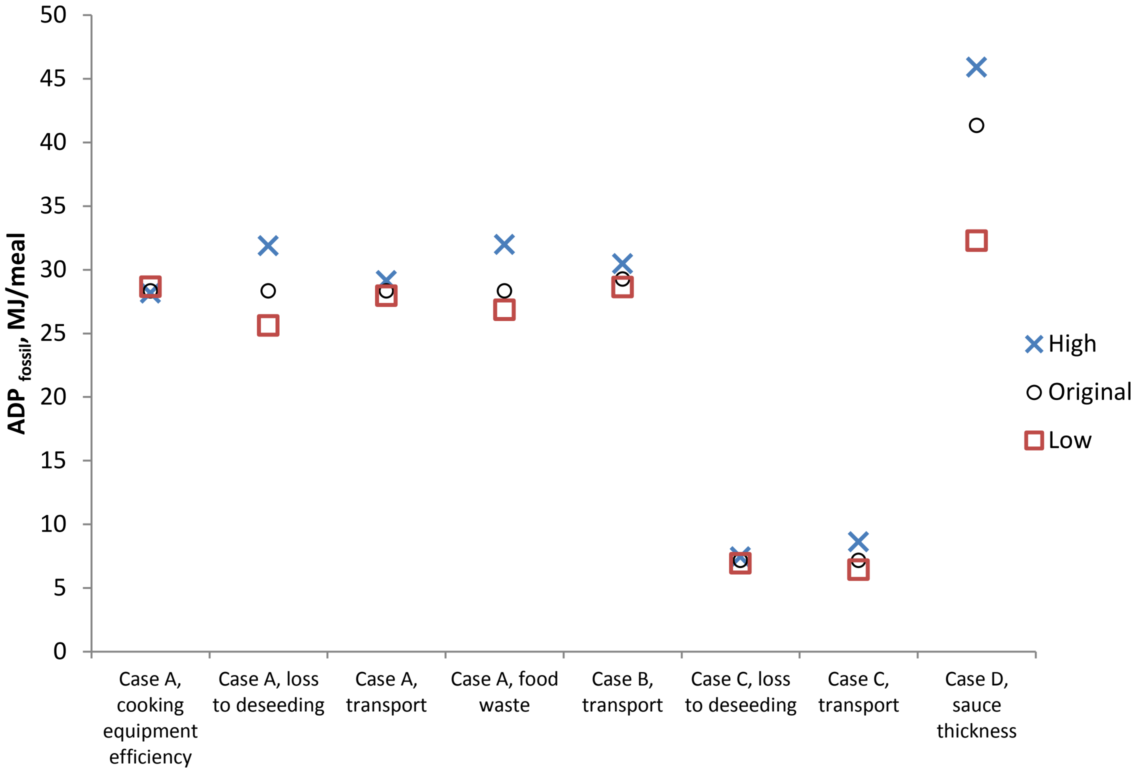
Sensitivity analysis is used to assess the level of influence of various assumptions on the results. Table 22 shows the parameters considered. Parameters to vary were chosen because they are expected to have a significant influence on the results in at least one impact category and because there is a wide range of reasonable values that could have been assumed. Sensitivity analysis is applied to illustrative cases where it is expected to be relevant. Loss to deseeding is applied to both Case A and Case C to show the difference between British and Spanish tomatoes. Since transport distance varies significantly between Cases A, B and C, sensitivity analysis on this parameter is applied to all three cases.

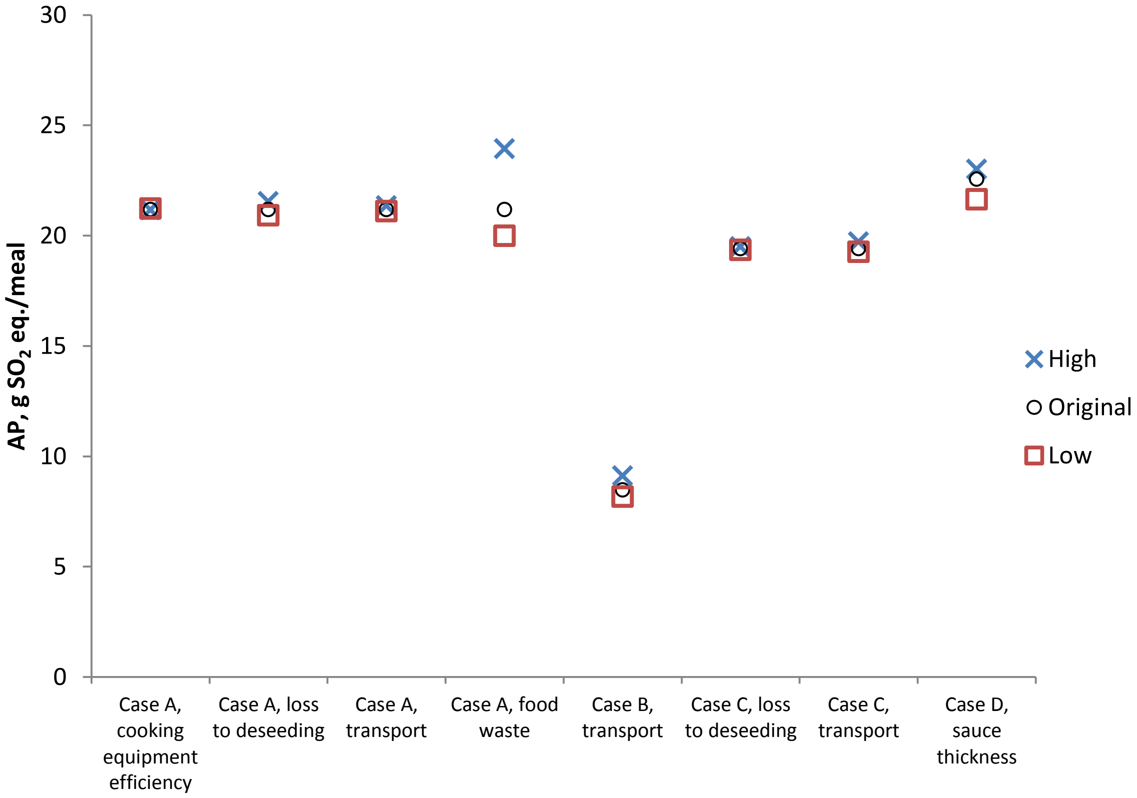
The results are shown in Figure 31. It can be seen that for the categories in which the agricultural stage dominates the results ($ADP_{elements}$, $ADP_{fossil}$, AP, EP, $GWP_{100}$, TETP and PED), the results are most sensitive to the parameters that change the amount of raw materials required, i.e. loss to deseeding, food waste and sauce thickness. This is less prominent where Spanish tomatoes are used (Case C), because of the relatively low energy use for Spanish tomatoes. For example, $GWP_{100}$ is 11% higher than the original value when the loss of tomato to deseeding in Case A is higher, but only 3% higher in Case C. Transport distance strongly affects HTP, MAETP, ODP and POCP. For example, in Case A, ODP increases by 43% with higher transport. Cooking equipment efficiency slightly affects HTP, MAETP, ODP and POCP. For example, higher efficiency reduces MAETP by 3% in Case A.

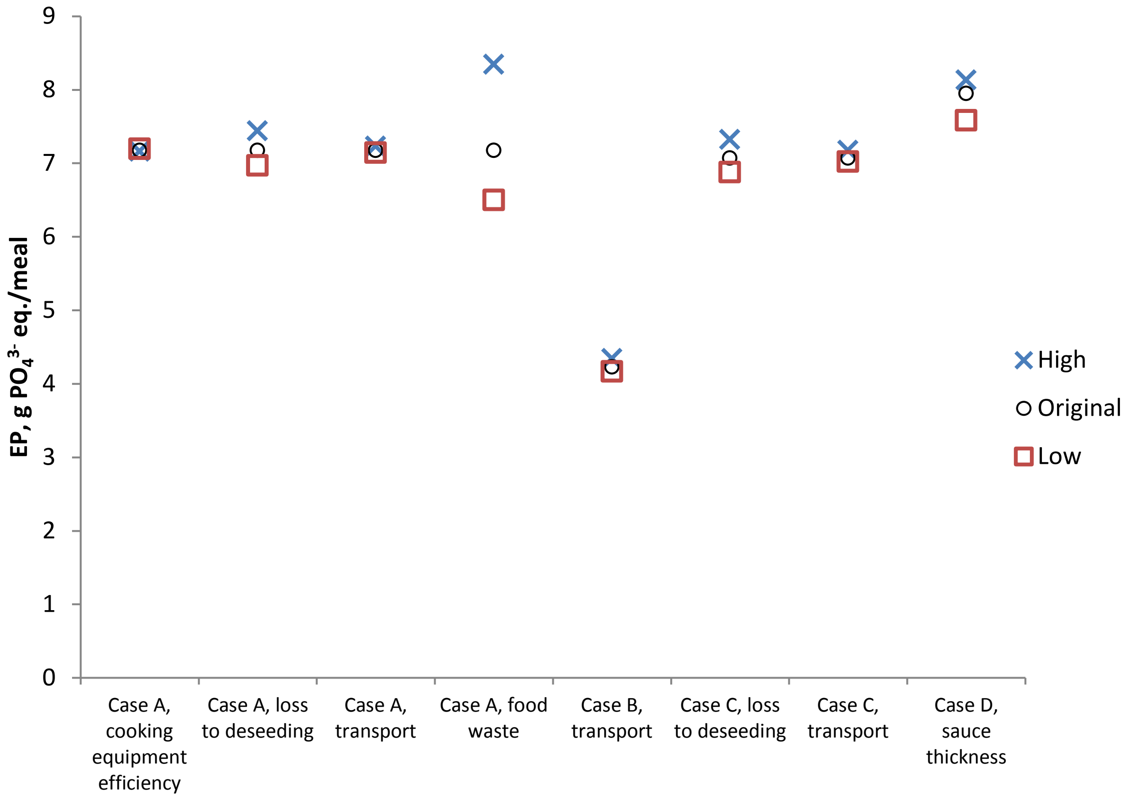
**Table 22: Parameters adjusted for sensitivity analysis**

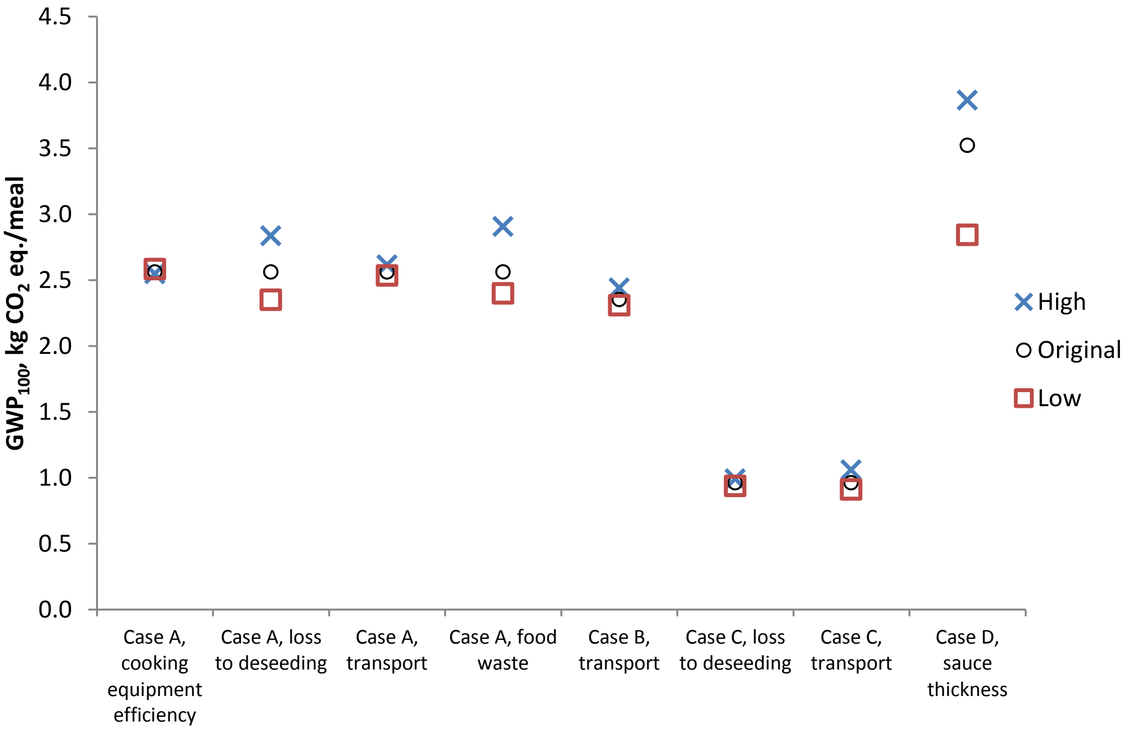
| **Parameter** | **Cases applied to** | **Description** |
|---|---|---|
| Cooking equipment efficiency | A | High efficiency: electric oven 80%, steam oven 80%, gas hob 40%.<br>Low efficiency: electric oven 50%, steam oven 50%, gas hob 25%.<br>Upper and lower estimates of efficiency are based on the ranges given by Food Service Technology Center (2002a) and Food Service Technology Center (2002b). |
| Loss to deseeding | A, C | High loss: 35% of tomato mass is discarded.<br>Low loss: 15% of tomato mass is discarded. |
| Transport distance | A, B, C | Transport of food only is doubled in the high transport case and halved in the low transport case. |
| Food waste | A | Food waste and disposal at the canteen stage only is considered.<br>High waste: based on restaurant subsector; 41 g of plate waste and 77 g of preparation and spoilage waste per 360 g meal.<br>Low waste: based on staff catering subsector; 7 g of plate waste and 4 g of preparation and spoilage waste per 360 g meal.<br>Waste levels are based on data from WRAP (2013b). |
| Sauce thickness | D | High thickness: three parts tomato paste to one part water.<br>Low thickness: one part tomato paste to one part water. |

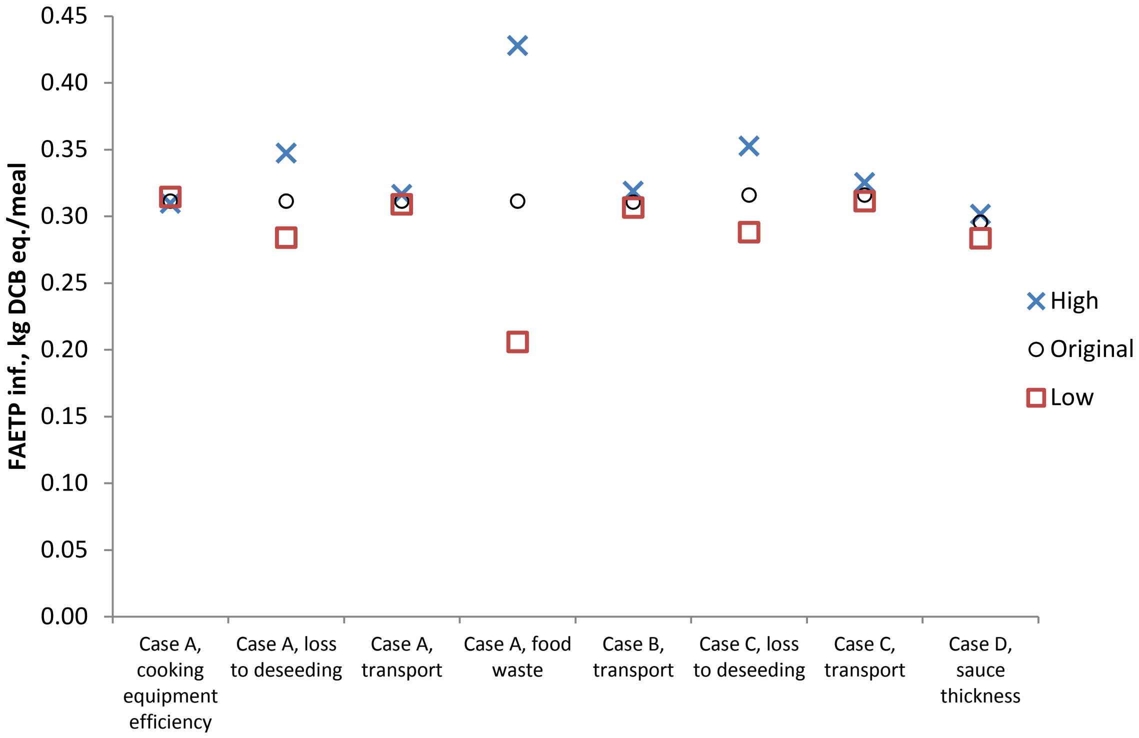


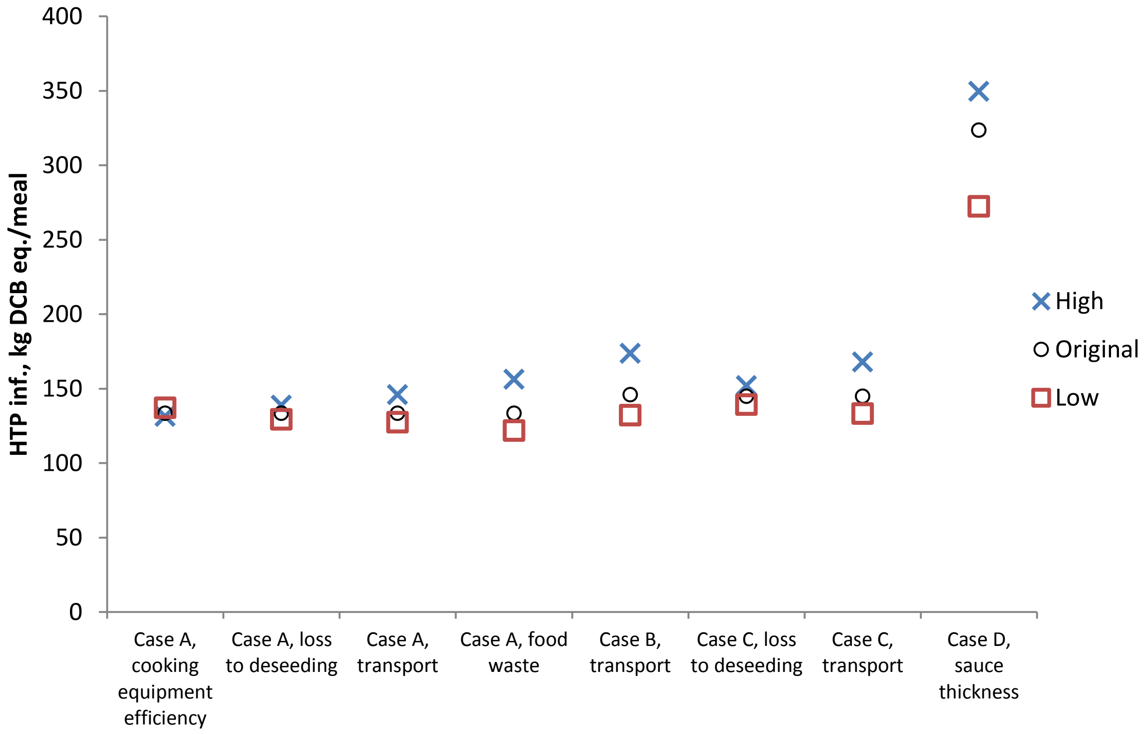

50
45
40
35
30
25
20
15
10
5
0
ADP fossil, MJ/meal
Case A, cooking equipment efficiency
Case A, loss to deseeding
Case A, transport
Case A, food waste
Case B, transport
Case C, loss to deseeding
Case C, transport
Case D, sauce thickness
High
Original
Low

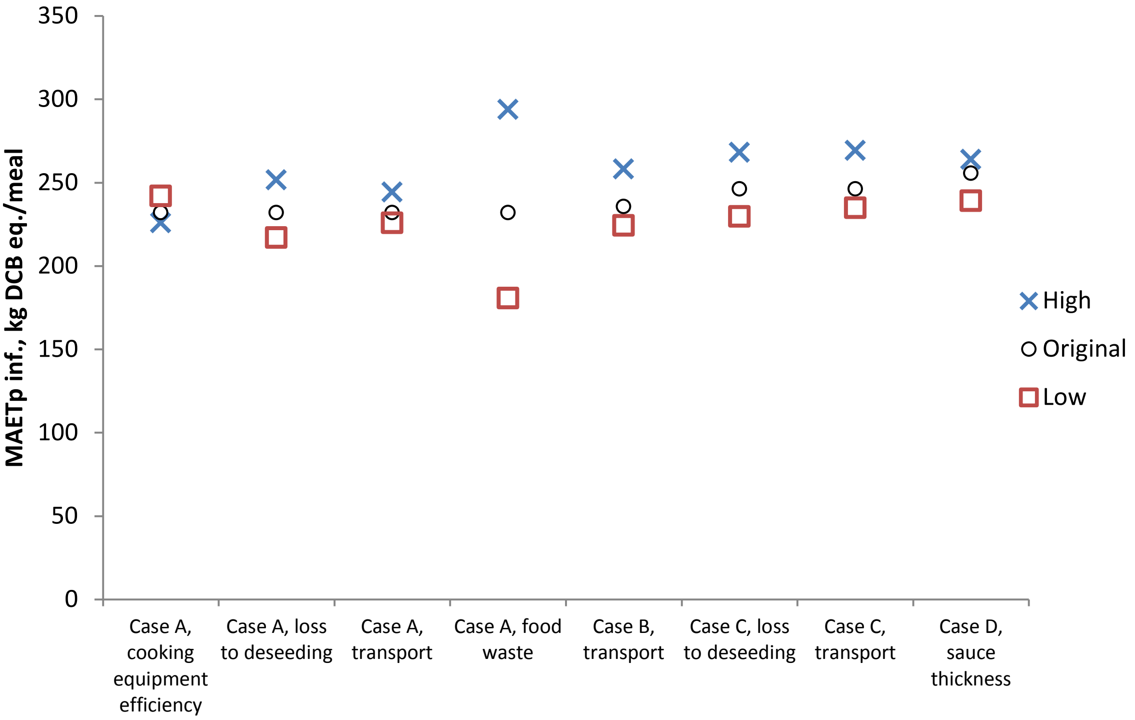

30
25
20
15
10
5
0
AP, g SO2 eq./meal
Case A, cooking equipment efficiency
Case A, loss to deseeding
Case A, transport
Case A, food waste
Case B, transport
Case C, loss to deseeding
Case C, transport
Case D, sauce thickness
High
Original
Low


EP, g $PO_4^{3-}$ eq./meal
0
1
2
3
4
5
6
7
8
9
Case A, cooking equipment efficiency
Case A, loss to deseeding
Case A, transport
Case A, food waste
Case B, transport
Case C, loss to deseeding
Case C, transport
Case D, sauce thickness
High
Original
Low

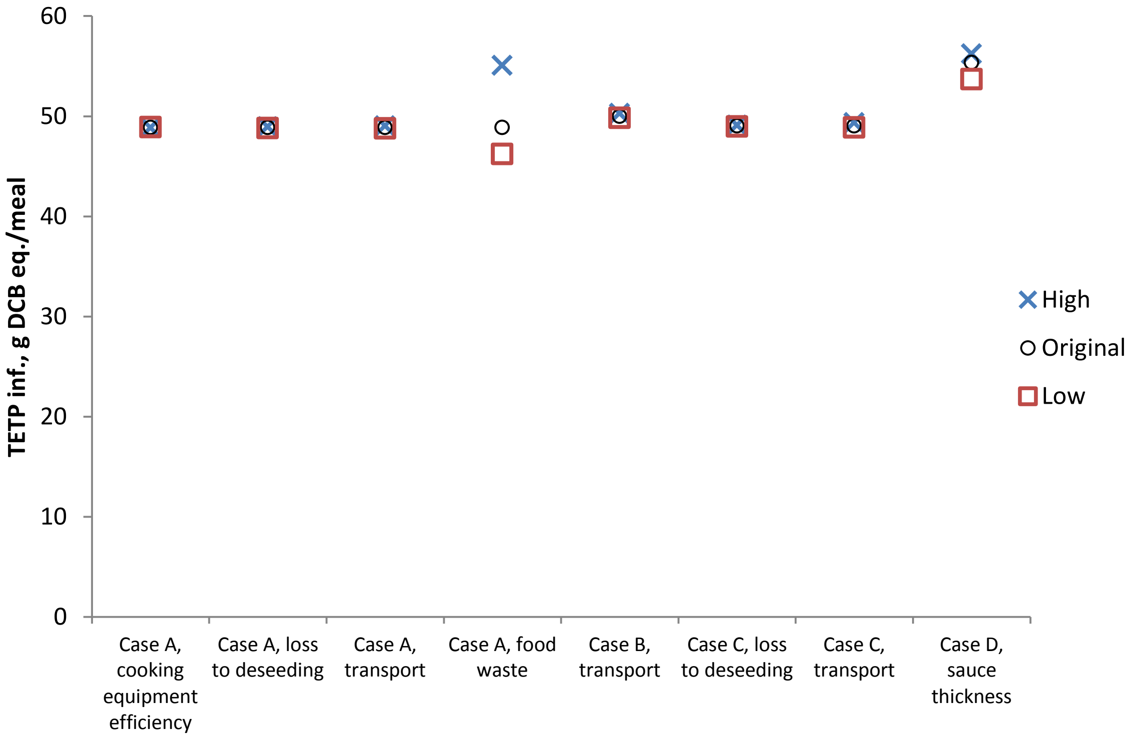

$GWP_{100}$, kg $CO_2$ eq./meal
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Case A, cooking equipment efficiency
Case A, loss to deseeding
Case A, transport
Case A, food waste
Case B, transport
Case C, loss to deseeding
Case C, transport
Case D, sauce thickness
High
Original
Low


0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
FAETP inf., kg DCB eq./meal
Case A, cooking equipment efficiency
Case A, loss to deseeding
Case A, transport
Case A, food waste
Case B, transport
Case C, loss to deseeding
Case C, transport
Case D, sauce thickness
High
Original
Low

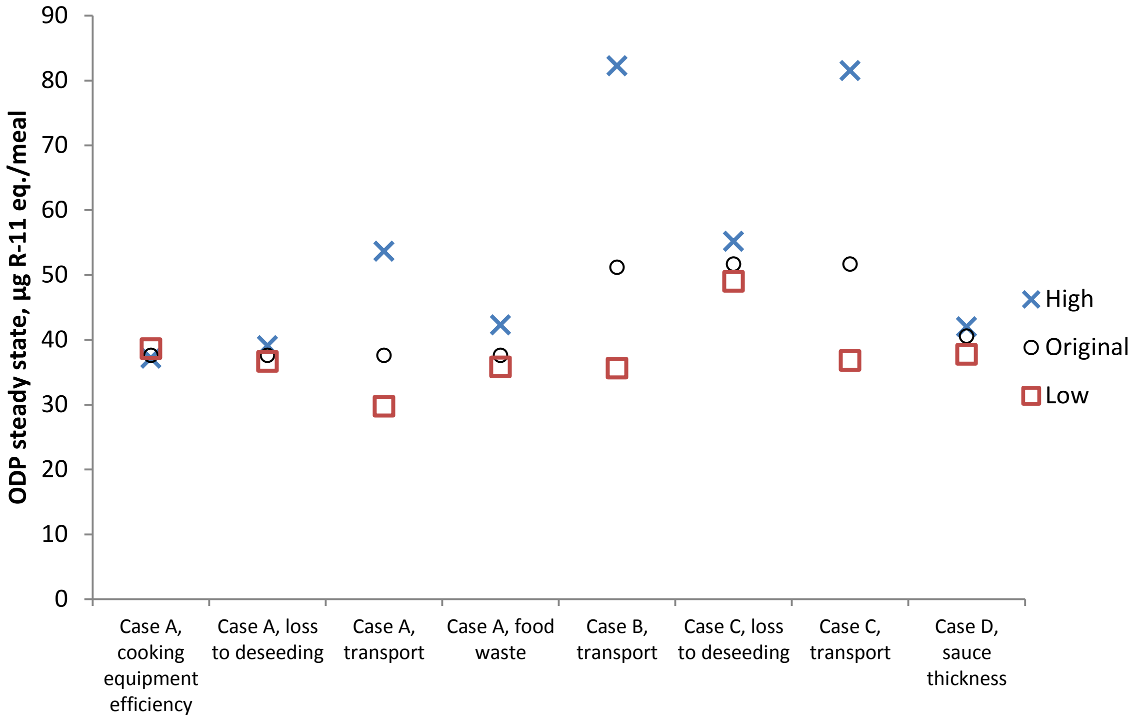

400
350
300
250
200
150
100
50
0
HTP inf., kg DCB eq./meal
Case A, cooking equipment efficiency
Case A, loss to deseeding
Case A, transport
Case A, food waste
Case B, transport
Case C, loss to deseeding
Case C, transport
Case D, sauce thickness
High
Original
Low

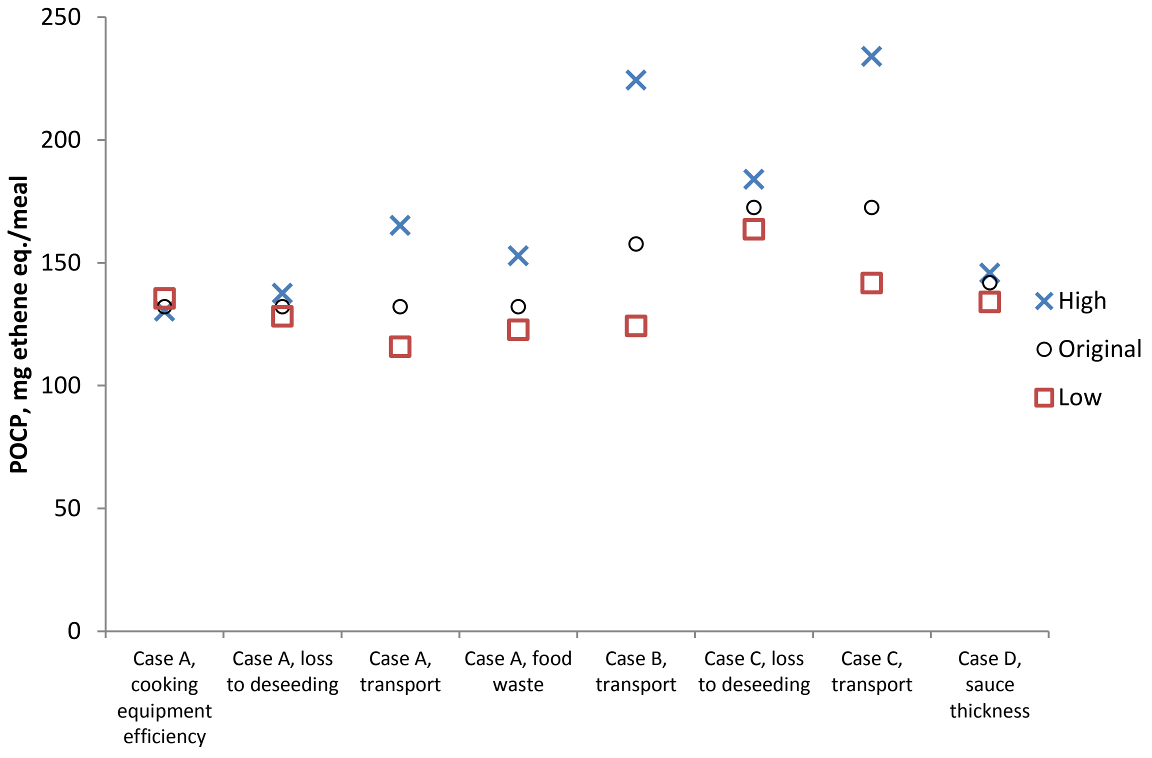


MAETp inf., kg DCB eq./meal
350
300
250
200
150
100
50
0
Case A, cooking equipment efficiency
Case A, loss to deseeding
Case A, transport
Case A, food waste
Case B, transport
Case C, loss to deseeding
Case C, transport
Case D, sauce thickness
High
Original
Low



TETP inf., g DCB eq./meal
60
50
40
30
20
10
0
Case A, cooking equipment efficiency
Case A, loss to deseeding
Case A, transport
Case A, food waste
Case B, transport
Case C, loss to deseeding
Case C, transport
Case D, sauce thickness
High
Original
Low


ODP steady state, µg R-11 eq./meal
90
80
70
60
50
40
30
20
10
0
Case A, cooking equipment efficiency
Case A, loss to deseeding
Case A, transport
Case A, food waste
Case B, transport
Case C, loss to deseeding
Case C, transport
Case D, sauce thickness
High
Original
Low


POCP, mg ethene eq./meal
250
200
150
100
50
0
Case A, cooking equipment efficiency
Case A, loss to deseeding
Case A, transport
Case A, food waste
Case B, transport
Case C, loss to deseeding
Case C, transport
Case D, sauce thickness
High
Original
Low

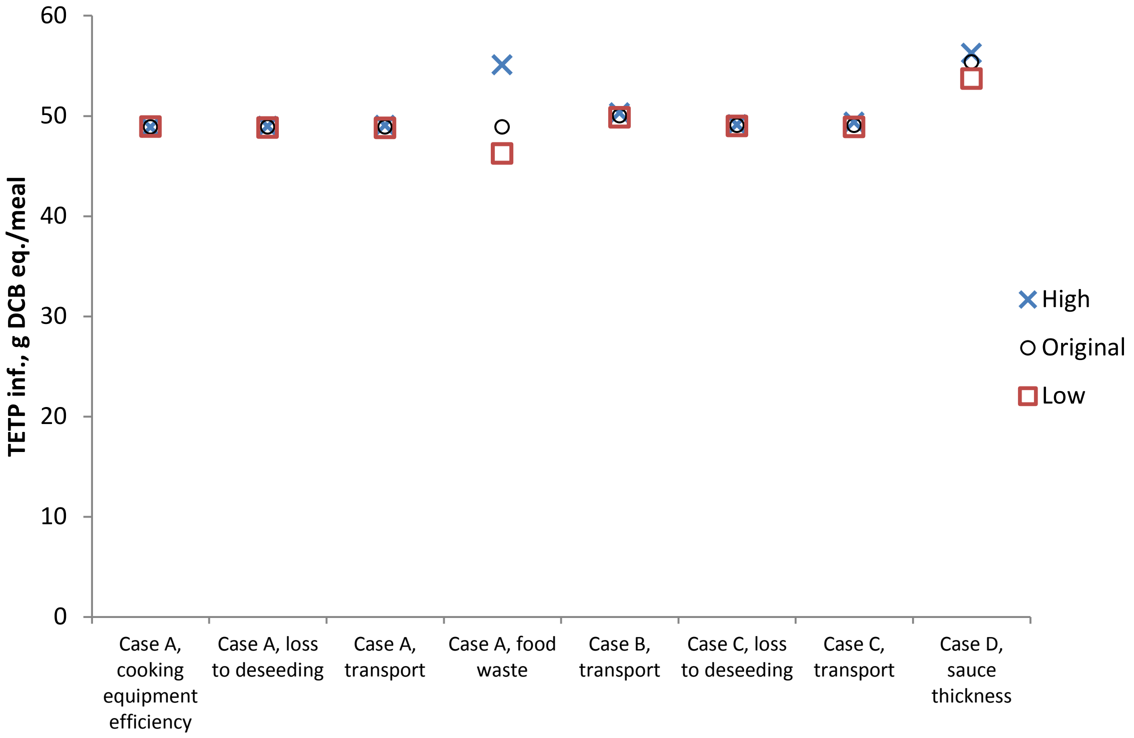


**Figure 31: Results of sensitivity analysis**

## 3.7 Data quality

### 3.7.1 Alternative data for agricultural ingredients

Since the results in several impact categories are dominated by agriculture, it is important to consider what the effect of using alternative data sources for agriculture would be. Figure 32 shows the environmental impacts for chicken and tomatoes from four different literature sources. The first source, Williams et al. (2006), is that used in the scenarios outlined above. Two other sources of data covering British chicken are included (Leinonen et al., 2012; Webb et al., 2013), both of which are more recent than Williams et al. (2006). Since all three of these only give the results for five of the relevant impact categories, information from the Agribalyse database (French Environment and Energy Management Agency, 2016) covering French broiler production is included in order to give an approximate value for the missing impact categories.

It can be seen that the different data sources give highly varying results. While the three British data sources give results in the same order of magnitude, the French data source gives results which are significantly lower. It is unclear whether this is due to actual differences in production conditions between French and British agriculture or instead due to differences in assessment methods. To put the magnitude of the Agribalyse results for FAETP, HTP, MAETP, ODP, POCP and

TETP into context, as a percentage of the post-farm-gate impacts for Case A they range from 1% (FAETP) to 42% (TETP).

Figure 33 shows the Life Cycle Assessment results for British tomato agriculture given by two different sources (Williams et al. (2006), which is used in the scenarios above, and Webb et al. (2013)). Webb et al. (2013) give significantly lower results than Williams et al. (2006), but the reason for this is unclear. The difference is not due to assumed yield, since this is similar for both data sources.

To illustrate how these differences could affect the overall results of this study, Figure 34 shows the results of Case A when using Williams et al. (2006), as above, and when using Webb et al. (2013) as the data source for both chicken and tomatoes. Only the five impact categories covered both sources are shown.

It can be seen that the choice of data source has a large effect on the results. $ADP_{elements}$, $ADP_{fossil}$ and $GWP_{100}$ decrease by more than half when Webb et al. (2013) is used, while AP and EP increase significantly. However, for both data sources, the agricultural stage remains the main contributor to these five impact categories.

### 3.7.2 Pedigree matrix

To assess the quality of data used to build the LCA models, a pedigree matrix is used, as suggested by Weidema and Wesnæs (1996). This rates each data source from 1 to 5 (1 being the best) in five categories, described in Table 23.

Table 24 shows the pedigree matrix for the agricultural data sources. A full pedigree matrix for the other data used in the LCA models can be found in Appendix H.

It can be seen that the weakest categories tend to be completeness and temporal correlation. The LCA model could therefore be made more reliable if it used more recent data and more representative data.

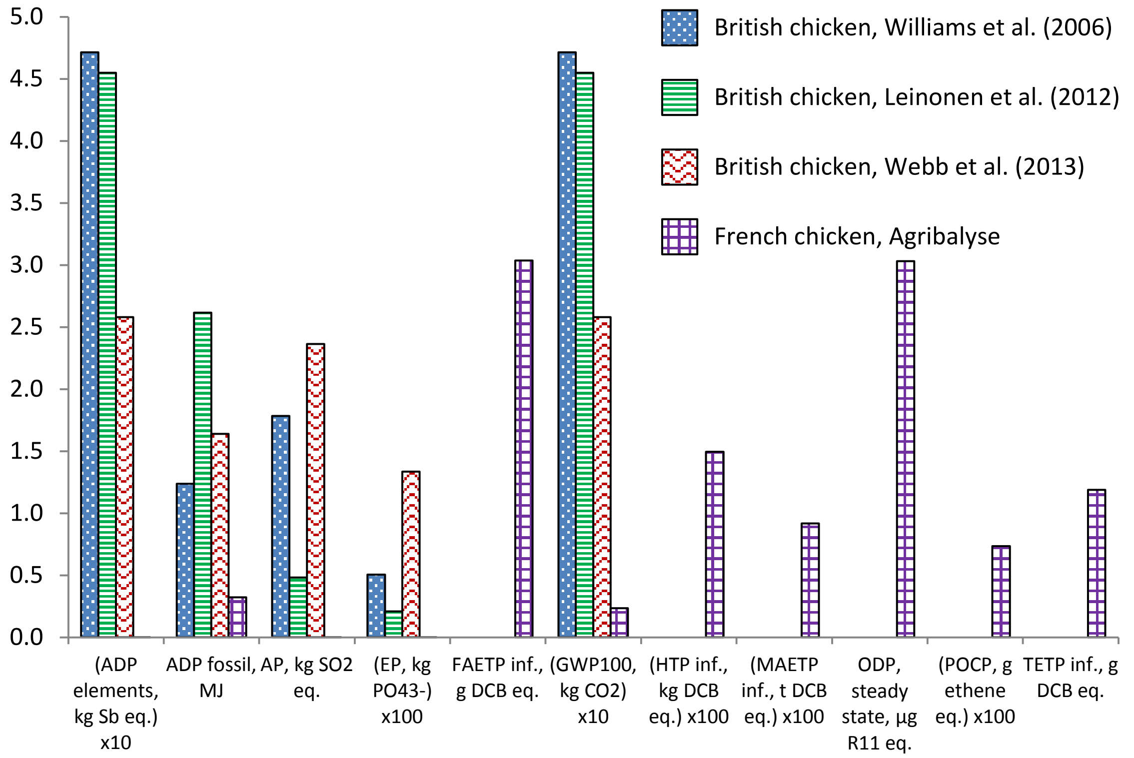


**Figure 32: Life cycle assessment results for chicken agriculture from different sources**

Environmental impacts are shown per meal, based on the weight of chicken used in Case A. Data sources are Williams et al. (2006), Leinonen et al. (2012), Webb et al. (2013) and French Environment and Energy Management Agency (2016). To find the impact value, divide the value shown on the graph by the multiplier shown for that impact category on the horizontal axis, e.g. the $GWP_{100}$ given by Williams et al. (2006) is 0.47 kg $CO_2$ eq.

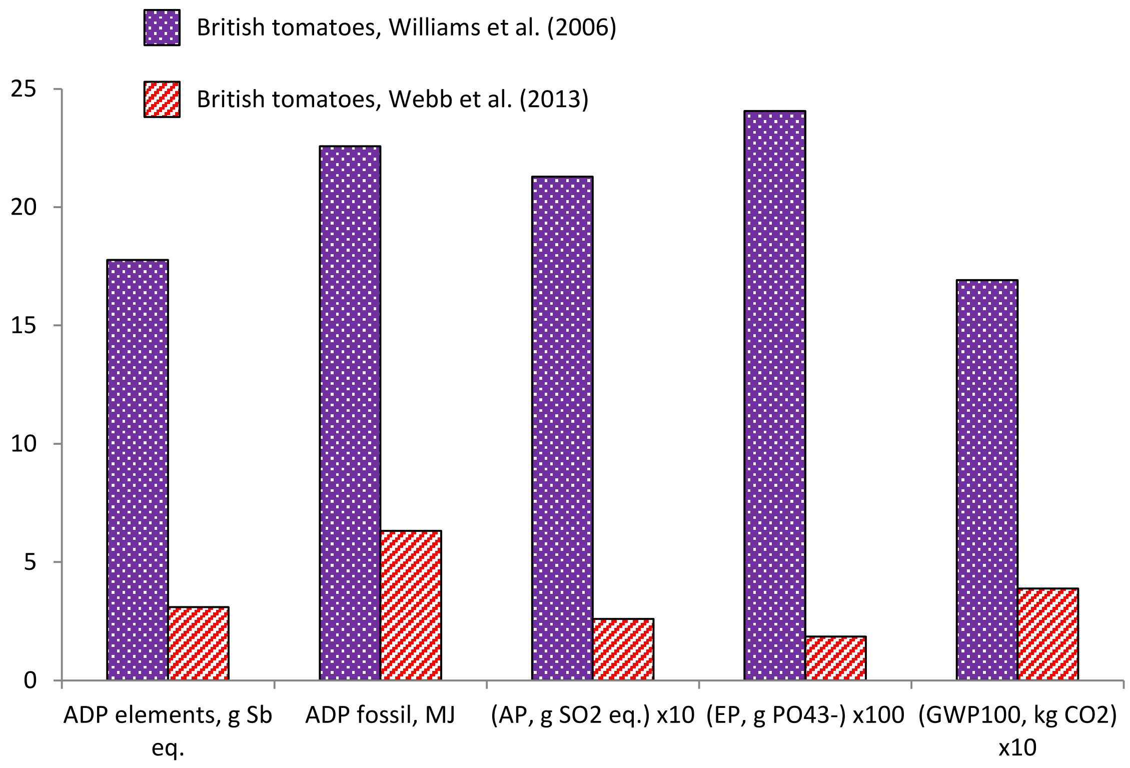


**Figure 33: Life cycle assessment results for tomato agriculture from different sources**

Environmental impacts are shown per meal, based on the weight of tomatoes used Case A. Data sources are Williams et al. (2006) and Webb et al. (2013).

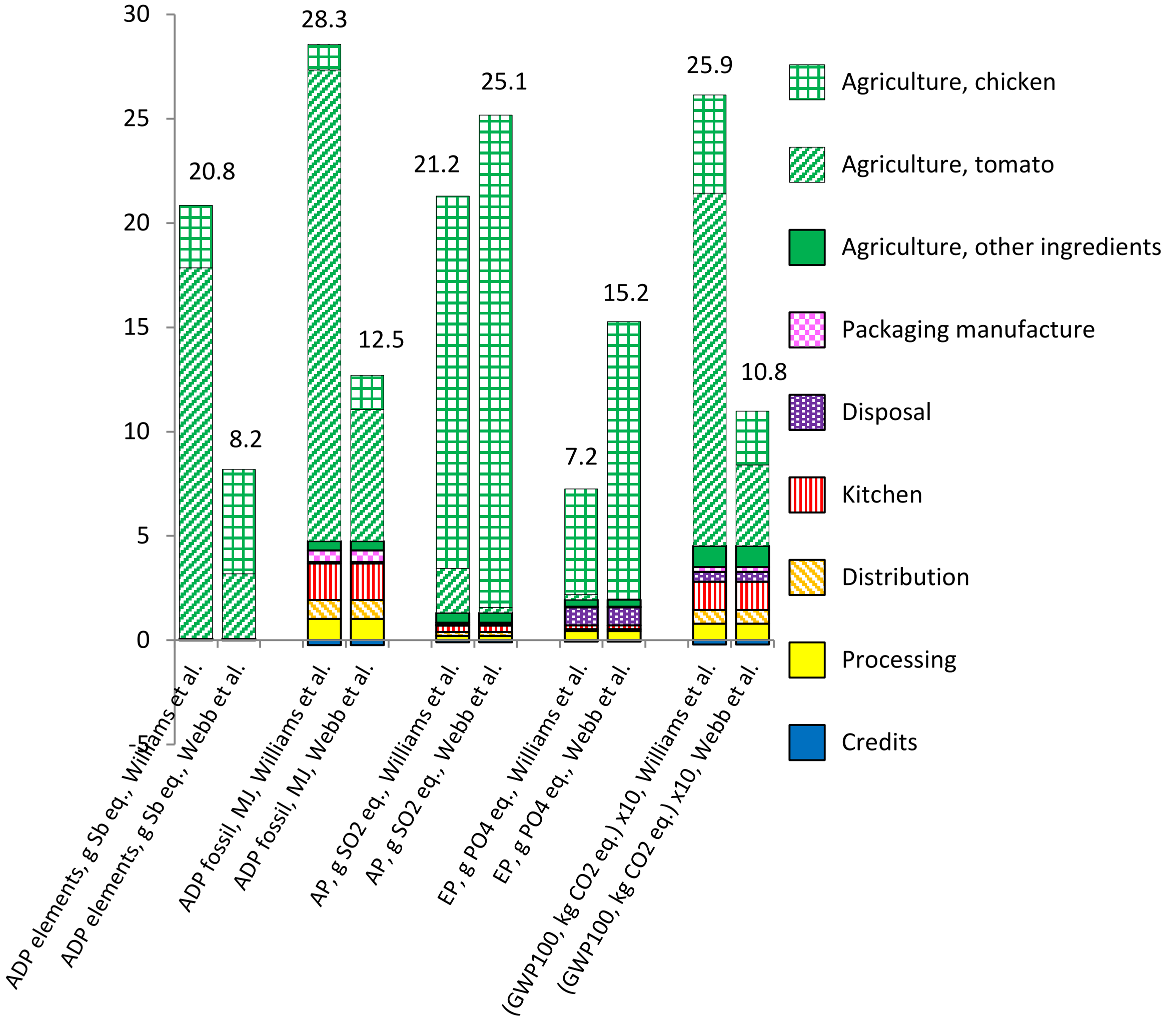


**Figure 34: Effect of agricultural data source for chicken and tomato on Case A results**

$GWP_{100}$ results have been scaled up by a factor of 10 to fit on the graph (the values are 2.59 and 1.08 kg $CO_2$ eq. for Williams et al. (2006) and Webb et al. (2013), respectively).

**Table 23: Overview of data quality indicators used in the pedigree matrix**

Full descriptions of each level (1 to 5) of each indicator are available in Weidema and Wesnæs (1996).

| **Data quality indicator** | **Description** |
|---|---|
| Reliability | Describes the sources, acquisition methods and verification procedures for the data used. |
| Completeness | Related to sample size and representativeness. |
| Temporal correlation | Based on the time difference between the study and the year in which the data were obtained. |
| Geographical correlation | Based on the match between the geographical area in which the data were gathered and the area under consideration in the study. |
| Further technological correlation | Describes the relevance of the processes and materials in the source of data. |

**Table 24: Pedigree matrix for agricultural data**

| Process | Reliability | Completeness | Temporal correlation | Geographical correlation | Further technological correlation | Data source |
|---|---|---|---|---|---|---|
| British non-organic and organic chicken and tomato; beef, pork and sheep. | 2 | 3 | 4 | 1 | 2 | Williams et al. (2006) |
| Brazilian chicken | 3 | 3 | 2 | 1 | 2 | Da Silva et al. (2014) |
| French faba bean | 2 | 2 | 4 | 2 | 2 | French Environment and Energy Management Agency (2016) |
| French sunflower seed | 3 | 1 | 4 | 1 | 1 | |
| Spanish tomato | 2 | 4 | 3 | 1 | 2 | Torrellas et al. (2012) and Fundación Cajamar (2008) |
| Potato | 2 | 3 | 3 | 1 | 2 | Williams et al. (2006) |
| Pea | 3 | 4 | 3 | 1 | 5 | Canals et al. (2008) |
| Onion | unknown | 5 | 5 | 3 | 2 | Nielsen et al. (2003) |
| Carrot | unknown | 5 | 5 | 3 | 2 | |
| Canola oil | 2 | 2 | 4 | 2 | 3 | Ecoinvent Centre (2010) |
| Salt | 3 | 5 | 5 | 2 | 2 | |

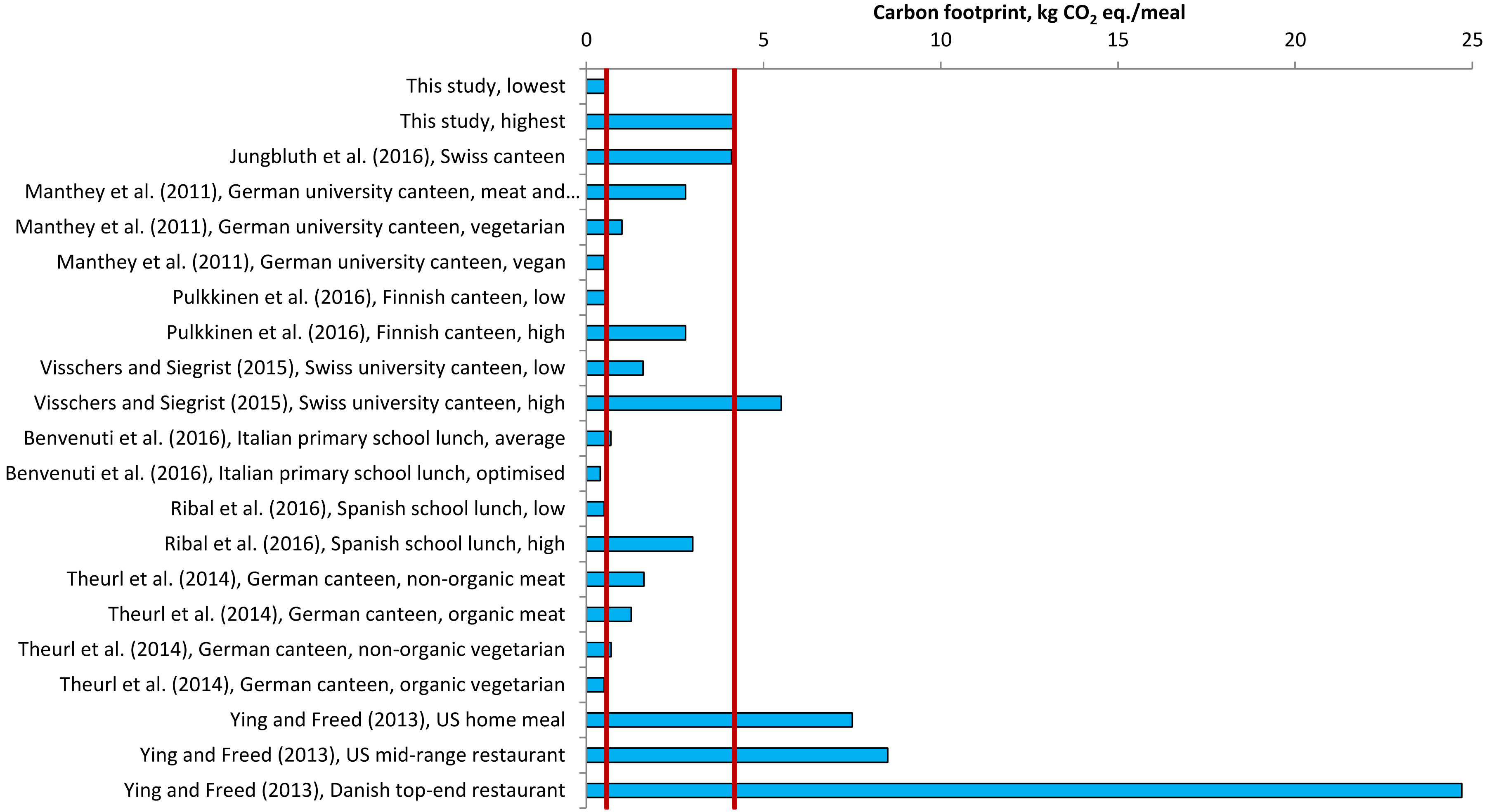


**Figure 35: Comparison of carbon footprint with literature values**

The vertical lines show the minimum and maximum carbon footprints found in this study.

## 3.8 Discussion

### 3.8.1 Comparison with literature

This study is, to the author's knowledge, the first LCA of a meal prepared in the UK food service sector. It is therefore not possible to compare the results with other LCA results for the UK food service sector. However, the results can be compared with case studies from the food service sector in other countries. Carbon footprints are more commonly reported in literature than other impact categories, so that is what the bulk of this comparison will focus on. Figure 35 shows carbon footprints given in literature for various food service systems and compares them to the minimum and maximum carbon footprints found in this study. All literature sources shown give ranges that overlap with the range of values found in this study, with the exception of the values given for restaurants (Ying and Freed, 2013).

Jungbluth et al. (2016) find that the average carbon footprint of a meal served in a chain of Swiss canteens is 4.1 kg $CO_2$ eq., which is towards the high end of the range of carbon footprints for the different scenarios in this study (0.6 kg $CO_2$ eq. to 4.3 kg $CO_2$ eq. per meal). Agriculture, particularly for meat, is found to be a significant contributor, which matches the findings of this study. Canteen operation including waste treatment accounts for about one quarter of the total carbon footprint, which is significantly higher than found in this study (except for Cases M and N, which have significantly lower carbon footprints at the agricultural stage and hence relatively greater impacts from the kitchen and disposal). This is probably partly due to the inclusion of services that were not included in the study system, such as space heating. Jungbluth et al. (2016) recommend reducing food waste, saving energy in the canteen, avoiding vegetables grown in heated greenhouses and reducing the average amount of meat per meal, which corresponds to the broad recommendations of this study.

Manthey et al. (2011) calculate the carbon footprint associated with meals prepared in German university canteens as 2.8 kg $CO_2$ eq. for meals containing meat and dairy, 1.0 kg $CO_2$ eq. for a vegetarian meal and 0.5 kg $CO_2$ eq. for a vegan meal. These results are similar to this study but do not include the operation of the canteen or the effects of food waste, so they are likely to be underestimates of the true impacts.

Pulkkinen et al. (2016) find that meals served in Finnish canteens have carbon footprints of between 0.6 and 2.8 kg $CO_2$ eq. These results are similar to those found in this study, but they did not include energy used in the kitchen or the disposal stage.

Visschers and Siegrist (2015) find that the carbon footprints of meals prepared in a Swiss university canteen vary between 1.6 kg $CO_2$ eq. and 5.5 kg $CO_2$ eq., of which 1.1 kg $CO_2$ eq. is for food preparation and disposal. The range of carbon footprints overlaps with those found in this study. However, in this study food preparation and disposal together account for significantly less than 1.1 kg $CO_2$ eq., e.g. in Case A they accounted for 0.2 kg $CO_2$ eq. This suggests that resource use at the canteen stage should be investigated further.

Benvenuti et al. (2016) study Italian primary school lunches and find that the average carbon footprint per meal is 0.69 kg $CO_2$ eq., which could be reduced to 0.39 kg $CO_2$ eq. by using an optimised set of menus. These carbon footprints only account for the production of the ingredients. This overlaps with the range of GWP for the agricultural stage in this study for those scenarios that do not use tomatoes from heated greenhouses (varying from 0.12 kg $CO_2$ eq. to 0.59 kg $CO_2$ eq.).

Ribal et al. (2016) find the carbon footprint of Spanish school lunches to vary between approximately 0.5 kg $CO_2$ eq. and 3.0 kg $CO_2$ eq. per meal, with an average of 1.4 kg $CO_2$ eq., which overlaps with the range found in this study. This includes the whole supply chain.

Theurl et al. (2014) calculate the carbon footprint for meals prepared in a German canteen as 1.6 kg $CO_2$ eq. for a meat-based meal and 0.7 kg $CO_2$ eq. for a vegetarian meal. This includes the whole supply chain up to and including the kitchen and overlaps with the range found in this study. Organic ingredients are found to have lower carbon footprints than non-organic ingredients, in contrast to the findings of this study. Kitchen operations are responsible for around 0.3 kg $CO_2$ eq. per meal, which is similar to the impact of the kitchen stage in this study.

Ying and Freed (2013) show that the carbon footprint of a sample meal cooked at home in the US is 7.5 kg $CO_2$ eq., compared to 8.5 kg $CO_2$ eq. for a mid-range restaurant in the US and 24.7 kg $CO_2$ eq. for a top-end Danish restaurant serving a multi-course meal. This is in contrast to the finding of this study that a home-cooked meal has higher impacts than a catered meal. This suggests that the impacts of food service vary highly between subsectors, which is unsurprising as restaurants tend to generate more food waste (WRAP, 2013c) and are less likely than canteens to cook in large batches. Furthermore, Ying and Freed (2013) use different recipes for all three cases. The carbon footprints are considerably larger than found in this study, which may be in part due to the different recipes (including multiple courses). In the recipes that included steak, steak accounted for the majority of the carbon footprint, which agrees with the importance of beef agriculture found in Case H.

SKM Enviros (2010) estimates the breakdown of GHG emissions in the UK supply chain, as shown in Table 5 of the literature review. According to this, transport and manufacture are notable contributors to total GWP, at 9% and 8% respectively. In Case A, transport and processing account for only 3% each, which is relatively low. This could be because all of the ingredients in this scenario are sourced in the UK and therefore transported a relatively low distance.

Furthermore, the large GWP of British tomato agriculture reduces the relative contribution of other stages. In Case C, the transport and processing steps account for 12% and 8% of GWP, respectively, which is in line with the estimates of SKM Enviros (2010). This is partly because the absolute GWP of Spanish tomato agriculture is lower and partly because of the greater distance the tomatoes are transported.

SKM Enviros (2010) also shows which stages of the UK food supply chain used the most energy, in terms of emissions caused by energy use. Table 25 compares the estimates of SKM Enviros (2010) to the net primary energy demand found in Cases A and C. In Case A, net primary energy demand is skewed heavily towards agriculture because of the use of heated greenhouses for the tomatoes. However, in Case C the breakdown is more similar to that estimated by SKM Enviros (2010), with the post-farm stages accounting for 68% of energy use (compared to 61% for the general UK food chain, if net trade is counted as pre-farm gate). Arguably, Case C is more representative of typical practice than Case A, because Spanish vegetables are readily available in the UK.

**Table 25: Comparison of energy use in the UK food chain and the canteen supply chain**

Percentages may not add up to 100 due to rounding. Data source: SKM Enviros (2010).

| **Stage** | **% of emissions due to energy use, UK food chain** | **Stage** | **% of net primary energy demand, canteen meal, Case A** | **% of net primary energy demand, canteen meal, Case C** |
|---|---|---|---|---|
| Pre-farm | 4 | | | |
| Agriculture | 7 | UK agriculture and inputs | 82 | 25 |
| Net trade | 28 | Spanish agriculture | - | 8 |
| Transport | 15 | Distribution | 3 | 19 |
| Manufacture | 12 | Processing and packaging manufacture | 7 | 24 |
| Retail | 8 | | | |
| Food service | 5 | Kitchen, disposal and credits | 7 | 25 |
| Domestic | 21 | | | |

Several literature studies present some broad conclusions for food sustainability (not specifically for the food service sector). For example, Nemecek et al. (2016) note that for many food products, agriculture is the main contributor to many impact categories (e.g. acidification and eutrophication), with post-farm processes being more important in categories such as cumulative energy demand, climate change, photochemical ozone formation and ozone depletion. This is mostly in agreement with the results of this study. Agriculture is the main contributor to AP for all cases except Case M and the main contributor to EP for all cases except Cases K and M. For POCP and ODP, the post-farm stages contribute on average 79% and 90%, respectively. Net primary energy demand is dominated by heated greenhouses when they are used, but when they are not used the post-farm stages contribute on average 60%. For GWP, in contrast, agriculture is generally the largest contributor in this study, contributing on average 52% when heated greenhouses are not used and 88% when they are used. Baldwin et al. (2011), Cerutti et al. (2016) and Sturtewagen et al. (2016) also note that, for food service supply chains, agriculture is a significant contributor to several impacts, including climate change, acidification and eutrophication. The fact that other studies find agriculture to be a major contributor suggests that this conclusion is valid, despite the sensitivity analysis showing that agricultural impacts depend highly on the data source used.

Nemecek et al. (2016) and Clune et al. (2016) specifically note the higher carbon footprints of fruit and vegetables grown in heated greenhouses compared to those grown in passive greenhouses. This confirms the sharp difference seen between British (grown in heated greenhouses) and Spanish (grown in unheated greenhouses) tomatoes in this study. For example, $GWP_{100}$ and net primary energy demand for Spanish tomato agriculture are only 3% of that of British tomatoes.

Nemecek et al. (2016) point out that animal-based foods generally have higher agricultural impacts than plant-based foods, with beef having the highest impacts, followed by pork and then poultry. This ranking is seen in this study for $ADP_{fossil}$, AP, EP and $GWP_{100}$. In the other category for which agricultural data are available ($ADP_{elements}$), pork has a higher impact than beef. Clune et al. (2016) found that, averaged across the world, beef and lamb have the highest carbon footprint per kg, with pork and chicken having intermediate carbon footprints and legumes, grains and vegetables having low carbon footprints. This implies that the advantages of avoiding beef in favour of poultry or plant-based protein may hold true across many different countries.

Nemecek et al. (2016) suggest that organic food has both environmental advantages and disadvantages compared to non-organic food. In contrast, in this study organic chicken and tomato agriculture was on average 86% worse than the non-organic equivalents across the categories of $ADP_{elements}$, $ADP_{fossil}$, AP, EP and $GWP_{100}$. No advantages were seen for organic agriculture. However, the data source did not provide sufficient information on pesticide release to see if organic agriculture might have an advantage in this respect.

This study shows that local food is not necessarily more environmentally sustainable than food that has been imported from further afield. For example, total impacts when Spanish tomatoes were used were shown to be on average reduced by 46% compared to British tomatoes in five CML impact categories ($ADP_{elements}$, $ADP_{fossil}$, AP, EP and $GWP_{100}$) and increased by 14% on average in the remaining CML impact categories. Nemecek et al. (2016) confirm that local does not automatically equal more sustainable.

The importance of agriculture, and hence of ingredient choice, suggests that implementing new menus may play an important role in improving food service sustainability. Food service outlets may face obstacles in changing their menus to use more environmentally sustainable ingredients. For example, some chefs may have less experience cooking with unfamiliar ingredients and consumers may resist the introduction of new recipes. However, literature describes some promising interventions. For example, Visschers and Siegrist (2015) found that labelling climate-friendly meals increased purchases of those meals and did not affect customer satisfaction. Kim et al. (2015) state that 75% of UK food service customers want to buy more sustainable food, and found that two-thirds of food service customers in South Korea would accept a 21% increase in price for more sustainable options. DEFRA (2016) shows that sales of "ethical" food (generally, rather than specifically to catering) have been increasing steadily for more than a decade. On the other hand, although Pulkkinen et al. (2016) find that labelling climate-friendly menu options in canteens raises awareness of carbon footprints among customers, they also find that carbon footprint is seen as less important than price and taste when choosing a meal. This suggests that further work may have to be done to find menu options that are both low-carbon and appealing to customers. A full analysis of these issues and their resolution is beyond the scope of this study.

### 3.8.2 Normalisation

The lack of full LCA studies for the food service sector makes it hard to compare the results for impact categories other than GWP with literature. Another way to put results into context is "normalisation", whereby results are compared to reference values for each impact category. Table 26 shows the results for Cases A, G and N as a percentage of daily global impacts per capita in the year 2000 (normalisation factors are obtained from Thinkstep (2015)). If the percentage shown were 100%, this would mean that one meal has as much impact as the average global citizen has in one day (in the year 2000).

Table 26 shows that normalised impacts are highest for $ADP_{elements}$ (for Case A, at 223 times larger per meal than global daily $ADP_{elements}$ divided by the world population, and for Case G, at 469 times larger) and MAETP. Recalling that $ADP_{elements}$ is primarily due to British tomato agriculture, and that the apparent impacts vary significantly between data sources (as shown in Figure 33 and Figure 34), it is possible that the high value is partly due to the choice of data source. It is also possible that the normalisation data are inaccurate. The normalisation value given for $ADP_{elements}$ in the CML 2013 (April 2015) version is 70% higher than the value used in Table 26 (CML 2001, April 2013 version), suggesting that there may be some uncertainty or variation behind the calculation of the normalisation value for $ADP_{elements}$ (none of the other normalisation values change between versions). Combining both the use of Webb et al. (2013) and the most recent normalisation value (both of which would be reasonable alternatives to the current calculation) would result in normalised $ADP_{elements}$ for Cases A and G being only 51 and 106 times larger than the global daily impact per capita. It is unclear whether these high values are anomalous and hence they should not be relied upon.

The lowest normalised impacts are in the ODP and POCP categories.

The remaining impact categories account for a substantial fraction of the average global citizen's daily impacts, except for Case N where $ADP_{fossil}$, AP, EP and $GWP_{100}$ account for single-digit percentages. These normalised results should not be interpreted as a percentage of one person's "fair share" of daily impacts, because that would imply that total global environmental impacts are sustainable.

**Table 26: Normalisation of LCA results**

Data source: Thinkstep (2015), CML 2001 (April 2013 version)

| **Impact category** | **Case A, % of daily global impacts per capita** | **Case G, % of daily global impacts per capita** | **Case N, % of daily global impacts per capita** |
|---|---|---|---|
| $ADP_{elements}$ | 22,304 | 46,858 | 434 |
| $ADP_{fossil}$ | 17 | 29 | 4 |
| AP | 20 | 33 | 3 |
| EP | 10 | 17 | 6 |
| FAETP inf. | 29 | 29 | 54 |
| $GWP_{100}$, excl. biogenic carbon | 14 | 23 | 3 |
| HTP inf. | 12 | 12 | 15 |
| MAETP inf. | 267 | 267 | 332 |
| ODP, steady state | 0.04 | 0.04 | 0.06 |
| POCP | 1 | 1 | 1 |
| TETP inf. | 10 | 10 | 24 |

### 3.8.3 Direct impacts from the canteen

The findings in Baldwin et al. (2011) agree with this study that cooking and food storage at the kitchen are not generally large contributors to impacts. However, Baldwin et al. (2011) find that, for a sample of American food service outlets, "operational support", which includes lighting, heating, cleaning supplies and administration, is a major contributor to fossil fuel use, carcinogens and ecotoxicity. This suggests that future work in this area should include items such as heating and lighting within the system boundaries. However, there may be complications such as accounting for the reduction in heating and lighting use in houses while customers are at a food service outlet.

AEA Technology Plc. (2012) finds that canteen operations in the UK contract catering sector (not including the rest of the supply chain) have the following breakdown for carbon emissions: refrigeration (33%), cooking (27%), extraction (21%), dishwashing (7%), serving (5%) and other (7%). The breakdown found in this study differs in that refrigeration and air handling account for much lower percentages (2% each in Case A), whereas the contributions from cooking, dishwashing and heated holding are much greater (54%, 25% and 16%, respectively). This suggests that some of the assumptions regarding refrigeration and ventilation may need to be re-examined in future work. For example, it may not be representative of the canteen sector to assume that only walk-in refrigerators are used.

US Environmental Protection Agency (undated-a) gives the energy use breakdown of a full-service restaurant in the US as cooking (35%), heating, ventilation and air-conditioning (28%), dishwashing (18%), lighting (13%) and refrigeration (6%). This suggests that heating and lighting, neither of which are included in this study, may in reality be significant contributors to energy use. However, it is likely that this varies highly between food service subsectors.

### 3.8.4 Limitations of the study

There are several limitations of the analysis performed in this study.

The absence of information in some impact categories for the agricultural stage means that the results of some impact categories may be underestimates. For example, there was not sufficient information on pesticide release for several ingredients, which is likely to affect the toxicity impact results in particular. The results in the toxicity impact categories should therefore be treated as lower bounds on the estimate of the actual impacts. It would be valid to focus mainly on the categories of $ADP_{elements}$, $ADP_{fossil}$, AP, EP and $GWP_{100}$ since the data were most complete in these categories.

This study did not consider total water consumption or land area as impact categories. However, these impacts are important as there is global pressure on both land area available for agriculture and fresh water supplies (Earth Policy Institute, 2009).  The study did not consider economic or social aspects of sustainability either.

Notarnicola et al. (2016) suggest that human excretion, which was not included within the system boundaries for this study, is actually an important contributor towards eutrophication.  Hence, excluding excretion (which was done for consistency with Schmidt Rivera et al. (2014)) could underestimate EP.

The literature review showed that a significant amount of energy use in some food service outlets is not actually used for food preparation, but is instead used for other purposes such as lighting and heating (Mudie et al., 2013a; Tassou et al., 2014).  These were not included in the study due to a lack of data and for consistency with the existing study of ready-made meals (Schmidt Rivera et al., 2014).  Furthermore, energy wastage due to staff behaviour such as leaving equipment switched on when it is not in use was not included in this study, again due to lack of data.

In this study, alternatives to chicken were considered on the basis of equal weight immediately prior to cooking in the kitchen.  In practice, it is unlikely that exactly the same weights would be used for all chicken alternatives, particularly for the plant-based alternatives.

As discussed in the data quality section, some of the data used in the study are old, are intended for different geographic locations, cover a process that is not exactly the same as the one under consideration or are otherwise not ideal.  Furthermore, many estimates have been made in the absence of data, such as transport distances.  Both data availability and the necessity of using estimates are limitations present in many LCA studies.

# 4. Conclusions and recommendations

This study has investigated environmental sustainability in the UK food service sector. The literature review showed that food service in the UK is a significant part of the food sector in terms of market size and environmental impacts. Despite several sustainability initiatives for food service existing, there is currently little information in the literature about the life cycle impacts of UK food service compared to the general food supply chain.

The study focused on life cycle environmental impacts of a meal prepared in a cook-hold canteen in the UK, taking into account several variations in the meal composition. The results suggest that ingredient choice can be the most effective way of reducing impacts in several impact categories. In particular, some impacts can be reduced by avoiding vegetables grown in heated greenhouses, even if they are locally grown. The choice of protein source also affects several impact categories strongly, with red meat often having higher impacts than chicken and plant-based alternatives having lower impacts. There are some trade-offs with increased impacts in other categories, particularly if different packaging is used. Due to the importance of agriculture, reducing food waste can also be highly beneficial. These opportunities for improvements are discussed in more detail below.

It was found that calculated $GWP_{100}$ was of the same order of magnitude as the values given in literature for food service outlets in other countries.

When normalised to daily global impacts per capita, the most significant impacts were $ADP_{elements}$ and MAETP.

Data quality assessment suggested that, despite high variability between agricultural data sources, the conclusion holds that agriculture is significant in several impact categories.

Comparison to the impacts of ready-made and home-made meals suggested that canteen meals may perform better in most impact categories due to the assumption of more efficient energy use in canteens than at home and lower food waste levels.

## 4.1 Recommendations to canteen operators

### 4.1.1 Reduce food waste

In the sensitivity analysis, lower food waste was shown to decrease all environmental impacts by decreasing the amount of food that has to be grown. For example, reducing waste levels from those typical of the education subsector (7% preparation and spoilage waste and 12% plate waste) to those of the staff catering subsector (1% preparation and spoilage waste and 2% plate waste) reduces $ADP_{fossil}$ of Case A by 5%. There appear to be no trade-offs between different impact categories, making reducing food waste a straightforward way to improve environmental sustainability. In practice, there is a possibility that reducing food waste may incur some extra environmental impacts, such as increased use of refrigerators to store leftover food. More data would be required to fully assess this.

### 4.1.2 Choice of protein source

The choice of protein source can have a large effect on overall environmental impacts. In terms of $ADP_{fossil}$, AP, EP and $GWP_{100}$, the red meat alternatives to chicken (beef, pork and sheep meat) have higher impacts than chicken, whereas the plant-based alternatives (faba beans and sunflower seeds) have lower impacts. For example, using beef increases AP by 131% relative to chicken, whereas using faba beans decreases AP by 82% relative to chicken. Likewise, a meal with beef has a 40% higher $GWP_{100}$ than a meal with chicken (if British tomatoes are used), whereas meals with faba beans or sunflower seeds have a $GWP_{100}$ 15% or 13% lower than with chicken. For $ADP_{elements}$, sheep meat and the plant-based alternatives perform better than chicken, but beef and pork perform worse. Insufficient data were available in the data sources used to determine the effect of protein choice on the remaining impact categories.

### 4.1.3 Consider carefully whether to use produce grown in heated greenhouses

The environmental impacts in several categories ($ADP_{elements}$, $ADP_{fossil}$, AP, EP and GWP) can be reduced significantly by choosing Spanish tomatoes over British tomatoes, due to the energy used to heat greenhouses in the UK. The reduction ranges from 84% for $ADP_{elements}$ to 1% for EP and averages 46%. There are trade-offs with other impact categories since the additional transport increases FAETP, HTP, MAETP, ODP, POCP and TETP, averaging 14% and ranging from 0.3% for TETP to 31% for POCP and 37% for ODP. Whether or not to choose produce from unheated greenhouses depends on which impact categories are deemed to be most important by the decision maker. However, especially since the normalisation process suggests that ODP and POCP are the least significant impact categories in terms of contribution to current impacts, it would be reasonable to decide that the greater reductions in some impact categories outweigh the smaller increases in others. In particular, if the decision maker wishes to focus primarily on climate change impacts (possibly the most well-known impact to the public), then choosing Spanish over British tomatoes could reduce $GWP_{100}$ by 62% (for Case A).

### 4.1.4 Transport distance is not an indicator of sustainability

The sensitivity analysis shows that impacts, particularly ODP and POCP, can be reduced by decreasing transport distance if the agricultural stage remains unchanged. For example, halving transport distances in Case A reduces ODP by 21% and POCP by 12%. However, because in practice the agricultural system can change dramatically between countries, transport distance alone cannot determine the environmental impacts of a meal. This does not only apply to the difference between heated and unheated greenhouses as discussed above. For example, choosing Brazilian chicken over British chicken can reduce overall AP by 60%, but increase $ADP_{fossil}$ by 3%. Hence, buying local ingredients should not be viewed as a simple, guaranteed way of reducing overall environmental impact. Procurement criteria based on minimising “food miles” may be therefore be counterproductive.

### 4.1.5 Organic food is not necessarily better

Organic chicken and tomatoes show a worsening of environmental performance compared to non-organic equivalents in the five impact categories covered by the data used ($ADP_{elements,}$ $ADP_{fossil}$, AP, EP and $GWP_{100}$). The increase in these impacts per meal ranges from 64% (for EP) to 110% (for $ADP_{elements}$), so this study does not support a recommendation to choose organic food. However, the effect on several impact categories is unknown due to lack of complete data in the sources used on, for example, pesticide release. It is possible that there are improvements in these categories not covered by the data source used.

## 4.2 Suggestions for future work

As a first LCA study in the UK food service sector, this work acts as a good starting point for understanding the environmental sustainability of the UK food service supply chain. Much more work can be done to build on this research. Some suggestions are presented below.

To improve accuracy of calculated agricultural impacts, the agricultural stage could be modelled in more detail. It may be necessary to use data from multiple sources to do this.

Future work could be improved by gathering more data about energy use and wastage in food service outlets and including this energy use within the system boundary. For example, lighting, space heating and cooking appliances not being switched off when not in use. It is likely that energy use will vary highly between different types of outlet. The impacts of human excretion, which were excluded in this study, could also be investigated.

A better understanding of the environmental trade-offs between different recipes could be gained by considering the nutritional content of each recipe. For example, recipes could be designed to provide equal amounts of protein or calories. Furthermore, vegetarian and vegan meals are often composed differently to meat-based meals, with multiple ingredients being used to complement each other as opposed to replacing meat with a single alternative. This could be taken into account when formulating alternative recipes.

This study looked at a canteen in the education subsector. The sensitivity analysis also considered waste levels typical of restaurants and staff catering. Canteens are also found in other subsectors such as staff catering, hospitals, the military and even department stores. Hence, the results could be used to estimate impacts in these subsectors as well, although adjustments would need to be made for factors such as different levels of food waste. However, the results of the study are not representative of the whole food service sector. It would be beneficial to perform Life Cycle Assessment for meals prepared in other subsectors of the UK food service sector, particularly those subsectors where the service style differs significantly from canteens. For example, takeaways often use a significant amount of packaging, top-end restaurants may cook meals to order instead of in batches and hospitals may transport meals to bed-bound patients using heated trolleys.

Furthermore, the meals and ingredients used in different subsectors vary extensively. To scale up environmental impacts to the level of a subsector, it would be necessary to know the types of menus most commonly served in each subsector.

Cooking methods are likely to vary highly with type of food served, even within one subsector. It would be useful from the point of view of saving energy to develop a thorough analysis of the most energy efficient ways to cook a particular set of ingredients.

Additional environmental impact categories such as total water resource use, land use and radioactivity could be considered. Furthermore, a holistic view of sustainability should also consider social and economic aspects as these are the other two “pillars of sustainability”.

For social sustainability, the impacts of the food service supply chain on multiple stakeholders should be considered. Some examples are consumers, employees, the community in which the outlet is located and communities which are affected by environmental impacts. Social Life Cycle Assessment can incorporate both qualitative and quantitative data to give a rounded picture of social impacts.

Economic sustainability can be assessed using several different indicators such as the food service outlet’s ability to make a profit or break even, whether it depends on subsidies and cost-benefit analysis of potential changes. Furthermore, environmental and social externalities can be converted to monetary values to calculate the “true price” to society of a product or service as opposed to the price paid by the consumer.

Another aspect of sustainability that should be assessed is the food service supply chain’s resilience to future changes or interruptions. For example, a food service outlet could choose to avoid using ingredients where production may be jeopardised by climate change.

As shown in the literature review, there exist several voluntary sustainability standards for food service operators in the UK. However, it is unclear whether all of the recommendations in the standards lead to a quantifiably better standard of sustainability. For example, local produce is recommended in some standards, but the study showed that British tomatoes use a lot more energy than Spanish tomatoes. To justify using the standards and to identify counter-productive recommendations, Life Cycle Assessment (for environmental impacts and other aspects of sustainability) could be performed on meals that do and do not follow the standards.

Finally, a very important aspect of sustainability is investigating the best way to put improvements into practice. This may involve measures such as understanding consumer motivation, developing advertising strategies to promote sustainable food service, collaboration in industry and perhaps considering new legislation.

# Appendix A: Agriculture

## Chicken

The data source used in the baseline scenario for British chicken agriculture is Table 56 of Williams et al. (2006). The system boundary is the farm gate, not including the slaughterhouse, but impacts were given per tonne of slaughtered chicken meat. To obtain the impacts per tonne of live chicken (shown in Table 27), the impacts were multiplied by the "killing out percentage" (the weight of slaughtered meat as a percentage of the weight of the live animal), which for poultry is 70% (given on p46 of Williams et al. (2006)). This is useful because the data on the slaughterhouse stage, obtained from another source uses a different killing out percentage. Since the impacts of rearing the whole chicken are attributed only to the edible portion, it makes sense that the impacts per tonne of live chicken are lower than the impacts per tonne of slaughtered chicken.

Williams et al. (2006) do not give results for all of the impact categories considered in this study. The "primary energy used" category has been assumed to be equivalent to $ADP_{fossil}$, because it is not possible to determine the proportion of renewable energy used from the information given. Although Williams et al. (2006) have assumed that 3.6% of British electricity is produced from renewable sources, this percentage cannot be applied to "primary energy used" to obtain the value of $ADP_{fossil}$, because electricity is not the only form of energy used. The category "abiotic resource use" has been assumed to be equivalent to $ADP_{elements}$ because p16 of Williams et al. (2006) states that the CML method has been used to aggregate abiotic resource use in terms of antimony equivalent. Carbon taken up by the crop is not assessed because it is likely to be released back into the atmosphere within a short time (p13 of Williams et al. (2006)).

Da Silva et al. (2014) consider two forms of chicken farming in Brazil: large-scale and small-scale. The average results of the two systems are used, shown in Table 28. The category "cumulative energy demand" includes energy from biomass, so to find $ADP_{fossil}$, the amount of energy from biomass (found in Table S5 of the supplementary material of Da Silva et al. (2014)) was subtracted from the cumulative energy demand.

**Table 27: Impact assessment results for non-free-range British chicken for 1000 kg of live chicken, to farm gate only**

Source: Williams et al. (2006)

| Impact category | Non-organic | Organic | Unit |
|---|---|---|---|
| Primary energy used | 8400 | 11060 | MJ |
| Abiotic resource use | 20.3 | 69.3 | kg of Sb eq. |
| Global warming potential, 100 years | 3.2 | 4.7 | tonnes $CO_2$ eq. |
| Eutrophication potential | 34.3 | 60.2 | kg $PO_4$ eq. |
| Acidification potential | 121 | 185 | kg $SO_2$ eq. |

**Table 28: Impact assessment results for Brazilian chicken, per 1000 kg of chicken cooled and packaged at the slaughterhouse gate**

Source: Da Silva et al. (2014)

| Impact category | Non-organic | Unit |
|---|---|---|
| Cumulative energy demand | 30.9 | GJ |
| …of which energy from biomass | 10.8 | GJ |
| Climate change | 2.35 | tonnes $CO_2$ eq. |
| Eutrophication potential | 20.2 | kg $PO_4$ eq. |
| Acidification potential | 43.9 | kg $SO_2$ eq. |
| Terrestrial ecotoxicity | 9.28 | kg 1,4-DCB eq. |

### Potatoes

The data source for British potato farming is Table 47 of Williams et al. (2006). Potato cooling and storage are inside the system boundary. This is important because potatoes can be stored for more than one year. It was assumed that main crop, non-organic potatoes are used. Again, the "primary energy used" result has been used directly as $ADP_{fossil}$.

**Table 29: Impact assessment results for British potatoes, including cooling and storage, for 1000 kg at the farm gate**

Source: Williams et al. (2006)

| Impact category | Non-organic | Organic | Unit |
|---|---|---|---|
| Primary energy used | 1.26 | 1.28 | GJ |
| Abiotic resource use | 0.9 | 1.1 | kg Sb eq. |
| Global warming potential, 100 years | 215 | 199 | kg $CO_2$ eq. |
| Eutrophication potential | 1.1 | 1.2 | kg $PO_4$ eq. |
| Acidification potential | 1.9 | 0.8 | kg $SO_2$ eq. |

### Tomatoes

The data source for British tomato agriculture is Table 64 of Williams et al. (2006). The author (Dr Adrian Williams) confirmed in an email that the table contained an error: the $GWP_{100}$ figure should have been given in tonnes, not in kg. The correct figure is shown in Table 30.

**Table 30: Impact assessment results for 1 tonne of British non-organic tomatoes**

Source: Williams et al. (2006)

| Impact category | Non-organic | Organic | Unit |
|---|---|---|---|
| Primary energy used | 122 | 229 | GJ |
| Abiotic resource use | 96 | 181 | kg Sb eq. |
| Global warming potential, 100 years | 9.14 | 17.5 | tonnes $CO_2$ eq. |
| Eutrophication potential | 1.3 | 5.5 | kg $PO_4$ eq. |
| Acidification potential | 11.5 | 34.6 | kg $SO_2$ eq. |

The data source for Spanish tomato agriculture is Torrellas et al. (2012). The tomatoes are grown in an unheated greenhouse. The category "cumulative energy demand" is again assumed to be roughly equivalent to "$ADP_{fossil}$".

**Table 31: Impact assessment results for Spanish tomato agriculture, per 1000 kg of loose classic tomatoes**

Source: Torrellas et al. (2012)

| Impact category | Non-organic | Unit |
|---|---|---|
| Cumulative energy demand | 4 | GJ |
| ADP elements | 1.7 | kg Sb eq. |
| Global warming potential, 100 years | 250 | kg $CO_2$ eq. |
| Eutrophication potential | 0.49 | kg $PO_4$ eq. |
| Acidification potential | 1 | kg $SO_2$ eq. |
| Photochemical ozone creation potential | 0.054 | kg ethene eq. |

### Carrots

The data source for British carrot agriculture is the database Nielsen et al. (2003), accessed via an Excel spreadsheet containing screenshots of the downloaded data since the webpage was not available at the time of preparing this thesis. Conventional (i.e. non-organic) carrot farming without straw was assumed to be used. The material and energy flows were modelled in GaBi using the assumptions given in Table 32 and Table 33. Although the data are for Danish production, they are assumed to be applicable to British agriculture. British data have been used for the inputs (e.g. electricity mix). The mass of fertiliser used in GaBi has been adjusted based on the content of the relevant element (N, P or K).

**Table 32: Assumptions made for carrot agriculture**

| | |
|---|---|
| **Transport of fertilisers from regional storehouse to farm** | 100 km by lorry, Euro 5 efficiency rating (for consistency with Schmidt Rivera et al. (2014)). |
| **Traction** | Traction is assumed to be provided by diesel. See<br>Table 34: Inventory data for traction provided by diesel<br>. |
| **Electricity from natural gas** | Electricity from natural gas is assumed to be the British mix. |

**Table 33: Material and energy used for British carrot agriculture**

Source: Nielsen et al. (2003)

| Flow | Non-organic carrots | Units |
|---|---|---|
| Carrots | 61600 | kg |
| Fertiliser (P) | 48 | kg |
| Fertiliser (N) | 83 | kg |
| Electricity (natural gas) | 518 | kWh |
| Traction | 14981 | MJ |
| Ammonia (emissions to air) | 9 | kg |
| Dinitrogen monoxide (emissions to air) | 2.5 | kg |
| Nitrate (emissions to water) | 76.5 | kg |
| Phosphate (emissions to water) | 2.7 | kg |

**Table 34: Inventory data for traction provided by diesel**

Source: Nielsen et al. (2003)

| Flow | Amount | Units |
|---|---|---|
| Diesel | 0.028 | kg |
| Traction | 1 | MJ |
| **Emissions to air** | | |
| $CO_2$ | 87 | g |
| Particles | 0.071 | g |
| Non-methane hydrocarbons | 0.17 | g |
| $CH_4$ | 0.0041 | g |
| $SO_2$ | 0.025 | g |
| CO | 0.28 | g |
| $NO_x$ | 1.1 | g |
| $N_2O$ | 0.0091 | g |

**Peas**

Following the suggestion of Schmidt Rivera et al. (2014), data for British green beans were used as a proxy for peas due to lack of data on pea agriculture. The green bean data source was Table 4-1 of Canals et al. (2008). It was assumed that UK early crop is used. The material and energy flows were modelled in GaBi. Carbon dioxide fixed from the air in the crop has not been considered. It was assumed that the pesticides, fertilisers, plastic parts and steel parts were transported 100 km to the farm by lorry (Euro 5 efficiency rating). Emissions from diesel are given in Table 34.

**Table 35: Summary of data for pea agriculture**

Source: Canals et al. (2008)

| Flow | Amount | Units |
|---|---|---|
| Green beans, crop | 12000 | kg |
| Diesel (for worker's transport) | 13.5 | litres |
| Diesel (for field operations) | 89.76 | litres |
| Pesticides (unspecified) | 5.3 | kg |
| Plastic (fleece, mulch…) | 151.4 | kg |
| Steel (spare parts replacement) | 1.78 | kg |
| Electricity (pumps) | 2772 | MJ |
| N fertiliser | 120.1 | kg |
| K fertiliser | 101.3 | kg |
| Blue water, groundwater | 700000 | kg |
| **Soil emissions** | | |
| $NH_3$ from soil | 10.404 | kg |
| $CO_2$ from soil | 1466.8 | kg |
| $CH_4$ from soil | 0.402 | kg |
| $NO_3^-$ from soil | 66.43 | kg |
| $NO_x$ from soil | 0.296 | kg |
| $N_2O$ from soil | 2.832 | kg |
| $PO_4^{3-}$ from soil | 3.065 | kg |

### Onions

The data source for British onion agriculture is the database Nielsen et al. (2003), accessed via an Excel spreadsheet containing screenshots of the downloaded data since the webpage was not available at the time of preparing this thesis. The information in Table 36 was used to model onion agriculture in GaBi. Soil emissions were not available. Again, it was assumed that fertilisers were transported 100 km by road to the farm. Traction data are taken from Table 34.

**Table 36: Summary of agricultural data for British non-organic onions**

Source: Nielsen et al. (2003)

| Flow | Amount | Units |
|---|---|---|
| Onions | 31.9 | ton |
| Tap water (from groundwater) | 0.6 | $m^3$ |
| Traction | 7920 | MJ |
| Fertilizer N | 156 | kg |
| Fertilizer K | 144 | kg |
| Fertilizer P | 40 | kg |

### Salt and vegetable oil

The data for salt and vegetable oil were taken from Ecoinvent Centre (2010). Canola oil (also known as rapeseed oil) was chosen to be representative of vegetable oil. Packaging is modelled separately. It is assumed that salt and oil are both packaged at the respective plants and then transported directly to the wholesaler depot, rather than being transported to a pre-processor.

### Chicken alternatives

Impact assessment results for British beef, pork and sheep meat are taken from Tables 54, 55 and 57, respectively, of Williams et al. (2006). They are shown in Table 37. Mutton and lamb are reported together as a single category, which is why they are referred to as sheep meat. The killing-out percentages for beef, pork and sheep are 55%, 75% and 47%, respectively.

**Table 37: Impact assessment results for British beef, pork and sheep meat at the farm gate**

Source: Williams et al. (2006)

| Impacts per tonne deadweight | Non-organic British beef, per tonne liveweight | Non-organic British pork, per tonne liveweight | Non-organic British sheep meat, per tonne liveweight |
|---|---|---|---|
| Primary energy used, MJ | 15290 | 12525 | 10857 |
| $GWP_{100}$, kg $CO_2$ eq. | 8690 | 4770 | 8225 |
| EP, kg $PO_4^{3-}$ eq. | 86.35 | 75 | 91.65 |
| AP, kg $SO_2$ eq. | 258 | 296 | 173 |
| Abiotic resource use, kg antimony eq. | 19.8 | 26.25 | 12.69 |

Inventory data for French faba bean and sunflower seed agriculture were downloaded from French Environment and Energy Management Agency (2016) and assessed in GaBi software.

# Appendix B: Processing

## Slaughterhouse

The inventory for a chicken slaughterhouse is given by Nielsen et al. (2003) and shown in Table 38. The figures are based on Danish data but are assumed to be applicable to the UK.

**Table 38: Inventory for Danish chicken slaughterhouse**

Source: Nielsen et al. (2003)

| Flow | Amount |
|---|---|
| Living chicken | 1 kg |
| Electricity | 0.2 kWh |
| Heat | 0.1 kWh |
| Water | 9 l |
| Slaughtered chicken | 0.73 kg |
| Blood, heads, intestines, etc. | 0.27 kg |
| Biological oxygen demand to municipal wastewater treatment plant | 21 g |
| Total nitrogen to municipal wastewater treatment plant | 2.2 g |
| Total phosphorus to municipal wastewater treatment plant | 0.3 g |

The ratio of heat sources used in slaughterhouses is assumed to be 67% natural gas and 33% light fuel oil, based on Nielsen et al. (2003).

Inventory data on bone, blood and meat meal production is also given by Nielsen et al. (2003) and shown in Table 39.

**Table 39: Inventory for processing of chicken waste from the slaughterhouse**

Source: Nielsen et al. (2003)

| Inputs | Amount |
|---|---|
| Slaughterhouse waste | 1.0 t |
| Electricity | 82 kWh |
| Heat | 0.53 MWh |
| Water | 900 litres |
| **Outputs** | **Amount** |
| Bone, blood and meat meal | 0.39 t |
| District heat | 45 kWh |
| Chemical oxygen demand to water | 44 g |
| Total N to water | 77 g |
| Total P to water | 0.10 g |
| Amino compounds to air | 15 g |
| Hydrogen sulphides | 0.65 g |

Nielsen et al. (2003) also provides the inventory for cattle and pig slaughterhouses, given in Table 40 and Table 41. For sheep slaughter, the cattle slaughterhouse inventory is used.

**Table 40: Inventory for Danish cattle slaughterhouse**

Source: Nielsen et al. (2003)

| Flow | Amount |
|---|---|
| Living cattle | 1.65 t |
| Electricity | 0.04 MWh |
| Heat | 165 MJ |
| Water | 2 $m^3$ |
| Cattle meat | 1.00 t |
| Blood, heads, intestines, etc. | 0.65 t |
| Biological oxygen demand to municipal wastewater treatment plant | 3.6 kg |
| Total nitrogen to municipal wastewater treatment plant | 0.6 kg |

**Table 41: Inventory for Danish pig slaughterhouse**

Source: Nielsen et al. (2003)

| Flow | Amount |
|---|---|
| Living pigs | 100 kg |
| Electricity | 8.4 kWh |
| Heat | 13 kWh |
| Water | 200 l |
| Pork meat | 74 kg |
| Bowels | 8.5 kg |
| Scraps | 15 kg |
| Manure | 0.8 kg |
| Total nitrogen to municipal wastewater treatment plant | 65 g |
| Bulk waste | 1.2 kg |

### Vegetable processing

The inventory for tomato paste processing is obtained from Table 3.22 of European Commission (2006) and Food and Agricultural Organisation (2009a).

**Table 42: Inventory for tomato paste processing, per tonne of paste**

Source: European Commission (2006) and Food and Agricultural Organisation (2009a).

| Input | Amount | Unit |
|---|---:|---|
| Water | 155 | $m^3$ |
| Solid waste | 185 | kg |
| Electricity | 107.5 | kWh |
| Thermal energy | 2550 | kg steam |
| Fresh tomatoes | 6000 | kg |

The calculated flows for each vegetable at the processing stage are shown in Table 43. The calculations are based on data from European Commission (2006) using only the relevant unit operations for each vegetable. For energy use during washing and sorting, values for frozen vegetables had to be used since the values for fresh vegetables are not available. If the vegetable being considered was not present in the data tables, the nearest match was chosen.

**Table 43: Flows in the processing stage, per tonne of product**

Source: European Commission (2006)

| Ingredient | Unit processes | Electricity, kWh | Steam, t | Water, $m^3$ | Waste water, $m^3$ | Solid waste, kg |
|---|---|---|---|---|---|---|
| Chilled potato | Washing<br>Sorting<br>Transportation belts<br>Peeling<br>Chopping | 24.5 | 0.9 | 5.1 | 6.0 | 40 |
| Chilled carrot | Washing<br>Sorting<br>Transportation belts<br>Peeling<br>Chopping | 24.5 | 0.9 | 5.9 | 6.8 | 200 |
| Chilled onion | Washing<br>Sorting<br>Transportation belts<br>Peeling<br>Chopping | 24.5 | 0.9 | 5.9 | 6.8 | 130 |
| Chilled tomato | Washing<br>Sorting<br>Transportation belts | 12.5 | 0.0 | 2.6 | 2.6 | 130 |
| Frozen pea | Washing<br>Sorting<br>Transportation belts<br>Blanching<br>Cooling<br>Freezing | 196.8 | 0.2 | 3.0 | 3.2 | 40 |
| Faba beans | Washing<br>Sorting<br>Transportation belts<br>Drum blanching<br>Packing and filling<br>Pasteurisation/ sterilisation | 17.4 | 0.9 | 4.8 | 5.7 | 40 |

# Appendix C: Packaging

## Primary packaging

Meat, potatoes, carrots, frozen peas, onions and sunflower seeds are all assumed to be delivered to the kitchen in plastic bags (based on Shucksmith (2015)). Flexible plastic food packaging is commonly made from polyethylene (page 50 of European Commission (2006)). The same source states that plastic films for packaging are often less than 0.25 mm. UK Packaging (undated) confirms that 0.25 mm thick polythene is "medium duty", so this thickness is assumed for the plastic bags in this study.

To estimate the amount of plastic used for one bag, a typical pack size for each ingredient was selected from the website of the main supplier to the sample kitchen (Bidvest 3663, 2015). The size and surface area of a cubic container needed to hold that weight was calculated (assuming that the product had the same density as when stacked on a pallet – see Table 44). The surface area was multiplied by the film thickness and the density of polyethylene (0.93 g/cm$^3$, from The Essential Chemical Industry (2015)) to obtain the weight of plastic film. The results ranged from 1.5% to 2.3% of the weight of the food itself. An average value of 2% was used.

Salt is delivered in a rigid polypropylene plastic tub (information from Shucksmith (2015) and Bidvest 3663 (2015)). Using the same method as for the plastic bag, but with a density of 0.91 g/m$^3$ (Hindle, 2015) and assuming that the plastic is 1 mm thick (Proto Labs, 2016), shows that this tub weighs around 4% of the weight of the salt it contains.

The same method is used for the cardboard box holding tomatoes. It is assumed that the cardboard is solid unbleached board with a weight of 330 g/m$^2$. This weight was in the middle of the range of weights given by Antalis (2011). The box weighs 2% of the weight of the tomatoes it holds.

Oil is delivered in a tin-plated steel can. The density of the oil is 920 kg/m$^3$ (Endmemo, 2015). The weight of the can is calculated from the surface area, thickness (0.2 mm, from Alibaba Group (2015)) and density (1.62 kg/m$^2$, from Carlos (2011)) of a cubic can that is assumed to have a height equal to its diameter and can hold 15 litres (Bidvest 3663, 2015). The tin weighs 4% of the oil it holds.

Tomato paste is assumed to be delivered in a tin-plated steel can of capacity 4.5 kg. Assuming that tomato paste has a density of 1120 kg/m$^3$ (AVCalc LLC, 2016) means that the can will weigh 5% of the weight of the paste it contains.

Faba beans are packed in a tin-plated steel can. The can also contains water, so the can has a greater relative weight, at 11% of the weight of the beans in contains.

**Table 44: Stacking densities of the ingredients**

| Ingredient | Stacking density (kg of product per Euro pallet, 1.2 m by 0.8 m by 1.6 m high) | Data source |
|---|---|---|
| Chicken | 625 | Table 3.9, p14, Tassou et al. (2008) (average of 500 to 750 kg) |
| Potatoes | 640 | Table 3.9, p14, Tassou et al. (2008) |
| Carrots | 810 | Homifreeze (2012) |
| Peas, frozen | 576 | Table 3.9, p14, Tassou et al. (2008) |
| Tomatoes | 720 | Villagrow (2015) (round tomatoes: 6 kg per box times 120 boxes per pallet) |
| Onions | 720 | Oerlemans (2012) |
| Salt | 1000 | Solino Grupa Orlen (undated) |
| Canola oil | 942 | Bunge (undated) and Endmemo (2016) for density of canola oil |
| Tomato paste | 1206 | Based on paste density (AVCalc LLC, 2016) |
| Canned faba beans | 947 | Indoocean (undated) |
| Sunflower seeds | 853 | |

**Tertiary packaging**

Euro pallets are made of wood and weigh 21 kg each (Fox's Pallets Ltd, undated). Products stacked on a Euro pallet are stabilised by being wrapped in stretch wrap made from linear low-density polyethylene. A typical pallet may require 56 metres of 50 cm wide film, corresponding to approximately 0.5 kg of film per pallet (Fromm Wrapping Systems, undated), using a density of 965 kg/m$^3$ from Plastics Europe (2008).

Pallets can be wrapped either manually or using a machine. Since it is likely that large factories will automate most processes, it is assumed that a machine is used. A sample machine (X400 from Pallet Wrappers UK (2008)) wraps 30 loads per hour and has an electric power of 1.5 kW, meaning that approximately 0.05 kWh of electricity is used per pallet wrapped.

The polypropylene crates used to transport food from the wholesale depot to the kitchen weigh 2.8 kg, hold 26.5 litres (Solent Plastics, 2015) and are re-used 1000 times.

**Packaging for transport from farm**

Live chickens are transported from the farm to the slaughterhouse in crates, which are stacked inside a lorry. A sample crate (Collins Nets Ltd, 2015) is made from high density polyethylene, weighs 7.5 kg and has floor dimensions of 97 cm x 58 cm. EU regulations specify that poultry should have 160 cm$^2$ of floor space per kg of liveweight during transport (for birds weighing 1.6 –

3.0 kg)(DEFRA, 2011). Hence, the sample crate can hold around 35 kg of liveweight. The crates are assumed to be re-used 1000 times. No packaging is considered for the transport of vegetables from the farm to the processor.

Packaging weights are summarised in Table 45.

**Table 45: Summary of types and weights of packaging used for different ingredients throughout the supply chain**

| Ingredient | Type of packaging | Weight of packaging per kg of food | Number of times packaging is used |
|---|---|---|---|
| Live animals | High density polyethylene crate | 0.213 kg | 1000 |
| Meat | Polyethylene bag | 0.020 kg | 1 |
| | Wooden pallet | 0.034 kg | 1000 |
| | Linear low density polyethylene stretch wrap | 0.86 g | 1 |
| | Polypropylene crate | 0.260 kg | 1000 |
| Sunflower seeds | Polyethylene bag | 0.020 kg | 1 |
| | Wooden pallet | 0.025 kg | 1000 |
| | Linear low density polyethylene stretch wrap | 0.63 g | 1 |
| | Polypropylene crate | 0.190 kg | 1000 |
| Faba bean | Tin-plate steel can | 0.183 kg | 1 |
| | Wooden pallet | 0.037 kg | 1000 |
| | Linear low density polyethylene stretch wrap | 0.95 g | 1 |
| | Polypropylene crate | 0.286 kg | 1000 |
| Potatoes | Polyethylene bag | 0.020 kg | 1 |
| | Wooden pallet | 0.033 kg | 1000 |
| | Linear low density polyethylene stretch wrap | 0.84 g | 1 |
| | Polypropylene crate | 0.254 kg | 1000 |
| Onions | Polyethylene bag | 0.020 kg | 1 |
| | Wooden pallet | 0.029 kg | 1000 |
| | Linear low density polyethylene stretch wrap | 0.75 g | 1 |
| | Polypropylene crate | 0.225 kg | 1000 |
| Carrots | Polyethylene bag | 0.020 kg | 1 |
| | Wooden pallet | 0.026 kg | 1000 |
| | Linear low density polyethylene stretch wrap | 0.67 g | 1 |
| | Polypropylene crate | 0.200 kg | 1000 |
| Peas | Polyethylene bag | 0.020 kg | 1 |
| | Wooden pallet | 0.037 kg | 1000 |
| | Linear low density polyethylene stretch wrap | 0.94 g | 1 |

| | | | |
|---|---|---|---|
| | Polypropylene crate | 0.282 kg | 1000 |
| Fresh tomatoes | Cardboard box | 0.020 kg | 1 |
| | Wooden pallet | 0.029 kg | 1000 |
| | Linear low density polyethylene stretch wrap | 0.75 g | 1 |
| | Polypropylene crate | 0.225 kg | 1000 |
| Tomato paste | Tin-plate steel can | 0.050 kg | 1 |
| | Wooden pallet | 0.017kg | 1000 |
| | Linear low density polyethylene stretch wrap | 0.45 g | 1 |
| | Polypropylene crate | 0.135 kg | 1000 |
| Salt | Polypropylene tub | 0.040 kg | 1 |
| | Wooden pallet | 0.021 kg | 1000 |
| | Linear low density polyethylene stretch wrap | 0.54 g | 1 |
| | Polypropylene crate | 0.162 kg | 1000 |
| Canola oil | Tin-plate steel can | 0.040 kg | 1 |
| | Wooden pallet | 0.022 kg | 1000 |
| | Linear low density polyethylene stretch wrap | 0.57 g | 1 |
| | Polypropylene crate | 0.172 kg | 1000 |

# Appendix D: Distribution

### Transport

Since temperature-controlled transport processes are not available in the GaBi or Ecoinvent databases (Ecoinvent Centre, 2010; Thinkstep, 2015), another approach was used to model transport. Tassou et al. (2008) gives the amount of diesel used in transport of goods. However, it does not give the emissions that arise except for $CO_2$. It is important to account for all of the different impacts from burning diesel in an engine, since different chemical species will contribute to different impact categories. Hence, the process outlined below is used to calculate (a) refrigerant leakage and (b) the amount of ambient transport capacity (which is available as a process in the Ecoinvent database, Ecoinvent Centre (2010)) which is equivalent to the required temperature-controlled transport.

1. Select the appropriate transport mode (e.g. medium rigid lorry, chilled multi-drop) and note the fuel consumption in ml/pallet-km from Table 3.6 of Tassou et al. (2008).
2. Calculate the percentage by which the chilled fuel consumption from Step 1 is greater than the equivalent ambient fuel consumption, e.g. 20%.
3. Assume that the fuel consumption of an empty return journey is 70% of the outward journey's ambient fuel consumption (p14 of Tassou et al. (2008)).
4. Add together the two percentages, e.g. 20% + 70% = 90%.
5. For one unit of packaging, the weight of the food and the packaging were added together, e.g. weight of food on one pallet plus weight of pallet, stretch wrap and primary packaging.
6. This total weight was multiplied by the one-way journey distance required to give a basic transport capacity in kg-km per unit of packaging.
7. The result from Step 6 was increased by the percentage from Step 4 to find the equivalent amount of ambient transport required, in kg-km per unit of packaging.
8. The result of Step 7 was divided by the weight of food per unit of packaging (e.g. kg of food per pallet) to give transport required in kg-km per kg of food.
9. The result of Step 8 was modelled in GaBi as an ambient transport process.

Results are given in Table 46. Since the ambient transport process does include some non-fuel impacts such as road maintenance, the multiplied result will not be exactly representative of chilled transport, but this is not expected to have a large impact on the overall results.

**Table 46: Transport requirements for each ingredient**

[a] = ambient, [c] = chilled, [f] = frozen. Source: Tassou et al. (2008)

| **kg-km per kg of food** | **Distribution stage** | | |
|---|---|---|---|
| **Ingredient** | **Farm to processor or slaughterhouse** | **Processor to wholesale depot** | **Wholesale depot to kitchen** |
| Chicken | 413 [a] | 200 [c] | 247 [c] |
| Other meat | 340 [a] | 200 [c] | 247 [c] |
| Faba bean | 1596 [c] | 321 [a] | 363 [a] |
| Sunflower seed | 1360 [a] | 178 [a] | 206 [a] |
| Potato | 380 [c] | 200 [c] | 246 [c] |
| Tomato | 380 [c] | 199 [c] | 241 [c] |
| Onion | 380 [c] | 199 [c] | 241 [c] |
| Carrot | 380 [c] | 199 [c] | 236 [c] |
| Pea | 380 [c] | 208 [f] | 262 [f] |
| Salt | - | 180 [a] | 204 [a] |
| Canola oil | - | 181 [a] | 206 [a] |
| Tomato paste | - | 182 [a] | 201 [a] |

The refrigerant used for chilled transport is assumed to be R134a in the baseline scenario (p10 of Tassou et al. (2008)). The average annual leakage figure is 23.5% of the initial charge, which is given in Table 3.8 of Tassou et al. (2008). Leakage is allocated to one kg of food based on the average capacity of each vehicle type, the return journey distance, an average distance travelled per year per lorry of 100,000 km and the capacity per pallet given in Table 44. The refrigerant leakage results are shown in Table 47 below.

Refrigerant leakage, kg per kg of food =

Initial refrigerant charge per lorry * annual leakage rate * 2 * journey distance /

(100,000 km per year per lorry * kg food per pallet * average pallets per lorry)

For transport of vegetables from the farm to the pre-processor, although no pallets are used, the amount of food per lorry is assumed to be the same as if pallets were present. The amount of refrigerant manufacture attributed to one kg of food is equal to the amount that is lost to leakage.

Table 47: Refrigerant leakage from temperature-controlled transport

| μg of R134a leaking per kg of food | Distribution stage | | |
|---|---|---|---|
| **Ingredient** | **Farm to processor or slaughterhouse** | **Processor to wholesale depot** | **Wholesale depot to kitchen** |
| Meat | - | 366 | 651 |
| Potato | 715 | 357 | 635 |
| Tomato | 636 | 318 | 565 |
| Onion | 636 | 318 | 565 |
| Carrot | 565 | 502 | 502 |
| Pea | 794 | 397 | 706 |
| Faba bean | 2542 | - | - |

**Wholesale storage**

Refrigerated or frozen storage at the wholesale depot takes place in large chilled warehouses. The refrigerant used is ammonia and the power source is electricity, according to p6 of Tassou et al. (2008).

The calculation method used to find electricity use and refrigerant leakage for the wholesale storage stage is as follows:

- Page 6 of Tassou et al. (2008) gives the annual electricity consumption of warehouses as 54.2 kWh/m$^3$ per year (based on a warehouse sized between 50000 and 100000 m$^3$). The figures are based on surveys of real warehouses.
- Ingredients are assumed to be stored on their pallet in the wholesale depot. The mass of each ingredient that can be stacked on one Euro pallet (from Table 44) is converted to kg/m$^3$ by assuming that the stackable volume of one pallet is 0.8 m * 1.2 m * 1.6 m = 1.536 m$^3$. Hence, kg/m$^3$ = (kg/pallet) / (1.536 m$^3$/pallet).
- Electricity use per kg of food per year is given by 54.2 kWh/m$^3$-yr divided by kg/m$^3$.
- Storage time of each ingredient in hours is given by Table 5.1 of Tassou et al. (2008).
- Electricity use per kg of food = kWh/kg-yr * (storage time in hours) / (365*24).
- Wholesale chilled storage is assumed to use ammonia as the refrigerant (p6, Tassou et al. (2008)).
- Table 4.4 of Tassou et al. (2008) shows that ammonia (R717) systems typically have a refrigerant charge of 0.15 kg/kW of refrigeration capacity.
- Since the annual leakage rate is not quantified (it is only mentioned that it is low compared to hydrofluorocarbon refrigerants), a value of 10% annual leakage (0.015 kg per kW per year) has been assumed.

- The refrigeration capacity is calculated by multiplying the electrical power in kW used per kg of food by the coefficient of performance of the refrigeration system, which is 2.5 for refrigerators and 1.3 for freezers. It is assumed for the purposes of calculating refrigeration capacity that all of the electricity is used for refrigeration, although in reality some of the electricity will be for lighting, etc.
- The amount of ammonia refrigerant charge per kg of food is calculated by multiplying kW/kg-food by 0.15 kg/kW.
- The amount of leaked ammonia per kg of food is 10% of the refrigerant charge in kg * storage time in hours / (365 * 24).

The electricity, ammonia leakage and storage time for each ingredient at the wholesale depot are shown in Table 48. No impacts are calculated for the ambient storage of salt, canola oil, tomato paste, faba beans or sunflower seeds.

Refrigerant transport from the factory to the point of use is not considered since the weight of refrigerant involved is negligible compared to the weight of packaging.

2% of food is assumed to be wasted at the wholesale depot, based on the figure cited for retail operations on p27 of Tassou et al. (2008).

**Table 48: Resource use at the wholesale depot**

Source: Tassou et al. (2008)

| Ingredient | Storage time, hours | Electricity used, Wh/kg-food | Ammonia leakage, µg/kg-food |
|---|---|---|---|
| Meat | 12 | 0.18 | 0.76 |
| Potato | 24 | 0.35 | 1.47 |
| Tomato | 24 | 0.31 | 1.31 |
| Onion | 24 | 0.31 | 1.31 |
| Carrot | 24 | 0.27 | 1.17 |
| Pea | 158 | 2.52 | 5.61 |

# Appendix E: Kitchen

## Cold storage

Walk-in fridges and freezers are assumed to be used in the kitchen, although some kitchens may use stand-alone fridges and freezers. According to Shucksmith (2015), chilled meat and vegetables are ordered to the kitchen every day and dry and frozen items are ordered three times a week. Hence, it is assumed that chilled items are stored for 24 hours in the kitchen and frozen items are stored for 48 hours. Salt, canola oil, tomato paste, faba beans and sunflower seeds are stored at ambient temperature.

Table 4.7 of Tassou et al. (2008) gives energy use and refrigerant leakage for walk-in cold storage based on the stacking density of different products (see Table 44). This is based on supermarkets but is assumed to be applicable to this study. Where the specific ingredient is not given in the table, energy use is recalculated based on the weight of the ingredient that can be stacked on one Euro pallet. Although it is unlikely that ingredients would be stacked on a pallet in the kitchen, the stacking density still gives an indication of how densely each product can be stored.

In Table 4.7 of Tassou et al. (2008), the electricity use in kWh/kg-h is based on the energy consumption data for walk-in coolers and freezers from Table 4.6. The energy consumption data in Table 4.6 shows a range of figures from literature, but values of 0.12 kWh/m$^2$-h for walk-in refrigerators and 0.3 kWh/m$^2$-h for walk-in freezers have been assumed to be representative values by the authors of Tassou et al. (2008).

The stacking density in kg/Euro-pallet is known for each product. Products are assumed to be stacked to 2.4 m high. Hence, the kg-product/m$^2$-floor area is given by:

$$\text{kg product per m}^2\text{ floor area} =$$
$$(1\text{ m}^2 * 2.4\text{ m} * \text{weight per pallet}) / (\text{area of pallet} * \text{height of pallet}) =$$
$$1.56 * \text{weight per pallet}$$

To calculate electricity use per m$^2$ of floor space, divide the electricity use in kWh/m$^2$-h by kg-food/m$^2$. Then divide by 0.6 to account for 40% of the floor space being empty.

This method assumes that the energy consumption of the walk-in fridge and freezer does not change with the amount stored. This is not strictly correct, since the amount of heat energy that must be removed from the cooler depends on the amount of products and their temperature when placed into the cooler. However, since the figures used in the calculations for Table 4.7 are estimated from a range of literature values, they are not precise enough to justify modelling the cooling system in more detail.

Tassou et al. (2008) assumes that walk-in refrigerators and freezers use the refrigerant R404A, which is a blend of refrigerants R-125 (pentafluoroethane), R-143A (trifluoroethane) and R134a (tetrafluoroethane) in the proportions 44%, 52% and 4% by mass, respectively (CAMEO Chemicals, undated; The Engineering Toolbox, undated-b). Although R404A is now being phased out by the European Union (ACRIB F Gas Implementation Group, 2014), it is likely that much existing equipment will use it. R404A has a $GWP_{100}$ of 3260 (The Australian Institute of Refrigeration, 2012).

Information is not available in the Ecoinvent database on the manufacture of R-125 and R143A. To account for their manufacture, the R-134a process has been used along with an additional emission stream of 9 kg $CO_2$ per kg of R-404A, as suggested by Bovea et al. (2007). However, emissions of all three refrigerants can be represented directly in GaBi.

The amount of refrigerant manufacture attributed to the stored food is equal to the amount of refrigerant lost to leakage, which is calculated by the following steps:

- Find the “refrigeration capacity” in kW/kg by multiplying the electricity use by the Coefficient of Performance (2.5 for fridge, 1.3 for freezer, both figures from Table 4.7), which is defined as cooling effect divided by work input (Walker and Bingham, 1994), so the refrigeration capacity (rate at which heat can be removed) is actually greater than the electricity required.
- Multiplying the charge of 3.5 kg refrigerant per kW refrigeration capacity (from Table 4.7 of Tassou et al. (2008)) by the kW/kg-food to get kg-ref/kg-food.
- Multiply this value by 0.15 to get annual leakage weight in kg.
- Attribute the fraction (refrigeration time/year) of the previous result to one kg of food.

**Table 49: Electricity use and refrigerant leakage for cold storage in the kitchen, per kg of food**

| Ingredient | Storage time, h | Storage method | Electricity, kJ | Refrigerant leakage, mg |
|---|---|---|---|---|
| Meat | 24 | Refrigerated | 17.7 | 0.736 |
| Potato | 24 | Refrigerated | 17.3 | 0.719 |
| Carrot | 24 | Refrigerated | 13.7 | 0.568 |
| Pea | 48 | Frozen | 96.8 | 2.094 |
| Tomato | 24 | Refrigerated | 15.4 | 0.639 |
| Onion | 24 | Refrigerated | 15.4 | 0.639 |

### Cooking energy

The cooking energy for each ingredient is calculated according to the following method:

- Calculate the minimum energy required to bring the ingredients to cooked temperature by multiplying the raw mass, the temperature change and the specific heat capacity of each ingredient.

- Calculate the energy required to evaporate enough water from the ingredients to produce the shrinkage shown in Table 50, using the latent heat of evaporation of water.
- Divide the sum of these two energies by the efficiency of the relevant cooking equipment (shown in Table 52) to get the total energy required. It is assumed that the equipment is working at full capacity.

**Table 50: Mass changes during cooking**

Yield factor is the mass of the edible, cooked part divided by the mass of the raw product.

| Ingredient | Yield factor | Data source |
|---|---|---|
| Roast chicken | 0.70 | Bognár (2002) |
| Roast beef, pork and mutton | 0.72 | |
| Steamed potato | 0.98 | |
| Carrots, steamed | 0.90 | |
| Green peas, steamed | 0.87 | |
| Onions, fried | 0.83 | |
| Tomatoes | 0.44 | Pick Your Own (2009); mass of raw tomato divided by mass of deseeded, cooked tomato |
| Salt, canola oil, faba beans and sunflower seeds | 1.00 | Assumption |

**Table 51: Specific heat capacity of ingredients**

| Ingredient | Specific heat capacity, kJ/kg K | Source | Notes |
|---|---|---|---|
| Chicken | 3.22 | The Engineering Toolbox (undated-a) | Chicken, broilers |
| Potato | 3.43 | | - |
| Carrot | 3.81 | | - |
| Pea, above freezing | 3.39 | | Peas, medium |
| Pea, below freezing | 1.67 | | |
| Onion | 3.77 | | - |
| Tomato | 3.98 | | Tomatoes, red |
| Canola oil | 2.37 | Fasina and Colley (2008) | Canola oil at 90°C |

**Table 52: Efficiency of kitchen equipment**

| Equipment | Thermal efficiency | Data source |
|---|---|---|
| Electric oven | 65% | Food Service Technology Center (2002a) |
| Steam oven | | |
| Gas hob | 33% | Food Service Technology Center (2002b) |

Table 53: Initial and final temperatures for cooking

| Ingredient | Initial temp, °C | Source | Final temp, °C | Source |
|---|---|---|---|---|
| Meat | 3 | Refrigerators should be set at 5°C or below Food Standards Agency (2015). | 111 | Midway between internal cooked temperature of 82°C (Brown (2015) and Perdue (2011)) and 140°C , the temperature at which browning occurs by the Maillard reaction (EDinformatics, 1999). Burning does not occur until 180°C (Myhrvold, 2013). |
| Onion | | | 140 | Hot enough to be browned by Maillard reaction (EDinformatics, 1999). |
| Tomato | | | 100 | Maximum temperature that steam can reach at atmospheric pressure. |
| Potato | | | | |
| Carrot | | | | |
| Pea | -18 | Recommendation for freezer temperatures (Food Standards Agency (2015)). | | |
| Faba beans | 18 | Assumption for ambient temperature. | | |
| Sunflower seeds | | | | |
| Canola oil | | | 160 | Below the smoke point (177°C) of semi-refined canola oil (Chu, 2004). |

Table 54: Energy required to cook each ingredient, Case A

Note that these energy figures are based on cooking a meal of 316g and do not include an allowance for the extra energy required to cook food that is wasted in the kitchen.

| Ingredient | Theoretical minimum cooking energy, kJ per meal | Cooking energy after applying cooking efficiencies, kJ per meal |
|---|---|---|
| Chicken | 100 | 155 |
| Potato | 33 | 51 |
| Carrot | 21 | 32 |
| Pea | 23 | 36 |
| Onion | 25 | 77 |
| Canola oil | 3 | 9 |
| Tomato | 147 | 446 |
| Total | 353 | 805 |

### Tomato seed waste

For the scenarios in which the tomato sauce is prepared from fresh tomatoes, the fresh tomatoes are first deseeded in accordance with both the recipe used and the recommendations of Shucksmith (2015). It is assumed that 25% of the weight of the whole tomatoes is lost at the deseeding stage.

### Steam oven water use

The steam oven uses water while it is running. The water consumption is estimated from sample data given by Sorenson and Young (2003). It is assumed that the oven is fully loaded (consistent with the assumptions made when calculating energy consumption of the steam oven). The data shows that a fully loaded oven with a capacity of 6.6 kg of raw chicken uses 15 litres of water per kg of raw food per hour of cooking time. This figure is applied to all steam cooked ingredients, since data are not available separately for each ingredient. Potatoes are cooked for 16 minutes and carrots and peas are cooked for 4 minutes (Miele Company Ltd, undated).

### Gas hob emissions

The emissions that result from the burning of gas in the hob are shown in Table 55.

**Table 55: Emissions factors for energy from the gas hob**

Source: Tables 2.5 and 3.13 of Intergovernmental Panel On Climate Change (2006), residential natural gas combustion.

| Species | Emissions factor | Unit |
|---|---|---|
| Carbon dioxide | 56100 | g/GJ |
| Methane | 5 | g/GJ |
| Nitrous oxide | 0.1 | g/GJ |
| Nitrogen oxides | 60 | g/GJ |
| Carbon monoxide | 30 | g/GJ |
| Non-methane volatile organic compounds | 2 | g/GJ |
| Sulphur oxides | 0.3 | g/GJ |
| Total suspended particulates | 2.2 | g/GJ |
| Particulate matter PM10 | 2.2 | g/GJ |
| Particulate matter PM2.5 | 2.2 | g/GJ |
| Lead | 0.0015 | mg/GJ |
| Cadmium | 0.00025 | mg/GJ |
| Mercury | 0.1 | mg/GJ |
| Arsenic | 0.12 | mg/GJ |
| Chromium | 0.00076 | mg/GJ |
| Copper | 0.000076 | mg/GJ |
| Nickel | 0.00051 | mg/GJ |
| Selenium | 0.011 | mg/GJ |
| Zinc | 0.0015 | mg/GJ |
| PCDD/F [dioxins] | 0.0000015 | mg 1-TEQ/GJ* |
| Benzo(a)pyrene | 0.00056 | mg/GJ |
| Benzofluoranthene | 0.00168 | mg/GJ |
| Indeno(1,2,3-cd)pyrene | 0.00084 | mg/GJ |

*TEQ = toxic equivalent weight to 2,3,7,8-Tetrachlorodibenzo-p-dioxin (Chlorine Chemistry Division of the American Chemistry Council, 2015).

**Electricity mix (mains)**

The UK mains electricity mix from 2014 is used (the latest year for which data was available at the time this study was being prepared). The data source is Department of Energy & Climate Change (2015b). Table 56 shows the percentages of electricity generated by each method.

**Table 56: UK mains electricity mix for 2014**

| **Source** | **% of total** |
|---|---:|
| Coal | 29.1 |
| Nuclear | 19.0 |
| Gas | 30.2 |
| Oil and other | 2.5 |
| Renewables | 19.2 |
| *of which* | |
| Onshore wind | 5.5 |
| Offshore wind | 4.0 |
| Hydroelectricity | 1.8 |
| Solar photovoltaic | 1.2 |
| Bioenergy (including co-firing) | 6.8 |
| Total | 100.0 |

**Ventilation**

The required air handling capacity is also calculated by the “thermal convection method” (Heating and Ventilating Contractors' Association, 2005).

Ventilation energy use has been estimated for the whole kitchen rather than just for the gas hob, since it removes cooking fumes and keeps the workplace at a comfortable temperature as well as preventing carbon monoxide build-up, which is only a concern with gas-fired appliances.

Table 57 shows the surface area of each piece of equipment used in the preparation of the meal. For each piece of equipment, the surface area is multiplied by a coefficient given by Heating and Ventilating Contractors' Association (2005) to find the minimum extraction flowrate required for that piece of equipment. The calculations are summarised in Table 57. The total flow rate is 1.59 $m^3/s$.

The canopy type used in the kitchen is assumed to be “overhead wall, closed both ends”, which has a canopy factor of 1.15. Hence, the required flow rate is 1.15 * 1.59 $m^3/s$ = 1.83 $m^3/s$.

Sample extractor hoods (Lincat Limited, 2014) are rated at 0.12 kW and are capable of extracting up to 0.64 $m^3/s$. Hence, 3 extractor hoods are required. It is assumed that the ventilation runs for 2 hours. The total electricity required for ventilation is 20.5 kJ per meal. Since the areas are only rough estimates, the energy used for ventilation is not recalculated for different cooking scenarios. It is assumed that the ventilation fan will work at the same capacity regardless of which equipment is being used.

Table 57: Kitchen ventilation capacity calculations

| Item | Surface area, $m^2$ | Reference for area | Coefficient, $m^3/s$ per $m^2$ | Flow rate, $m^3/s$ |
|---|---|---|---|---|
| Range top | 0.72 | Nisbets Plc. (undated-a) | 0.35 | 0.25 |
| Steam oven | 0.65 | Nisbets Plc. (undated-d) | 0.30 | 0.20 |
| Fan oven x 2 | 0.90 | Nisbets Plc. (undated-f) | 0.30 | 0.27 |
| Sink | 0.90 | Nisbets Plc. (undated-b) | 0.15 | 0.14 |
| Dishwasher | 0.39 | Champion Industries Inc. (undated) | 0.40 | 0.16 |
| Hot cupboard | 1.19 | Nisbets Plc. (undated-e) | 0.20 | 0.24 |
| Servery counter - hot food | 0.79 | Nisbets Plc. (undated-c) | 0.24 | 0.19 |
| Worktops | 5.00 | Assumption | 0.03 | 0.15 |
| | | | **Total** | 1.59 |

**Hot holding**

For heated display, the total number of 1/1 Gastronorm (GN) trays used for 120 meals is: 3 for chicken; 3 for potatoes; 3 for vegetables; 5 for tomato sauce (assuming 4 kg per 1/1 GN tray). There are fourteen 1/1 GN trays in total. It is assumed that four of the trays are displayed in a display unit heated by the base and by overhead lamps (Nisbets Plc., undated-c) and that the other ten trays are stored in a hot cupboard (Nisbets Plc., undated-e). A heating time of one hour is assumed as an average. The power of the hot cupboard is 2.5 kW (Lincat Limited, 2014). The power of the display unit is 2.75 kW (Nisbets Plc., undated-c). The electricity required for hot holding is therefore 158 kJ per meal.

**Dishwashing**

The data shown in Table 58 is taken from a sample model of dishwasher (Livchak and Swierczyna, 2014), which can wash 10 plates at once, using 416 Wh of electricity and 3.86 litres of water per cycle. More data would be needed to determine whether this model is representative of typical food service dishwashing practices. A dose of detergent at 0.5% of the water used has been considered (Delphis Eco, 2011). This is represented by soap in GaBi (the most similar material available in the Ecoinvent Centre (2010) database). A dishwasher capacity of “1.5 plates” is attributed to each meal to account for washing cooking trays and pans.

Table 58: Resource use for dishwashing

| **Resource** | Electricity | Water | Detergent |
|---|---|---|---|
| **Per meal** | 62 Wh | 0.58 litres | 2.9 g |

## Appendix F: Waste disposal

### Waste management of food and packaging

The proportions of different waste management methods used for food and packaging waste at various supply chain stages (shown in Table 59) are mostly based on national data, in order to make the study as representative as possible. For all waste management processes, it is assumed that materials are transported 25 km by road to the waste management site.

**Table 59: Waste treatment methods for each waste stream (excluding food waste from the kitchen)**

Based on WRAP (2013a) and DEFRA (2015b)

| Waste stage and type | Breakdown of waste treatment methods, by mass treated | Comments |
|---|---|---|
| Crates used for chicken transport; stretch wrap; crates for transport to kitchen; primary packaging from wholesale depot | 91% Recycling<br>9% Incineration | Data source: WRAP (2013a), Figure 2, retailer/wholesale packaging waste |
| Solid biodegradable waste from processing | 53% Land spreading<br>35% Composting<br>11% Incineration<br>1% Landfill | Data source: WRAP (2013a), Figure 2, manufacturing food waste, as proportions of the known treatment methods only. |
| Food waste from wholesale depot | 62% Recycling<br>34% Landfill<br>4% Incineration | WRAP (2013a), Table 15, wholesale and DEFRA (2015a) for ratio of incineration to landfill |
| Pallets from wholesale depot | 87% Incineration<br>13% Recycling | Moore (2010) |
| Primary packaging, plastic, from kitchen | 21% Recycling<br>70% Landfill<br>9% Incineration | Figure 5.3 of DEFRA (2015b) based on UK hospitality and food service sector |
| Primary packaging, steel, from kitchen | 9% Recycling<br>81% Landfill<br>10% Incineration | |
| Primary packaging, cardboard, from kitchen | 58% Recycling<br>37% Landfill<br>5% Incineration | |

### System credits

To account for the benefits of reclaiming waste materials and energy, the system is credited for the reduction in the amount of virgin raw materials and energy required.

Land spreading refers to the “spreading of waste on agricultural land to provide agricultural or ecological benefit”, i.e. fertilisation (Peacock and Turrell, 2009). Waste food that is either composted or spread directly on farmland and blood, bone and meat meal from chicken slaughter are credited to the system as reduced fertiliser use. This is based on the nutrient content (nitrogen, phosphorus and potassium) of each reclaimed material.

Processing of slaughterhouse waste also produces district heating for which the system has been credited.

Recycled materials (plastic, cardboard and steel) are credited as a reduction in the virgin raw materials used.

To credit the system for reduced fertiliser use, the nutrient (N, P and K) compositions of compost, food for land spreading and blood, bone and meat meal were calculated using the sources shown in Table 60. This was then converted into an amount of each type of fertiliser.

**Table 60: Data sources for nutrient composition of reclaimed food waste**

| Reclaimed material | Data source |
|---|---|
| Compost | WRAP (2015a) |
| Food for land spreading | University of Hertfordshire (2011) |
| Meal from slaughterhouse waste | Tammeorg (2010) |

**Food waste levels in the canteen**

Food waste at the consumption stage falls into two categories: “preparation and spoilage waste”, which includes all food wasted in the kitchen itself (e.g. stale food, burned meals, vegetable peelings, etc.), and “plate waste”, which is food left behind by the consumer after eating the meal.

Figures on waste levels are obtained from Table 33 of WRAP (2013c). In the baseline scenario, waste levels from the “education” subsector are used. Plate waste is assumed to be “total food waste” minus “total preparation & spoilage waste”. The total amount of cooked food prepared per meal served is therefore given by the weight of the meal plus the weight of preparation & spoilage waste (since the plate waste is included in the meal weight).

It is assumed that all food waste from the kitchen has been cooked but not kept in the hot cupboard or heated display unit. This means that the amounts of energy, etc., used for cooking and chilled storage are higher than they would otherwise be. This may result in a slight overestimate of the amount of energy required for cooking, since in reality it is likely that some food will be lost to spoilage and hence will not be cooked. However, in the absence of more detailed data, and since cooking energy is not a huge contributor to most impact categories, this assumption should not affect the final results too much. This assumption also means that yield factors (to account for shrinkage during cooking) must be applied to get the total amount of raw ingredients purchased, rather than directly adding the preparation and spoilage figures to the meal weight. It is assumed that the same percentage of all ingredients is wasted.

**Table 61: Amounts of food waste produced per meal, based on the education subsector, Case A**

Note that the "preparation and spoilage waste" figure shown for tomatoes does not include tomato seed waste.

| Ingredient | Cooked weight in meal, g | Plate waste, g | Preparation and spoilage waste, g | Weight of cooked ingredient prepared, g per meal |
|---|---|---|---|---|
| Chicken | 68.6 | 8.5 | 5.0 | 73.6 |
| Potatoes | 85.8 | 10.6 | 6.2 | 92.0 |
| Carrots | 31.5 | 3.9 | 2.3 | 33.8 |
| Peas | 30.5 | 3.8 | 2.2 | 32.7 |
| Tomatoes | 66.2 | 8.2 | 4.8 | 71.0 |
| Onions | 23.5 | 2.9 | 1.7 | 25.2 |
| Salt | 1.0 | 0.1 | 0.1 | 1.1 |
| Vegetable oil | 9.0 | 1.1 | 0.7 | 9.7 |
| Total | 316.0 | 39.2 | 23.0 | 339.0 |

**Table 62: Amounts of food waste produced per meal, based on the restaurant and staff catering subsectors, Case A**

Note that the "preparation and spoilage waste" figure shown for tomatoes does not include tomato seed waste.

| | Restaurants | | | Staff catering | | |
|---|---|---|---|---|---|---|
| Ingredient | Plate waste, g | Preparation and spoilage waste, g | Weight of cooked ingredient prepared, g per meal | Plate waste, g | Preparation and spoilage waste, g | Weight of cooked ingredient prepared, g per meal |
| Chicken | 7.9 | 14.6 | 83.2 | 1.4 | 0.8 | 69.4 |
| Potatoes | 9.8 | 18.3 | 104.0 | 1.7 | 1.0 | 86.7 |
| Carrots | 3.6 | 6.7 | 38.2 | 0.6 | 0.4 | 31.9 |
| Peas | 3.5 | 6.5 | 36.9 | 0.6 | 0.3 | 30.8 |
| Tomatoes | 7.6 | 14.1 | 80.3 | 1.3 | 0.8 | 67.0 |
| Onions | 2.7 | 5.0 | 28.5 | 0.5 | 0.3 | 23.8 |
| Salt | 0.1 | 0.2 | 1.2 | 0.0 | 0.0 | 1.0 |
| Vegetable oil | 1.0 | 1.9 | 10.9 | 0.2 | 0.1 | 9.1 |
| Total | 36.3 | 67.4 | 383.4 | 6.4 | 3.6 | 319.6 |

Note that waste levels vary greatly between subsectors. It is therefore important to examine the effects of using different waste values in the sensitivity analysis stage. Since "preparation & spoilage waste" affects the amount of food bought, this value should have a large impact on the overall results. Plate waste values do not affect the amount of food bought, so plate waste may have less of an impact on the LCA results than preparation and spoilage waste. However, if the functional unit were changed to only include food actually eaten, then plate waste would also strongly affect overall results.

### Disposal of food waste from the kitchen

Figure 1.6 of WRAP (2013b) gives the percentages of food waste going to different management methods by subsector. DEFRA (2015b), Figure 5.3, is used to estimate the ratio of landfill to incineration for waste that WRAP (2013b) states is disposed of with “residual waste”. Although there are some restrictions on high-risk food waste (such as raw meat and fish) going to landfill, it can be assumed that some food waste does go to landfill since medium and low risk food waste is allowed to be landfilled (DEFRA, 2014b). Table 63 gives the percentage breakdown of waste treatment methods. The education subsector figures are used in the baseline scenario, with the restaurant and staff catering figures being used in the sensitivity analysis.

**Table 63: Treatment methods for food waste from the kitchen**

| Subsector | % compost/anaerobic digestion | % sink-top disposal unit | % landfill | % incineration |
|---|---|---|---|---|
| Restaurants | 0 | 7 | 83 | 10 |
| Staff catering | 18 | 28 | 48 | 6 |
| Education | 8 | 11 | 72 | 9 |

### Sink-top disposal unit

The sink-top disposal unit grinds up food with tap water and flushes it down the drain. Table 64 gives the resource use of a sample unit. The data source (Imperial Machine Company Ltd, 2007) gives several different models, so the smallest model capable of dealing with tough waste such as bones was selected.

**Table 64: Electricity and water consumption of a sample sink-top disposal unit**

Source: Imperial Machine Company Ltd (2007), model 825.

| **Model specifications:** | | **To dispose of 1 kg of food waste:** | |
|---|---|---|---|
| Motor power | 2.2 kW, electric | Time | 0.1 min |
| Capacity | 600 kg waste/h | Electricity | 3.67 Wh |
| Water use | 18 – 27 l/min | Water | 2.25 l |

### Waste water treatment

The composition of each waste water stream is shown in Table 66 and the volumes are shown in Table 65.

The composition of waste water from processing is given directly by European Commission (2006). The volume of wastewater is calculated by adding together the water used and the steam used for each vegetable (see Table 43).

The volume of wastewater from the slaughterhouse and bone, blood and meat meal process are assumed to be equal to the volume of water used (see Table 38 and Table 39). The compositions of these streams are found by dividing the weight of $N_{tot}$ (total nitrogen) and BOD (biological oxygen demand) produced by the volume of waste water (Nielsen et al., 2003).

Waste water from the kitchen comes from the following sources: dishwasher, condensed water from the steam oven, washing tomatoes, sink-top disposal unit and water content of food waste disposed of in the sink-top disposer unit. The amount of water, $N_{tot}$ and total organic carbon (TOC) in the preparation and spoilage waste is calculated using data from Zhang et al. (2013). TOC is then converted to BOD5 using a rule-of-thumb from Quayle et al. (2009). The rule-of-thumb states that BOD5 = 2.3 * TOC and was based on effluent from a winery. This is considered to be applicable since the effluent consists of organic waste in both cases. Tomato seed waste composition is calculated separately because it has particularly high water content (OECD, 2015).

**Table 65: Volume of each waste water stream**

| Waste water stream | Volume |
|---|---|
| Potato processing | 6.0 $m^3$/tonne product |
| Carrot processing | 6.8 $m^3$/tonne product |
| Onion processing | 6.8 $m^3$/tonne product |
| Tomato processing | 2.6 $m^3$/tonne product |
| Pea processing | 2.76 $m^3$/tonne product |
| Chicken slaughter | 9 litres per kg of live chicken |
| Bone, blood and meat meal production | 900 litres per tonne of chicken waste |
| Water from kitchen, baseline scenario | 1.39 l per meal (baseline scenario) |

The Ecoinvent database (Ecoinvent Centre, 2010) contains many waste water treatment options. For accuracy, it is best to select the option which treats water of a composition closest to that produced by the processing of each ingredient. Two Ecoinvent processes (the treatment of effluent from the production of maize starch and of potato starch) were combined in a ratio determined by the BOD and $N_{tot}$ of each waste water stream. These two parameters affect waste water treatment energy use, according to Nielsen et al. (2003). Table 66 includes the composition of the two organic waste water streams from Ecoinvent Centre (2010).

**Table 66: Composition of waste water streams and two Ecoinvent treatment options**

| Waste water stream | BOD, kg/$m^3$ | $N_{tot}$, kg/$m^3$ |
|---|---|---|
| Ecoinvent process: treatment, maize starch production effluent, to wastewater treatment, class 2 | 6.13 | 0.57 |
| Ecoinvent process: treatment, potato starch production effluent, to wastewater treatment, class 2 | 1.35 | 0.01 |
| Chicken slaughterhouse | 2.33 | 0.24 |
| Blood, bone and meat meal production | - | 0.09 |
| Potato processing | 3.00 | 0.15 |
| Carrot processing | 2.70 | - |
| Onion processing | 3.00 | 0.15 |
| Tomato processing | 2.70 | 0.03 |
| Pea processing | 3.00 | 0.15 |
| Water from kitchen, baseline scenario | 2.98 | 0.06 |

For the treatment of waste stream *i*, "maize starch" and "potato starch" treatment processes are combined in the ratio of:

$$x_i : (1 - x_i)$$

where $x_i$ is the fraction by volume which is treated by "maize" treatment.

The aim is to find a value of $x_i$ such that the composition ideally treated by the combined processes is as close as possible to the actual composition of the waste water stream. If waste water streams with the recommended composition for each treatment process are combined in the ratio shown above, the composition of the mixed stream is:

$$BOD_i = x_i BOD_{maize} + (1 - x_i) BOD_{potato}$$

$$N_{tot,i} = x_i N_{tot,maize} + (1 - x_i) N_{tot,potato}$$

The differences in composition between the mixed treatment stream and actual waste stream *i* are calculated as follows:

$$dBOD_i = BOD_{mix} - BOD_i$$

$$dN_{tot,i} = N_{tot,mix} - N_{tot,i}$$

The overall error is calculated as follows:

$$Error_i = \left( (dBOD_i)^2 + \left(dN_{tot,i}\right)^2 \right)^{0.5}$$

$Error_i$ is minimised by using Excel Solver, based on adjusting the value of $x_i$. If BOD and $N_{tot}$ are not both available for a waste stream, then $x_i$ is calculated on the basis of the available value. The solution is converted into a percentage. The results are shown in Table 67.

**Table 67: Percentage of water treatment options used to represent treatment of vegetable processing waste water**

| Ingredient | Ecoinvent treatment option | |
|---|---|---|
| | **"Maize starch" production effluent** | **"Potato starch" production effluent** |
| Chicken slaughterhouse | 21% | 79% |
| Blood, bone and meat meal production | 14% | 86% |
| Potato processing | 34% | 66% |
| Carrot processing | 28% | 72% |
| Onion processing | 34% | 66% |
| Tomato processing | 28% | 72% |
| Pea processing | 34% | 66% |
| Water from kitchen, baseline scenario | 34% | 66% |

# Appendix G: Numerical LCA results

**Table 68: ADP elements, g Sb eq. per meal**

| Case | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Credits | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Processing | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Distribution | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Kitchen | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Disposal | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Packaging manufacture | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Agriculture, tomato | 17.76 | 17.76 | 0.31 | 27.81 | 0.49 | 17.76 | 33.49 | 17.76 | 17.76 | 17.76 | 17.76 | 17.76 | 0.31 | 0.31 |
| Agriculture, chicken or replacement | 2.99 | 0.00 | 2.99 | 2.99 | 2.99 | 2.99 | 10.21 | 3.50 | 3.80 | 2.25 | 0.00 | 0.00 | 0.00 | 0.00 |
| Agriculture, other ingredients | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| Total | 20.85 | 17.85 | 3.40 | 30.89 | 3.57 | 20.85 | 43.79 | 21.36 | 21.66 | 20.10 | 17.86 | 17.85 | 0.41 | 0.41 |

**Table 69: ADP fossil, MJ per meal**

| Case | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Credits | -0.24 | -0.14 | -0.24 | -0.22 | -0.22 | -0.24 | -0.24 | -0.31 | -0.23 | -0.31 | -0.22 | -0.14 | -0.22 | -0.14 |
| Processing | 1.02 | 0.66 | 1.02 | 1.56 | 1.56 | 1.02 | 1.02 | 0.90 | 0.92 | 0.90 | 0.98 | 0.66 | 0.98 | 0.66 |
| Distribution | 0.90 | 1.33 | 1.56 | 0.89 | 1.06 | 0.90 | 0.90 | 0.90 | 0.88 | 0.90 | 0.94 | 1.02 | 1.60 | 1.68 |
| Kitchen | 1.75 | 1.75 | 1.75 | 1.38 | 1.38 | 2.64 | 1.75 | 1.72 | 1.72 | 1.72 | 1.55 | 1.49 | 1.55 | 1.49 |
| Disposal | 0.07 | 0.07 | 0.07 | 0.03 | 0.03 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.06 | 0.07 | 0.06 | 0.07 |
| Packaging manufacture | 0.56 | 0.39 | 0.56 | 0.66 | 0.66 | 0.56 | 0.56 | 0.56 | 0.56 | 0.56 | 1.60 | 0.55 | 1.60 | 0.55 |
| Agriculture, tomato | 22.58 | 22.58 | 0.74 | 35.34 | 1.16 | 22.58 | 42.37 | 22.58 | 22.58 | 22.58 | 22.58 | 22.58 | 0.74 | 0.74 |
| Agriculture, chicken or replacement | 1.24 | 2.15 | 1.24 | 1.24 | 1.24 | 1.24 | 1.63 | 2.71 | 1.81 | 1.92 | 0.04 | 1.11 | 0.04 | 1.11 |
| Agriculture, other ingredients | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 | 0.44 |
| Total | 28.32 | 29.24 | 7.15 | 41.32 | 7.31 | 29.21 | 48.52 | 29.56 | 28.75 | 28.78 | 27.97 | 27.79 | 6.80 | 6.62 |

**Table 70: AP, g $SO_2$ eq. per meal**

| **Case** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** | **L** | **M** | **N** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Credits | -0.10 | -0.03 | -0.10 | -0.09 | -0.09 | -0.10 | -0.10 | -0.14 | -0.09 | -0.14 | -0.08 | -0.03 | -0.08 | -0.03 |
| Processing | 0.20 | 0.13 | 0.20 | 0.35 | 0.37 | 0.20 | 0.20 | 0.16 | 0.17 | 0.16 | 0.19 | 0.13 | 0.19 | 0.13 |
| Distribution | 0.19 | 0.65 | 0.36 | 0.19 | 0.28 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.20 | 0.21 | 0.37 | 0.39 |
| Kitchen | 0.30 | 0.30 | 0.30 | 0.29 | 0.29 | 0.30 | 0.30 | 0.30 | 0.30 | 0.30 | 0.26 | 0.24 | 0.26 | 0.24 |
| Disposal | 0.05 | 0.05 | 0.05 | 0.03 | 0.03 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.03 | 0.05 | 0.03 | 0.05 |
| Packaging manufacture | 0.10 | 0.08 | 0.10 | 0.15 | 0.15 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.64 | 0.10 | 0.64 | 0.10 |
| Agriculture, tomato | 2.13 | 2.13 | 0.19 | 3.33 | 0.29 | 2.13 | 6.40 | 2.13 | 2.13 | 2.13 | 2.13 | 2.13 | 0.19 | 0.19 |
| Agriculture, chicken or replacement | 17.84 | 4.70 | 17.84 | 17.84 | 17.84 | 17.84 | 27.23 | 45.64 | 42.93 | 30.60 | 0.05 | 1.65 | 0.05 | 1.65 |
| Agriculture, other ingredients | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 |
| Total | 21.19 | 8.49 | 19.42 | 22.56 | 19.63 | 21.18 | 34.85 | 48.89 | 46.24 | 33.85 | 3.89 | 4.96 | 2.12 | 3.19 |

**Table 71: EP, g $PO_4^{3-}$ eq. per meal**

| **Case** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** | **L** | **M** | **N** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Credits | -0.07 | -0.01 | -0.07 | -0.07 | -0.07 | -0.07 | -0.07 | -0.11 | -0.06 | -0.11 | -0.03 | -0.01 | -0.03 | -0.01 |
| Processing | 0.43 | 0.26 | 0.43 | 1.39 | 1.39 | 0.43 | 0.43 | 0.29 | 0.33 | 0.29 | 0.36 | 0.26 | 0.36 | 0.26 |
| Distribution | 0.10 | 0.16 | 0.15 | 0.09 | 0.11 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.11 | 0.15 | 0.15 |
| Kitchen | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.17 | 0.18 | 0.18 | 0.18 | 0.18 | 0.37 | 0.15 | 0.37 | 0.15 |
| Disposal | 0.87 | 0.87 | 0.87 | 0.53 | 0.53 | 0.83 | 0.87 | 0.87 | 0.87 | 0.87 | 0.66 | 0.91 | 0.66 | 0.91 |
| Packaging manufacture | 0.03 | 0.02 | 0.03 | 0.05 | 0.05 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.25 | 0.03 | 0.25 | 0.03 |
| Agriculture, tomato | 0.24 | 0.24 | 0.09 | 0.38 | 0.14 | 0.24 | 1.02 | 0.24 | 0.24 | 0.24 | 0.24 | 0.24 | 0.09 | 0.09 |
| Agriculture, chicken or replacement | 5.05 | 2.17 | 5.05 | 5.05 | 5.05 | 5.05 | 8.87 | 15.28 | 10.87 | 16.22 | 0.13 | 2.36 | 0.13 | 2.36 |
| Agriculture, other ingredients | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 | 0.34 |
| Total | 7.17 | 4.23 | 7.07 | 7.95 | 7.73 | 7.13 | 11.77 | 17.21 | 12.89 | 18.15 | 2.42 | 4.38 | 2.32 | 4.28 |

**Table 72: FAETP inf., g DCB eq. per meal**

| Case | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Credits | -3.1 | -1.5 | -3.1 | -5.8 | -5.8 | -3.1 | -3.1 | -4.3 | -3.0 | -4.3 | -27.5 | -1.5 | -27.5 | -1.5 |
| Processing | 9.9 | 4.9 | 9.9 | 15.6 | 15.8 | 9.9 | 9.9 | 6.5 | 7.2 | 6.5 | 6.3 | 4.9 | 6.3 | 4.9 |
| Distribution | 13.9 | 17.0 | 18.4 | 12.8 | 14.2 | 13.9 | 13.9 | 13.8 | 13.7 | 13.8 | 14.8 | 14.6 | 19.3 | 19.1 |
| Kitchen | 28.6 | 28.6 | 28.6 | 28.4 | 28.4 | 24.6 | 28.6 | 28.0 | 28.0 | 28.0 | 23.9 | 23.0 | 23.9 | 23.0 |
| Disposal | 152.5 | 152.5 | 152.5 | 100.0 | 100.0 | 152.4 | 152.5 | 152.9 | 152.9 | 152.9 | 194.7 | 160.6 | 194.7 | 160.6 |
| Packaging manufacture | 8.6 | 7.9 | 8.6 | 43.2 | 43.2 | 8.6 | 8.6 | 8.5 | 8.5 | 8.5 | 291.5 | 8.5 | 291.5 | 8.5 |
| Agriculture, tomato | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Agriculture, chicken or replacement | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.7 | 254.1 | 1.7 | 254.1 |
| Agriculture, other ingredients | 101.0 | 101.0 | 101.0 | 101.0 | 101.0 | 101.0 | 101.0 | 101.0 | 101.0 | 101.0 | 101.0 | 101.0 | 101.0 | 101.0 |
| Total | 311.3 | 310.5 | 315.8 | 295.3 | 296.8 | 307.3 | 311.3 | 306.5 | 308.4 | 306.5 | 606.3 | 565.4 | 610.9 | 570.0 |

**Table 73: GWP$_{100}$ excluding biogenic carbon, kg CO$_2$ eq. per meal**

| Case | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Credits | -0.02 | -0.01 | -0.02 | -0.02 | -0.02 | -0.02 | -0.02 | -0.03 | -0.02 | -0.03 | -0.01 | -0.01 | -0.01 | -0.01 |
| Processing | 0.08 | 0.05 | 0.08 | 0.12 | 0.12 | 0.08 | 0.08 | 0.07 | 0.07 | 0.07 | 0.07 | 0.05 | 0.07 | 0.05 |
| Distribution | 0.07 | 0.10 | 0.11 | 0.06 | 0.08 | 0.07 | 0.07 | 0.07 | 0.06 | 0.07 | 0.07 | 0.07 | 0.11 | 0.12 |
| Kitchen | 0.14 | 0.14 | 0.14 | 0.11 | 0.11 | 0.19 | 0.14 | 0.13 | 0.13 | 0.13 | 0.12 | 0.11 | 0.12 | 0.11 |
| Disposal | 0.05 | 0.05 | 0.05 | 0.03 | 0.03 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| Packaging manufacture | 0.02 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.12 | 0.02 | 0.12 | 0.02 |
| Agriculture, tomato | 1.69 | 1.69 | 0.05 | 2.65 | 0.07 | 1.69 | 3.24 | 1.69 | 1.69 | 1.69 | 1.69 | 1.69 | 0.05 | 0.05 |
| Agriculture, chicken or replacement | 0.47 | 0.25 | 0.47 | 0.47 | 0.47 | 0.47 | 0.69 | 1.54 | 0.69 | 1.46 | 0.01 | 0.17 | 0.01 | 0.17 |
| Agriculture, other ingredients | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 | 0.07 |
| Total | 2.56 | 2.35 | 0.96 | 3.52 | 0.96 | 2.62 | 4.33 | 3.60 | 2.77 | 3.52 | 2.18 | 2.23 | 0.58 | 0.63 |

**Table 74: HTP inf., g DCB eq. per meal**

| **Case** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** | **L** | **M** | **N** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Credits | -10.6 | -5.0 | -10.6 | -27.4 | -27.4 | -10.6 | -10.6 | -14.8 | -10.2 | -14.8 | -151.5 | -5.0 | -151.5 | -5.0 |
| Processing | 20.7 | 13.2 | 20.7 | 37.8 | 38.1 | 20.7 | 20.7 | 16.2 | 17.1 | 16.2 | 19.1 | 13.3 | 19.1 | 13.3 |
| Distribution | 15.7 | 31.0 | 27.0 | 15.7 | 19.3 | 15.7 | 15.7 | 15.7 | 15.4 | 15.7 | 16.5 | 17.6 | 27.8 | 28.9 |
| Kitchen | 31.8 | 31.8 | 31.8 | 31.5 | 31.5 | 27.3 | 31.8 | 31.1 | 31.1 | 31.1 | 27.1 | 25.1 | 27.1 | 25.1 |
| Disposal | 20.2 | 20.2 | 20.2 | 13.2 | 13.2 | 20.2 | 20.2 | 20.2 | 20.2 | 20.2 | 19.5 | 21.1 | 19.5 | 21.1 |
| Packaging manufacture | 37.7 | 36.7 | 37.7 | 234.8 | 234.8 | 37.7 | 37.7 | 37.7 | 37.7 | 37.7 | 1626.2 | 37.7 | 1626.2 | 37.7 |
| Agriculture, tomato | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Agriculture, chicken or replacement | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.5 | 32.4 | 1.5 | 32.4 |
| Agriculture, other ingredients | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 | 18.0 |
| Total | 133.5 | 146.0 | 144.8 | 323.7 | 327.6 | 129.0 | 133.5 | 124.1 | 129.3 | 124.1 | 1576.4 | 160.2 | 1587.7 | 171.5 |

**Table 75: MAETP inf., kg DCB eq. per meal**

| **Case** | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** | **J** | **K** | **L** | **M** | **N** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Credits | -14.7 | -3.6 | -14.7 | -16.7 | -16.7 | -14.7 | -14.7 | -23.0 | -13.9 | -23.0 | -32.0 | -3.6 | -32.0 | -3.6 |
| Processing | 30.3 | 14.5 | 30.3 | 47.4 | 49.3 | 30.3 | 30.3 | 19.5 | 21.9 | 19.5 | 19.4 | 14.5 | 19.4 | 14.5 |
| Distribution | 23.0 | 33.1 | 37.3 | 23.9 | 32.3 | 23.0 | 23.0 | 22.9 | 22.7 | 22.9 | 23.9 | 24.8 | 38.2 | 39.1 |
| Kitchen | 82.8 | 82.8 | 82.8 | 82.3 | 82.3 | 69.2 | 82.8 | 80.8 | 80.8 | 80.8 | 65.9 | 63.9 | 65.9 | 63.9 |
| Disposal | 80.4 | 80.4 | 80.4 | 52.2 | 52.2 | 80.2 | 80.4 | 80.6 | 80.6 | 80.6 | 91.1 | 84.4 | 91.1 | 84.4 |
| Packaging manufacture | 14.6 | 12.7 | 14.6 | 50.8 | 50.8 | 14.6 | 14.6 | 14.6 | 14.6 | 14.6 | 323.8 | 14.5 | 323.8 | 14.5 |
| Agriculture, tomato | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Agriculture, chicken or replacement | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.6 | 59.8 | 2.6 | 59.8 |
| Agriculture, other ingredients | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 | 15.6 |
| Total | 232.0 | 235.6 | 246.3 | 255.6 | 265.8 | 218.2 | 232.0 | 211.0 | 222.2 | 211.0 | 510.4 | 274.1 | 524.7 | 288.4 |

**Table 76: ODP steady state, µg R-11 eq. per meal**

| Case | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Credits | -1.15 | -0.23 | -1.06 | -0.98 | -0.98 | -1.06 | -1.06 | -1.68 | -1.00 | -1.68 | -0.78 | -0.23 | -0.78 | -0.23 |
| Processing | 8.33 | 5.87 | 8.33 | 14.29 | 14.33 | 8.33 | 8.33 | 7.84 | 7.89 | 7.84 | 8.82 | 5.87 | 8.82 | 5.87 |
| Distribution | 16.34 | 31.52 | 30.33 | 15.17 | 17.15 | 16.34 | 16.34 | 16.33 | 16.13 | 16.33 | 16.51 | 16.51 | 30.49 | 30.49 |
| Kitchen | 9.60 | 9.60 | 9.60 | 7.64 | 7.64 | 11.50 | 9.60 | 9.49 | 9.49 | 9.49 | 8.40 | 7.85 | 8.40 | 7.85 |
| Disposal | 0.97 | 0.97 | 0.97 | 0.46 | 0.46 | 0.89 | 0.97 | 0.98 | 0.98 | 0.98 | 0.63 | 1.03 | 0.63 | 1.03 |
| Packaging manufacture | 0.62 | 0.54 | 0.62 | 1.11 | 1.11 | 0.62 | 0.62 | 0.62 | 0.62 | 0.62 | 6.64 | 0.61 | 6.64 | 0.61 |
| Agriculture, tomato | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Agriculture, chicken or replacement | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.44 | 10.66 | 0.44 | 10.66 |
| Agriculture, other ingredients | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 |
| Total | 37.59 | 51.14 | 51.66 | 40.55 | 42.57 | 39.49 | 37.68 | 36.43 | 36.97 | 36.43 | 43.52 | 45.17 | 57.50 | 59.15 |

**Table 77: POCP, mg ethene eq. per meal**

| Case | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Credits | -9.1 | -5.2 | -8.9 | -8.1 | -8.1 | -8.9 | -8.9 | -11.6 | -8.6 | -11.6 | -9.2 | -5.2 | -9.2 | -5.2 |
| Processing | 18.6 | 12.1 | 18.6 | 32.1 | 32.9 | 18.6 | 18.6 | 16.0 | 16.4 | 16.0 | 17.9 | 12.2 | 17.9 | 12.2 |
| Distribution | 35.2 | 69.0 | 65.4 | 33.9 | 43.7 | 35.2 | 35.2 | 35.1 | 34.4 | 35.1 | 36.8 | 40.3 | 67.0 | 70.5 |
| Kitchen | 31.0 | 31.0 | 31.0 | 29.0 | 29.0 | 33.3 | 31.0 | 30.5 | 30.5 | 30.5 | 28.1 | 26.7 | 28.1 | 26.7 |
| Disposal | 13.5 | 13.5 | 13.5 | 7.8 | 7.8 | 13.5 | 13.5 | 13.6 | 13.6 | 13.6 | 13.3 | 14.2 | 13.3 | 14.2 |
| Packaging manufacture | 20.1 | 14.5 | 20.1 | 24.4 | 24.4 | 20.1 | 20.1 | 20.1 | 20.1 | 20.1 | 68.9 | 19.9 | 68.9 | 19.9 |
| Agriculture, tomato | 0.0 | 0.0 | 10.0 | 0.0 | 15.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 10.0 | 10.0 |
| Agriculture, chicken or replacement | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.9 | 65.5 | 2.9 | 65.5 |
| Agriculture, other ingredients | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 | 22.6 |
| Total | 132.0 | 157.6 | 172.4 | 141.8 | 168.0 | 134.4 | 132.2 | 126.3 | 129.0 | 126.3 | 181.2 | 196.2 | 221.4 | 236.4 |

Table 78: TETP inf., g DCB eq. per meal

| Case | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Credits | -0.23 | -0.13 | -0.22 | -0.82 | -0.82 | -0.22 | -0.22 | -0.30 | -0.22 | -0.30 | -5.10 | -0.13 | -5.10 | -0.13 |
| Processing | 0.38 | 0.29 | 0.38 | 0.83 | 0.83 | 0.38 | 0.38 | 0.32 | 0.33 | 0.32 | 0.43 | 0.29 | 0.43 | 0.29 |
| Distribution | 0.19 | 0.31 | 0.35 | 0.19 | 0.24 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.20 | 0.22 | 0.36 | 0.37 |
| Kitchen | 2.05 | 2.05 | 2.05 | 2.04 | 2.04 | 2.02 | 2.05 | 2.04 | 2.04 | 2.04 | 2.06 | 2.00 | 2.06 | 2.00 |
| Disposal | 0.19 | 0.19 | 0.19 | 0.11 | 0.11 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.13 | 0.20 | 0.13 | 0.20 |
| Packaging manufacture | 1.17 | 1.16 | 1.17 | 7.90 | 7.90 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 55.06 | 1.17 | 55.06 | 1.17 |
| Agriculture, tomato | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Agriculture, chicken or chicken replacement | 0.00 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -1.23 | 68.30 | -1.23 | 68.30 |
| Agriculture, other ingredients | 45.13 | 45.13 | 45.13 | 45.13 | 45.13 | 45.13 | 45.13 | 45.12 | 45.12 | 45.12 | 45.13 | 45.13 | 45.13 | 45.13 |
| Total | 48.88 | 49.99 | 49.03 | 55.38 | 55.43 | 48.85 | 48.88 | 48.73 | 48.81 | 48.73 | 96.69 | 117.17 | 96.84 | 117.33 |

Table 79: Primary energy demand, net, MJ per meal

| Case | A | B | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Credits | -0.40 | -0.28 | -0.39 | -0.26 | -0.26 | -0.39 | -0.39 | -0.47 | -0.38 | -0.47 | -0.40 | -0.28 | -0.40 | -0.28 |
| Processing | 1.24 | 0.75 | 1.24 | 1.94 | 1.94 | 1.24 | 1.24 | 1.02 | 1.06 | 1.02 | 1.09 | 0.75 | 1.09 | 0.75 |
| Distribution | 1.02 | 1.49 | 1.74 | 1.02 | 1.22 | 1.02 | 1.02 | 1.02 | 1.00 | 1.02 | 1.08 | 1.15 | 1.80 | 1.87 |
| Kitchen | 2.53 | 2.53 | 2.53 | 2.16 | 2.16 | 3.31 | 2.53 | 2.49 | 2.49 | 2.49 | 2.22 | 2.13 | 2.22 | 2.13 |
| Disposal | 0.12 | 0.12 | 0.12 | 0.06 | 0.06 | 0.11 | 0.12 | 0.12 | 0.12 | 0.12 | 0.08 | 0.12 | 0.08 | 0.12 |
| Packaging manufacture | 0.90 | 0.70 | 0.90 | 0.82 | 0.82 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 2.39 | 0.89 | 2.39 | 0.89 |
| Agriculture, tomato | 22.58 | 22.58 | 0.74 | 35.34 | 1.16 | 22.58 | 42.37 | 22.58 | 22.58 | 22.58 | 22.58 | 22.58 | 0.74 | 0.74 |
| Agriculture, chicken or chicken replacement | 1.24 | 3.31 | 1.24 | 1.24 | 1.24 | 1.24 | 1.63 | 2.71 | 1.81 | 1.92 | 0.58 | 9.77 | 0.58 | 9.77 |
| Agriculture, other ingredients | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 | 1.02 |
| Total | 30.24 | 32.21 | 9.14 | 43.34 | 9.36 | 31.03 | 50.45 | 31.37 | 30.59 | 30.59 | 30.62 | 38.12 | 9.50 | 17.00 |

# Appendix H: Pedigree Matrix

Table 80 shows the estimated data quality in five different categories for inputs to the LCA model (except for agricultural data, which is shown in Table 24). The precise meanings of the ratings 1 to 5 are explained in Weidema and Wesnæs (1996).

**Table 80: Pedigree matrix**

| **Process** | **Reliability** | **Completeness** | **Temporal correlation** | **Geographical correlation** | **Further technological correlation** |
|---|---|---|---|---|---|
| **Agriculture inputs** | | | | | |
| Traction | 3 | 3 | 5 | 3 | 2 |
| Ammonium nitrate, as N, at regional storehouse | 3 | 4 | 5 | 2 | 2 |
| Triple superphosphate, as $P_2O_5$, at regional storehouse | 3 | 4 | 5 | 2 | 2 |
| Potassium chloride, as $K_2O$, at regional storehouse | 3 | 5 | 5 | 3 | 2 |
| Pesticide unspecified, at regional storehouse | 3 | 3 | 4 | 2 | 2 |
| | | | | | |
| **Transport** | | | | | |
| Transport, lorry 7.5-16 t, EURO5 | 3 | 4 | 4 | 2 | 2 |
| Transport, lorry 16-32 t, EURO5 | 3 | 5 | 4 | 2 | 4 |
| Transport, lorry >16 t, fleet average | 3 | 5 | 4 | 2 | 4 |
| Transport, lorry 3.5-7.5 t, EURO5 | 3 | 4 | 4 | 2 | 2 |
| Transport, lorry >32 t, EURO5 | 3 | 4 | 4 | 2 | 4 |
| Transporting chicken to slaughterhouse | 3 | 4 | 3 | 1 | 2 |
| Transport, transoceanic freight ship | 3 | 4 | 5 | 4 | 2 |
| | | | | | |
| **Processing** | | | | | |
| Farm cooling | 4 | 4 | 3 | 1 | 2 |
| Chicken slaughter | 3 | 2 | 5 | 3 | 2 |
| Blood-, meat- and bone-meal production | 2 | 4 | 5 | 3 | 2 |
| Vegetable processing | 4 | 5 | 3 | 2 | 2 |
| | | | | | |
| **Packaging** | | | | | |
| Polypropylene, granulate, at plant | 3 | 4 | 4 | 2 | 4 |
| Tin plated chromium steel sheet, 2 mm, at plant | 2 | 4 | 5 | 2 | 4 |
| Packaging film, low density polyethylene, at plant | 3 | 5 | 5 | 2 | 2 |
| EUR-flat pallet | 3 | 5 | 4 | 2 | 2 |
| Solid unbleached board, at | 4 | 5 | 5 | 2 | 2 |

| | | | | | |
|---|---|---|---|---|---|
| plant | 🟧 | 🟥 | 🟥 | 🟩 | 🟩 |
| Polyethylene, high density, granulate, at plant | 3 | 3 | 5 | 2 | 4 |
| | | | | | |
| **Wholesale** | | | | | |
| Refrigerated storage | 2 | 1 | 4 | 4 | 2 |
| | | | | | |
| **Kitchen** | | | | | |
| Kitchen refrigeration | 3 | 5 | 5 | 3 | 3 |
| Cooking equipment efficiency | 1 | 5 | 4 | 3 | 2 |
| Heated holding | 4 | 5 | 1 | 1 | 3 |
| Dish washing | 2 | 5 | 1 | 3 | 3 |
| Food waste levels | 2 | 3 | 2 | 1 | 2 |
| | | | | | |
| **Disposal** | | | | | |
| Waste management division by method | 4 | 1 | 2 | 1 | 4 |
| Disposal, plastics, mixture, 15.3% water, to municipal incineration | 3 | 3 | 4 | 3 | 4 |
| Plastic recycling, polyethylene | 3 | 5 | 5 | 3 | 2 |
| Disposal, plastics, mixture, 15.3% water, to sanitary landfill | 3 | 4 | 5 | 3 | 3 |
| Disposal, municipal solid waste, 22.9% water, to sanitary landfill | 3 | 5 | 5 | 3 | 3 |
| Disposal, wood ash mixture, pure, 0% water, to sanitary landfill | 3 | 5 | 5 | 3 | 3 |
| Disposal, biowaste, 60% $H_2O$, to municipal incineration, future, alloc. Price | 3 | 3 | 2 | 3 | 4 |
| Disposal, building, reinforcement steel, to recycling | 3 | 5 | 5 | 3 | 5 |
| Disposal, steel, 0% water, to inert material landfill | 3 | 5 | 5 | 3 | 2 |
| Disposal, steel, 0% water, to municipal incineration | 3 | 3 | 5 | 3 | 2 |
| Sink-top disposal unit | 2 | 5 | 3 | 3 | 3 |
| Treatment, potato starch production effluent, to wastewater treatment, class 2 | 4 | 3 | 5 | 3 | 3 |
| Treatment, maize starch production effluent, to wastewater treatment, class 2 | 4 | 3 | 5 | 3 | 3 |
| Composting of solid municipal waste | 3 | 5 | 5 | 3 | 4 |
| Plastic recycling, polyethylene | 3 | 5 | 5 | 3 | 2 |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Energy** | | | | | |
| British electricity grid mix 2014 | 1 | 1 | 1 | 1 | 1 |
| Spanish electricity mix | 1 | 1 | 4 | 1 | 1 |
| Electricity, hard coal, at power plant | 3 | 1 | 5 | 3 | 2 |
| Electricity, nuclear, at power plant | 3 | 4 | 5 | 3 | 2 |
| Electricity, natural gas, at power plant | 2 | 1 | 5 | 1 | 2 |
| Electricity, at wind power plant | 3 | 3 | 4 | 2 | 2 |
| Electricity, hydropower, at power plant | unknown | unknown | 5 | 1 | unknown |
| Electricity, production mix photovoltaic, at plant | 3 | 3 | 3 | 3 | 2 |
| Electricity, at cogen 6400 kWth, wood, allocation energy | 2 | 4 | 4 | 3 | 3 |
| Electricity, oil, at power plant | 3 | 5 | 5 | 1 | 2 |
| Diesel, at regional storage | 3 | 3 | 4 | 3 | 2 |
| Heat, natural gas, at boiler modulating >100 kW | 3 | 5 | 5 | 3 | 3 |
| Heat, light fuel oil, at boiler 100 kW, non-modulating | 3 | 5 | 5 | 3 | 3 |
| Steam, for chemical processes, at plant | 3 | 3 | 5 | 2 | 4 |
| Slaughterhouse heat | 3 | 3 | 5 | 3 | 2 |
| Natural gas, high pressure, at consumer | 3 | 5 | 5 | 3 | 2 |
| Heat, at local distribution cogen 160 kWe Jakobsberg, allocation energy | 3 | 5 | 5 | 3 | 2 |
| Natural gas hob emissions | 4 | 5 | 3 | 3 | 3 |
| | | | | | |
| **Other material inputs** | | | | | |
| Refrigerant R134a, at plant | 3 | 5 | 5 | 2 | 2 |
| Ammonia, liquid, at regional storehouse | 3 | 5 | 5 | 2 | 2 |
| R404a production | 5 | 5 | 4 | 4 | 5 |
| Tap water, at user | 3 | 5 | 5 | 3 | 2 |
| Soap, at plant | 3 | 4 | 5 | 2 | 5 |

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Scope diagram for Case A including main data sources, colour coded by life cycle stage