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The greenhouse gas footprint of Booths

26/09/2012

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Contents

Tables

Document control

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Title:	The greenhouse gas footprint of Booths
Status:	Final
Dated:	26 September, 2012
Approved by:	
Expected Changes:	

Document Details

Reference:	Booths GHG Report 2012 Final
No of pages:	56

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 2011, builds upon previous work updating and improving upon similar reports for 2009 and 2007. Most significantly, the list of emissions factors for different foods has been improved in the light of recent research and more rigorous selection. The food categories have been rearranged to be more user-friendly and self explanatory.

1.2 Results

The annual carbon footprint of Booths and its product supply chains is estimated at 255,010 tonnes CO_2e per year. This is roughly one four-thousandth of the GHG footprint of UK consumption.[1] To put this into perspective, this equates to a best estimate of 970g of CO_2e per £ 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 7.4% of the total, packaging 6.4%, refrigeration (comprising both gas leakage and electricity) 5.4%, warehousing and distribution 1% and other 'overheads' (the running of stores, offices and other Booths operations) at 11.5%.

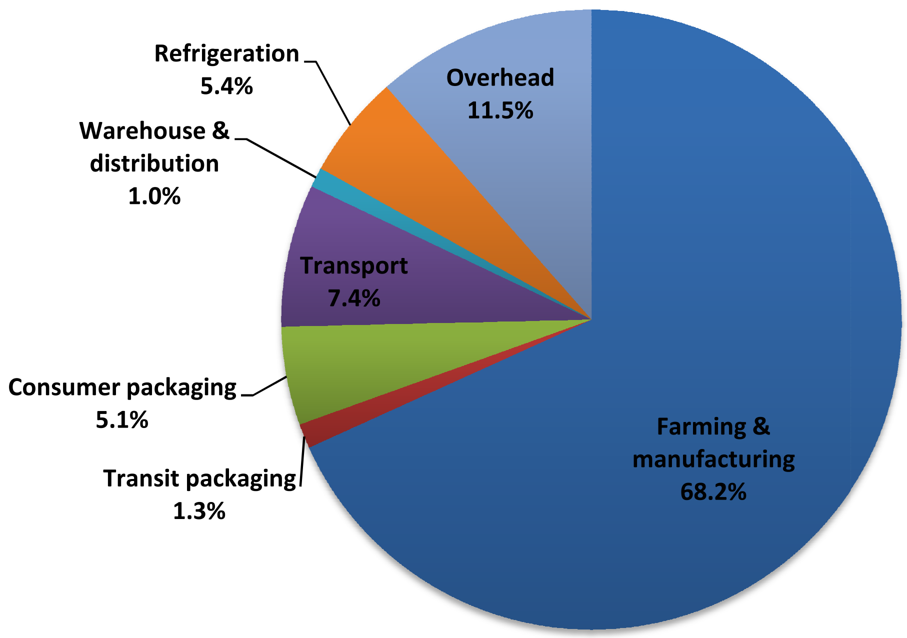

Figure 1: Total footprint of Booths products and supply chains 255,010 tonnes CO_2e

When the whole Booths footprint is attributed to goods sold, animal products and their 'alternatives' make up 47% 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.

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

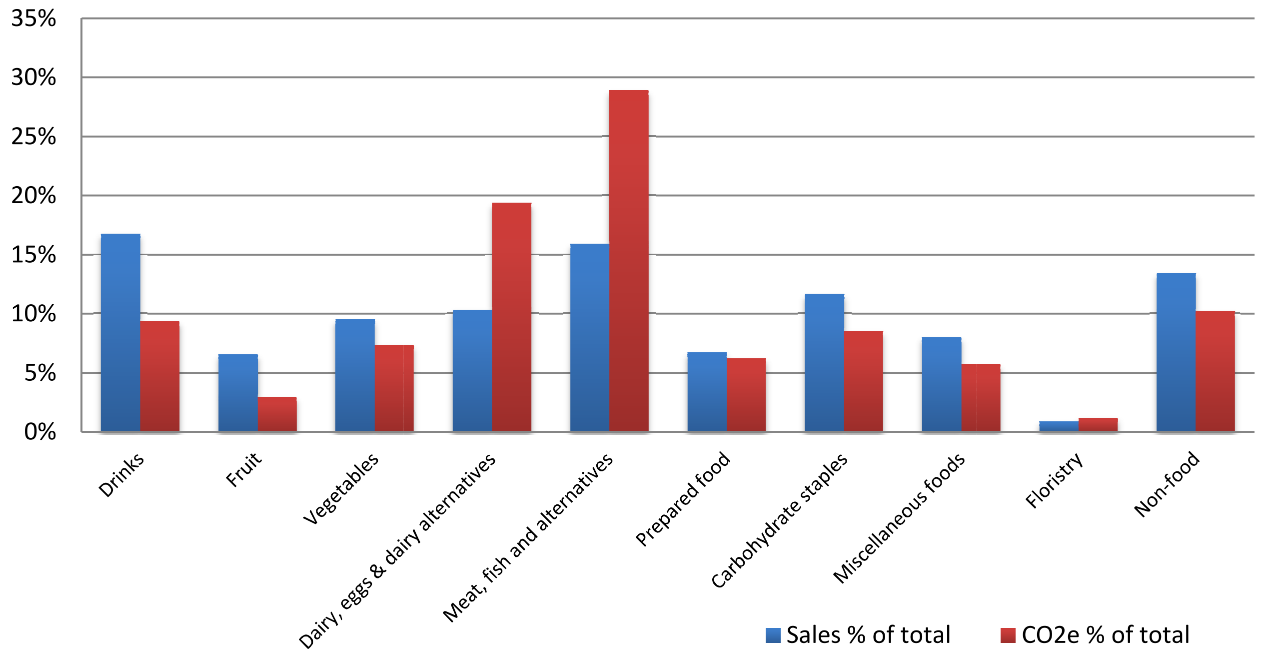

Figure 2: Footprint and sales for product categories as a proportion of the total

Fruit and vegetables together make up just 10% of the footprint, non food (excluding floristry) a further 10% and drinks (both alcoholic and soft) another 9%. 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.

2 Introduction

2.1 This report

This report maps out the greenhouse gas (GHG) emissions of Booths products up to the checkout. It covers the entire product range with the exception of foods supplied to cafés and restaurants. Emissions are broken down into 77 product categories and by life-cycle stage from primary production to retail. This is key information which enables 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.

This report updates and improves upon previous estimates carried out in 2007 and 2009. Whilst considerable effort has been made to ensure rigour and transparency, as with all supply chain emissions estimates, there remains a degree of uncertainty.

By making this report publically available, Booths seeks to demonstrate a transparent approach to this agenda.

2.2 The contribution of food to UK greenhouse gas emissions

Excluding the effect of changes in land use, food purchased from shops accounts for around 12% of the GHG footprint of all UK consumption. This figure rises to about 20% when the emissions resulting from shopping, cooking, food waste and eating out are taken into account[2]. This figure is thought to rise to around 30% when the effect of land use change is taken into account[3].

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.

2.3 What Booths has done so far

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,

[2] See 3.7: A note on Environmental Input–Output analysis (EIO)
[3] Audsley *et al*., 2009.

    - 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.

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,
- the *Everywine* online wine sales operation,
- food purchased for teashops and Artisan restaurants,
- impacts that might be attributable to National Lottery sales.

[4] Defra, 2011.

3.3 Greenhouse Gas Protocol guidelines

The assessment follows the reporting principles of the 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 Greenhouse Gas Protocol (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 *5.7.5 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 5.7.1 and 5.7.2 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 *5.7.6 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.

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8 Defra, 2011.

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. 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 GHG 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 123 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 255,010 tonnes CO_2e per year. This is roughly one four-thousandth of the GHG footprint of UK consumption.[17] To put this into perspective, this equates to a best estimate of 970g 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, storage, packaging and distribution is responsible for 211,947 tonnes CO_2e, 83% of the total footprint.

We estimate the overhead (including refrigeration), which consists of electricity and gas consumed in offices and stores, refrigerant gas leaks, staff travel and the procurement of goods and services not for re-sale, to be 43,063 tonnes CO_2e, approximately 17% of the total footprint.

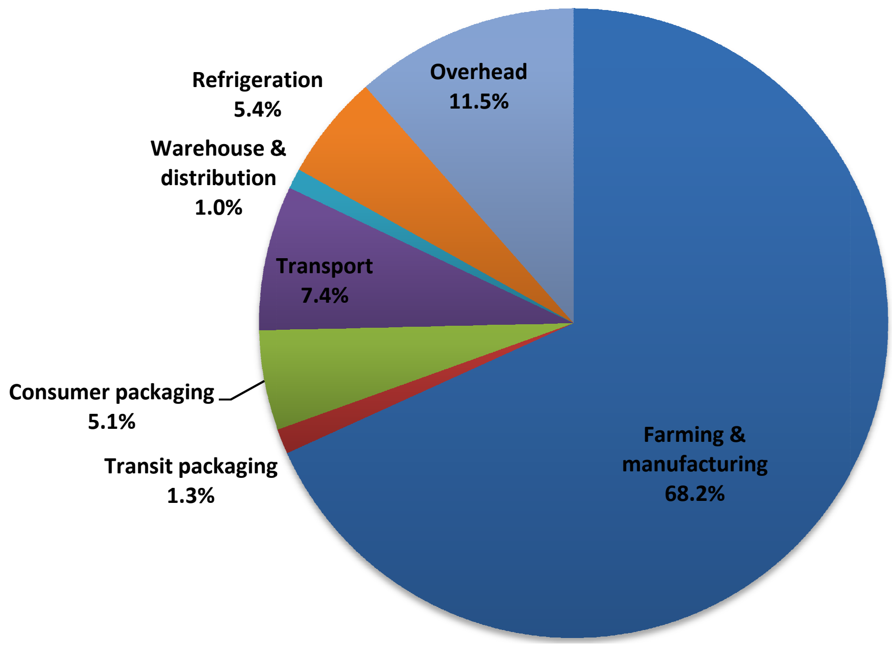


Figure 3: Total footprint of Booths products and supply chains 255,010 tonnes CO_2e.

4.2 Breakdown of the footprint

The largest components of the footprint are as follows.

4.2.1 Farming and manufacturing

173,972 tonnes CO_2e; 68.1% 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.

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

Agricultural footprints also tend to be dramatically higher where products are grown in artificially heated conditions. Examples of this are winter flowers grown in the Netherlands and tomatoes grown out of season in the UK. According to one study, the impact of growing flowers in unsuitable climates is so dramatic that a six-fold improvement can be made by switching roses imported from the Netherlands for a similar product air-freighted from Kenya (Williams, 2007).

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 10% (18,143 tonnes) of all farming and manufacturing in Booths product supply chains.

4.2.2 Transport

18,959 tonnes CO_2e; 7.4% of Booths total footprint

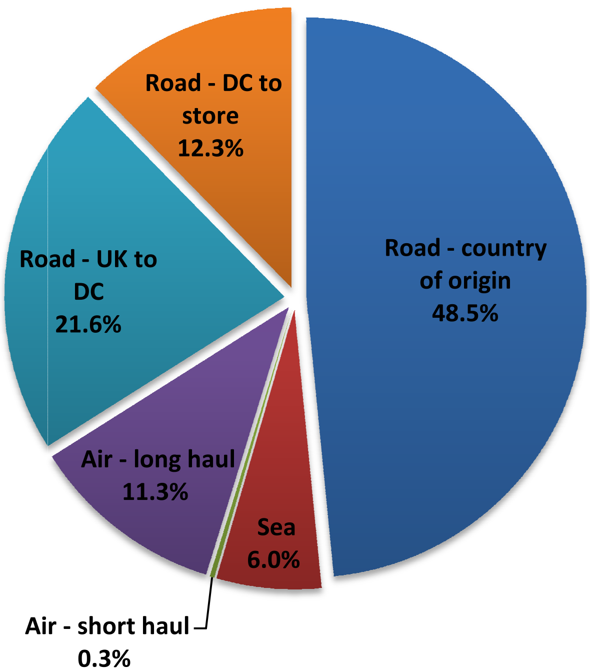


Figure 4: Transport 18,959 tonnes CO_2e, 7.4% of the total footprint

Our estimate of transport emissions is significantly lower than our estimate in 2009. This is partly because updated emissions factors for sea freight are somewhat lower, partly because more accurate data on fruit and vegetable journeys has revealed less air transport than previously thought and partly because over the last two years Booths has reduced its air freight and increased 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 6.1% 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 distribution centres.

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 12% of all transport emissions (0.9% of Booths' total footprint). The vast majority of this results from the importing of exotic vegetables, some exotic fruit and flowers.

Shipping turns out to be only of limited significance (6.0% of the transport footprint but just 0.4% 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).

Actions to reduce transport emissions include;

- strongly promoting local and UK produce when in season,
- efficiency improvements in the Booths distribution,
- changes to the sourcing of some products (see sections 4.3.3 Fruit; and 4.3.4 Vegetables).

4.2.3 Packaging

16,364 tonnes CO_2e; 6.4% of Booths' total footprint

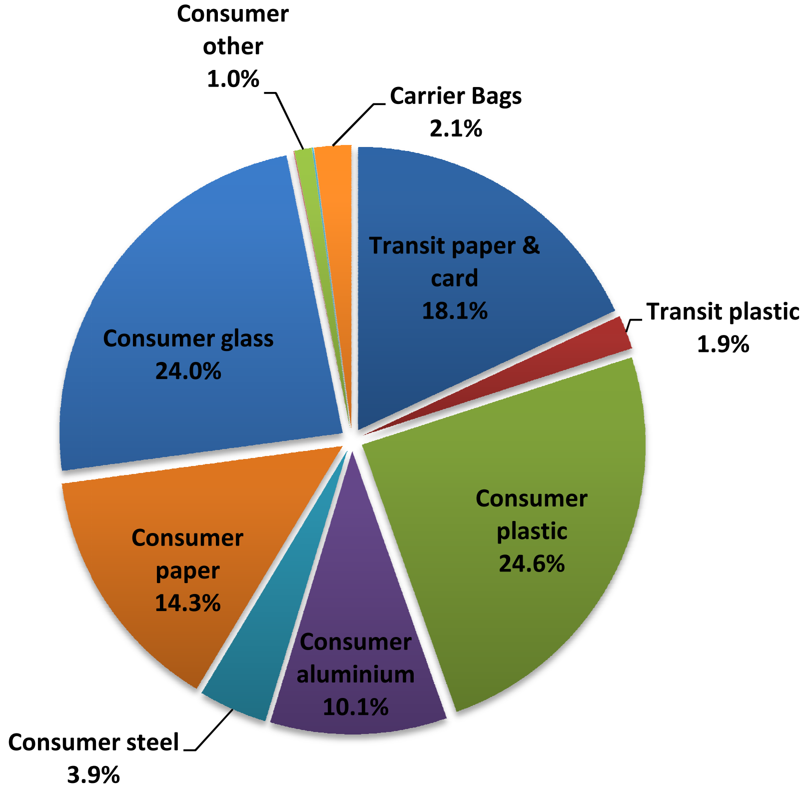


Figure 5: Packaging, 16,364 tonnes CO_2e, 6.4% of the total footprint

The footprint of packaging at Booths remains unchanged from previous estimates both in size and profile.

The majority of the packaging footprint results from consumer packaging (13,091 tonnes CO_2e; 78%) with plastic and glass being the greatest contributors (24% and 25% respectively). 3,274 tonnes CO_2e (20%) result from transit packaging. Carrier bags contribute only 2.1% 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 Overhead

44,303 tonnes CO_2e; 17% of total footprint

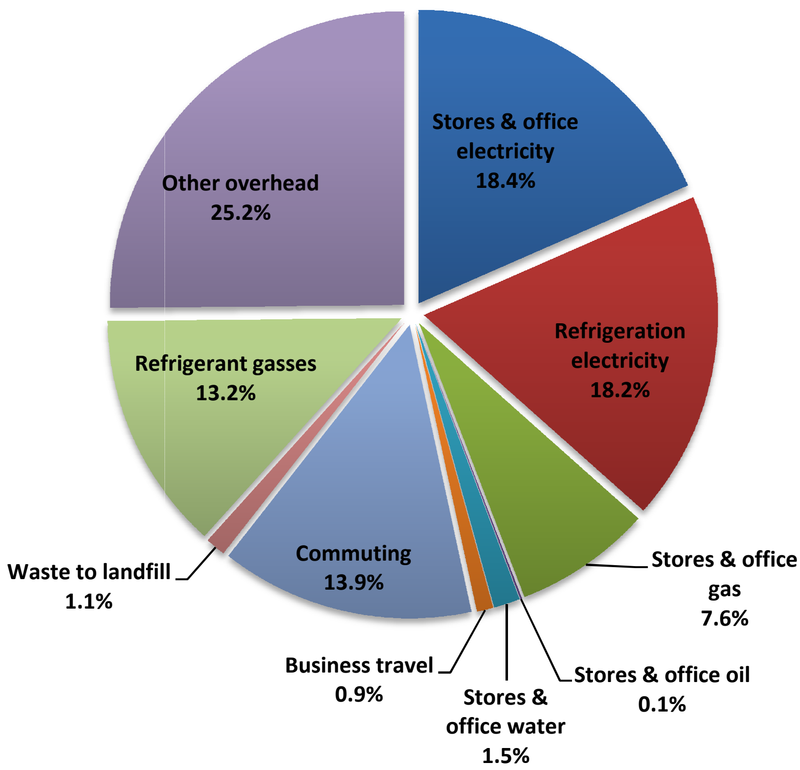


Figure 6: Overhead, 44,303 tonnes CO_2e, 17% of the total footprint

Our treatment of overheads has become more inclusive since the 2009 report and this, rather than an increase in impact has resulted in a significant increase the figures. This is seen in the 'other overhead' category which now makes up 25% of the overhead and consists mainly of the supply chain emissions resulting from the operational expenditure at Booths.

As in previous assessments, the remainder of the overhead footprint consists mainly of energy consumption within buildings (including energy for refrigeration). In comparison with the 2009 estimate electricity consumption has increased by 7%, gas by 21% and oil by 54% overall resulting in a 9% (approximately 1,600 tonnes CO_2e) increase in the footprint of energy consumption at Booths. This can be more than accounted for by the opening of new stores.

Refrigerant gas leaks account for 5,780 tonnes CO_2e; 13% of the overhead and 2.3% of the total footprint. The 32% increase since 2009 reflects two significant leakage incidents in 2011. Refrigeration in total (electricity and gas leaks together) accounts for 31% of the overhead and 5.5% of Booths' total footprint.

Based on an average weekly commute of approximately 60 miles the footprint of commuting is thought to result in approximately 6,127 tonnes CO_2e (14% of the overhead and 2.4% of the overall footprint). Business travel is only a very small contributor to the overhead footprint (0.9%). Whilst the costs of commuting do not fall directly on Booths they affect the prosperity of staff and can provide a good opportunity to engage staff with the broader sustainability agenda at Booths. The footprint could potentially be reduced through such measures as encouraging lift shares (also good for staff communication and relationships), cycling and walking to work. Changes here also stand to send a cultural message to staff, as well as delivering considerable time and financial savings.

The footprint of waste to landfill is small (489 tonnes CO_2e; 1.1% 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. The impact of consumer waste is outside the scope of this report.

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 to 10 stores so far and planned roll-out to all others. This has delivered electricity efficiency improvements of up to 13%,
- fitting doors to fridges in 5 new stores so far. A refit to an older store is currently underway, as a pilot for the retrofitting of doors to all stores,
- installing heat recovery systems in new stores,
- fitting air sources heap pumps in some new stores,
- increasing use of LED lighting.

All new refrigeration systems are expected to be CO_2 based, eliminating the need for more intense greenhouse gasses.

4.2.5 Storage, packing and processing at distribution centres

2,650 tonnes CO_2e; 1.0% of total footprint

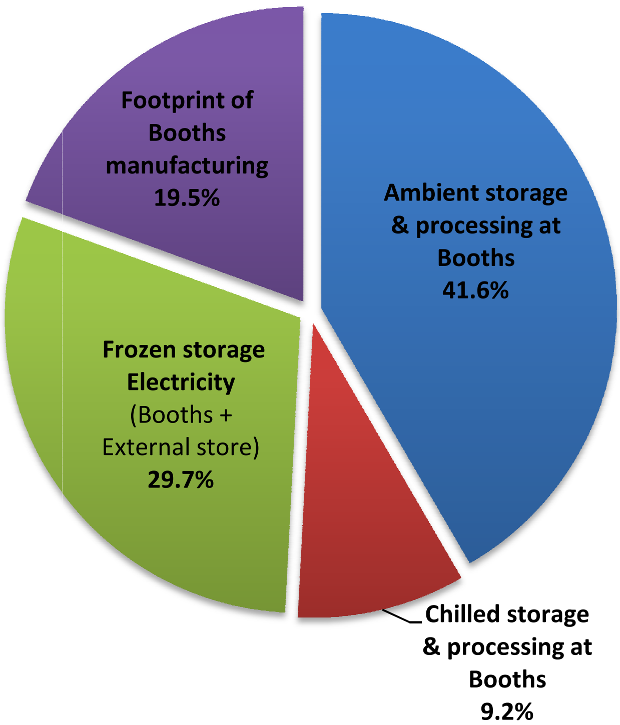


Figure 7: Breakdown of distribution centre footprint: 2,650 tonnes CO_2e, 1% of the total footprint

4.3 Analysis by 10 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 8 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. Comparing the bars gives a measure of the ***carbon intensity*** of a product category, the GHG emissions per unit retail value.

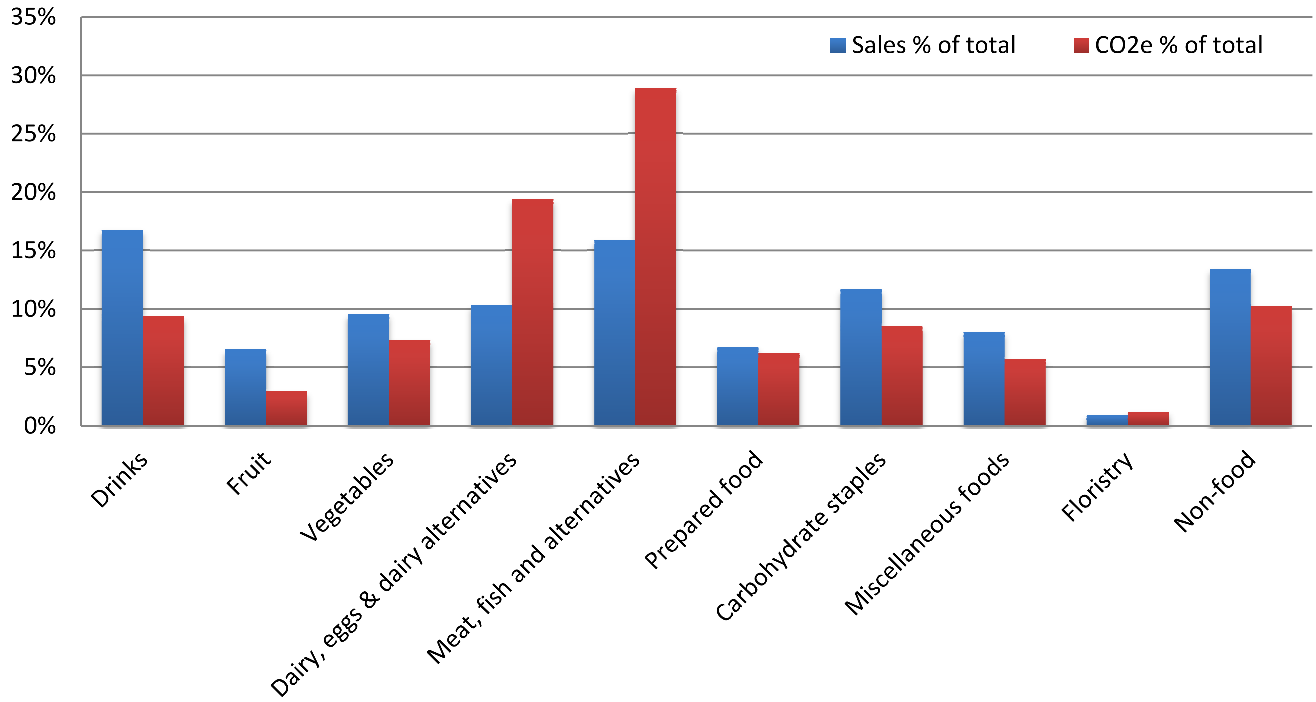
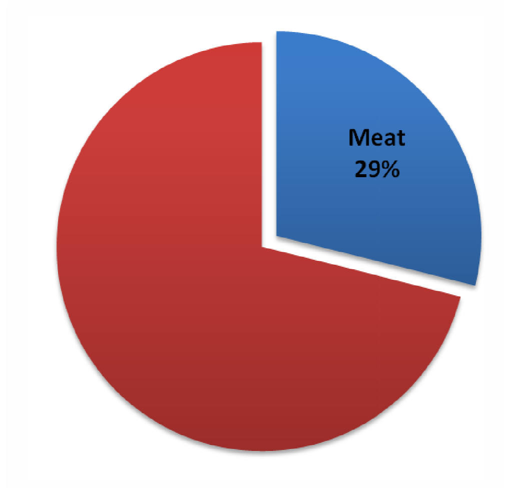


Figure 8: Footprint and sales for product categories as a proportion of the total

4.3.1 Meat, fish and meat alternatives



This is the product group with the highest footprint.

The pre-farm-gate emissions make up 87%. 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 5%, although vast majority of this category is chilled.

Transport contributes only 2%, helped by Booths' sourcing 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.

Booths' recent waste reduction project has brought significant savings in this area.

Further carbon saving may come about 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.

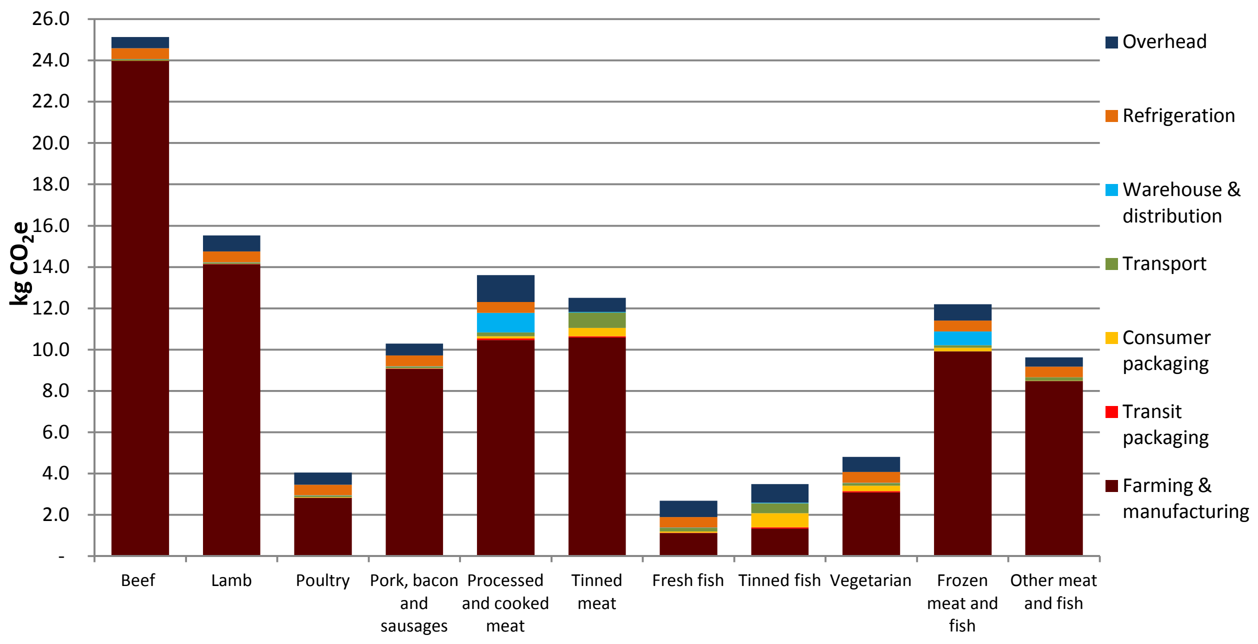
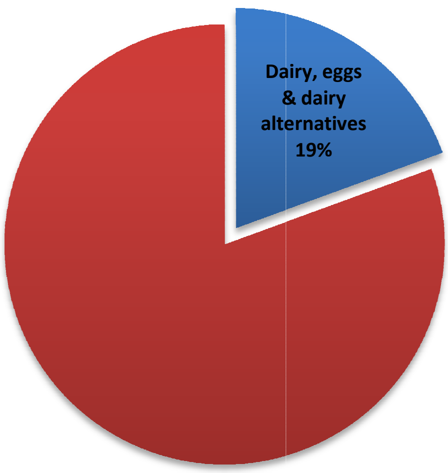


Figure 9: Breakdown of meat by product type and life-cycle stage per kg of product

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.

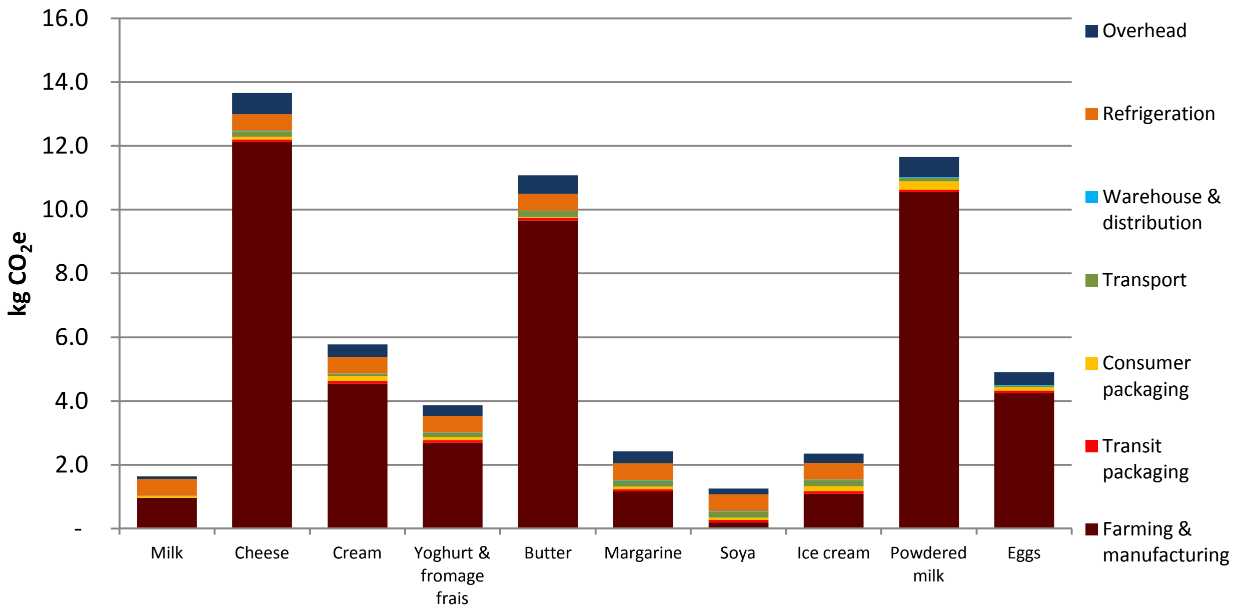
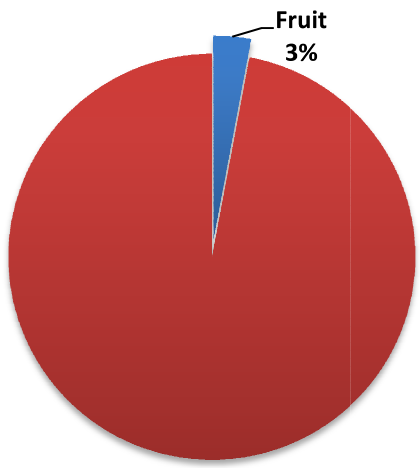


Figure 10: Breakdown of dairy product type and life-cycle stage per kg of product

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 (37%) and is relatively constant throughout the different product categories except where hot housing takes place for out of season products such as soft fruit and berries and for tinned and frozen fruit which incur additional processing emissions.

Transport is also a large contributor (31%). While only a very small proportion of Booths fruit is air freighted, this has high associated emissions (see for example 'exotic fruit' and 'berries').

The recent emphasis on local, seasonal produce is very 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.

Specific success stories include:

- dramatically reducing air freight of cherries from California,
- processing prepared fruit in the UK, thereby avoiding the need to air freight short-life produce.

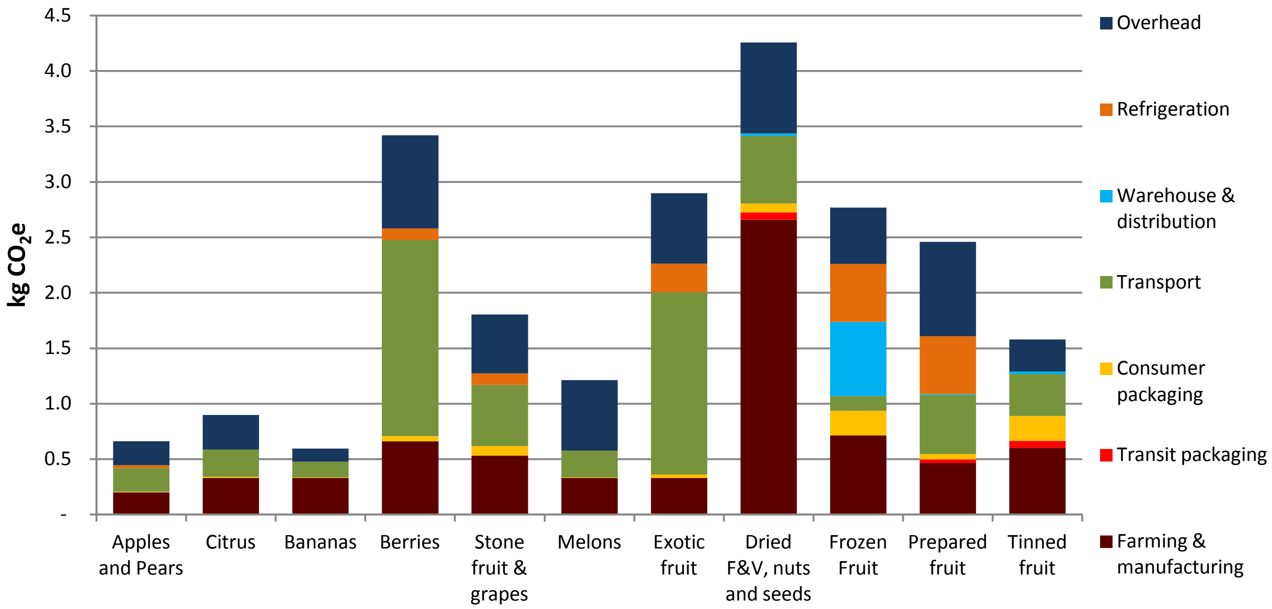
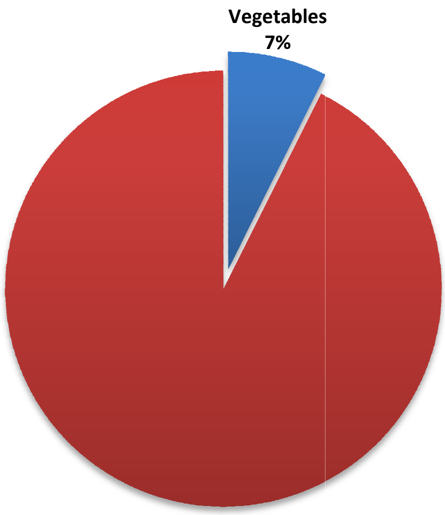


Figure 11: Breakdown of fruits by product type and life-cycle stage per kg of product

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 (53%). 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 (15%). 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.

Recent success stories include:

- increased promotion of seasonal and local produce,
- stretching the UK asparagus season to reduce air freight,
- increased local sourcing of onions and salads.

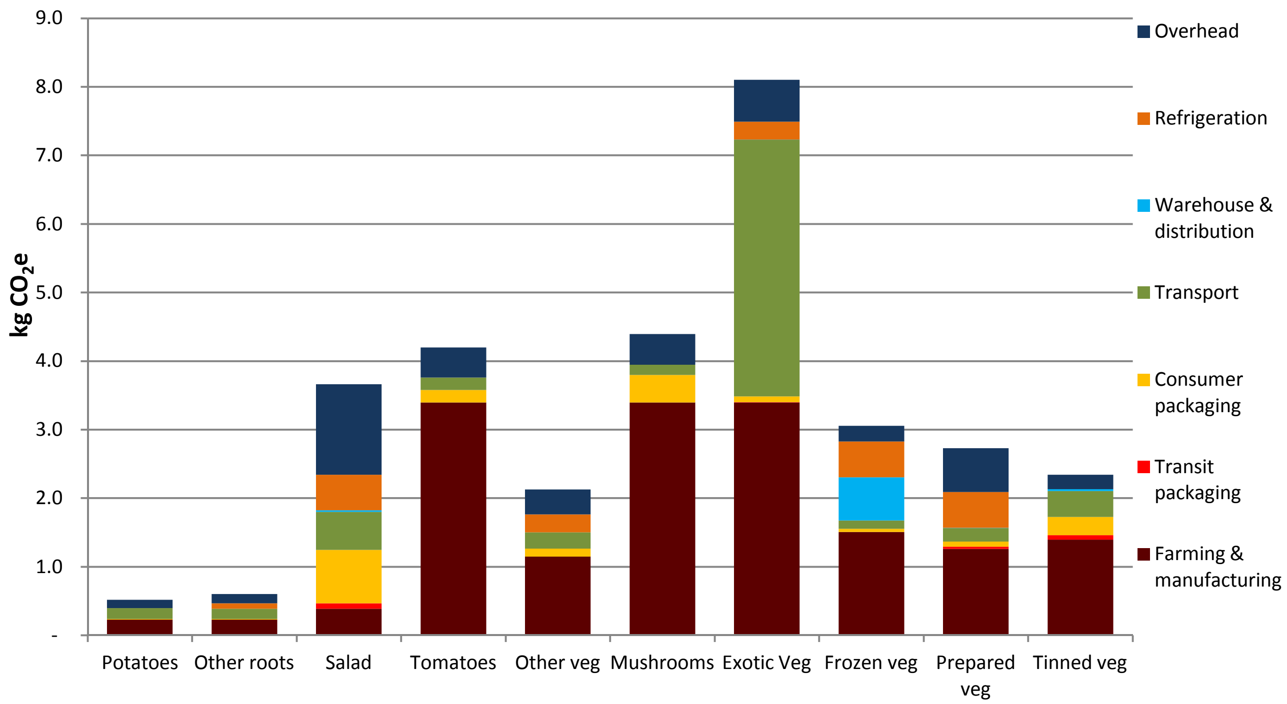
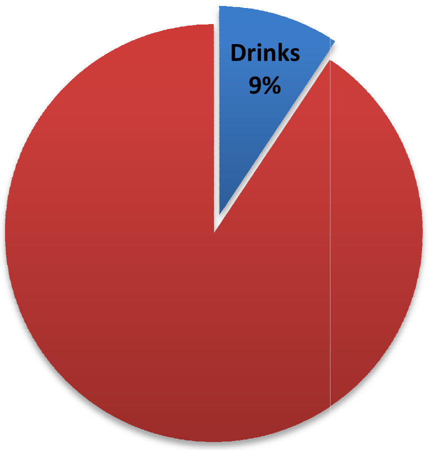


Figure 12: Breakdown of vegetables by product type and life-cycle stage per kg of product

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 (3.2 and 2.4 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 (24% of the carbon footprint of drinks), particularly glass.

Farming and manufacturing makes up just 23% of the overall footprint of drinks. This is highest for wines and juice as they are produced from fruit.

Transport impacts are relatively high (22% 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.

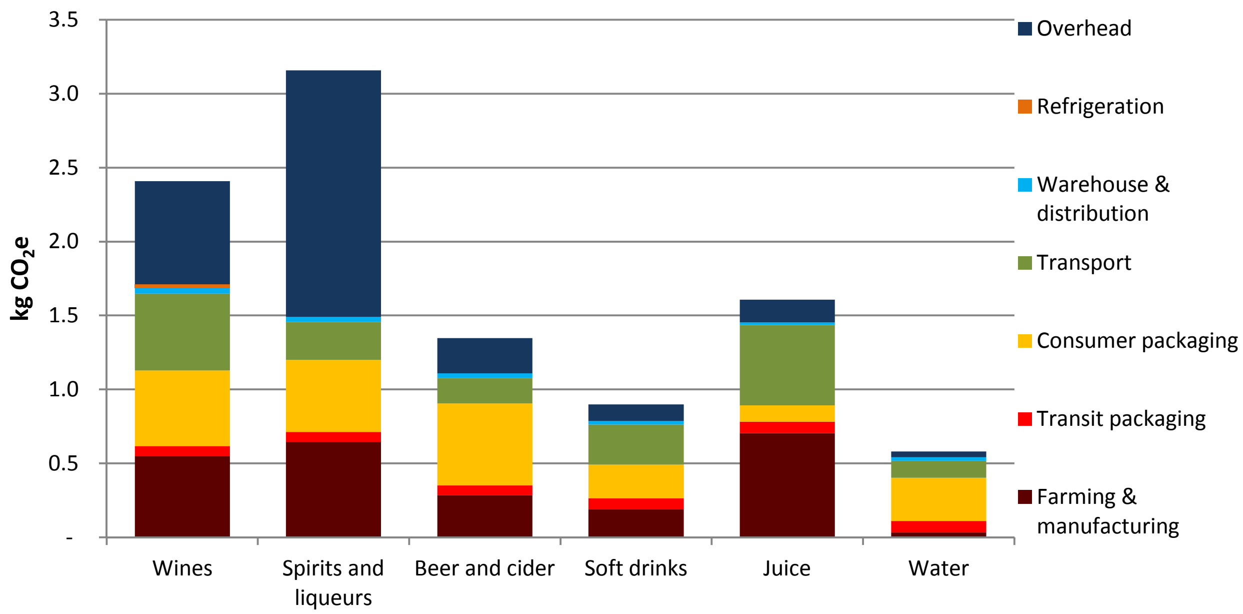
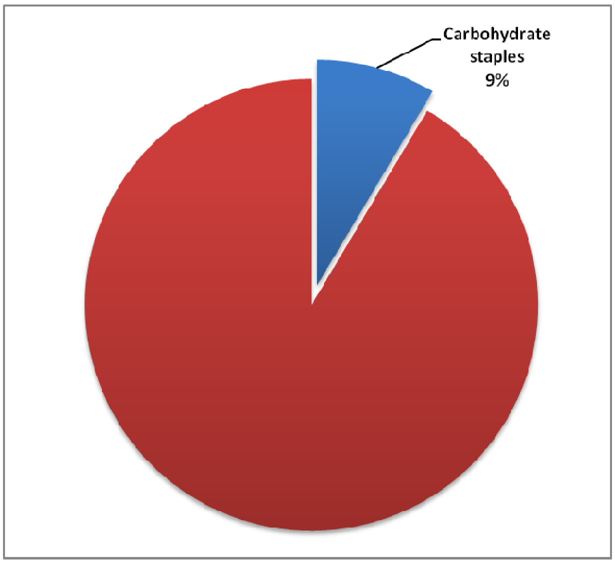


Figure 13: Breakdown of drinks by product type and life-cycle stage per litre

4.3.6 Carbohydrate staples



All carbohydrate staples form a relatively low carbon part of a healthy diet. Although rice is significantly more carbon intensive than wheat, cereals, bread and pasta, it too is a relatively low carbon food.

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.

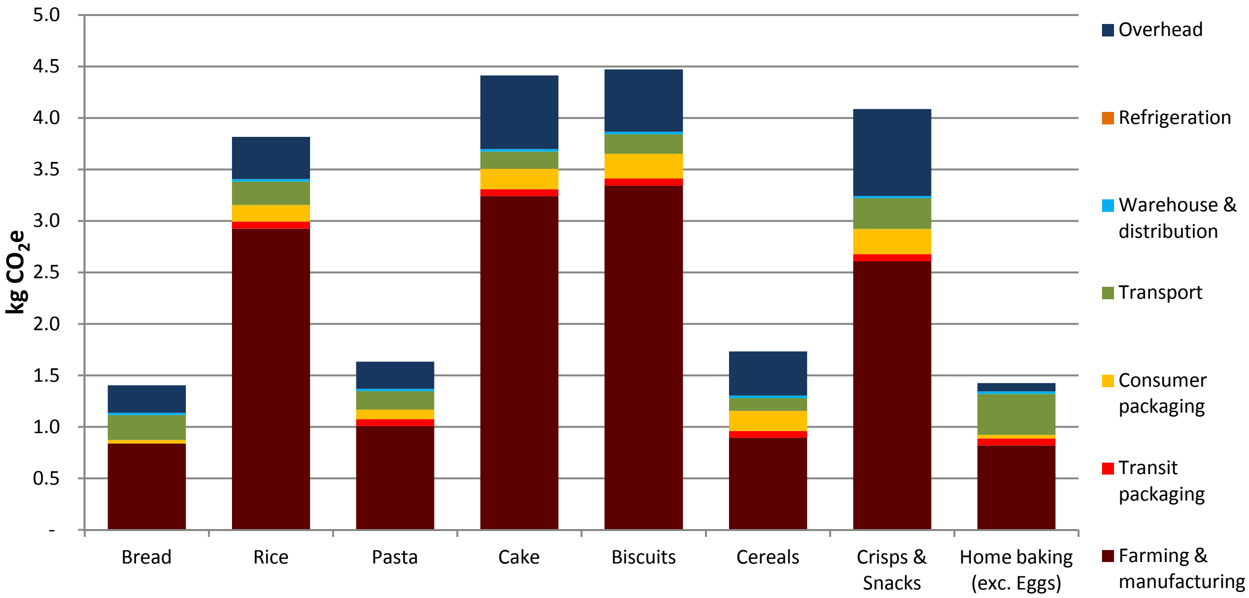
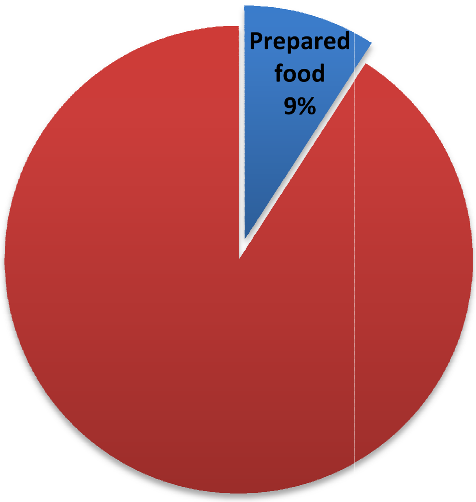


Figure 14: Breakdown of carbohydrate staples by product type and life-cycle stage per kg of product

4.3.7 Prepared food



This is a varied and complex group, with each product being made up of a number of ingredients, combined through processing. 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 should be helpful here. Post-purchase emissions may benefit from the avoidance of promotions that encourage over-buying of on short shelf life products.

Ensuring that products with less carbon intensive fillings are as appetising as possible can only help.

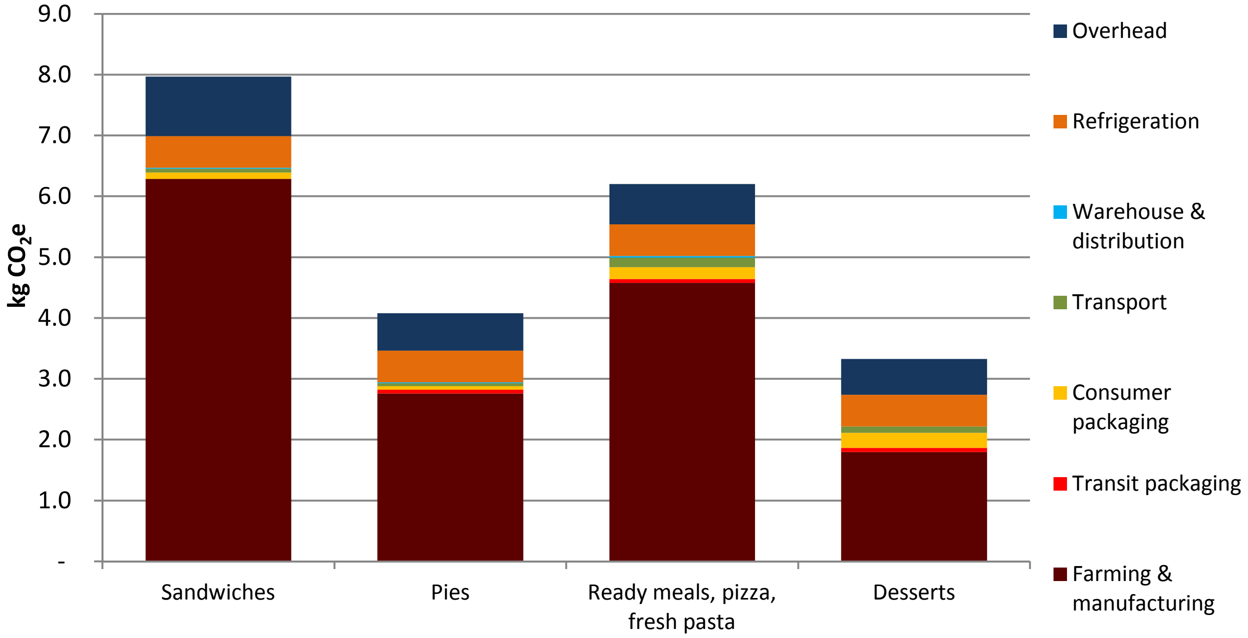
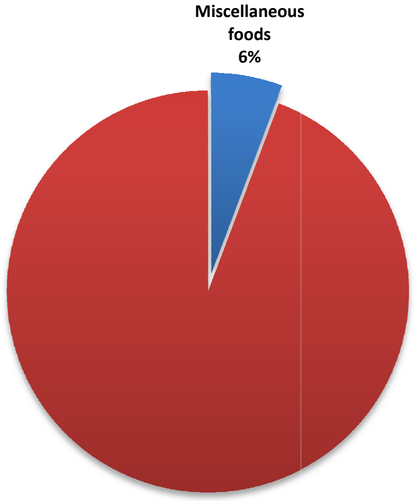


Figure 15: Breakdown of prepared foods by product type and life-cycle stage per kg of product

4.3.8 Miscellaneous foods



This complex and varied group is probably not deserving of priority attention for carbon management. However, it is worth noting that packaging and transport are relatively high components of their footprint.

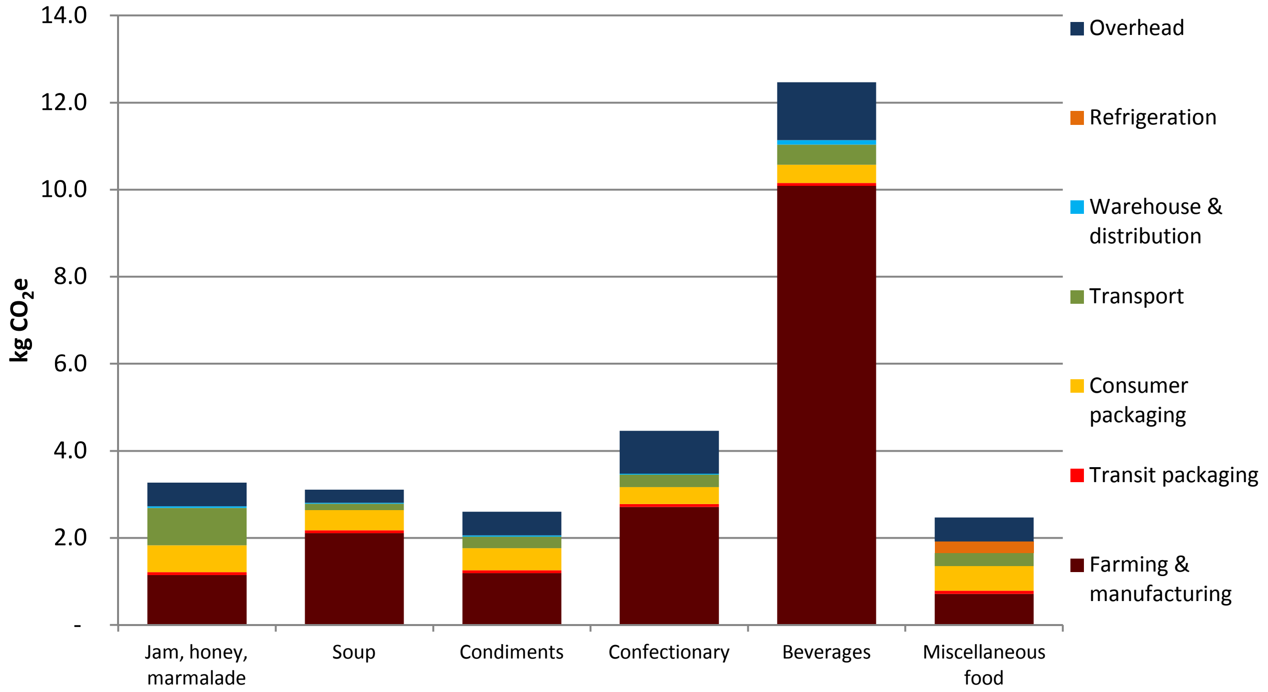
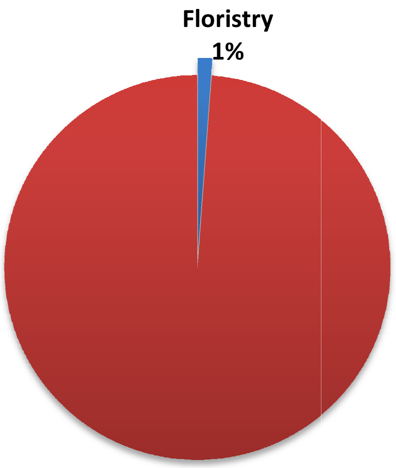


Figure 16: Breakdown of miscellaneous foods by product type and life-cycle stage per kg of product

4.3.9 Floristry



This category contains a few very carbon-intensive products and was the focus of a mini-report we compiled for Booths in 2009, summarised here.

We believe that around 26% of flowers (by value) are grown in season in the UK without requiring artificial heat. This is the lowest carbon option.

Around 6% are grown in other parts of Europe in season (Holland, Italy, Germany) and are transported by road. This is also a fairly low carbon option.

Around 18% are imported by air, mainly from Kenya, with some from Israel and Columbia

Around 50% are grown in artificially heated greenhouses, mainly in Holland. This is almost certainly the most carbon-intensive option. One study by Cranfield University estimated that the footprint of a single cut rose from the Netherlands had a footprint of 3.2 kg CO_2e. The same study estimated that the footprint could be cut by a factor of six by importing by air from Kenya (Williams, 2007).

Figure 17 shows our best estimate of the floristry category in more detail and highlights the striking difference in carbon intensity of different flowers. Of particular note is the contrast between daffodils grown in indoors compared to those grown outdoors.

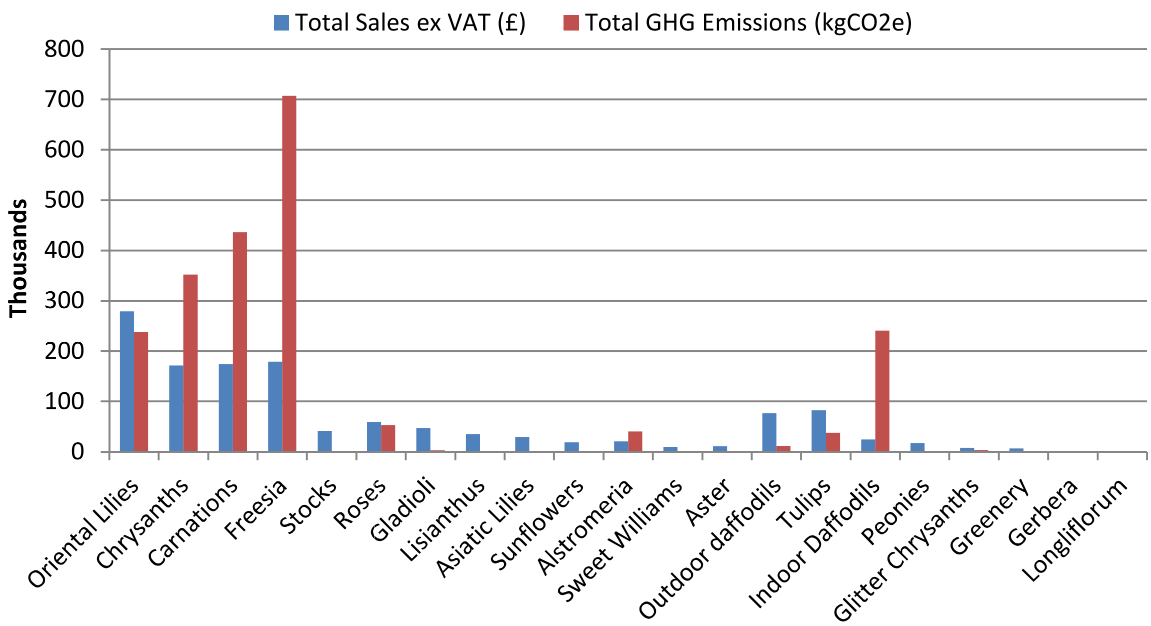
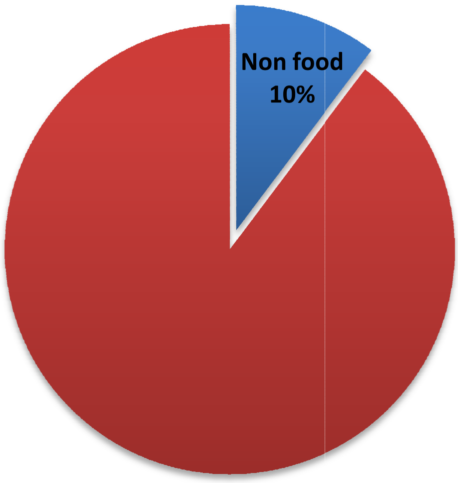


Figure 17: Comparison of total GHG emissions and total sales (2009 data)

There has been relatively little research globally on the complex GHG impact of the floriculture industry. There remains, therefore, high uncertainty in our footprint estimates, particularly of the individual flower types.
All commercial cut flowers raise further sustainability issues which deserve consideration alongside carbon and commercial issues.

One recent success story, since 2009, has been the de-ranging of indoor daffodils, followed by their re-introduction from a significantly less intensively heated source.

4.3.10 Non-food



Our analysis of these diverse categories was fairly generic. It is worth noting that, as a general rule, the importing of manufactured goods from less carbon efficient countries has more impact than sourcing from developed countries.

Some non food products can encourage lower carbon lifestyles. Potential examples include storage containers for left-over food and gardening equipment.

(Note that Figure 18 shows the carbon intensity per £ rather than per kg since this is more meaningful in this product group.)

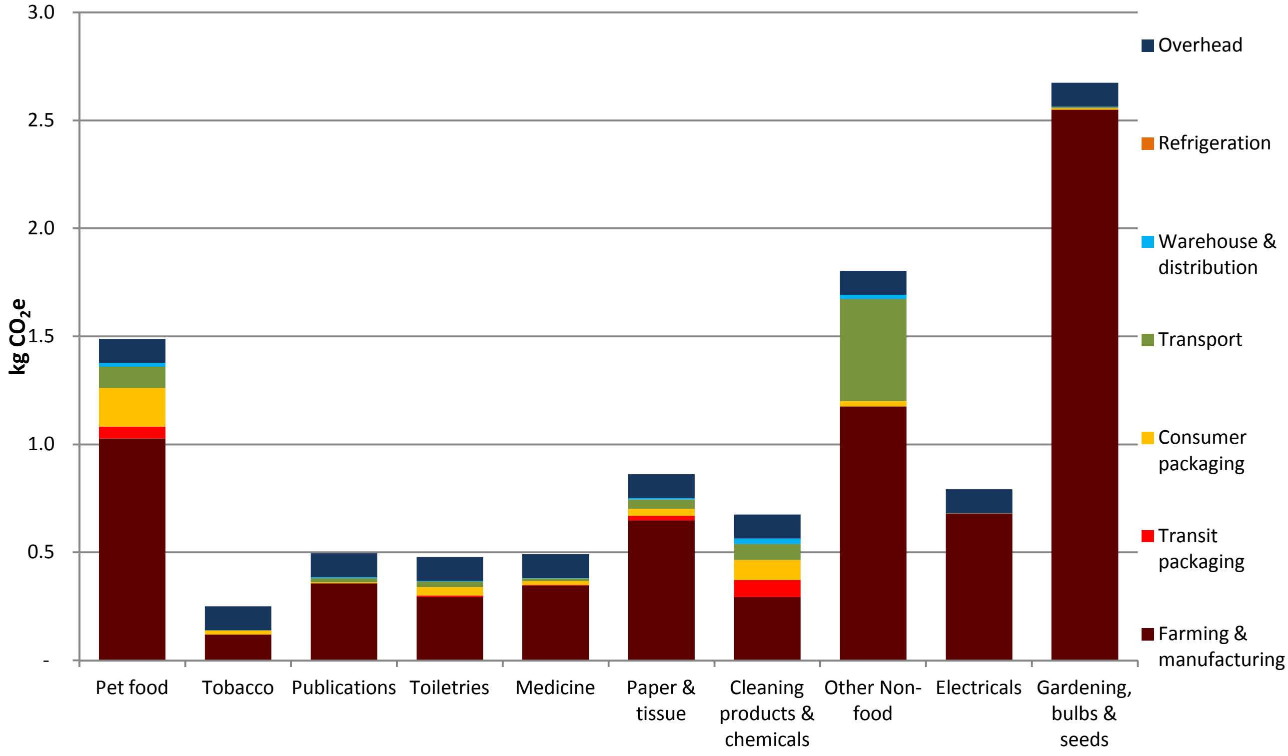


Figure 18: Breakdown of non-food products by product type and life-cycle stage per £

4.4 Analysis by 77 product categories

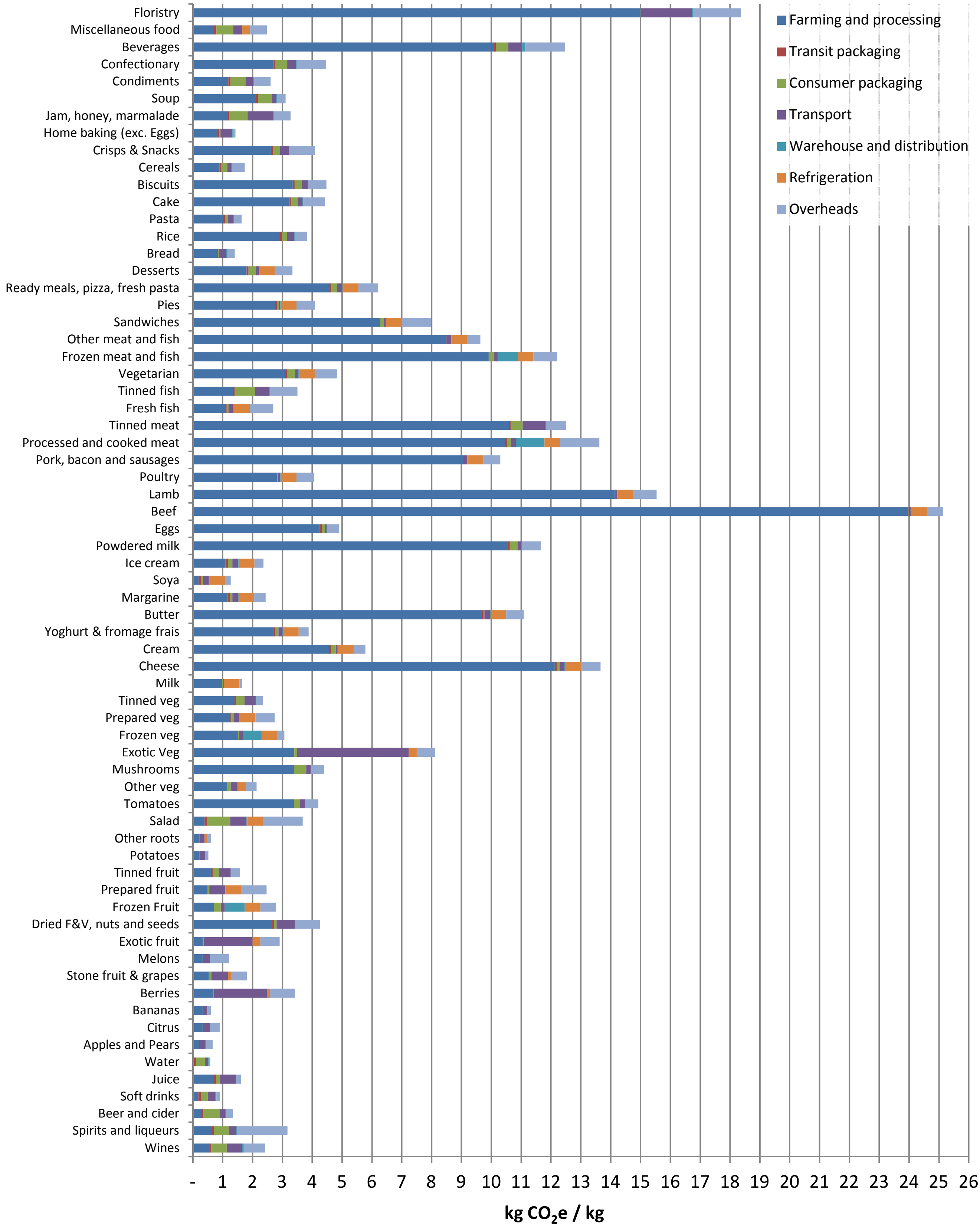


Figure 19: Comparison of kg CO_2e per kg of products (food products and floristry only)

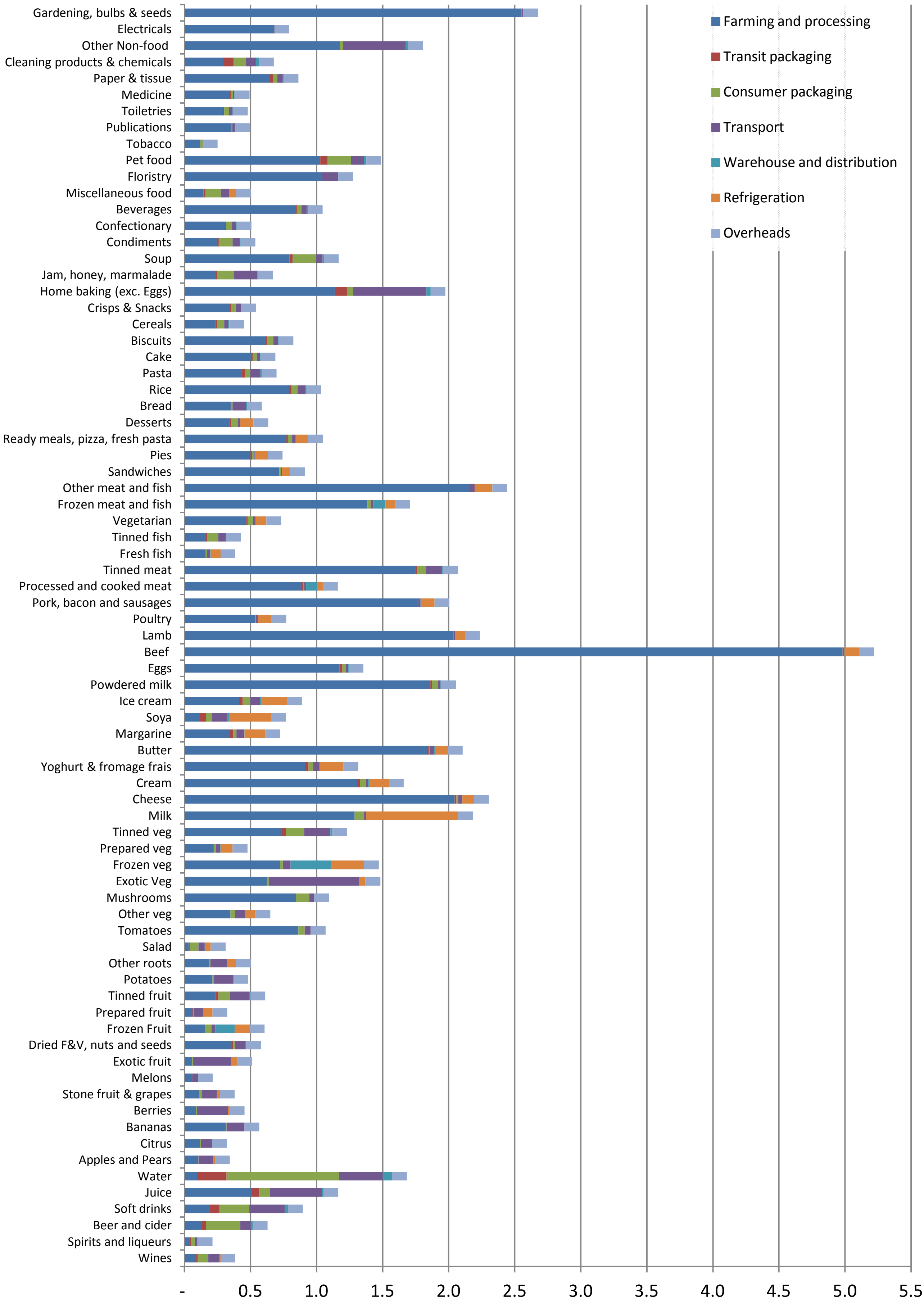


Figure 20: Comparison of kg CO_2e per £ of products

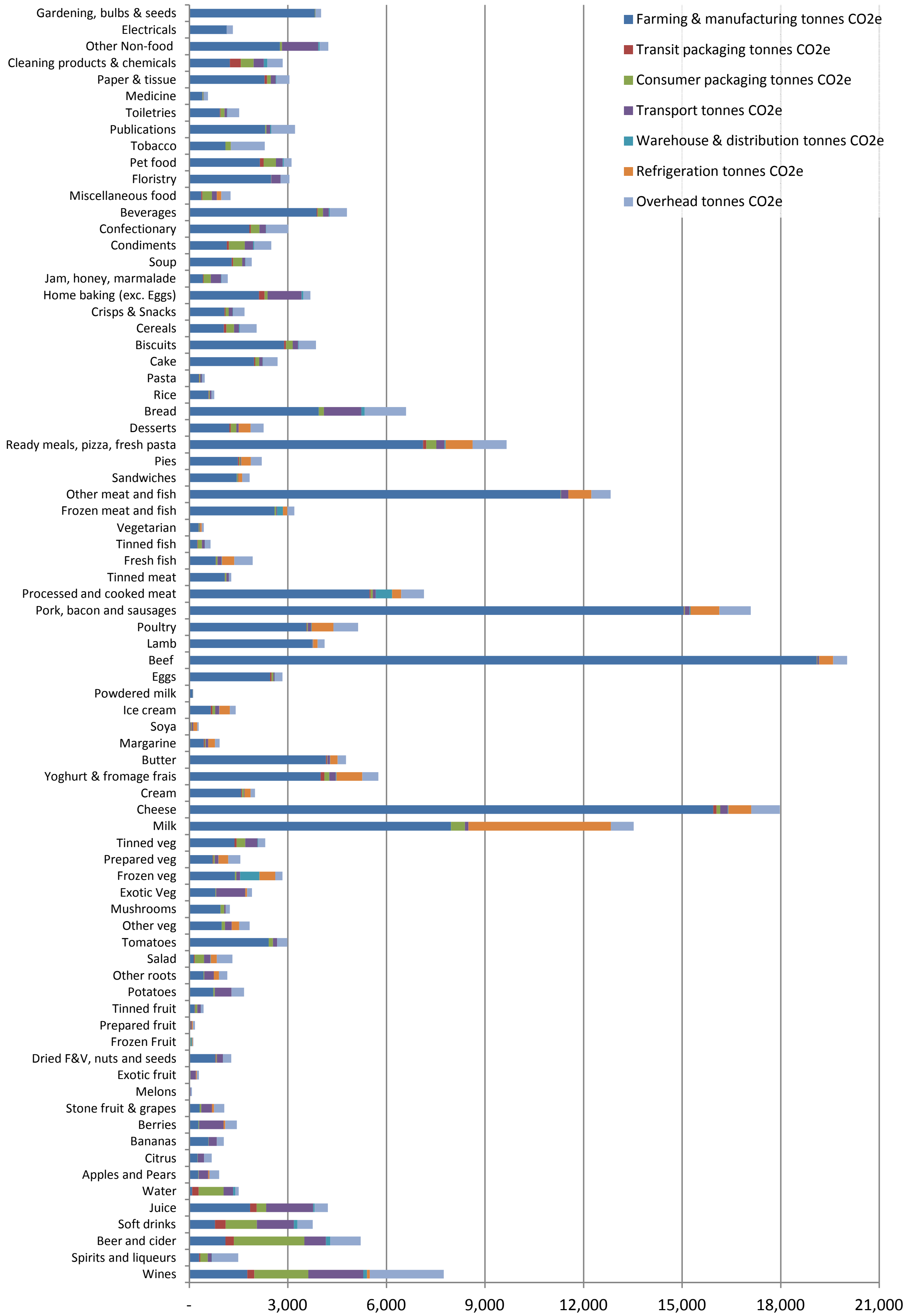


Figure 21: Comparison of total tonnes CO_2e of products

Figures 19 and 20 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 21 shows the total emissions from each category. The top 5 contributors to the total footprint are:

- Beef
- Cheese
- Pork, bacon and sausages
- Milk
- Other meat and fish.

These 5 categories account for nearly a third (32%) of the total footprint.

5 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.

5.1 Food product life-cycle analysis overview

5.1.1 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.

5.1.2 Boundaries and functional units

Similar reviews have been attempted before, the most commonly cited being a Swedish study by Wallén *et al*[18]. 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.

5.1.3 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.

[18] Wallén *et al*., 2004.

Category	Source	Total EF within study boundary (kg CO_2e/kg)	Boundary of study	Does the source enable cradle - primary processing to be distinguished?	EF (kg CO_2e/kg) 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**

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

Table 2: Full list of food emissions factors

The following sections provide a summary of the review undertaken. Each section contains a comparison with the emission factors (EF) used in our 2009 assessment along with a brief discussion of the sources selected.

5.2 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 CO_2e 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 64.7grams).

5.3 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.

5.4 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 CO_2e 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.

5.5 Fruit and vegetables

	2009	2011

[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.

	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 CO_2e 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.

5.6 Note on other products

Numerous other emissions factors have been collated see Table 2.

5.6.1 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.

5.6.2 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.

5.6.3 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.

5.6.4 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.

5.6.5 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].

5.6.6 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).

5.6.7 Non-food product categories

EFs for non-food product categories have been estimated using EIO methodology. (See sectio*n 5.7.6 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.

5.7 Non product related EF

5.7.1 Energy and fuel

Direct emission emissions factors were taken from Defra[32]. 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	0.62	kg CO_2e / kWh
Natural Gas	0.24	kg CO_2e / kWh
Gas Oil	3.40	kg CO_2e / litre
Diesel	3.55	kg CO_2e / litre
Petrol	3.16	kg CO_2e / litre

Table 7: Energy and fuel emissions factors

5.7.2 Refrigerant gas leakage

For blends of refrigerant gases, two sources were used, Bitzer[33] and Tecumseh[34] and for R507C, which is not included in these two sources Hamilton Clarke provided their own EF.

Refrigerant gas	EF	Unit
R507	3,850	kg CO_2e / kg
R507C	1,520	kg CO_2e / kg
R22	1,700	kg CO_2e / kg
R404A	3,780	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

5.7.3 Commuting and staff business travel

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.

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

Mode	EF	Unit
Average car	0.71	kg CO_2e / mile
National Rail	0.88	kg CO_2e / £

[32] Defra, 2011.

[33] Bitzer 2010.

[34] Tecumseh 2009.

[35] Defra, 2011.

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

5.7.4 Freight transport

Direct emission emissions factors are taken from Defra[36]. 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 approx 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	0.38	kg CO_2e / tonne mile
Rail	0.09	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	5.35	kg CO_2e / tonne mile
Long-haul International Air Freight	2.44	kg CO_2e / tonne mile
Flowers Road Transport	0.96	kg CO_2e / tonne mile
Flowers Sea Transport	0.14	kg CO_2e / tonne mile
Flowers Short-haul air freight	24.84	kg CO_2e / tonne mile
Flowers Long-haul air freight	3.80	kg CO_2e / tonne mile

Table 10: Derivation of freight emissions factors

5.7.5 Consumer food packaging

The emissions factors for packaging were mostly derived from the emissions of the raw materials from which they are made[37]. 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[38] these have not been updated for the 2011 report.

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

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[39], 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.

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

[39] Hammond and Jones, 2006.

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%[40] compared to a steel packaging rate of 44%[41] 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%[42] compared to a UK aluminium packaging recycling rate of 32.5%[43]. 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

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[44] 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

[40] Hammond and Jones, 2006.
[41] Waste Online: Metals, 2003.
[42] Hammond & Jones, 2006.
[43] Alupro, 2006.
[44] Hammond & Jones, 2011.

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

5.7.6 Other goods and services

Other goods and services were categorised according to a representative IO category based on data for 123 industrial sectors[45] 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
Textile fibres	0.60
Textile weaving	0.87
Textile finishing	1.02
Made-up textiles	0.29
Carpets and rugs	0.19
Other textiles	0.70
Knitted goods	0.99
Wearing apparel & fur products	0.29
Leather goods	0.57
Footwear	0.19
Wood and wood products	0.84
Pulp, paper and paperboard	1.13
Paper and paperboard products	0.65
Printing and publishing	0.36
Coke ovens, refined petroleum & nuclear fuel	0.66
Industrial gases and dyes	2.29
Inorganic chemicals	1.29
Organic chemicals	1.67
Fertilisers	3.38
Plastics & Synthetic resins etc	1.47
Pesticides	1.21
Paints, varnishes, printing ink etc	0.65
Pharmaceuticals	0.35
Soap and toilet preparations	0.29
Other Chemical products	1.04
Man-made fibres	2.78

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
Jewellery & related products	1.20
Sports goods and toys	0.24
Miscellaneous manufacturing nec, recycling	0.80
Electricity production & distribution	5.63
Gas distribution	1.40
Water supply	1.02
Construction	0.52
Motor vehicle distribution & repair, fuel	0.49
Wholesale distribution	4.59
Retail distribution	3.12
Hotels, catering, pubs etc	0.50
Railway transport	0.88
Other land transport	0.93
Water transport	1.99
Air Transport	4.68
Ancillary Transport services	0.40
Postal and courier services	0.49
Telecommunications	0.45
Banking and finance	0.24
Insurance and pension funds	0.38
Auxiliary financial services	0.28
Owning and dealing in real estate	0.17
Letting of dwellings	0.14
Estate agent activities	0.16
Renting of machinery etc	0.68
Computer services	0.16

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

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

5.7.7 Miscellaneous materials

Other emissions factors for materials were taken from the updated ICE model[46].

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

5.7.8 Waste

Defra[47] 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] Hammond & Jones, 2011

[47] Defra, 2011.

6 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[48]. In the UK, the main data sources are the *'Combined Supply and Use Matrix for 123 sectors'*[49] and the *'UK environmental accounts'*[50], 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[51]. 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[52].
- 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

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

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

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

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

[52] 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[53].

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[54]. (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[55] 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

[53] 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.
[54] ONS (Office of National Statistics), 2010[a]
[55] 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[56], based on the IPCC's discussion of aviation in its Fourth Assessment Report[57]. 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[58] (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 ($\mathbf{G}_{UK}$). This is the vector of GHG intensity of each sector per unit financial output.

For each industry,

$$g_{UK_i} = e_{D_i} / o_{BP_i}$$ i = 1 to 123 (industrial sectors) 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:

$$e_{ij} = l_{ij} . g_i$$ i= 1 to 123 (industries), j= 1 to 123 (industries) 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

$$e_{Total_{ij}} = e_{ij} . f_{BP_j}$$ 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.

[56] Defra, 2011
[57] IPCC, 2007
[58] 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,

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

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.

7 Appendix C: Sources

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