SMALL WORLD CONSULTING

The greenhouse gas footprint of Booths

June 2015

Covering the year 2013-14

Final

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1 Executive summary

1.1 Context

In the UK, food is widely thought to account for at least 20% of the greenhouse gas (GHG) emissions resulting from household consumption. This report sets out to break down the GHG footprint of the Booths product range up to the checkout, by 77 food types in 10 groups, and by life-cycle stage. We believe it provides the most comprehensive and transparent account of emissions in the supply chains of any UK supermarket.

This report, for the year 2013-14, builds upon previous work updating and improving upon similar reports for 2011, 2009 and 2007. This latest report compares our assessment of emissions in 2013-14 with the previous estimate, although changes result from methodological improvements as well as changes in activities on the ground.

1.2 Results

The annual carbon footprint of Booths and its product supply chains is estimated at 279,048 tonnes CO_2e per year. This is roughly one four-thousandth of the GHG footprint of UK consumption[1]. To put this in perspective, this equates to a best estimate of 1.0 kg of CO_2e per pound (£) spent by customers on the products covered in this study. Just over two-thirds of this is attributable to farming and manufacturing. We estimate transport up to the distribution centre to be just 5.7% of the total; packaging 5.5%; refrigeration (comprising both gas leakage and electricity) at 5.7%; warehousing and distribution centres at 0.8%; and other operations (the running of stores, offices and other Booths operations) at 10%.

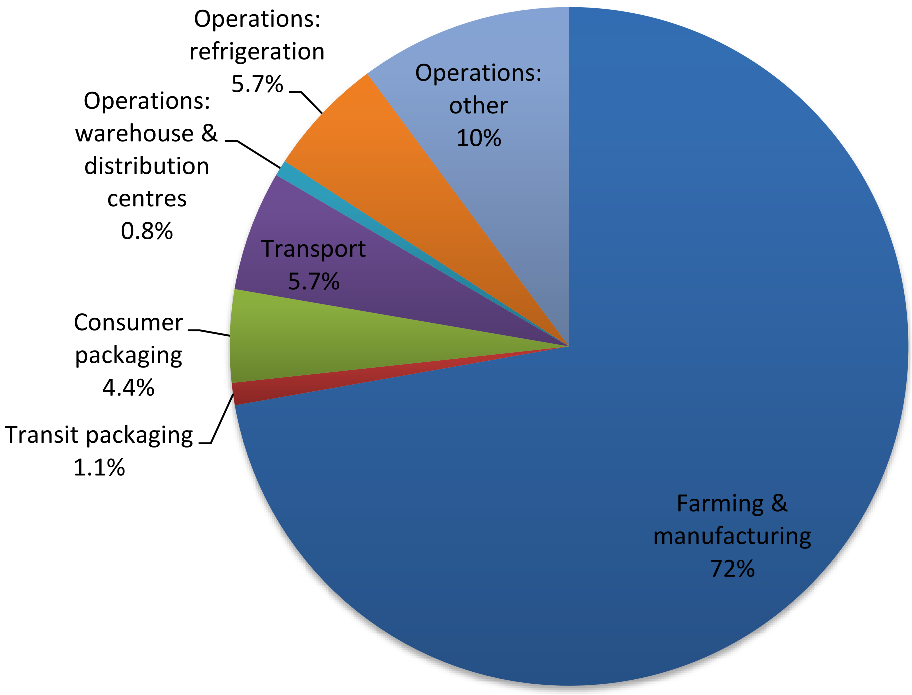
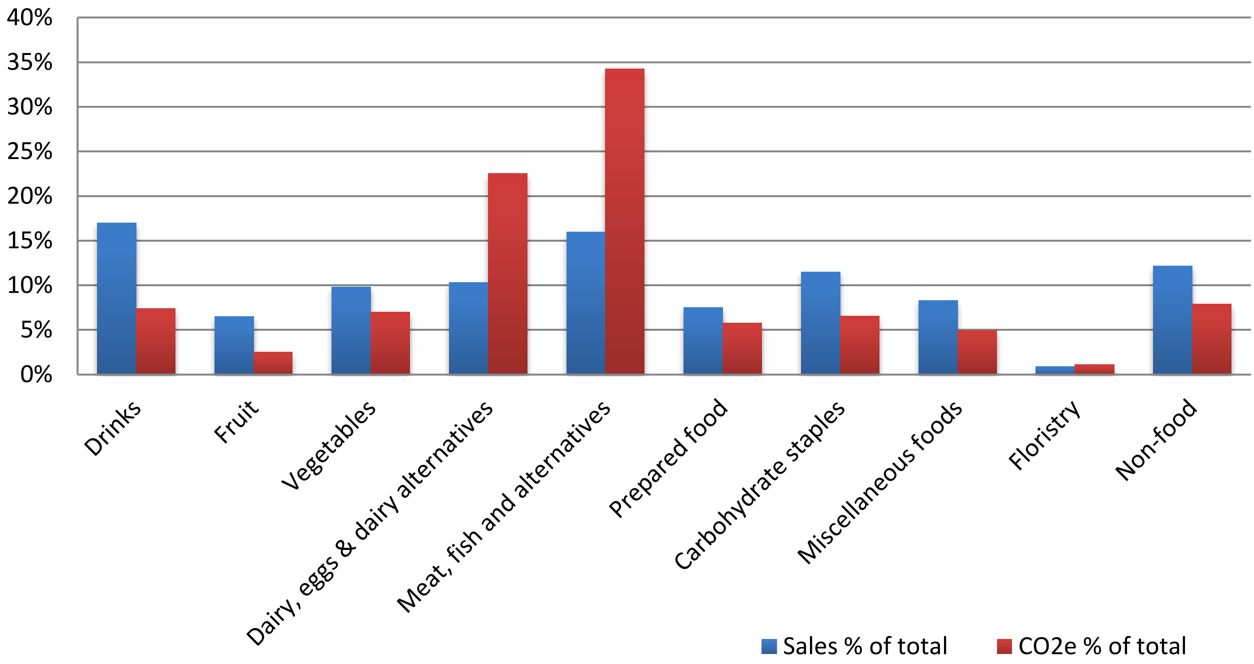


Figure 1: Total footprint of Booths products and supply chains 279,048 tonnes CO_2e

[1] Based on 862 million tonnes CO_2e for annual UK consumption, derived from the input–output analysis used throughout this report.

When the whole Booths footprint is attributed to goods sold, animal products and their 'alternatives' make up 57% of the total. These are generally the most carbon intensive products per £ at the checkout, although



there is high variation, for example, between types of meat.

Figure 2: Footprint and sales for product categories as a proportion of the total

Fruit and vegetables together make up just 10% of the footprint, non-food (excluding floristry) a further 8%, and drinks (both alcoholic and soft) another 7%. Drinks are generally among the least carbon intensive per £ at the checkout, but this is partly due to tax on alcohol. Fruit is also low carbon per £ due to the predominance of seasonally grown produce that is either local or shipped.

1.3 Mitigation actions

For some years Booths has been seeking to integrate its response to climate change across all aspects of its operation. Actions in the last two years include the following:

- increasing marketing emphasis on more sustainable products, particularly within fruit and vegetable ranges;
- improving refrigeration systems in some stores, including moving to CO_2 as the refrigerant gas and a range of energy efficiency improvements (see below);
- implementing a major waste reduction initiative;
- improving efficiency of distribution;
- building new stores to high sustainability specifications;
- a range of energy efficiency improvements including:
    - voltage optimisation improvements,
    - fitting doors to retail fridges,
    - increased use of LED lighting,
    - air sourced heat pumps,
    - heat recovery systems;

- adjusting the way some products are sourced to mitigate GHG hotspots;
- engaging and informing staff throughout the business, from the board level downwards;
- informing the sustainable food debate by:
  - making carbon analysis publically available,
  - supporting academic research,
  - supporting national and regional policy;
- installation of a solar panel array at the distribution centre for future emissions reduction.

Some of the improvements achieved through the above measures have been offset by a serious rise in refrigerant gas leaks from some aging equipment in a few stores.

1.4 Comparison with 2011-12

When methodological differences have been accounted for, emissions have risen by 2% since the 2011-12 study, despite a 4% rise in sales and the opening of a new store. The intensity of emissions per unit sales value has fallen by 2%. Considerable steps have been taken to encourage customers to reduce waste, but these are not quantified in this analysis which looks only at emissions from the field to the checkout.

2 Introduction

2.1 A Simple Overview of the Global Food System

For broad context, we provide here a simplified account of a highly complex system.

2.1.1 Greenhouse Gas Emissions

Food accounts for roughly 20% of global GHG emissions. The main sources are:

- methane from ruminating cows and sheep, and from flooded paddy fields;
- nitrous oxide from fertilizer use;
- carbon dioxide from deforestation attributable to cattle farming and animal feed production;
- fossil fuel usage throughout the food supply chain including agricultural machinery, heating, transport and processing, and retail[2].

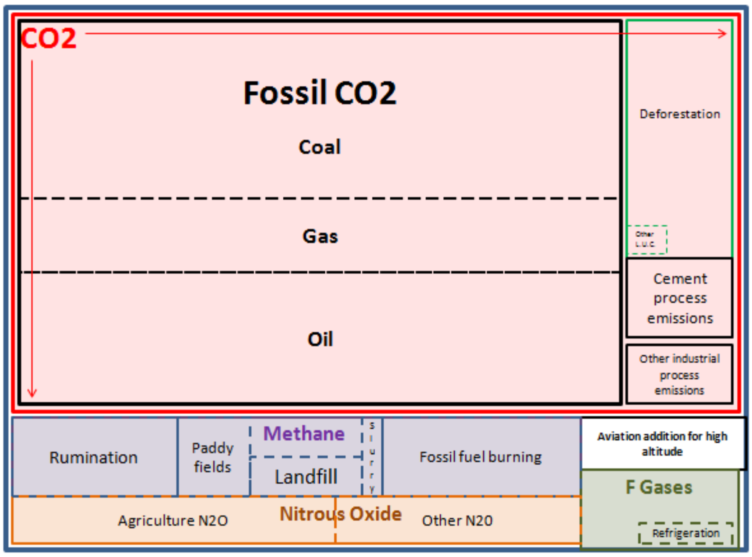


Figure 3: Global greenhouse gas emissions - roughly 50 billion tonnes of carbon dioxide equivalent per year; mainly carbon dioxide from fossil fuel, but other important components include carbon dioxide from deforestation, methane and nitrous oxide.

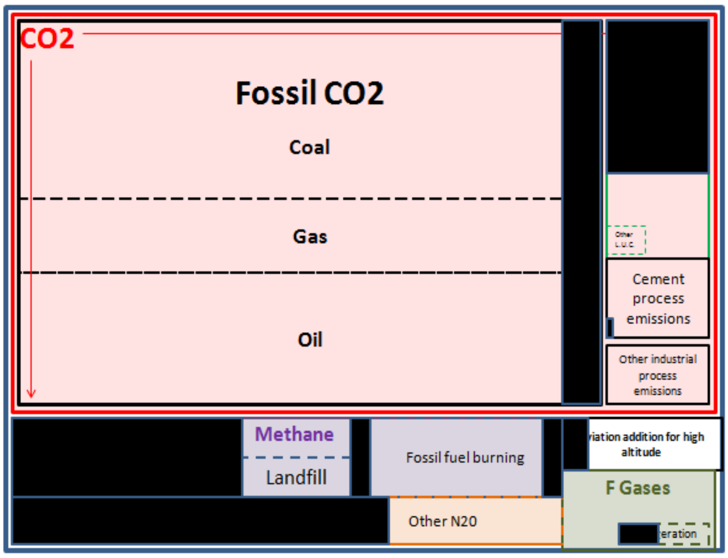


Figure 4: Food's 20% contribution to global emissions is highlighted in black.

[2] Carbon dioxide Equivalent (CO_2e) defined over a 100 year timeframe. Over a 50 year timeframe, methane becomes almost twice as prominent. Data from The Burning Question, p146, p236 (Berners-Lee, M and Clark, D 2013)

2.1.2 Losses in the Food System

The world grows roughly 6000 kcal per person per day. Only around 2000 of these are eaten by humans with the remainder slipping out of the food system, in the following ways:

- allowed to spoil in the field – 900 kcal;
- used for biofuels – 500 kcal;
- post-harvest waste; mainly in developing countries through poor storage facilities – 600 kcal;
- the inherent inefficiency of introducing animals into the food system for meat and dairy production (1700 kcal plus grass feed converts to 500 kcal of meat and dairy);
- other waste, primarily in developed countries, and mainly in households, but also in processing and retail – 800 kcal[3].

The average of 2000 kcal per day consumed by humans would be just enough for the global population if it was optimally distributed, however unequal distribution results instead in roughly 1.5 million obese people and 1 billion people going hungry.

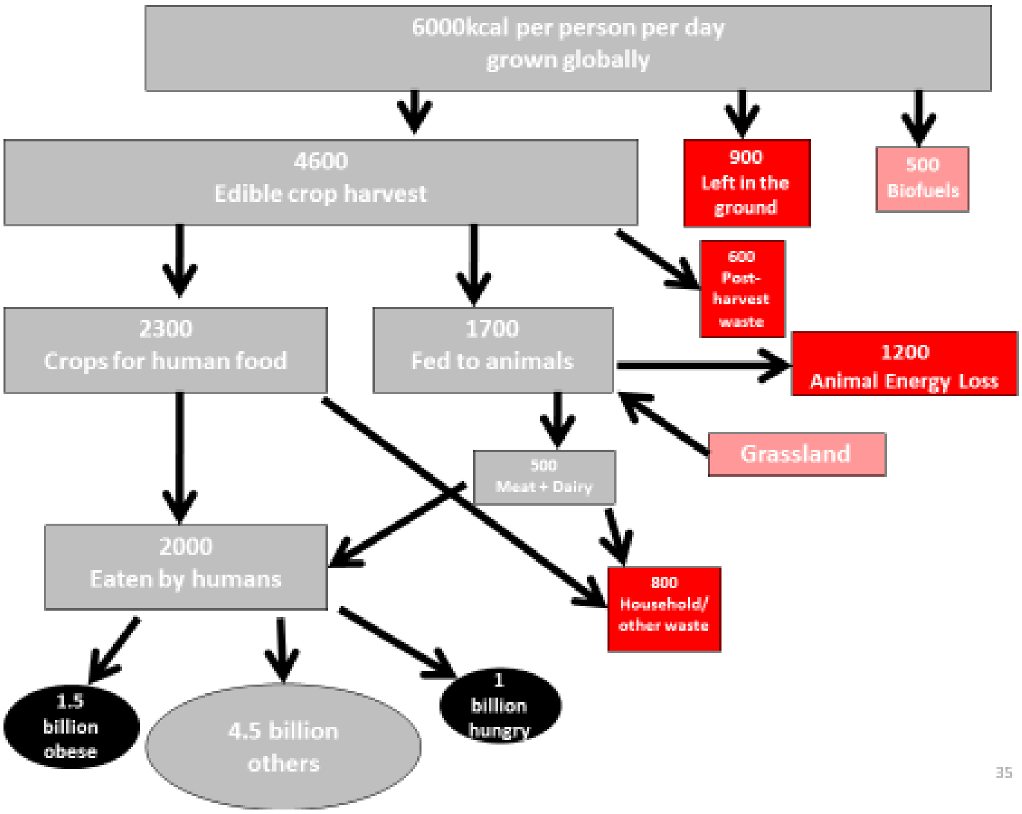


Figure 5: Where do the calories go? A rough map of the global food system in which only a third of the edible calories grown end up being eaten.

[3] Figure 5 and statistics adapted from The Burning Question p 163, Berners-Lee, M and Clark, D 2013).

2.1.3 The Sustainable Food Challenge

The sustainable food challenge is to feed everyone in a way that addresses poverty whilst maintaining biodiversity, reducing emissions and providing some biofuel.

Several factors look set to make this challenge harder:

- population growth by 30 – 50% this century;
- reductions in land fertility and increasing water scarcity in some regions resulting from climate change;
- a trend of rising meat consumption which, if it continues, will result in an increase of 70% in meat demand by 2050.

Improvements are needed in:

- developing and deploying practices and technologies that raise yields and cut emissions, whilst improving biodiversity;
- waste reduction throughout the supply chain;
- food storage;
- diet – especially reversing the global trend in rising meat consumption;
- use of the food system to alleviate poverty.

2.2 This report

Although more significant than domestic energy and car fuel combined, the climate change impact of the UK's food is still poorly understood. The science of agricultural emissions is complex and the implications of different practices are often unclear. The number, the complexity and the seasonal variation of supply chains of products in UK supermarkets make detailed modelling of each one an impractical exercise.

Nevertheless, it is possible, by drawing upon the most credible publically available life-cycle analyses (LCA) and sensible, transparent assumptions, to provide realistic management advice.

This report looks at sustainability throughout Booths, with a particular focus on climate change. It maps out the greenhouse gas (GHG) emissions of products up to the checkout, covering the entire range with the exception of foods supplied to cafés and restaurants. This is key information to enable Booths to develop an effective response to climate change and to communicate the issues to its staff and to others who are interested in the sustainable food agenda. Emissions are broken down into 77 product categories and by life-cycle stage from primary production to retail.

This report updates and improves upon previous estimates carried out in 2011, 2009 and 2007. This year's report compares emissions with those in 2011, reflecting on the reasons for changes which include changes in the business, as well as methodological improvements.

2.3 Booths and sustainability

Booths seeks to enable a sustainable food system by:

- facing the issues and working from the facts as best they can be understood;
- treating staff, customers and suppliers with fairness and respect;
- making sustainable practices attractive for customers and supply chains;
- enhancing appreciation of food, where it comes from, and the experience it gives us;

- demonstrating to the food industry and beyond how practical sustainability can help a business to thrive;
- providing transparent, rigorous and publically available analysis to contribute to the sustainable food debate;
- efficient use of energy;
- reducing food waste (food not sold or given for human consumption) to almost zero.

This report is made publically available- including the detailed description of the methodology and emissions factors and sources- in order to demonstrate transparency. It is also hoped that the findings can continue to inform the sustainable food agenda and be used in academic research.

2.4 What Booths has done so far

For some years Booths has been seeking to integrate sustainability across all aspects of its operation. Past and current actions have included the following:

- increasing marketing emphasis on more sustainable products, particularly within fruit and vegetable ranges;
- improving refrigeration systems in some stores, including moving to CO_2 as the refrigerant gas;
- implementing a major waste reduction initiative;
- improving efficiency of distribution;
- building new stores to high sustainability specifications;
- a range of energy efficiency improvements including:
    - voltage optimisation improvements,
    - fitting doors to retail fridges,
    - increased use of LED lighting,
    - air sourced heat pumps,
    - heat recovery systems;
- installing a large solar panel array on the main warehouse roof in Preston;
- adjusting the way some products are sourced to mitigate GHG hotspots;
- initiating a 'Fair Milk' scheme by which local farmers are guaranteed the highest price offered by any UK supermarket, and coupling this with an initiative to explore sustainability opportunities on the farms;
- ensuring all scallops are hand dived and never dredged;
- ensuring all fish complies with Fish Conservation Society guidelines;
- engaging and informing staff throughout the business, from the board level downwards;
- informing the sustainable food debate by:
    - making carbon analysis publically available,
    - supporting academic research,
    - supporting national and regional policy.

In recognition for its work on sustainability, in 2013, Booths was the only UK business to be awarded a Ruban D'Honeur for sustainability in the European Business Awards and was runner-up in two sustainability categories of the national 'Business In The Community' Awards.

3 Methodology

This section contains an overview of the methods used for the current footprint assessment. *'Appendix A: Emissions factors'* contains an account of the emissions factors used and *'Appendix B: Detail of EIO Methodology'* contains further details on the Environmental Input–output (EIO) model.

3.1 Footprinting principles

In this report we use the term 'footprint' to mean the sum of the direct and indirect emissions that arise throughout supply chains of activities and products. As an example, the footprint of yogurt includes contributions for carbon dioxide, methane and nitrous oxide emitted on the farm and the footprint of transport, processing, packaging and storage of the product prior to sale. To give another example, the footprint of vehicle travel includes not only the direct vehicle emissions as covered by emissions factors issued by Defra[4], but also components for the extraction, shipping, refining and distribution of fuel, and components for the manufacture and maintenance of vehicles, and so on.

This inclusive treatment of supply chain emissions differs from more standard production-based assessments but gives a more complete and realistic view of impacts, despite the complexities and uncertainties involved. Footprints of this kind are essential metrics for responsible management.

3.2 Boundaries

The study covers GHG emissions from Booths product supply chains from primary production to the checkout.

Specifically, the following were included:

- primary production;
- transport;
- processing;
- packaging (including consumer packaging, transit packaging and carrier bags);
- energy consumption by stores, warehouses and offices;
- goods and services procured by Booths for general operations;
- waste disposal;
- leakage of refrigerant gases;
- staff business travel and commuting.

The following are specifically excluded from the study:

- the life-cycle of products and packaging after they have been sold by Booths, including the impacts of customer travel, cooking and waste disposal;
- the activities of staff other than when at work or travelling between work and home;
- the embodied emissions in buildings;
- food purchased for teashops and Artisan restaurants;
- impacts that might be attributable to National Lottery sales.

[4] Defra, 2013.

3.3 Greenhouse Gas Protocol guidelines

The assessment follows the reporting principles of the Greenhouse Gas Protocol (GGP) published by the World Business Council for Sustainable Development (WBCSD) and the World Resources Institute (WRI)[5].

We therefore cover all the gases specified in the GGP expressed in terms of carbon dioxide equivalent (CO_2e)- the sum of the weights of each gas emitted multiplied by their global warming potential (GWP) relative to carbon dioxide over a 100-year period.

The GGP provides three choices for emissions reporting. Scope 1 covers direct emissions from company-owned vehicles and facilities. Scope 2 includes net emissions from energy imports and exports, such as electricity. Scope 3 includes other indirect emissions resulting from company activities, as detailed by the boundaries of the study. This report includes all Scope 1 and 2 emissions and comprehensive treatment of Scope 3 supply chain emissions within the boundaries laid out above.

3.4 Treatment of high-altitude emissions

High-altitude emissions from aircraft are known to have a higher global warming impact than would be caused by burning the equivalent fuel at ground level. Although the science is still poorly understood, we have applied an emissions weighting factor of 1.9 to aircraft emissions, to accommodate this. This is the figure suggested in Defra's *Guidelines for Company Reporting on Greenhouse Gas Emissions*[6]. The figure can also be inferred from the Intergovernmental Panel on Climate Change's *Fourth Assessment Review*[7].

3.5 Modelling the footprint of products

We allocate all Booths products to 66 food and 11 non-food categories, which are constructed to enable clearly defined and accurate carbon stories to be told. These in turn fall into 10 broader categories as shown in Table 1.

Main category	Subgroups
Drinks	Wines; Beer and cider; Spirits and liqueurs; Soft drinks; Juice; Bottled water.
Fruit	Apples and pears; Citrus; Bananas; Berries; Stone fruit and grapes; Melons; Exotic fruit; Dried fruit, nuts and seeds; Frozen fruit; Prepared fruit; Tinned fruit.
Vegetables	Potatoes; Other roots; Salad; Tomatoes; Other vegetables; Mushrooms; Exotic vegetables; Frozen vegetables; Prepared vegetables; Tinned vegetables.
Dairy, eggs & dairy alternatives	Milk; Cheese; Cream; Yoghurt & fromage frais; Butter; Margarine; Soya; Ice cream; Powdered milk; Eggs.
Meat, fish and alternatives	Beef; Lamb; Poultry; Pork, bacon and sausages; Processed and cooked meat; Tinned meat; Fresh fish; Tinned fish; Vegetarian; Frozen meat and fish; Other meat and fish (contains offal, game and meat categories that cannot be separated into other categories or not classified elsewhere (<2% of total sales value)).
Prepared food	Sandwiches; Pies; Ready meals, pizza and fresh pasta; Desserts.
Carbohydrate staples	Bread; Rice; Pasta; Cake; Biscuits; Cereals; Crisps and snacks; Home baking (excludes eggs and dried fruit).
Miscellaneous foods	Jam, honey, marmalade; Soup; Condiments; Confectionary; Beverages; Miscellaneous food (contains sauces, chutneys and pickles as well as a small volume of food that either could not be separated into main group areas or not elsewhere classified (<0.1% of total value of food sold)).
Floristry	Flowers.
Non-food	Pet food; Tobacco; Publications; Toiletries; Medication; Paper and tissue; Cleaning products and chemicals; Electricals; Gardening, bulbs and seeds; Other non-food.

Table 1: Product classification structure

[5] Ranganathan *et al.*, 2006.

[6] Defra, 2011; more recently DECC has published supply chain emissions factors for energy use. We have not used these since they include only certain parts of the supply chains.

[7] IPCC, 2007.

The embodied GHG emission estimates for each of the 77 categories include components for farming and manufacturing, transport, packaging, storage and supermarket operations.

Emissions up to the farm-gate are estimated by taking a selection of representative products within each of the categories and applying emission factors from previously published life-cycle analyses (LCAs). The specific LCAs used have been selected on the basis of credibility, consistency of method and closeness of the supply chains studied to those adopted by Booths itself. The full list of sources and emissions factors is in *Appendix A: Emissions factors.*

The emissions associated with transport from the point of production to the supermarket distribution centre are estimated by modelling scenarios for a range of representative products within each category. Emission factors for each transport mode are from Defra[8] and environmental input–output methods are used to take account of emissions within the supply chains of each transport journey (see *3.7: A note on Environmental Input–Output analysis (EIO)* for details). Neither Defra's emissions factors for international freight nor the input–output model used take account of any differences in the carbon intensity of transport modes between countries. For example, the emissions resulting from transporting a tonne of grain for one kilometre in Brazil is assumed to be the same as it would be in the UK.

Food processing emissions are often provided in the LCA selected. Where this is not the case, or estimates for products are derived from their ingredients, food processing emissions are inferred from Foster *et al*[9].

Emissions embodied in food packaging materials are estimated using data on the mass of packaging materials associated with each food category, as logged at the checkout, together with emission factors for different materials. Secondary (transit) packaging is taken into account in the same way, although attribution to product groups was less exact since only aggregated records were available. See section *6.7.5 Consumer food packaging* for more information and sources.

Emissions resulting from refrigeration at the Booths distribution centre and stores are calculated from data on refrigerant gas consumption and estimates of electricity use for refrigeration. This consumption data is then combined with emissions factors (see section 6.7.1 and 6.7.2 for details and sources) and allocated to chilled and frozen products by weight sold. A similar process is used to estimate the emissions from warehousing.

Other direct and indirect GHG emissions resulting from supermarket operations within the boundaries outlined above (defined as 'Overhead') are calculated and attributed to food product categories by value. See section *6.7.6 Other goods and services* for details.

3.6 Uncertainties

The complexity of supply chains, the crude state of scientific understanding regarding agricultural emissions and, in some cases, the difficulties in obtaining accurate data dictate that GHG emissions estimates of foods can only offer a best estimate rather than an exact measure. The figures in this report should be viewed in that context.

8 Defra, 2013.

9 Foster *et al.,* 2006.

3.6.1 The quality of data

The validity of estimates clearly depends on the accuracy and completeness of the Booths data used. This has been gathered jointly by Booths staff and Small World Consulting. Where ideal data sets could not be found estimates have been made or direct measurements taken.

The value and quantity of products sold is accurately known and in many cases, so too is the associated weight. For most other product categories, total weights sold have been extrapolated from a proportion by value of known product weights and the results 'sense checked' by weighed examples. A few food product weights were taken manually from product packaging. For 2013 we have also made some estimates based on online research of similar products at other supermarkets. While some uncertainty remains, the majority of product category weights are thought to be fairly accurate.

Data on consumer packaging, transit packaging and carrier bags came directly from Booths, having been systematically collated in line with the WEEE directive[10]. This is assumed to be accurate. Transit packaging and carrier bags were attributed across relevant product categories by product weight.

Fuel consumption within Booths buildings and distribution is thought to be accurately known. Data for third party distribution and storage is based on estimates from the third party suppliers.

Transport impacts are based on estimates of typical journeys; up to five weighted journeys to represent each of the 77 categories. These journeys were modelled in consultation with the Booths buying team. More care was taken over bulky categories and those where air freight was used.

Operational expenditure data is thought to be accurately known.

3.6.2 Uncertainties over emissions factors

The areas in which the relationship between consumption and emissions is best understood are gas and electricity consumption. There is relatively good consensus over emissions factors to within around 10% in these areas. The next most certain group of emissions factors are those for travel and transport. In this category, those relating to aviation are the least well understood, due to uncertainties around the impact of high-altitude emissions and the paucity of detailed flight modelling for climate change impact studies.

It should be noted that this study does not look into the specific circumstances of the particular farms in the Booths supply chains but contains figures relating to representative production systems. Despite recent attempts to develop standards, the assessment of food climate change impacts remains fraught with problems of both methodology and practicality and looks set to remain an inherently crude exercise for the foreseeable future[11].

Food product LCAs model specific supply chains and production systems for given products. Therefore their results can differ significantly, even where system boundaries align, as is frequently not the case. Furthermore, although improving, scientific understanding of the GHG emissions from agricultural processes is still imprecise and the pool of credible studies which take account of the full basket of GHGs is still fairly small. Consequently some of the most significant areas of uncertainty are in estimating the emissions up to the farm-gate. We draw predominantly on a few of the most credible studies, and sense-check their findings

[10] Environment Agency 2006.

[11] There are several ongoing developments in the formation of life-cycle assessment standards. In the UK, a revised PAS (Publicly Available Standard) 2050 was released in 2011 (BSI, 2011). However the revision does not address the fundamental concerns raised in Defra's review of its methodology, which we broadly endorse (Minx *et al*., 2007). Through the Sustainable Consumption Institute, Tesco continues to fund the development of a food-specific footprint standard, drawing from, but not directly compliant with, the PAS 2050. The World Resources Institute also released a standard for Scope 3 product assessments and although less specific this deals more realistically with system boundaries. All of these standards face problems of methodology and practicality.

against other reputable studies where possible (see *Appendix A: Emissions factors* for an overview of the sources used).

All process-based life-cycle assessments suffer from difficulties over the definition of boundaries for the study and the problem of 'truncation error'; the number of pathways in the supply chain of a product is infinite, and only the most significant can be followed. For this reason, purely process-based life-cycle analyses have a systematic tendency to underestimate impacts to some degree. This study has drawn on environmental input–output analysis (EIO; see below) for many non-food supply chains.

3.7 A note on Environmental Input–Output analysis (EIO)

EIO combines economic information about the trade between industrial sectors with environmental information about the emissions arising directly from those sectors to produce estimates of the emissions per unit of output from each sector. The central technique is well established and documented[12]. In the UK, the main data sources are the *'Combined Supply and Use Matrix for 110 sectors'*[13] and the *'UK environmental accounts'*[14], both provided by the Office of National Statistics.

The specific model used in this project was developed by Small World Consulting with Lancaster University and is described in detail in

Appendix B: Detail of EIO Methodology and elsewhere[15]. This model takes account of such factors as the impact of high altitude emissions that are not factored into the environmental accounts and the effect of imports. In order to use more up-to-date (2008 rather than 1995) data, we employ a simple algorithm to convert between basic and purchasers prices. We use industry specific consumer price indices to adjust for price changes since the date to which the supply and use tables relate.

Three main advantages of EIO over more traditional process-based life-cycle analysis (LCA) approaches to GHG footprinting are worth noting:

- EIO attributes all the emissions in the economy to final consumption. Although, as with process-based LCA, there may be inaccuracies in the ways in which it does this, it does not suffer from the systematic underestimation (truncation error) that process-based LCAs incur through their inability to trace every pathway in the supply chains[16];
- EIO has at its root a transparently impartial process for the calculation of emissions factors per unit of expenditure, whereas process-based LCA approaches entail subjective judgements over the setting of boundaries and the selection of secondary emissions factors;
- through EIO, it is possible to make estimates of the footprints resulting from complex activities such as the purchase of intangible services that LCAs struggle to take into account.

One of the limitations of EIO in its most basic form is that it assumes that the demands placed upon (and therefore the direct emissions from) other sectors by a unit of output within one sector are homogeneous. As an example, a basic EIO model does not take account of the carbon efficiencies that may arise from switching the expenditure on paper from a virgin source to a renewable source without reducing the actual spend. An assumption in the model used here is that goods from overseas are produced with the same

[12] for example Leontief, 1986; Miller & Blair, 2009.
[13] ONS (Office of National Statistics), 2010[a].
[14] ONS (Office of National Statistics), 2010[b].
[15] Berners-Lee, *et al*., 2011.
[16] Lenzen, M., 2001; Nässén *et al*., 2007.

carbon efficiency as they would have been in the UK. Overall, this assumption usually results in an underestimation of the footprint of purchased goods.

4 Results

4.1 Overview

The annual carbon footprint of Booths and its product supply chains is estimated at 279,048 tonnes CO_2e. To put this into perspective, this equates to a best estimate of 1.0 kg of CO_2e per £ spent by customers on the products covered in this study.

The product-related component of the footprint- that which is directly dependent on sales and includes the footprint of primary production, processing, transport, packaging and distribution- is responsible for 232,801 tonnes CO_2e, 83% of the total footprint.

We estimate the footprint of operations including electricity and gas consumed in buildings, the procurement of goods and services not for re-sale, staff travel and refrigerant gas leaks, to be 46,248 tonnes CO_2e, approximately 17% of the total footprint.

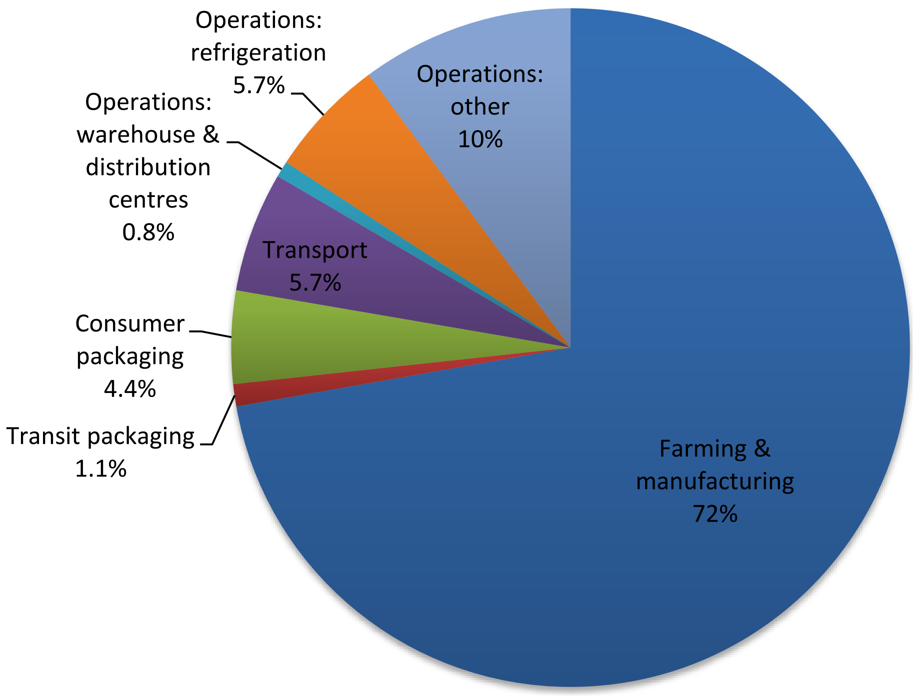


Figure 6: Total footprint of Booths products and supply chains 279,048 tonnes CO_2e.

4.2 Breakdown of the footprint

The largest components of the footprint are as follows.

4.2.1 Farming and manufacturing

201,531 tonnes CO_2e; 72% of Booths total footprint

Along with carbon dioxide, nitrous oxide resulting from the application of fertiliser and methane from ruminant animals are important contributors to agricultural GHG emissions. Animal products tend to have higher associated emissions per unit weight than vegetable-based alternative foods, largely due to the inefficiencies incurred by drawing human nutrition from a higher level in the food chain.

Agricultural footprints also tend to be dramatically higher where products are grown in artificially heated conditions.

Organic farming can sometimes have a lower footprint than standard production methods but this is not necessarily the case if yields are lower per unit of farm energy required. This study does not specifically explore the differences between organic and conventional production.

In this report we amalgamate the farming and manufacturing processes, since many of our sources aggregate these processes. However, in the 2009 report we estimated that food processing from ingredients accounted for approximately 3.8% of the total footprint and this is not thought to have changed dramatically since then. Emissions from the processing of foods can have the effect of reducing the need for processing in the home. Overall, therefore, this fairly small component of the Booths footprint does not stand out as a hot-spot for priority attention.

Manufacturing of non-food products represents approximately 8% (16,667 tonnes) of all farming and manufacturing in Booths product supply chains.

4.2.2 Transport

15,865 tonnes CO_2e; 5.7% of Booths total footprint

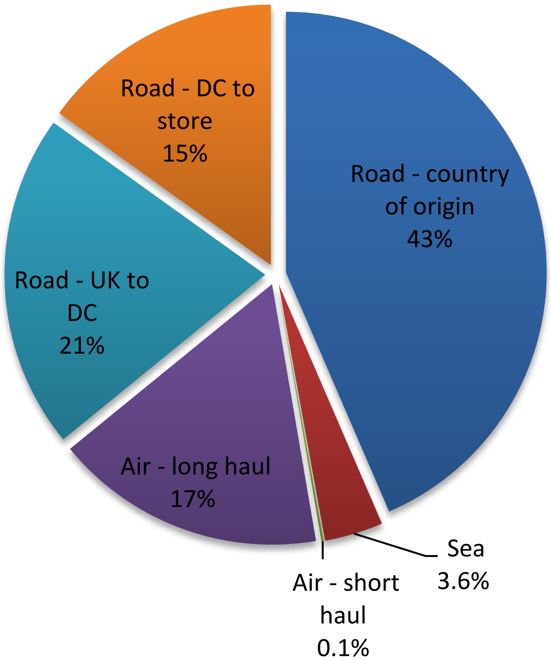


Figure 7: Transport 15,865 tonnes CO2e, 5.7% of the total footprint

Our estimate of transport emissions is significantly lower than our estimate in 2011. This is mainly due to a methodological change but also partly because over the last two years Booths has continued to reduce its air freight and increase its local sourcing.

Examples of steps taken to reduce transport emissions include:

- strong promotion of seasonal, UK and regional fruit and vegetables;
- dramatic reduction in air freight of Californian cherries, replaced by sea freight from other locations including the UK and Europe;
- stretching the UK asparagus season, reducing the need for air freight from Peru;
- increase in local sourcing of UK products, including onions and salads.

A further helpful factor in minimising transport emissions is Booths' practice of processing its prepared fruit in the UK rather than overseas. This allows the transport to be by boat and sea rather than by air.

Road transport accounts for just 4.5% of Booths' total footprint, and the majority of this is attributable to overseas transport of imported goods. As well as Booths policy of stocking a high proportion of UK and regional produce, there is efficiency in having all its stores fairly close to the single distribution centre. In the last two years, efficiency improvements have led to a reduction in Booths delivery miles and emissions, despite opening new stores, growing sales and taking on third party deliveries for the first time. Measures taken include efficient double decker vehicles, back hauling, training in efficient driving techniques and improved delivery logistics. In the coming year, further transport efficiencies are planned following the acquisition of Sharrocks, the fresh fruit and vegetables supplier.

Although most of Booths product categories are free from air-freight, the little there is in its supply chains has a dramatic impact, accounting for nearly 17% of all transport emissions (0.9% of Booths' total footprint).

The majority of this results from the importing of exotic vegetables, some exotic fruit and flowers, and fresh tuna from the Maldives and Sri Lanka.

Shipping turns out to be only of limited significance (3.6% of the transport footprint but just 0.3% of Booths' total footprint), even though it accounts for the majority of food miles. Provided air freight is avoided, it is generally more important that products are grown in an appropriate climate than that they are grown in the UK. The 'food mile' is therefore an inadequate measure of environmental impact. The government's *Food 2030* report also makes this point clearly (Defra, 2010).

4.2.3 Packaging

15,300 tonnes CO_2e; 5.5% of Booths' total footprint

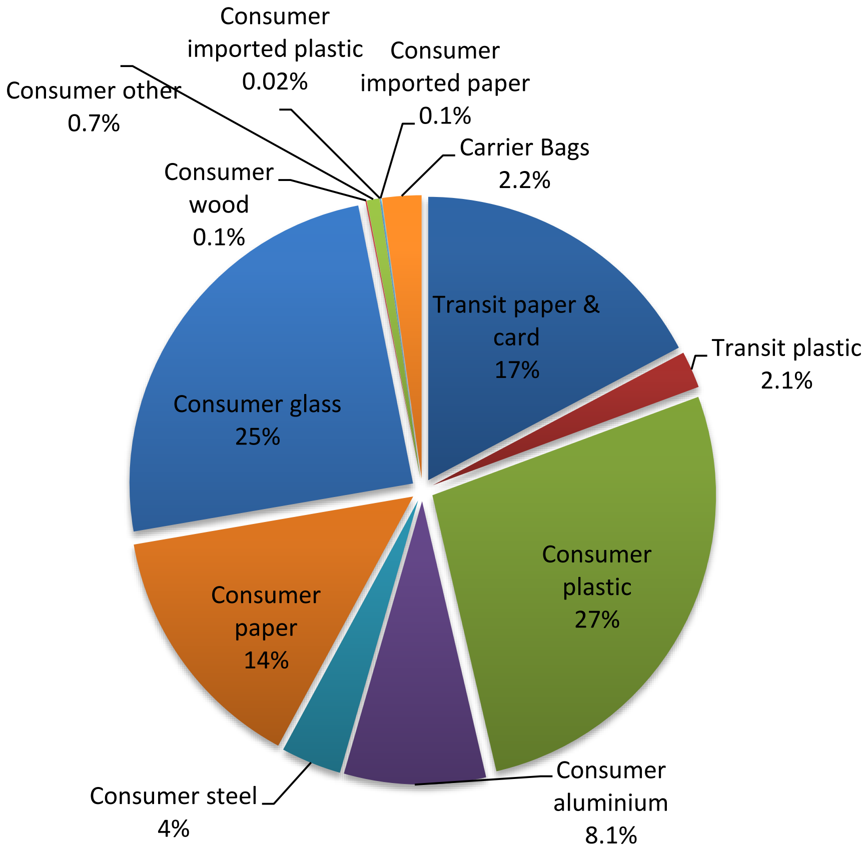


Figure 8: Packaging, 15291 tonnes CO2e, 5.5% of the total footprint

Encouragingly, the footprint of packaging at Booths is 6.6% lower than in 2011 despite growth in sales.

The majority of the packaging footprint results from consumer packaging (11,996 tonnes CO_2e; 79%) with plastic and glass being the greatest contributors (27% and 25% respectively). 2,961 tonnes CO_2e (19%) result from transit packaging. Carrier bags contribute only 2.2% (reduced from 2.4% in 2011) of the packaging footprint (342 tonnes CO_2e) and despite their high profile as an environmental issue, account for less than 0.2% of Booths' total footprint.

Booths has been seeking to minimise its own label packaging.

4.2.4 Operations

44,978 tonnes CO_2e; 16% of total footprint

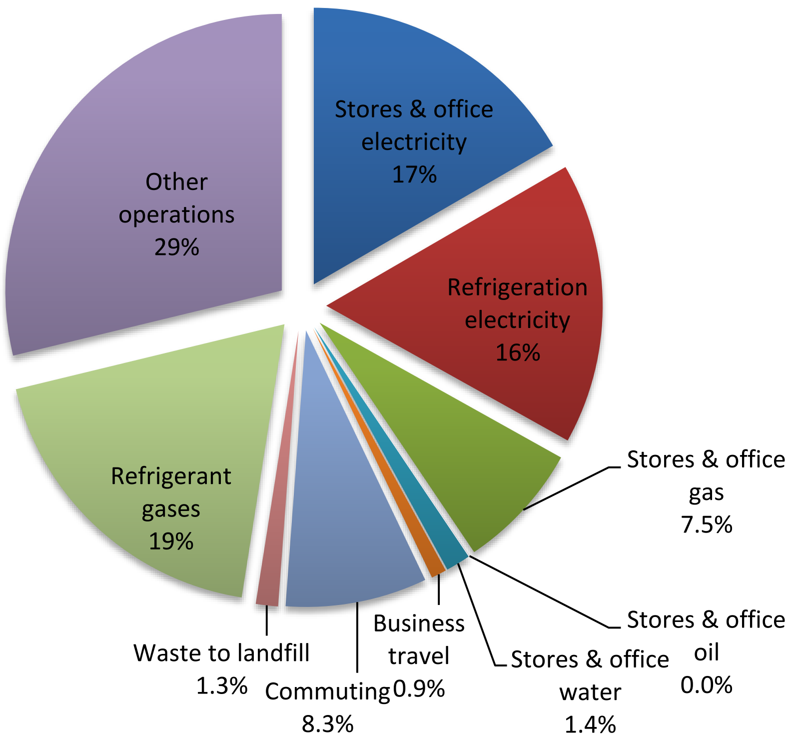


Figure 9: Overhead, 44,978 tonnes CO2e, 15.8% of the total footprint

As in previous assessments, the operational footprint consists mainly of energy consumption within buildings (including electricity for refrigeration). Since 2011, 92% of the oil heating at Booths has been replaced by gas and electricity powered systems. The carbon intensity of UK grid electricity has also fallen. These two factors have led to an overall 8% decrease (approximately 1,600 tonnes CO_2e) in the footprint of energy consumption at Booths. Replacement of oil and opening of new stores is thought to be the primary reason for the 10% increase in electricity consumption and 11% increase in gas use. Going forwards, the recent installation of a large solar panel array at Bluebell Way should help to reduce net electricity consumption.

Recent and ongoing actions to reduce energy consumption are expected to produce marked efficiency improvements over the next one or two years. Actions include:

- fitting voltage optimisation systems;
- fitting doors to fridges in more stores;
- installing heat recovery systems in new stores;
- fitting air sources heap pumps in some new stores;
- increasing use of LED lighting.

Refrigerant gas leaks account for 8,430 tonnes CO_2e; 19% of the overhead and 3.0% of the total footprint. Refrigeration in total (electricity and gas leaks together) has risen to from 31% to 35% of the overhead and from 5.4% to 5.7% of Booths' total footprint. The 46% increase in gas leaks since 2011 is thought to reflect aging equipment in a small number of stores having become prone to serious leakage. This problem is now being resolved. All new refrigeration systems are expected to be CO_2 based, eliminating the need for more intense greenhouse gases.

Based on an average weekly commute of approximately 56 miles, the footprint of commuting is thought to result in approximately 3,723 tonnes CO_2e (8% of the overhead and 1% of the overall footprint). This has reduced by 39% since 2011 due to a combination of a different method of estimating the miles travelled and an improvement in the efficiency of cars. Whilst the costs of commuting do not fall directly on Booths they affect the prosperity of staff. The footprint could potentially be reduced through such measures as encouraging lift shares (also potentially good for staff communication and relationships), and cycling and walking to work (which also have health benefits). Changes here also stand to send a cultural message.

Business travel is only a small contributor to the overhead footprint (0.9%).

The footprint of waste to landfill is small (584 tonnes CO_2e; 1.3% of the overhead footprint), and this can be attributed to Booths' good practice of recycling the vast majority of its waste. Booths is seeking to reduce waste to landfill as far as is practically possible.

Whilst the impact of consumer waste is outside the scope of this analysis, Booths has encouraged reductions through such initiatives as Shop Smart (helping customers to buy only what they need), making it easy for customers to buy small portions at counters, selling loose fruit and vegetables (which enables customers to buy exactly what they need), and brochures which encourage meals from leftovers.

4.2.5 Storage, packing and processing at distribution centres

2,125 tonnes CO_2e; 0.8% of total footprint

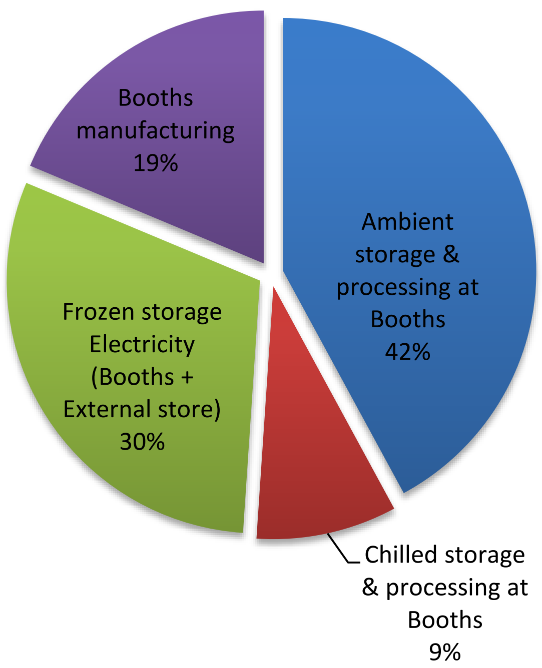


Figure 10: Breakdown of distribution centre footprint: 2,125 tonnes CO2e, 0.8% of the total footprint

4.3 Analysis by 10 broad product categories

The 77 product categories have been grouped into 10 broader categories that share similar characteristics, both as products and in terms of their footprint.

Figure 11 presents each of the 10 product categories in terms of its footprint as a proportion of the overall product footprint and as a proportion of total sales from those products at retail.

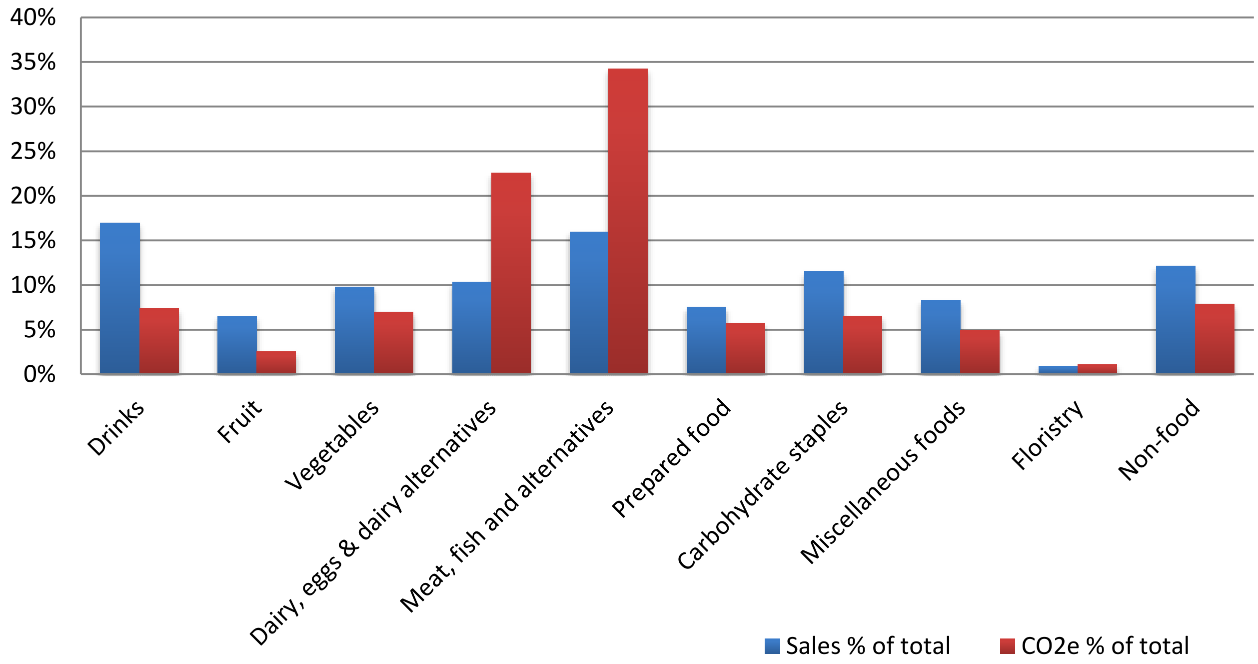
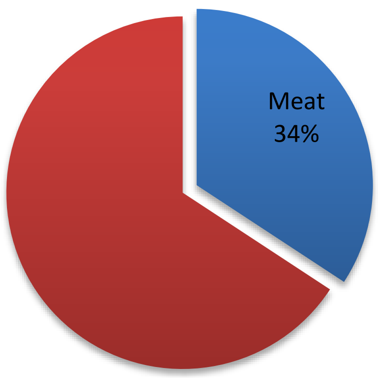


Figure 11: Footprint and sales for product categories as a proportion of the total

4.3.1 Meat, fish and meat alternatives



This is the product group with the highest footprint.

Pre-farm-gate emissions make up 88%. Three greenhouse gases are important: methane emissions from ruminant animals but also from slurry, nitrous oxide resulting mainly from fertiliser use and carbon dioxide emissions from energy use.

Refrigeration by Booths contributes only 4.3%, although the vast majority of this category is chilled.

Transport contributes only 1.5%, helped by Booths' sourcing of all beef, lamb and poultry from the UK.

While all the meat categories have relatively high carbon intensity per £ and per kg, there are important differences between the meats. Beef and lamb (the ruminants) appear as the most carbon-intensive meats per kilogram, followed by bacon, with poultry and most fish at the lower end of the spectrum.

Sourcing the majority of meats and all beef and lamb from the UK is advantageous in reducing transport emissions but much more importantly by reducing potential emissions from changes in land use (deforestation) that results from some overseas production.

Further carbon saving would arise if the profile of sales were to shift further away from ruminant animals to poultry, fish (provided stocks are not threatened) and vegetarian options. There may be scope for beef and lamb to become higher premium products without any threat to Booths overall sales or to UK farmers.

All Booths fish complies with Marine Conservation Society guidelines. Booths scallops are hand-dived rather than dredged. However, fresh tuna is currently air freighted from the Maldives and Sri Lanka.

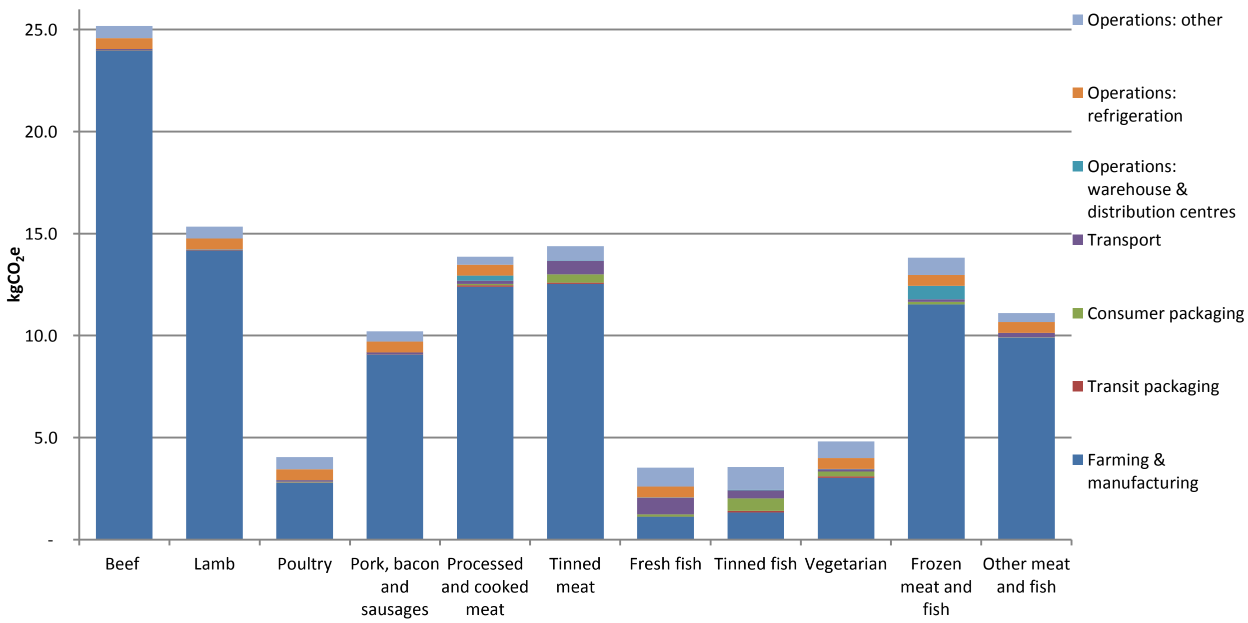
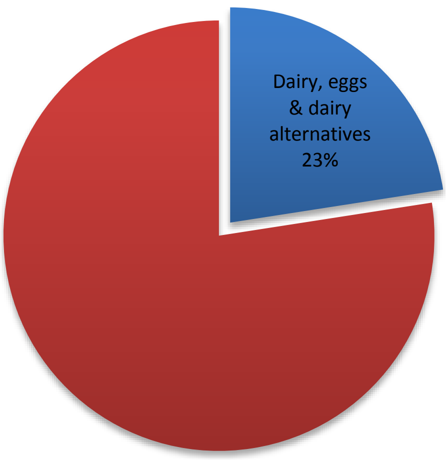


Figure 12: Breakdown of meat by product type and life-cycle stage per kg of product

4.3.2 Dairy, eggs and dairy alternatives



This category is roughly as carbon-intensive as meat, incurring the same inefficiencies of deriving food from higher up the food chain than plant-based foods.

Milk, being bulky, incurs relatively high transport emissions per mile and the practice of sourcing a high proportion locally is helpful.

It is generally helpful (in both carbon and health terms) if alternatives to meat are not too high in cheese content and made as attractive to customers as possible.

Booths offers a popular and wide range of milk alternatives.

Since the 2011 report Booths has launched the Fair Milk scheme which guarantees farmers the highest price offered by any UK supermarket. Recently we have begun engaging with the farmers involved to explore how this can be combined with practical advice and research on sustainable farming practices.

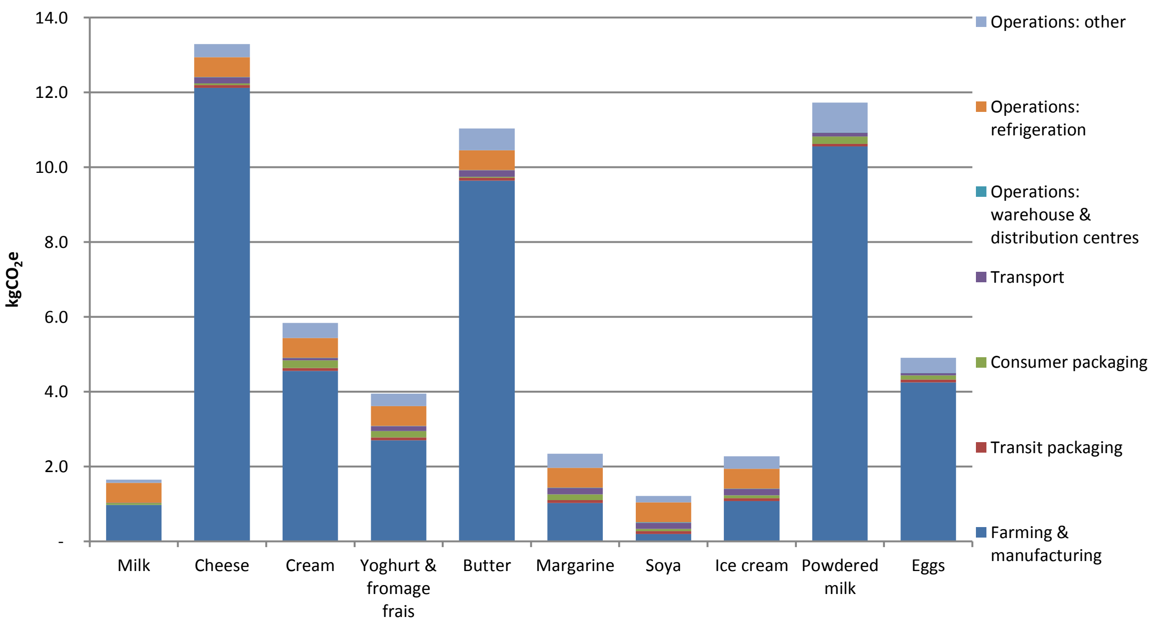
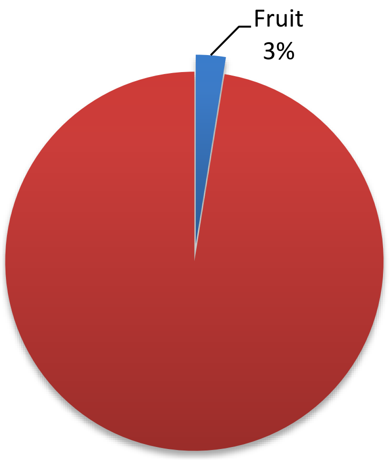


Figure 13: Breakdown of dairy product type and life-cycle stage per kg of product

4.3.3 Fruit



While only a small contributor to the overall footprint, it is worth noting that the carbon intensity of fruits can be relatively high and there are dramatic differences between product categories.

Farming and manufacturing is the biggest component overall (38%). Hot housing to produce fruits and berries out of season is carbon intensive. Tinned and frozen fruit incur additional processing and packaging emissions. Dried fruit, nuts and seeds are carbon intensive per kg but have a high nutritional content for their weight.

Transport makes up 29% of emissions, most of which result from the small proportion of fruit that travels by air; only a very small proportion of Booths fruit is air freighted.

The recent emphasis on local, seasonal produce is helpful in reducing emissions. Outside the UK season, shipped produce and even frozen and tinned fruit are generally a big improvement on air freight or hot housing.

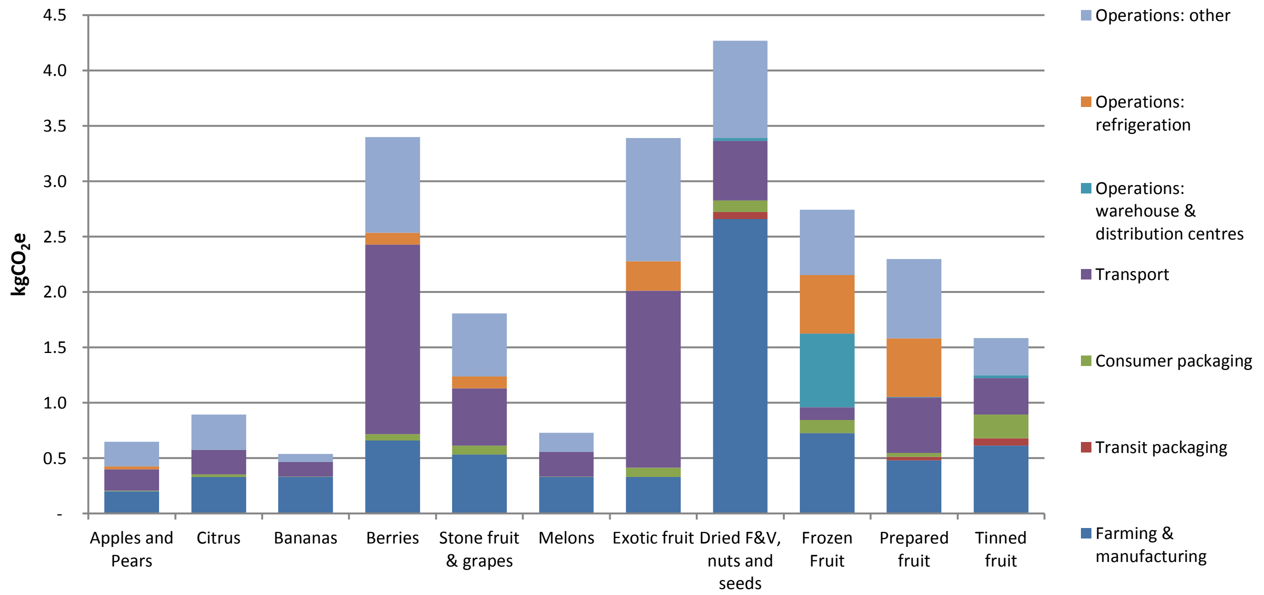
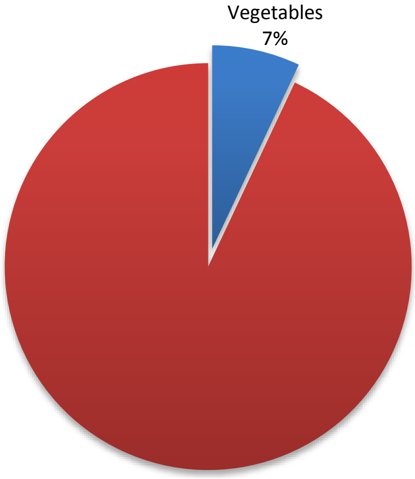


Figure 14: Breakdown of fruits by product type and life-cycle stage per kg of product

4.3.4 Vegetables



The main messages for vegetables are similar to those for fruits and there are clear differences in the carbon intensity of different products.

Overall the footprint of farming and manufacturing is the greatest component of the footprint in this category (46%). This is particularly the case for products that are grown out-of-season and artificially heated.

Transport is another key contributor to the footprint of vegetables (16%). Booths' policies of promoting seasonal and regional produce, combined with the efficiency of having all its stores fairly close to distribution centres, helps to reduce the footprint. However the small proportion of vegetable produce that is air freighted has a significant impact.

Success stories include:

- increased promotion of seasonal and local produce;
- increased local sourcing of onions and salads.

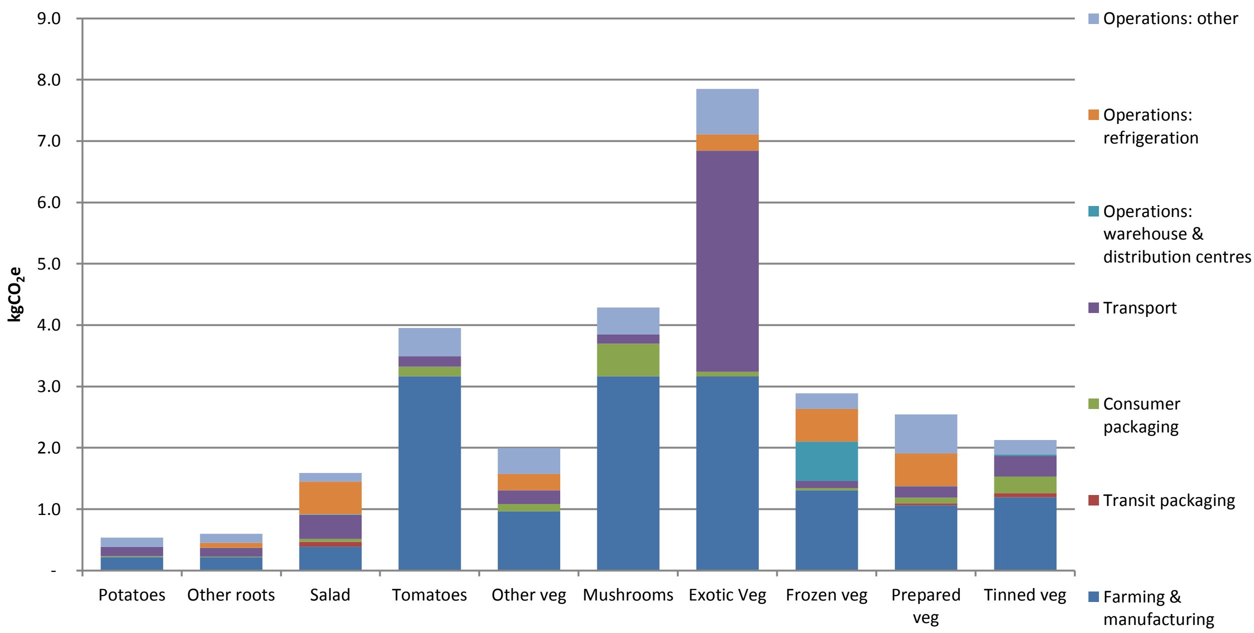
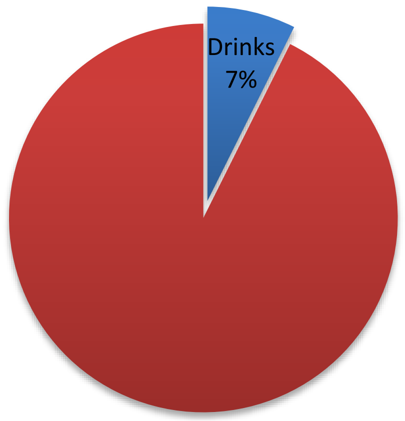


Figure 15: Breakdown of vegetables by product type and life-cycle stage per kg of product

4.3.5 Drinks



This section includes both alcoholic and soft drinks, which, broadly speaking, have similar carbon characteristics. Overall this category offers fairly low carbon per £ sales, partly accounted for by tax on alcohol.

On average, drinks result in approximately 1.4 kg CO_2e per litre of product although there are substantial variations. Spirits and liqueurs and wines are more GHG intensive (3.0 and 2.1 kg CO_2e per litre respectively) than bottled water and soft drinks (0.6 and 0.9 kg CO_2e per litre respectively) but less so per £ of retail value.

Consumer packaging is a key contributor to the footprint of drinks (28%), particularly glass.

Farming and manufacturing makes up just 19% of the overall footprint of drinks. This is highest for wines and juice which incur the footprint of fruit production.

Transport impacts are relatively high (21% of the carbon footprint of drinks), since the products are bulky and while most are shipped from overseas, the road miles incurred in the country of origin are often high.

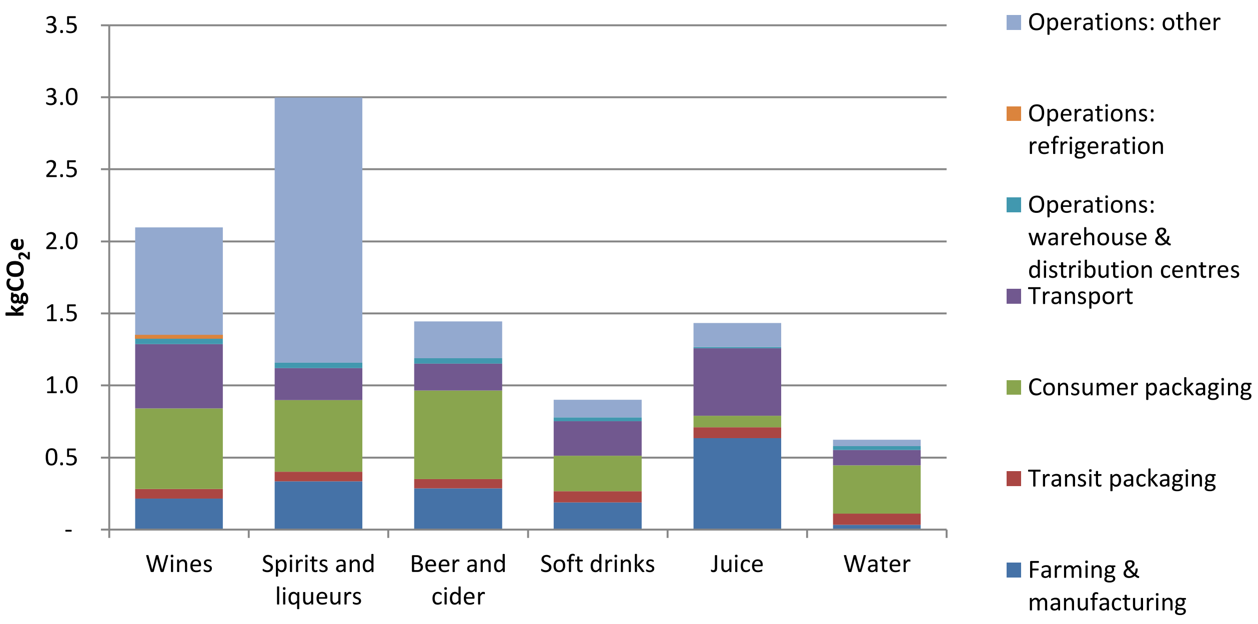
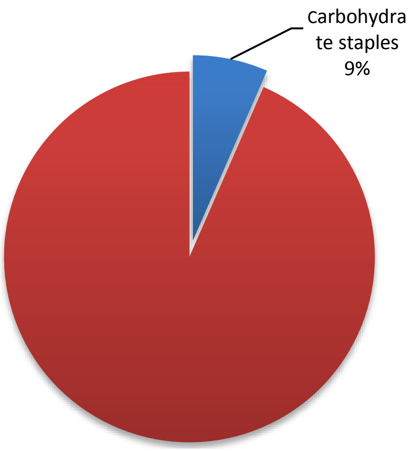


Figure 16: Breakdown of drinks by product type and life-cycle stage per litre

4.3.6 Carbohydrate staples



All carbohydrate staples form a relatively low-carbon part of a healthy diet.

It is important with short shelf-life products, such as bread and some cakes, to ensure that they are not wasted in the store or the home. The recent waste reduction project at Booths has been helpful in this regard.

Rice is significantly more carbon intensive than wheat, cereals, bread and pasta. Globally, rice production accounts for around 2% of anthropogenic greenhouse gas emissions, much of which is caused by excessive use of fertilizer and avoidable flooding of paddy fields. Over the coming year Booths will be exploring opportunities to source a more sustainable rice product.

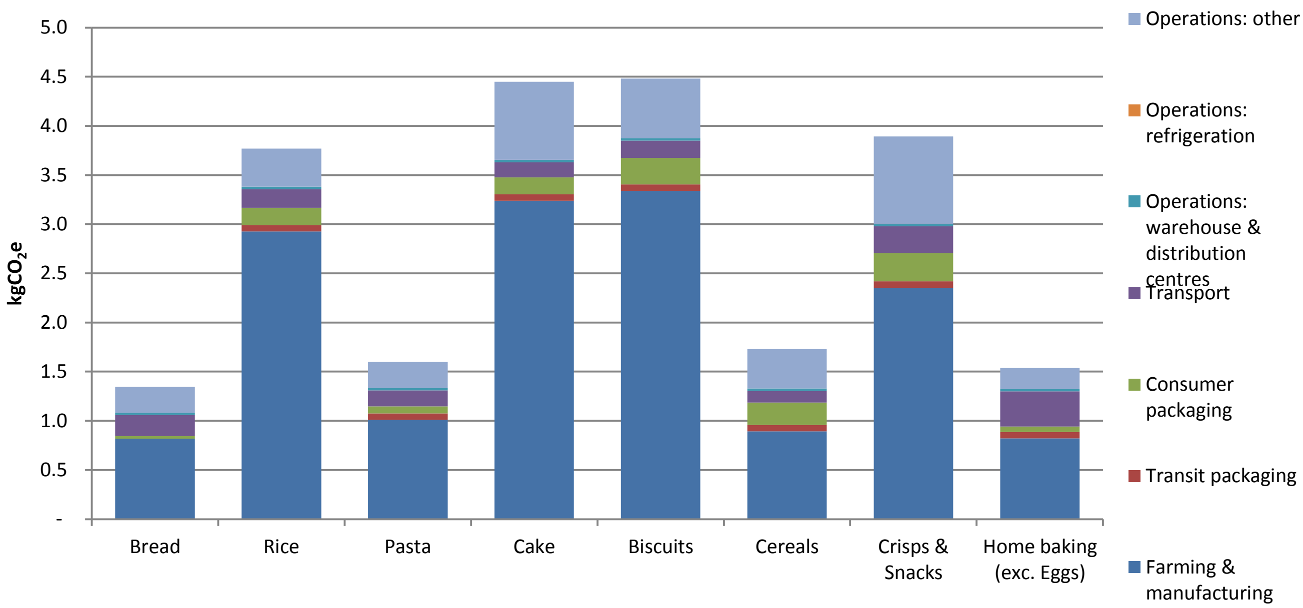
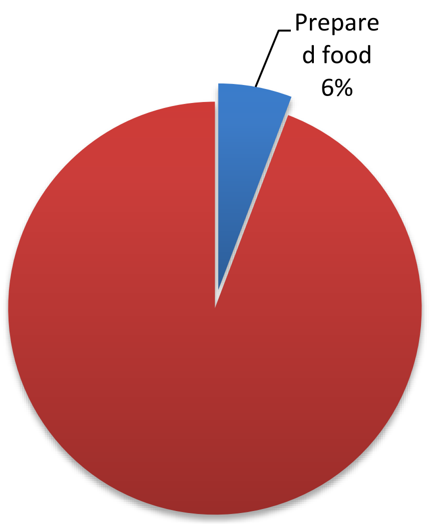


Figure 17: Breakdown of carbohydrate staples by product type and life-cycle stage per kg of product

4.3.7 Prepared foods



This is a varied and complex category, with each product being made up of a number of ingredients which are then processed and packaged. In theory at least, processing food in the factory rather than in the home can be carbon efficient, provided undue waste is not incurred.

As with bread, a major issue is the wastage of short shelf-life products in the store and at home. Booths' waste reduction project has been helpful here. Responsible promotion of perishable foods avoids encouraging people to buy more than they can eat within the shelf-life.

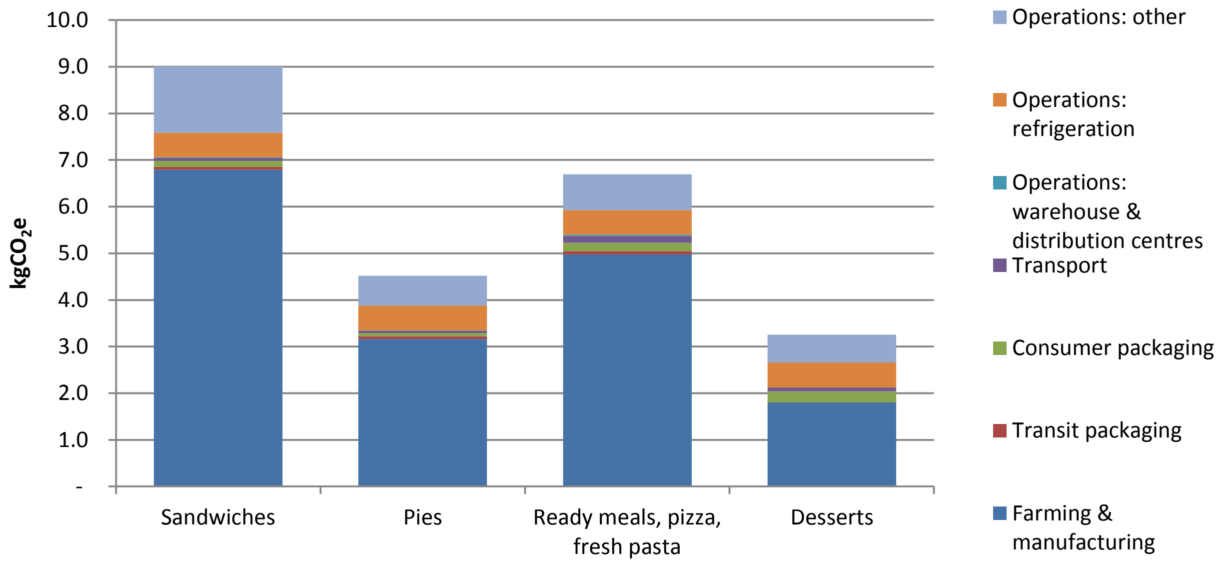
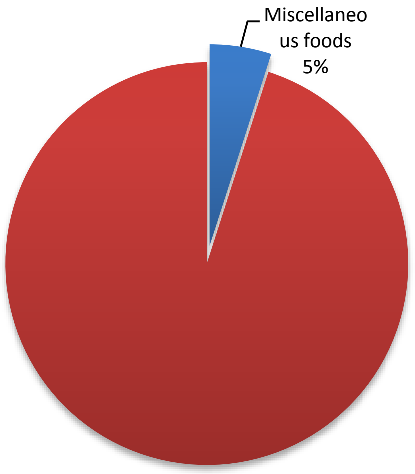


Figure 18: Breakdown of prepared foods by product type and life-cycle stage per kg of product

4.3.8 Miscellaneous foods



This category is a catch-all for all foods not covered elsewhere, most of which are non-perishable.

Beverages are high carbon per kg but are used in small quantities. ‘Fair Trade’ is well established in this category and expected by many.

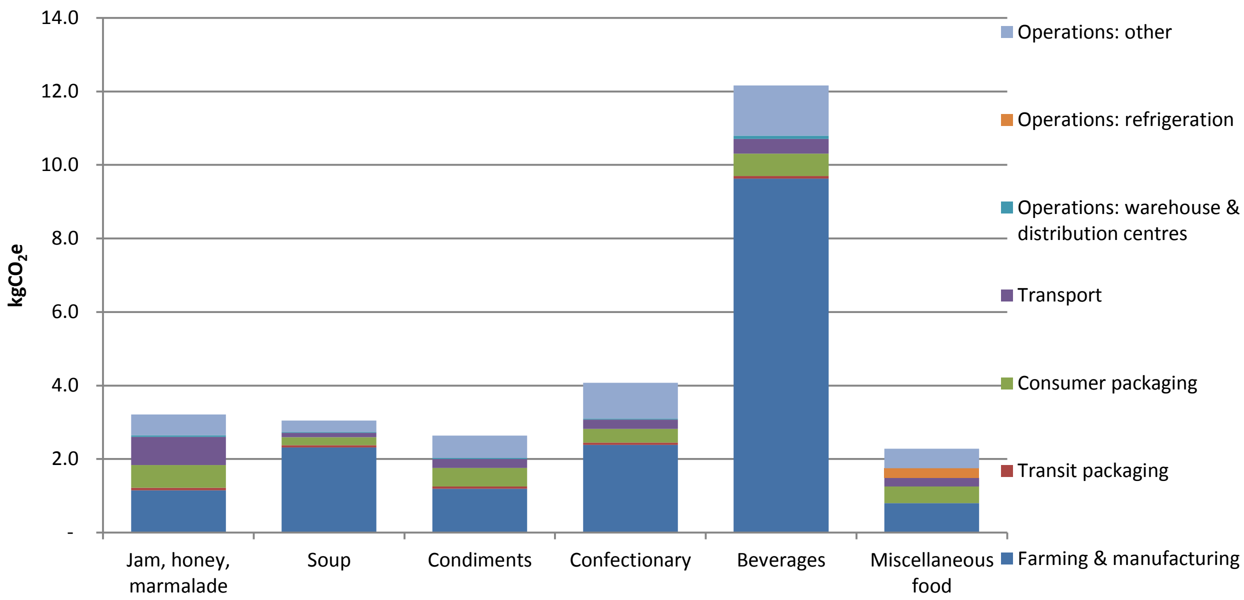
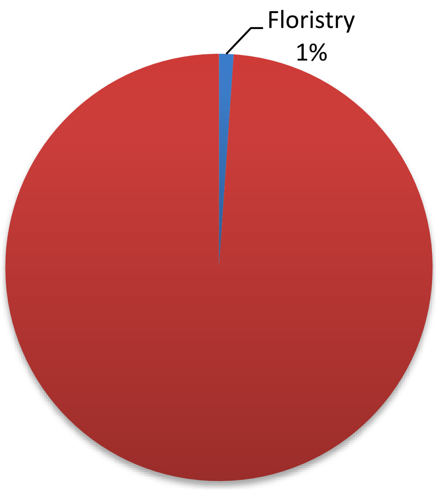


Figure 19: Breakdown of miscellaneous foods by product type and life-cycle stage per kg of product

4.3.9 Floristry



This category contains a few very carbon-intensive products although local flowers in season can be very low carbon.

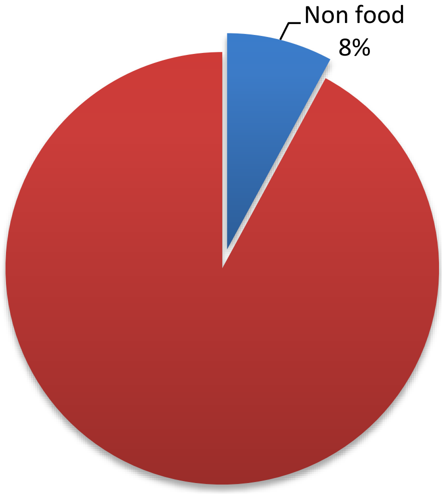
Out of season flowers are almost always highly carbon intensive, requiring either air freight from a hot climate or energy intensive hot housing.

Many flowers are grown in developing countries and workers' rights are often not respected. There is currently no ethical trade labelling for flowers and it is difficult to ensure ethical sourcing.

In the context of the global food challenge, a third consideration for this product category is that land used for flower production contributes to meeting neither the world's nutritional nor its energy needs. Flowers are inherently a luxury item.

Booths has been exploring potential opportunities to support the resurgence of a local seasonal flowers industry. The biggest barrier to overcome is the need for growers to have advanced commitment from buyers. Quality is high and price and quality both seem realistic.

4.3.10 Non-food



Our analysis of these diverse categories was fairly generic.

This category contains items such as storage containers, which can help customers to reduce their food waste. Booths is looking at opportunities to develop this range. This is an important area, given the scale of household waste in the developed world.

(Note that Figure 20 shows the carbon intensity per £ rather than per kg since this is more meaningful in this product group.)

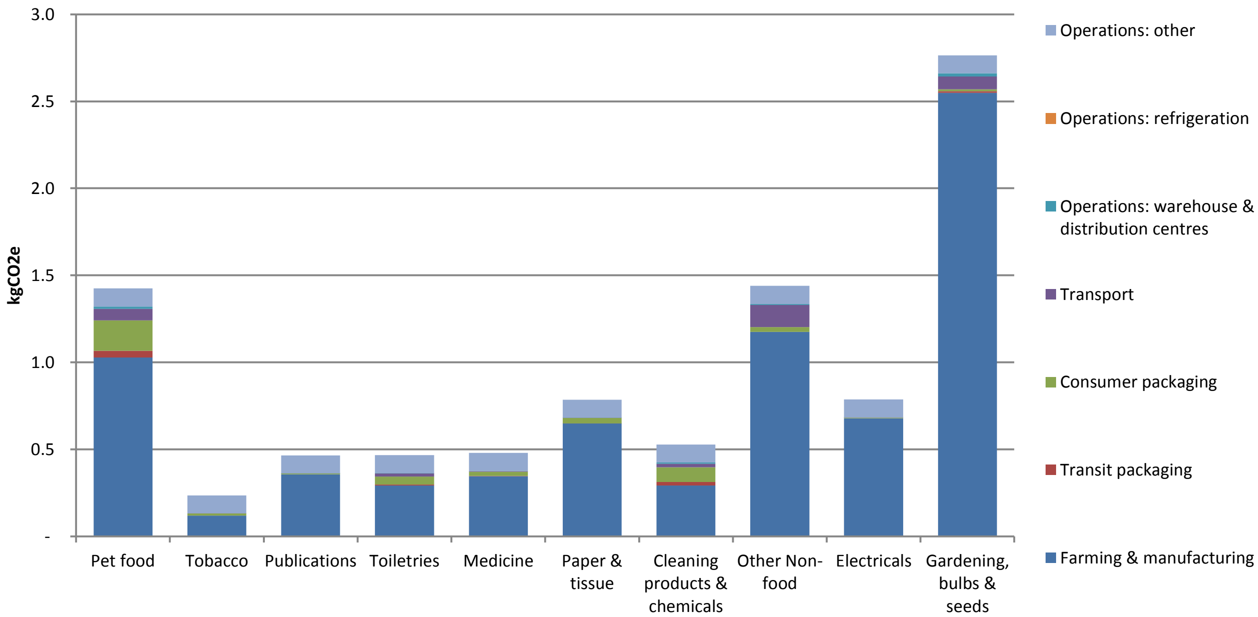


Figure 20: Breakdown of non-food products by product type and life-cycle stage per £

4.4 Analysis by 77 product categories

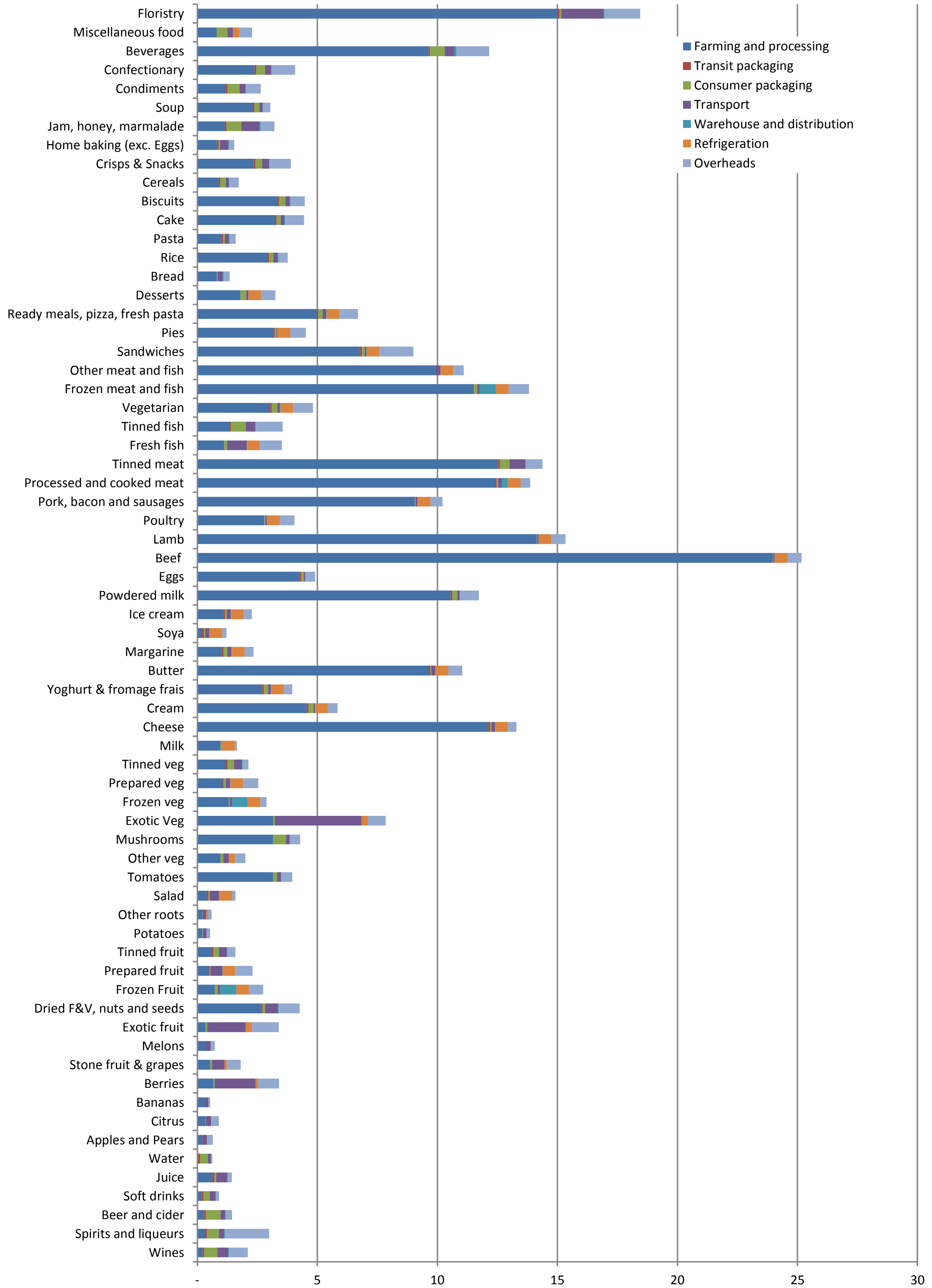


Figure 21: Comparison of kg CO_2e per kg of products (food products and floristry only)

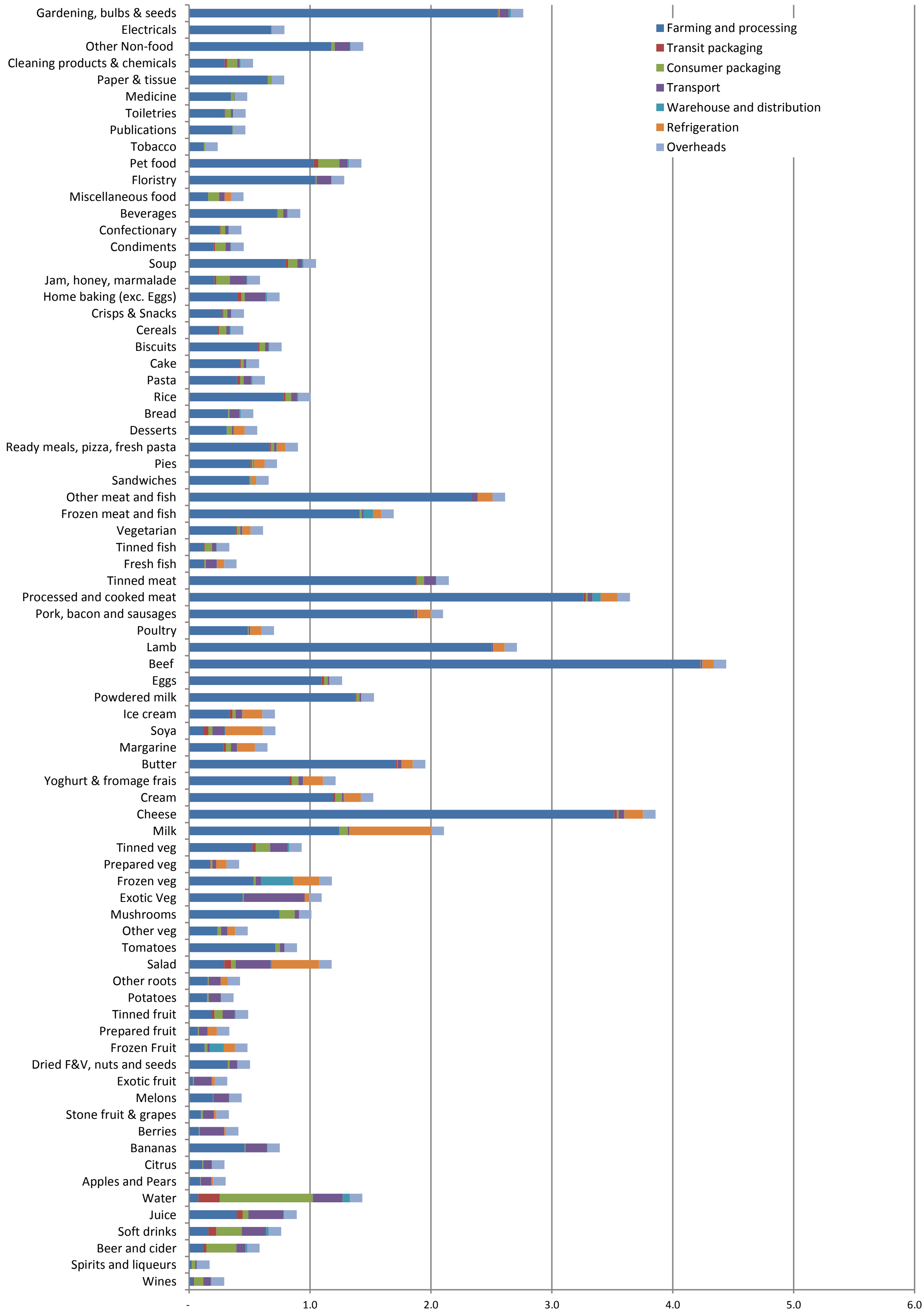


Figure 22: Comparison of kg CO2e per £ of products

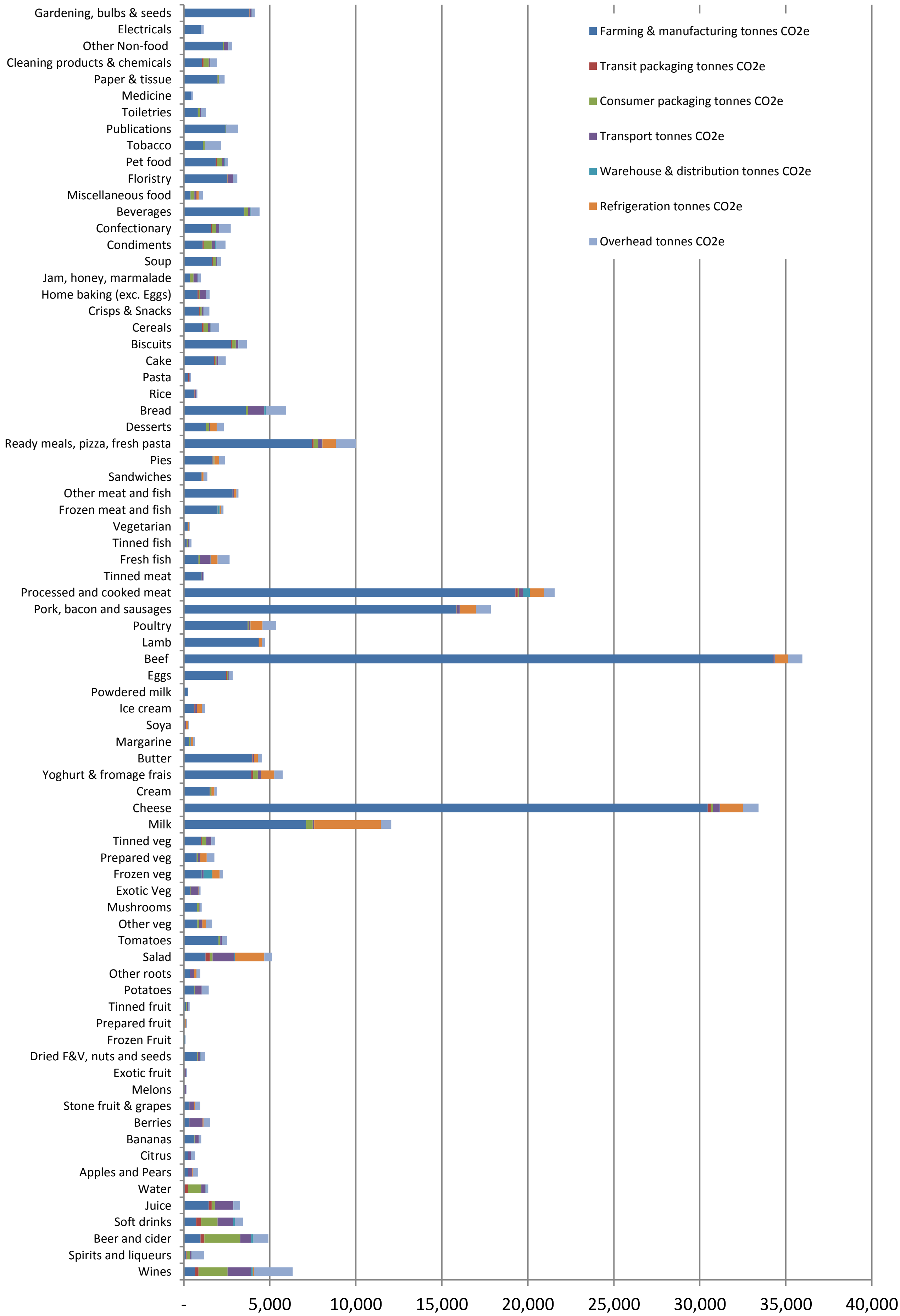


Figure 23: Comparison of total tonnes CO2e of products

Figures 21 and 22 show the footprint of each product category per kg and per £ respectively with a breakdown into components: primary production (up to the farm-gate), processing (from ingredients to final product, excluding processing by Booths), packaging, transport, storage and processing.

- The graphs illustrate the dominance of agricultural emissions in most categories, especially for meat and dairy and, where artificial heat is required, some fruit, vegetables and flowers.
- Transport is a major component in just a few categories: where there is either air-freight or long road haulage of heavy products such as drinks.
- Packaging can be seen as a key carbon issue in a few categories, particularly drinks and other bottled products.
- Refrigeration is significant in some categories but never more than 10% of a category's footprint.

Figure 23 shows the total emissions from each category. The top 5 contributors to the total footprint are:

- Beef;
- Cheese;
- Processed and cooked meats;
- Pork, bacon and sausages;
- Milk.

These 5 categories account for over a third (43%) of the total footprint.

5 Understanding changes in Booths' GHG footprint between 2012 and 2014.

Our estimate of Booths' total emissions has risen by 23,561 tonnes CO_2e between the 2011-12 and 2013-14 reports. The difference results from methodological changes as well as changes in activities at Booths and its supply chains.

When methodological changes are taken out of the picture, the underlying change is a 2% rise in emissions, despite a 4% rise in sales and the opening of a new store. Emissions per £ have fallen by 2%.

There have been significant efficiency improvements in energy use and distribution. Going forwards, the solar panel array at the Blue Bell Way Warehouse should reduce the Booths footprint further. Continuing emphasis on local fruit and vegetables almost certainly has a positive effect on supply chain emissions. Initiatives to reduce waste in stores were largely in place for the year 2011-12. More recent actions which are likely to reduce consumer waste are not reflected in this analysis. However an increase in refrigerant gas leaks from ageing equipment in a small number of stores have partially offset these gains, adding around 1% to Booths' total footprint.

The main methodological changes are as follows:

1. Booths has made changes to how it classifies some of its food categories (for example "Cabinets Raw – Game" has been reclassified by Booths as "Cabinets Poultry and Game – Game").
2. We have come to a better understanding of what is included in some of Booths' categories in cases where the data had been confusing and "#Multivalue" tags had hidden the true identity of a product.
3. We have corrected some order of magnitude errors in Booths' weights data (for example many items within home baking had been recorded as being sold in quantities of 1000kg rather than 1kg).
4. We have attempted to improve our understanding of the weight of products for which there was little or no data, by either extrapolation from known weights within the category or researching typical weights of products from other supermarkets (for example, data from other supermarkets has been used to estimate the weight of many salad products and the known weights within the "Counter savoury – salads and olives" category were extrapolated to estimate the unknown weights within the category).

The overall effect of improved understanding of the weights of different foods sold has been picture of a somewhat carbon intensive product mix.

6 Appendix A: Emissions factors

This appendix details the emissions factors used and their sources. We have included a brief review of the existing literature highlighting issues, assumptions and uncertainties relevant to this project.

6.1 Food product life-cycle analysis overview

6.1.1 Process

A review of a range of products was undertaken using the *Food Climate Research Network*, *Google Scholar*, and *Science Direct* and the most recent available sources analysed. The emissions factors (EF) used in this report reflect the latest findings of research in carbon footprint analysis from both academic and other reputable sources. The specific LCAs used were selected on the basis of credibility, consistency of method and closeness of the supply chains studied to those adopted by the case-study supermarket itself.

In some cases this has meant retiring EFs used in previous years where sensible assumptions were thought to provide a better representation of the emissions resulting from the cultivation and processing from products.

6.1.2 Boundaries and functional units

Similar reviews have been attempted before, the most commonly cited being a Swedish study by Wallén *et al*[17]. However this report improves on these by accounting for the variations in system boundaries and reporting principles of different LCA. **Wherever possible secondary data has been used to calculate the GHG emissions per unit weight of product up to and including the primary processing stage**. In most cases this equates to cradle to regional distribution centre (RDC) minus transport to the RDC and packaging for which we have bespoke data from Booths. In a few cases it was not possible to separate out the transport to the regional distribution centre (RDC) and packaging. In these instances we have deducted our estimate of the contribution from packaging and transport emissions that we derived from the Booths data in order to obtain an emissions factor for the finished, unpackaged product at the farm-gate (FG) or factory gate. In this way we eliminated double counting whilst making full use of the most accurate and bespoke data available for each life cycle stage.

6.1.3 Summary

The following table provides a summary of the product categories along with the breakdown by life cycle stage, the boundaries of the original source and the EF used.

[17] Wallén *et al*., 2004.

					EF (kg CO_2e/kg)						
Category	Source	Total EF **within study boundary (kg CO_2e/kg)**	Boundary of study	Does the source enable cradle - primary processing to be distinguished?	**Cradle to FG**	Transport: FG to processing plant	Processing	Packaging	Transport: Processing plant to retail	Storage	**Cradle to primary processed used in the Booths model**
Dairy											
Cheese	FAO (2010)	12.26	Cradle - FG, FG - retail	Yes	11.24	0.11	0.57	0.25	0.09		**11.81**
Milk powder	FAO (2010)	10.75	Cradle - FG, FG - retail	Yes	9.62	0.12	0.63	0.28	0.10		**10.25**
Fermented milk	FAO (2010)	3.31	Cradle - FG, FG - retail	Yes	2.71	0.06	0.33	0.15	0.05		**3.05**
Fresh milk	FAO (2010)	1.00	Cradle - FG, FG - retail	Yes	0.90	0.01	0.06	0.02	0.01		**0.96**
Cream	FAO (2010)	4.69	Cradle - FG, FG - retail	Yes	4.22	0.05	0.27	0.12	0.04		**4.48**
Butter	Nilsson *et al.*, (2010)	9.6	Cradle to RDC	No	-	-	-	-	-	-	**9.60**
Eggs	Williams *et al.*, (2006)	4.25	cradle to FG	Yes	-	-	-	-	-	-	**4.25**
Margarine	Nilsson *et al.*, (2010)	1.1	cradle to RDC	No	-	-	-	-	-	-	**1.1**
Spreadable	Nilsson *et al.*, (2010)	7.4	cradle to RDC	No	-	-	-	-	-	-	**7.4**
Meat											
Poultry	Williams *et al.*, (2008)	2.82	cradle to RDC	Yes*	2.53	-	0.25	-	-	-	**2.82**
Poultry - Brazil	Williams *et al.*, (2008)	3.05	cradle to RDC	Yes*	2.57	-	0.10	-	-	-	**3.05**
Beef	Williams *et al.*, (2008)	23.97	cradle to RDC	Yes*	23.78	-	0.11	-	-	-	**23.97**
Beef - Brazil	Williams *et al.*, (2008)	32.15	cradle to RDC	Yes*	31.69	-	0.07	-	-	-	**32.15**
Lamb	Williams *et al.*, (2008)	14.14	cradle to RDC	Yes*	13.45	-	0.64	-	-	-	**14.14**
Lamb - NZ	Williams *et al.*, (2008)	11.56	cradle to RDC	Yes*	9.71	-	1.20	-	-	-	**11.56**
Pork	Williams *et al.*, (2006)	9.07	cradle to FG	Yes	-	-	0.11	-	-	-	**9.07**
Fish											
Fresh fish - Flat fish	Nielsen *et al.* , (2003)	3.30	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**3.30**
Fresh fish - Cod	Nielsen *et al.* , (2003)	1.20	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**1.20**
Fresh fish - Herring	Nielsen *et al.* , (2003)	0.63	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**0.58**
Fresh fish - Mackerel	Nielsen *et al.* , (2003)	0.22	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**0.17**
Fresh fish - Lobster	Nielsen *et al.* , (2003)	20.20	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**20.20**
Fresh fish - Shrimp	Nielsen *et al.* , (2003)	3.00	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**2.94**
Fresh fish - Mussels	Nielsen *et al.* , (2003)	0.09	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**0.04**
Frozen fish - Flat fish	Nielsen *et al.* , (2003)	7.80	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**7.50**
Frozen fish - Cod	Nielsen *et al.* , (2003)	3.20	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**2.80**
Frozen fish - Herring	Nielsen *et al.* , (2003)	1.80	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**1.40**
Frozen fish - Mackerel	Nielsen *et al.* , (2003)	0.96	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**0.62**
Frozen fish - Shrimp	Nielsen *et al.* , (2003)	10.50	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**1.01**
Prepared fish - Flat fish	Nielsen *et al.* , (2003)	7.40	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**7.40**
Prepared fish - Cod	Nielsen *et al.* , (2003)	2.80	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**2.70**
Prepared fish - herring	Nielsen *et al.* , (2003)	1.30	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**1.30**
Prepared fish - mackerel	Nielsen *et al.* , (2003)	0.51	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**0.46**
Fresh fish - farmed trout	Nielsen *et al.* , (2003)	-	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**1.80**
Frozen fish - farmed trout	Nielsen *et al.* , (2003)	4.47	ex. Harbour/ex. Retail	Yes	-	-	-	-	-	-	**4.09**
Fruit											
Apples - stored	Williams *et al.* (2008)	0.35	cradle to RDC	Yes	0.16	-	0.04	0.05	0.04	0.06	**0.26**
Apples - stored NZ	Williams *et al.* (2008)	0.86	cradle to RDC	Yes	0.08	-	0.03	0.08	0.62	0.05	**0.16**
Apples - fresh	Williams *et al.* (2008)	0.30	cradle to RDC	Yes	0.16	-	0.05	0.05	0.04	-	**0.21**
Apples - fresh NZ	Williams *et al.* (2008)	0.92	cradle to RDC	Yes	0.09	-	0.04	0.09	0.71	-	**0.13**
Apples	Williams *et al.* (2008)	0.33	cradle to RDC	Yes	0.16	-	0.04	0.05	0.04	0.03	**0.23**
Apples - NZ	Williams *et al.* (2008)	0.89	cradle to RDC	Yes	0.09	-	0.03	0.08	0.67	0.02	**0.14**

Oranges - organic	Ribal, *et al.*, (2009)	0.22	cradle to FG	Yes	-	-	-	-	-	-	**0.22**
Oranges	Ribal, *et al.*, (2009)	0.33	cradle to FG	Yes	-	-	-	-	-	-	**0.33**
Strawberries	Williams *et al*. (2008)	0.99	cradle to RDC	Yes	0.85	-	0.02	0.09	0.03	-	**0.87**
Strawberries -Spain	Williams *et al*. (2008)	1.03	cradle to RDC	Yes	0.47	-	-	0.40	0.10	0.05	**0.53**
Vegetables											
Green beans - Open field	Romero-Gámez *et al.*, (2011)	0.25	cradle to FG	Yes	0.25	-	-	-	-	-	**0.25**
Green beans - Screenhouse	Romero-Gámez *et al.*, (2011)	0.14	cradle to FG	Yes	0.14	-	-	-	-	-	**0.14**
Green beans - Screenhouse + Misting	Romero-Gámez *et al.*, (2011)	1.50	cradle to FG	Yes	1.50	-	-	-	-	-	**1.50**
Salad - British outdoors	Hospido *et al.*, (2009)	0.33	cradle to RDC	Yes*	0.27	-	-	-	-	-	**0.33**
Salad - British indoors	Hospido *et al.*, (2009)	0.24	cradle to RDC	Yes*	0.18	-	-	-	-	-	**0.24**
Salad - British heated indoors	Hospido *et al.*, (2009)	2.62	cradle to RDC	Yes*	2.55	-	-	-	-	-	**2.62**
Salad - Spanish	Hospido *et al.*, (2009)	0.45	cradle to RDC	Yes*	0.26	-	-	-	-	-	**0.45**
Potatoes - main crop	Williams *et al.*, (2008)	0.25	cradle to RDC	Yes*	0.11	-	0.03	-	-	0.08	**0.22**
Potatoes - main crop - Israel	Williams *et al.*, (2008)	0.48	cradle to RDC	Yes*	0.16	-	0.03	-	0.22	0.04	**0.26**
Potatoes - earlies	Williams *et al.*, (2008)	0.27	cradle to RDC	Yes*	0.19	-	0.04	-	-	-	**0.24**
Potatoes - earlies Israel	Williams *et al.*, (2008)	0.71	cradle to RDC	Yes*	0.39	-	0.03	-	0.22	0.04	**0.49**
Tomatoes- loose	Williams *et al.*, (2008)	2.24	cradle to RDC	Yes	2.11	-	0.02	0.09	0.02	-	**2.13**
Tomatoes- loose - Spain	Williams *et al.*, (2008)	0.76	cradle to RDC	Yes	0.27	-	0.01	0.12	0.33	-	**0.31**
Tomatoes loose - (UK summer/Sp winter)	Average calculated from Williams *et al.*, (2008)	1.50	cradle to RDC	Yes	1.19	-	0.02	0.11	0.17	-	**1.22**
Tomatoes - vine	Williams *et al.*, (2008)	5.12	cradle to RDC	Yes	4.99	-	0.02	0.08	0.03	-	**5.02**
Tomatoes - vine - Spain	Williams *et al.*, (2008)	1.05	cradle to RDC	No	0.62	-	-	-	-	-	**1.05**
Tomatoes vine - (UK summer/Sp winter)	Average calculated from Williams *et al.*, (2008)	3.09	cradle to RDC	Yes	2.81	-	0.01	0.04	0.01	-	**3.03**
Tomatoes - baby plum	Williams *et al.*, (2008)	5.86	cradle to RDC	No	5.73	-	-	-	-	-	**5.86**
Tomatoes - baby plum - Spain	Williams *et al.*, (2008)	3.11	cradle to RDC	No	2.64	-	-	-	-	-	**3.11**
Tomatoes baby plum - (UK summer/Sp winter)	Average calculated from Williams *et al.*, (2008)	4.49	cradle to RDC	No	4.19	-	-	-	-	-	**4.49**
Tomatoes baby plum on vine - (UK summer/Sp winter)	Average calculated from Williams *et al.*, (2008)	3.41	cradle to RDC	No	3.41	-	-	-	-	-	**3.41**
Drinks											
Natural fruit juice	Beccali *et al.*, (2010)	0.75	cradle to RDC	Yes*	-	-	-	-	-	-	**0.71**
Conc. fruit juice	Beccali *et al.*, (2010)	4.85	cradle to RDC	Yes*	-	-	-	-	-	-	**3.84**
Beer	FCRN (2007)	0.28	to brewery gate	Yes	-	-	-	-	-	-	**0.28**
Wine	FCRN (2007)	0.55	to end of production	Yes	-	-	-	-	-	-	**0.55**
Spirits	FCRN (2007)	0.65	to distillery gate	Yes	-	-	-	-	-	-	**0.65**
Bottled water	Bespoke calculations based on Foster *et al.*, (2006)	0.65		Yes	-	-	-	0.37	-	-	**0.37**
Other											
Tea	Doublet & Jungbluth (2010)	7.74	Cradle - grave	Yes	2.43	-	3.77	0.96	0.57	-	**6.21**
Coffee	Busser *et al.*, (2008)	17.50	Cradle - grave	Yes	-	-	-	-	-	-	**17.50**
Cocoa	Ntiamoah & Afrane (2008)	0.32	Cradle to RDC	Yes*	-	-	-	-	-	-	**0.31**
Chocolate	Busser & Jungbluth (2009)	3.05	Cradle to RDC	Yes*	-	-	-	-	-	-	**2.80**
Crisps	Nilsson *et al.*, (2011)	2.40	Factory gate	yes	-	-	-	-	-	-	**2.40**
Sweets	Nilsson *et al.*, (2011)	2.62	to factory gate	yes	-	-	-	-	-	-	**2.62**
Rice	Kasmaprapruet *et al.*, (2009)	2.93	to Mill gate	Yes	-	-	-	-	-	-	**2.93**
Bread	Nielsen *et al.*, (2003)	0.84	to bakery/ retail	Yes	-	-	-	-	-	-	**0.78**
Bread rolls	Nielsen *et al.*, (2003)	0.93	to bakery/ retail	Yes	-	-	-	-	-	-	**0.88**
Rye Bread	Nielsen *et al.*, (2003)	0.79	to bakery/ retail	Yes	-	-	-	-	-	-	**0.72**
Oats	Nielsen *et al.*, (2003)	0.57	to RDC	No	-	-	-	-	-	-	**0.57**
Wheat flour	Williams *et al.*, (2006)	0.80	to FG	Yes	-	-	-	-	-	-	**0.80**
Grain Maize	Williams *et al.*, (2006)	0.65	to FG	Yes	-	-	-	-	-	-	**0.65**
Soyabean	Williams *et al.*, (2006)	1.30	to FG	Yes	-	-	-	-	-	-	**1.30**

Table 2: Full list of food emissions factors

* Yes - however cannot distinguish between transport pre and post-processing plant

The following sections provide a summary of the review undertaken before the 2011 analysis. Each section contains a comparison with the emission factors (EF) used in our 2009 assessment along with a brief discussion of the sources selected for the 2011-12 and 2013-14 reports.

6.2 Meat and meat products

The main sources for meat and meat products were Williams *et al.,* (2008) *'Comparative life-cycle assessment of food commodities procured for UK consumption'*[1] and Williams *et al.,* (2006) *'Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities'*[2]. These were both produced for Defra and provide a thorough review of existing literature and transparent calculations relating to UK production. The former also enables home production to be compared to imported goods.

	2009	2011
Beef	16.00	23.89
Lamb	17.00	14.09
Chicken	4.60	2.78
Pork	6.40	9.07*
Eggs	4.25	4.25*

Table 3: Emissions factors for meat (kg CO2e per kg)

There are several reasons for the differences between 2009 and 2011 EFs:

- differences in LCA data; the authors acknowledge that the emissions factors are based on highly specific data therefore differences between the modelled production systems will result in differences in the EF;
- different allocation to end products e.g. In the allocation of sheep to lamb, mutton and wool;
- in Williams *et al.,* (2006) the functional unit is per tonne of carcass meat to the farm-gate while Williams *et al.,* (2008) is per tonnes of meat to the RDC as edible product.

Where differences remain unexplained we have used Williams *et al.,* (2008) as an update to Williams *et al.,* (2006) and assumed it reflects the best available current research.

The emissions factor for pork remains the same as previous years although adjusted from carcass to saleable meat with based on a 70% yield.

Eggs remain unchanged from previous year and are adjusted from Williams *et al.,* (2006) to reflect the actual weight of Booths' eggs (average 64.7 grams).

6.3 Fish

The emissions factors are unchanged from 2009 as Nielsen *et al.* (2003) remains the most comprehensive analysis identified. The Sea Fish Industry Authority have published findings for a small selection of fish for UK consumption however we have not selected these , since there was insufficient transparency in the

[1] Williams, A.G. *et al.,* (2008) Defra Project report FO0103: Comparative life-cycle assessment of food commodities procured for UK consumption through a diversity of supply chains. Available online: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=15001 [Accessed: 2.2.12].

[2] Williams, A.G. *et al.,* (2006) Defra project report ISO205: Determining the Environmental Burdens and resource use in the production of agricultural and horticultural commodities. Available online: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=11442[Accessed: 2.2.12].

reporting and inconsistency between their findings for poultry and those of other sources which we deemed to be relatively robust. See Table 2 for the list of emissions factors collated for fish.

6.4 Dairy products

The main source for this section was the U.N. Food and Agriculture Organisation's (FAO) *'Greenhouse gas emissions from the dairy sector'*[3]. A mass balance calculation adjusted by economic value of the end product based on DairyCo[4] data enabled the emissions factor for raw milk to be adapted for dairy products. Post-farm-gate emissions were allocated accordingly.

	2009	2011
Fresh milk	1.06[5]	1.00
Cream	1.06[6]	4.65
Cheese	12.12 Previously taken as an average of 10.71[6]; 14.50[7]; 11.20[8]	12.16
Milk powder	8.83 Based on the assumption that 1l of milk makes 120g of powdered milk	10.65
Yoghurt (fermented milk)	N/A	3.25
Butter		9.6*

Table 4: Emissions factors for dairy (kg CO2e per kg)

The results for fresh milk were in-line with previous sources and the calculations provided in the FAO report give a sound basis for estimating the GHG emissions for other dairy products. However the EF provided by the FAO for raw milk is a western European average and in the future we may wish to improve upon this if a UK specific value and details become available.

The EF calculated for cheese is close to that used in previous years which was based on the assumption that 10 litres of milk produces 1kg of cheese.

The EF for butter is taken from an alternative source (Nilsson *et al*., 2010)[9] and provides an EF from cradle to RDC thus includes transport from processing plant to RDC.

[3] FAO (2010) *'Greenhouse Gas Emissions from the Dairy Sector: A Life-cycle Assessment'* http://www.fao.org/docrep/012/k7930e/k7930e00.pdf [Accessed 3.1.12]

[4] DairyCo 2011. Datum - The market information service of DairyCo Available online: http://www.dairyco.org.uk/datum values for end of 2011 year.

[5] Williams, A.G. *et al.,* (2006) Defra project report IS0205: Determining the Environmental Burdens and resource use in the production of agricultural and horticultural commodities. Available online: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=11442[Accessed: 2.2.12].

[6] Calculated from Williams, A.G. *et al.,* (2006) Defra project report IS0205: Determining the Environmental Burdens and resource use in the production of agricultural and horticultural commodities. Available online: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=11442[Accessed: 2.2.12].

[7] Foster *et al.,* (2006) *'Environmental Impacts of Food Production and Consumption'*. A report to Defra.

[8] Nielsen PH, Nielsen AM, Weidman BP, Dalgaard R and Halberg N (2003). LCA food data base. "Lifecycle Assessment of Basic Food" (2000 to 2003) Aarhus University, Denmark.

[9] Nilsson, K., Flysjö, A., Davis, J., Sim, S., Unger, N. & Bell, S. (2010) 'Comparative life-cycle assessment of margarine and butter consumed in the UK, Germany and France'. International Journal of Life-cycle assessment 15:916-926.

6.5 Fruit and vegetables

	2009		2011	
	EF	Source	EF	Source
Potatoes - main crop	0.22	Nielsen PH *et al.*, (2003)	0.22	Williams, *et al.*, (2008)
Potatoes - earlies	As above		0.24	Williams, *et al.*, (2008)
Tomatoes loose (UK summer / Spanish winter)	2.95	Williams, *et al.*, (2006)	1.22	Williams, *et al.*, (2008)
Tomatoes vine (UK summer / Spanish winter)	7.05	Williams, *et al.*, (2006)	3.03	Williams, *et al.*, (2008)
Tomatoes baby plum (UK summer / Spanish winter)	5.95	Williams, *et al.*, (2006)	4.49	Williams, *et al.*, (2008)
Tomatoes baby plum on vine (UK summer / Spanish winter)	14.25	Williams, *et al.*, (2006)	3.41	Williams, *et al.*, (2008)
Juice - Not from concentrate	N/A		0.71	Beccali, *et al.*, (2010)
Juice - Concentrate	N/A		3.84	Beccali, *et al.*, (2010)
Salad - British outdoors	3.30	Wallén *et al.*, (2004)	0.33	Hospido *et al.*, (2009)
Salad - British indoors	As above		0.24	Hospido *et al.*, (2009)
Salad - British heated indoors	As above		2.62	Hospido *et al.*, (2009)
Apples - stored UK	0.24	Wallén *et al.*, (2004)	0.26	Williams *et al.*, (2008)
Apples - fresh UK	As above		0.21	Williams *et al.* , (2008)
Apples - UK (fresh, stored mix)	As above		0.23	Williams *et al.* , (2008)
Oranges	0.25	Wallén *et al.*, (2004)	0.33	Ribal *et al.*, (2009)
Oranges - organic	As above		0.22	Ribal *et al.*, (2009)
Strawberries	0.79	Wallén *et al.*, (2004)	0.87	Williams *et al.* , (2008)

Table 5: Emissions factors for fruit and vegetables (kg CO2e per kg)

The review provided by Wallén *et al.,* (2004) was relied upon heavily for fruit and vegetables in our 2009 assessment, and it was felt that significant improvements could be made[10].

The sources listed provide only a small selection of fruits and vegetables yet we believe there is sufficient variation to provide a basis for sensible assumptions to be made in the absence of credible LCA having been produced for all products. Garnett (2006)[11] provides extensive discussion on the available literature in 2006 along with a broad process for grouping fruits and vegetables in terms of their carbon impact. Combined with the list of EFs above this provides a reasonable basis for estimates but this is an obvious area for improvement as and when new sources become available.

EFs for year-round tomato supplies were calculated as an average of UK and Spanish production as supplied by Williams *et al.,* (2008). This presents an improvement to our 2009 estimate in which we assumed that UK summer and Spanish winter production was half as intensive as all year-round UK production.

6.6 Note on other products

Numerous other emissions factors have been collated see **Error! Reference source not found.**2.

6.6.1 Bread

In 2009 a bread EF was calculated from ingredients but Nielsen *et al.,* (2003) provide a comprehensive, reputable source covering a range of products. As a sense check these are broadly in-line with previous estimates, but we think more accurate.

[10] Garnett, T., (2006) 'Fruit and Vegetables & UK Greenhouse Gas Emissions: Exploring the relationship'. Working paper produced as part of the work of the Food Climate Research Network.

[11] Garnett, T., (2006) 'Fruit and Vegetables & UK Greenhouse Gas Emissions: Exploring the relationship'. Working paper produced as part of the work of the Food Climate Research Network.

6.6.2 Beverages

The 'tea, coffee and cocoa' category used in the 2009 assessment was based on Wallén *et al.,* (2004) and provided an average based on energy use in the production and transportation of coffee. We have identified individual LCA for each product which provide a basis for disaggregating this category.

6.6.3 Rice

In 2009 the EF for rice was based on an estimate made from top-down data. An academic report by Kasmaprapruet *et al.,* (2009) quantifies the emissions resulting from rice production in Thailand at 2.93 kg CO_2e per kg milled rice to the mill gate. In the absence of sufficient data to suggest otherwise this is taken as representative of rice production in general.

6.6.4 Sweets, crisps and chocolate

Wallén *et al.,* (2004) uses primarily data on energy consumption in the manufacturing of sweets. We identified a LCA for sweets, crisps and soft drinks produced by the Nordic Council of Ministers which provides an EF for a range of products. A LCA for various chocolate products was also found.

6.6.5 Drinks

Beer, wine and spirits remain unchanged from previous years, derived from Garnett (2007)[12]. We have estimated the GHG emissions resulting from bottled water based on information provided by Foster *et al.,* (2006)[13].

6.6.6 Other

For a small number of product categories not represented by the emissions factors in the main table averages, or estimates based on main ingredients provide proxy data. For example an emissions factor for cakes is derived from its ingredients as follows:

Ingredient	% by mass of total product	EF	Source
Wheat flour	50%	0.80	Williams *et al.,* (2006)
Eggs	10%	4.25	Williams *et al.,* (2006)
Butter	20%	9.66	Nilsson *et al.,* (2010)
Sugar	20%	0.84	Nielsen *et al.,* (2003)

Table 6: Derivation of emissions factor for cake

Broad estimates for the emissions resulting from processing from ingredients to final products are taken from Foster *et al.*, (2006).

6.6.7 Non-food product categories

EFs for non-food product categories have been estimated using EIO methodology. (See sectio*n 6.7.6 Other goods and services* for a list of EFs and

Appendix B: Detail of EIO Methodology for details.)

[12] Garnett, T. 2007: The Alcohol we drink and its contribution to UK Greenhouse Gas Emissions - A discussion paper. FCRN

[13] Foster *et al.,* (2006) *'Environmental Impacts of Food Production and Consumption'.* A report to Defra.

6.7 Non product related EF

6.7.1 Energy and fuel

Direct emission emissions factors were taken from Defra[31]. Supply chain emissions other than through energy use during electricity production and gas consumption were estimated by input–output (IO) analysis *See*

Appendix B: Detail of EIO Methodology for details.

	EF	Unit
Electricity	0.51	kg CO_2e / kWh
Natural Gas	0.24	kg CO_2e / kWh
Gas Oil	3.30	kg CO_2e / litre
Diesel	3.56	kg CO_2e / litre
Petrol	3.16	kg CO_2e / litre

Table 7: Energy and fuel emissions factors

6.7.2 Refrigerant gas leakage

For blends of refrigerant gases, two sources were used, Bitzer[32] and Tecumseh[33] and for R507C, which is not included in these two sources Hamilton Clarke provided their own EF.

Refrigerant gas	EF	Unit
R507	3,300	kg CO_2e / kg
R507C	1,520	kg CO_2e / kg
R22	1,700	kg CO_2e / kg
R404A	3,260	kg CO_2e / kg
R413A	1,920	kg CO_2e / kg
R69L	4,310	kg CO_2e / kg
R409A	1,540	kg CO_2e / kg

Table 8: Refrigerant gas emissions factors

[31] Defra, 2013.

[32] Bitzer 2010.

[33] Tecumseh 2009.

6.7.3 Commuting and staff business travel

Direct emission emissions factors are taken from Defra[34]. Supply chain emissions other than through direct energy use were estimated by IO analysis, *See*

Appendix B: Detail of EIO Methodology for details.

Detailed information was not available about staff car types so all figures are based on an average car.

Mode	EF	Unit
Average car	0.53	kg CO_2e / mile
National Rail	0.88	kg CO_2e / £
Short haul international (average)	4.68	kg CO_2e / £
Car parking	0.40	kg CO_2e / £
Taxi	1.19	kg CO_2e / £
Bus	1.19	kg CO_2e / £
Fuel (average of petrol and diesel)	3.35	kg CO_2e / litre
Hotel Stays	0.50	kg CO_2e / £

Table 9: Staff commuting and business travel emissions factors

6.7.4 Freight transport

Direct emission emissions factors are taken from Defra[35]. Supply chain emissions other than through direct energy use were estimated by IO analysis, *See*

Appendix B: Detail of EIO Methodology for details.

Based on the assumption that a bunch weighs approximately 200g, flowers have different transport emissions factors as they take up more space and therefore the vehicles run less full by weight. For further details see the mini report compiled in 2009 for Booths.

Transport Type	EF	Unit
Average van	2.26	kg CO_2e / tonne mile
All HGVs - UK average	0.33	kg CO_2e / tonne mile
Rail	0.07	kg CO_2e / tonne mile
Small Tanker	0.09	kg CO_2e / tonne mile
Large Tanker	0.01	kg CO_2e / tonne mile
Small Bulk Carrier	0.02	kg CO_2e / tonne mile
Large Bulk Carrier	0.01	kg CO_2e / tonne mile
Short-haul International Air Freight	4.68	kg CO_2e / tonne mile
Long-haul International Air Freight	2.38	kg CO_2e / tonne mile
Flowers Road Transport	0.77	kg CO_2e / tonne mile
Flowers Sea Transport	0.14	kg CO_2e / tonne mile
Flowers Short-haul air freight	21.72	kg CO_2e / tonne mile

[34] Defra, 2013.
[35] Defra, 2013.

Flowers Long-haul air freight	3.71	kg CO_2e / tonne mile

Table 10: Derivation of freight emissions factors

6.7.5 Consumer food packaging

The emissions factors for packaging were mostly derived from the emissions of the raw materials from which they are made[36]. For some materials recycling is also taken into account. As only marginal changes to some of the categories have been made in the most recent ICE updates[37] these have not been updated for the 2011 report.

Glass

The emissions factor for glass relates to 'General glass', i.e. not toughened, with a recycling rate of 38%, which is representative of the recycled content of container glass.

Paper

Paper used in food packaging can be categorised as either printed labels, or cardboard. The EF for printed labels is based on the value calculated for printed materials. The EF for cardboard is taken from Hammond and Jones (2006). For general paper packaging an average has been used.

Type of paper used in packaging	EF	Unit
Printed paper	2.59	kg CO_2e /kg
Cardboard packaging	1.63	kg CO_2e /kg
Average paper packaging	2.11	kg CO_2e /kg

Table 11: Paper packaging emissions factors

Plastic

Figures are available for a wide range of plastics[38], but only those relating to plastic food packaging are shown below. It should be noted that these include only CO_2 emissions and not the effect of other GHGs. Other gases would be expected to make only a very small contribution to the overall emissions factors in this area. The benefits of plastic recycling are also not included in the figures, with the assumption being made that only virgin plastics are used.

It has been assumed that there are five broad types of plastics used in food packaging:

- films (used for bags and laminates in tins);
- bottles (e.g. for soft drinks and milk);
- absorbent trays (used for raw products);
- lightweight trays (used for fruit);
- tubs (used for butter, ice cream, ready meals etc.).

By assigning a plastic type to each product category (e.g. soft drink = bottle, butter = tub), data from a supermarket has been used to calculate the proportion of each packaging type in use, by weight.

[36] Hammond and Jones, 2006.
[37] Hammond and Jones, 2011.
[38] Hammond and Jones, 2006.

Plastic Category	Example	Plastic Type	Proportion of all plastic packaging (by mass) (%)	EF($kgCO_2e/kg$)
Film	Bags, laminates in tins	Polypropylene (PP) oriented film	29	2.7
Bottles	Soft drinks, milk	Polyethylene terephthalate (PET) Bottles	62	4.1
Absorbent trays	Raw products e.g. meat	Expanded polystyrene	1	2.5
Lightweight trays	Fruit punnets	Amorphous PET	2	2.8
Tubs	Butter, ready meals	Polystyrene (PS)	6	2.7
Average	-	-	**100**	**3.57**

Table 12: Plastic packaging emissions factors

Steel

An emissions factor for sheet steel has been used for steel packaging. Sheet steel is assumed to have a recycling rate of 42.3%[39] compared to a steel packaging rate of 44%[40] so this is currently an adequate estimate, although it may alter with a likely increase in recycling as kerbside collections become more widespread. Therefore the emissions are given below both at the current recycling rate and in a form that can be altered to account for different recycling rates.

Steel Packaging Recycling Rate	Steel Packaging EF ($kgCO_2e/kg$)
42.3%	1.64
R (expressed as a decimal e.g. 33% = 0.33)	2.52-2.07R

Table 13: Steel packaging emissions factors

Aluminium

Aluminium in food packaging is used for drinks cans and foil items and therefore a figure for rolled aluminium is most appropriate. This assumes a recycling rate of 33%[41] compared to a UK aluminium packaging recycling rate of 32.5%[42]. Therefore the estimate is currently adequate, but may later change with increased recycling due to kerbside recycling becoming more widespread. Therefore an emissions factor has been included which will take this into account.

Aluminium Packaging Recycling Rate	Aluminium Packaging EF ($kgCO_2e/kg$)
33%	8.35
R (expressed as a decimal e.g. 33% = 0.33)	11.64-9.97R

Table 14: Aluminium packaging emissions factors

[39] Hammond and Jones, 2006.
[40] Waste Online: Metals, 2003.
[41] Hammond & Jones, 2006.
[42] Alupro, 2006.

Wood

Wood accounts for only 0.16% by mass of food packaging materials used and therefore we have not gone to great lengths to arrive at an accurate emissions factor. The ICE[43] value for timber has been used.

Other

For other materials an average of known packaging material has been be used.

NB: Imported materials make up only a very small percentage by mass of the total packaging used in the UK and therefore for the purposes of this study it has been assumed that the emissions factors will be the same regardless of the country of origin.

Packaging Material	EF	Unit
Plastic (mixed)	3.57	kg CO_2e / kg
Aluminium	8.53	kg CO_2e / kg
Steel	1.64	kg CO_2e / kg
Paper & card	2.11	kg CO_2e / kg
Glass	0.77	kg CO_2e / kg
Wood	0.44	kg CO_2e / kg
Other	2.79	kg CO_2e / kg

Table 15: Summary of packaging emissions factors

6.7.6 Other goods and services

Other goods and services were categorised according to a representative IO category based on data for 123 industrial sectors[44] and their GHG emissions calculated based on expenditure.

For full details of this methodology see

Appendix B: Detail of EIO Methodology*.*

IO category	EF (kg CO_2e / £)
Agriculture	2.55
Forestry	0.54
Fishing	0.82
Coal extraction	3.31
Oil and gas extraction	0.79
Metal ores extraction	14.50
Other mining and quarrying	0.89
Meat processing	1.03
Fish and fruit processing	0.79
Oils and fats processing	0.63
Dairy products	1.42
Grain milling and starch	1.13
Animal feed	1.11
Bread, biscuits, etc	0.80
Sugar	1.07
Confectionery	0.38
Other food products	0.74
Alcoholic beverages	0.28
Soft drinks & mineral waters	0.60
Tobacco products	0.12

IO category	EF (kg CO_2e / £)
Mechanical power equipment	1.28
General purpose machinery	1.30
Agricultural machinery	1.05
Machine tools	0.86
Special purpose machinery	1.11
Weapons and ammunition	0.76
Domestic appliances nec	0.67
Office machinery & computers	0.61
Electric motors and generators etc	0.88
Insulated wire and cable	3.17
Electrical equipment nec	0.68
Electronic components	0.73
Transmitters for TV, radio and phone	0.59
Receivers for TV and radio	0.36
Medical and precision instruments	0.53
Motor vehicles	1.19
Shipbuilding and repair	0.91
Other transport equipment	0.58
Aircraft and spacecraft	1.17
Furniture	0.60

[43] Hammond & Jones, 2011.

[44] ONS (Office of National Statistics) 2010[a&b]

Textile fibres	0.60	Jewellery & related products	1.20
Textile weaving	0.87	Sports goods and toys	0.24
Textile finishing	1.02	Miscellaneous manufacturing nec, recycling	0.80
Made-up textiles	0.29	Electricity production & distribution	5.63
Carpets and rugs	0.19	Gas distribution	1.40
Other textiles	0.70	Water supply	1.02
Knitted goods	0.99	Construction	0.52
Wearing apparel & fur products	0.29	Motor vehicle distribution & repair, fuel	0.49
Leather goods	0.57	Wholesale distribution	4.59
Footwear	0.19	Retail distribution	3.12
Wood and wood products	0.84	Hotels, catering, pubs etc	0.50
Pulp, paper and paperboard	1.13	Railway transport	0.88
Paper and paperboard products	0.65	Other land transport	0.93
Printing and publishing	0.36	Water transport	1.99
Coke ovens, refined petroleum & nuclear fuel	0.66	Air Transport	4.68
Industrial gases and dyes	2.29	Ancillary Transport services	0.40
Inorganic chemicals	1.29	Postal and courier services	0.49
Organic chemicals	1.67	Telecommunications	0.45
Fertilisers	3.38	Banking and finance	0.24
Plastics & Synthetic resins etc	1.47	Insurance and pension funds	0.38
Pesticides	1.21	Auxiliary financial services	0.28
Paints, varnishes, printing ink etc	0.65	Owning and dealing in real estate	0.17
Pharmaceuticals	0.35	Letting of dwellings	0.14
Soap and toilet preparations	0.29	Estate agent activities	0.16
Other Chemical products	1.04	Renting of machinery etc	0.68
Man-made fibres	2.78	Computer services	0.16
Rubber products	1.07	Research and development	0.30
Plastic products	1.05	Legal activities	0.15
Glass and glass products	1.07	Accountancy services	0.21
Ceramic goods	0.63	Market research, management consultancy	0.22
Structural clay products	0.81	Architectural activities & Tech. Consult	0.21
Cement, lime and plaster	3.83	Advertising	0.25
Articles of concrete, stone etc	1.51	Other business services	0.21
Iron and steel	2.91	Public administration & defence	0.47
Non-ferrous metals	8.91	Education	0.25
Metal castings	2.31	Health and veterinary services	0.31
Structural metal products	1.70	Social work activities	0.35
Metal boilers & radiators	1.10	Sewage and Sanitary services	1.89
Metal forging, pressing, etc	1.50	Membership organisations nec	0.24
Cutlery, tools etc	0.80	Recreational services	0.39
Other Metal products	1.93	Other service activities	0.30
		Unknown (assumed average)	1.20

Table 16: IO Emissions factors

6.7.7 Miscellaneous materials

Other emissions factors for materials were taken from the updated ICE model[45].

Material	EF	Unit
General Polyethylene	2.54	kg CO_2e / kg
Nylon 6	9.14	kg CO_2e / kg
Polypropylene, Orientated Film	3.43	kg CO_2e / kg
Expanded Polystyrene	3.29	kg CO_2e / kg
General steel	1.46	kg CO_2e / kg
Ceramics	1.61	kg CO_2e / kg
Cotton fabric	6.78	kg CO_2e / kg

Table 17: Emissions factors of miscellaneous materials

[45] Hammond & Jones, 2011

6.7.8 Waste

Defra[46] provides data on the emissions arising from the processing of waste in landfill. They also provide an estimate of the emissions saving through recycling. These figures are inclusive of all the significant stages in waste treatment.

[46] Defra, 2013.

7 Appendix B: Detail of EIO Methodology

EIO combines economic information about the trade between industrial sectors with environmental information about the emissions arising directly from those sectors to produce estimates of the emissions per unit of output from each sector. The central technique is well established and documented[47]. In the UK, the main data sources are the *'Combined Supply and Use Matrix for 123 sectors'*[48] and the *'UK environmental accounts'*[49], both provided by the Office of National Statistics (ONS).

The specific model used for this project was developed by Small World Consulting with Lancaster University and is described in detail below and elsewhere[50]. This model takes account of such factors as the impact of high altitude emissions that are not factored into the environmental accounts and the effect of imports. In order to use more up to date (2008 rather than 1995) data, we have employed a simple algorithm for converting between basic and purchasers prices. We have used consumer industry specific consumer price indices to adjust for price changes since the date to which the supply and use tables relate.

Three main advantages of EIO over more traditional process-based life-cycle analysis (LCA) approaches to GHG footprinting are worth noting:

- EIO attributes all the emissions in the economy to final consumption. Although, as with process-based LCA, there may be inaccuracies in the ways in which it does this, it does not suffer from the systematic underestimation (truncation error) that process-based LCAs incur through their inability to trace every pathway in the supply chains[51].
- EIO has at its root a transparently impartial process for the calculation of emissions factors per unit of expenditure, whereas process-based LCA approaches entail subjective judgements over the setting of boundaries and the selection of secondary emissions factors.
- Through EIO, it is possible to make estimates of the footprints resulting from complex activities such as the purchase of intangible services that LCAs struggle to take into account.

One of the limitations of EIO in its most basic form is that it assumes that the demands placed upon (and therefore the direct emissions from) other sectors by a unit of output within one sector are homogeneous. As an example, a basic EIO model does not take account of the carbon efficiencies that may arise from switching the expenditure on paper from a virgin source to a renewable source without reducing the actual spend. An assumption in the model used here is that goods from overseas are produced with the same carbon efficiency as they would have been in the UK. Overall, this assumption usually results in an underestimation of the footprint of purchased goods. A further omission for this and all EIO models that we are aware of is that the impact of land-use change

[47] for example Leontief, 1986; Miller & Blair2009.

[48] ONS (Office of National Statistics), 2010[a].

[49] ONS (Office of National Statistics), 2010[b].

[50] Berners-Lee, M. *et al*,. 2011.

[51] Lenzen, M., 2001; Nässén *et al*., 2007.

around the world has not been taken into account. This would be likely to result in an increased assessment of the footprint of foods, especially animal products[52].

The specific methodology and sources underpinning our model are outlined below in steps, along with some brief discussion.

Throughout the following matrices and vectors are written in capitalized bold font, while the individual elements of a matrix are denoted by the small cap of the name of the matrix and are not bolded. The operations in equations involving matrix or vector elements are standard mathematical operations while those in equations involving matrices are the corresponding matrix operations.

Step 1: A technical coefficients matrix of inputs from each sector per unit output of each sector (**A**) has been derived from an update to the UK Input–Output Analyses 2010 edition, Table 3 'Demand for products in 2008 Combined Use Matrix', based on 2008 data and obtained from the ONS[53]. The ONS publishes on only 93 sectors for 2007, but released to us a 123 sector breakdown of 'unbalanced' figures. We used these judging that the benefit of disaggregation outweighs the risks from not going through the balancing process. Encouragingly, the disaggregated data set was in line with estimates based on extrapolation from the 2008 data set. This matrix deals with the UK economy broken down into 123 industry groups. The process assumes that the output stimulated in each sector per unit demand at purchaser's prices is homogeneous and independent of the purchaser.

The matrix is usually derived from use tables of inputs at basic prices, which are output prices before distributers' margins, taxes or subsidies have been applied. However, for the UK these have not been published since 1995. By using purchasers' prices rather than basic prices to determine the technical input coefficients more recent data from 2008 data can be used rather than 1995 data. The trade-off is that it entails the assumption that demand at purchasers prices (including taxes, subsidies and distributors margins) is as good a guide to industry activity as demand at basic prices. Both of these values are surrogates for the stimulation of emissions-causing activity.

Step 2: Gross fixed capital formation is reallocated from final demand to intermediate demand, since the ongoing formation of capital is required to support the supply of goods and services, and is therefore instrumental in enabling the production of goods and services.

Step 3: The Leontief inverse (**L**) of the technical coefficients matrix consists of a matrix of sectoral output coefficients as stimulated per unit final demand, all at basic prices.

$$\mathbf{L} = (\mathbf{I}-\mathbf{A})^{-1} \qquad \text{Equation 1}$$

Where **I** is the identity matrix.

Step 4: The UK Environmental Accounts[54] give the GHG emissions in 2008 arising directly from 93 SIC (Standard Industrial Code) sectors. These are mapped onto the 123 ONS IO Table industry groups

[52] Audsley *et al*., (2009); This report estimates that emissions from red meat production outside Europe rises by a factor around five when land-use change is taken into account.

[53] ONS (Office of National Statistics), 2010[a]

[54] ONS (Office of National Statistics), 2010[b]

by a process of splitting out SIC code emissions into IO industry groups in proportion to total output at basic prices and where necessary combining SIC codes into single Input–Output industry groups.

Step 5: Emissions from aviation at altitude are known to have a higher impact than the same emission at ground level. An emissions weighting factor of 1.9 was applied to the CO_2 emissions associated with the air transport sector to reflect additional radiative forcing per unit of GHG emitted. This simple mark-up factor is the figure proposed by Defra[55], based on the IPCC's discussion of aviation in its Fourth Assessment Report[56]. The application of this multiplier provides a first approximation to the impact of a complex and as yet poorly understood set of scientific phenomena surrounding aviation emissions.

Step 6: UK output by sector at basic prices[57] (ONS, 2010[a]) was combined with UK GHG emissions arising directly from each sector to derive a vector of coefficients of emissions per unit (£) of UK output from each sector at basic prices ($\mathbf{G}_{\mathbf{UK}}$). This is the vector of GHG intensity of each sector per unit financial output.

For each industry,

$$g_{UK_i} = e_{D_i} / o_{BP_i} \quad \text{i = 1 to 123 (industrial sectors)} \qquad \text{Equation 2}$$

where $\mathbf{O_{BP}}$ is the vector of UK sector-specific output at basic prices and $\mathbf{E_D}$ is the vector of sector specific direct emissions.

Step 7: The matrix (**E**) of GHG emissions arising from each industry (i) per unit of final demand for each industry (j) at 2008 basic prices is calculated as:

$$e_{ij} = l_{ij}.g_i \quad \text{i= 1 to 123 (industries), j= 1 to 123 (industries)} \qquad \text{Equation 3}$$

Emissions intensity matrices based on different levels of import from within and beyond the EU can be constructed. In particular, we can substitute for g_i in the above equation to explore emissions intensities that might result where supply chains are typical of UK supply ($\mathbf{G_{UK\ Mix}}$), are based solely in the UK ($\mathbf{G_{UK}}$), solely in the EU ($\mathbf{G_{EU}}$), or solely outside the EU ($\mathbf{G_{Non\ EU}}$).

Step 8: Total emissions from each industry (i) arising from UK final demand for each industry (j) is given by

$$e_{Total_{ij}} = e_{ij}.f_{BP_j} \qquad \text{Equation 4}$$

Where $\mathbf{E_{Total}}$ is the matrix of total emissions from each sector arising from final demand for each sector, and $\mathbf{F_{BP}}$ is the vector of final demand at 2008 UK basic prices.

Note that $\mathbf{F_{BP}}$ includes exports. To understand the impact of UK final demand, emissions from exports can be subtracted from each sector on a proportional basis.

[55] Defra, 2011
[56] IPCC, 2007
[57] ONS (Office of National Statistics), 2010[a]

Step 9: To obtain $\mathbf{F_{BP}}$, the final demand at purchasers' prices is adjusted by subtracting distributors' margins taxes and subsidies, based on the assumption that these are split between domestic outputs at basic prices and imported products in the ratio of their respective monetary values

For industry i,

$$f_{BP_i} = f_{PP_i} - (d_i + t_i - s_i).(o_{BP_i} / (o_{BP_i} + b_i)) \qquad \text{Equation 5}$$

Where:

$\mathbf{F_{BP}}$ = Final demand at Basic Prices,

$\mathbf{F_{PP}}$ = Final Demand at Purchasers prices and

D,T,S, $\mathbf{O_{BP}}$ and **B** are the vectors of distributors' margins, taxes, subsidies, total output at basic prices and imports respectively.

A key assumption here is that distributor's margins, tax and subsidies are applied to domestic production and imports at the same rates, and can therefore be apportioned according to monetary value.

The data are obtained from Tables 2 and 3 in the UK Input–Output Analysis Tables (ONS, 2010[a]).

Step 10: This step converts emissions factors from basic prices to purchasers' prices**.** The majority of this conversion is done simply by dividing by the ratio of final demands at purchasers and basic prices. However, there remains the question of allocating emissions arising from distribution services to the sectors whose products use those sectors.

In the UK IO tables, three distributor sectors require special treatment, since the products they deal with are not counted as inputs and only the marginal increase in their value is counted as outputs for those sectors. These sectors are 'Motor vehicle distributors', 'Wholesalers' and 'Retail'. The emissions associated with these three sectors have been aggregated and redistributed between the industries they serve in proportion to the distributor's margins that are associated with their products.

The core assumption here is that emissions arising from distribution services are in proportion to the margins they generate for the products of each other industry.

8 Appendix C: Sources

Source	Web link
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