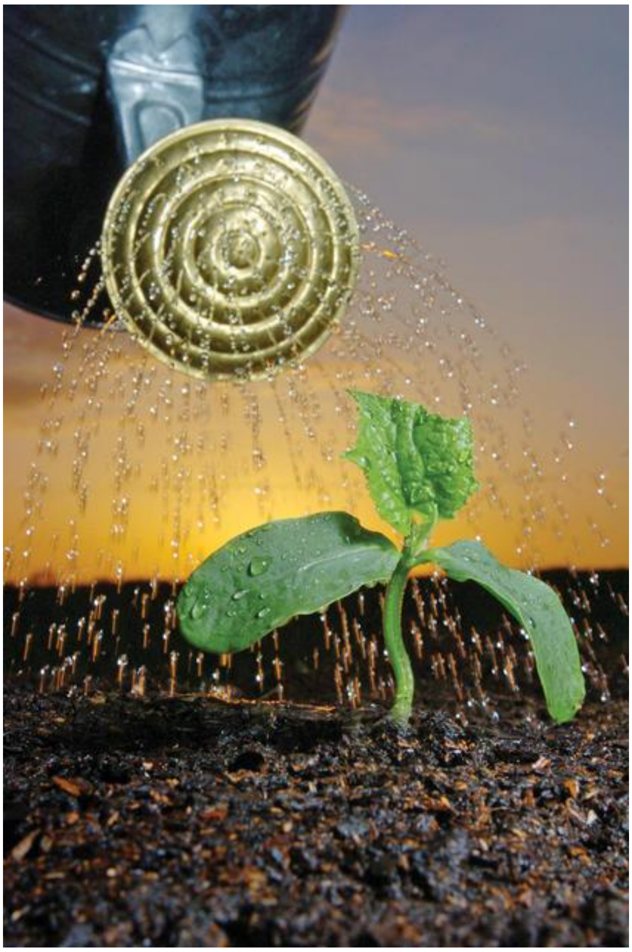
Material change for a better environment

WORKING TOGETHER FOR A WORLD WITHOUT WASTE

WWF

Final report

The water and carbon footprint of household food and drink waste in the UK



A report containing quantification and analysis of the water and carbon footprint of different types of household food and drink waste in the UK. In addition to raising awareness, the information can be used in developing national and regional policies targeting a reduction in the impacts of our carbon and water footprint related to our food system. It can also be used by the food industry to understand and minimise water-related business risk associated with food supplies to the UK.

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Front cover photography: Watering Seedling (Graham Flack)

Executive summary

In 2009, WRAP (Waste & Resources Action Programme) identified that UK households dispose of 8.3 million tonnes of food and drink waste every year, most of which could have been eaten. This avoidable food waste has a value of at least £12 billion. However, financial cost is not the only impact. By wasting food, we also waste the water and energy that was used to grow and process those foods, create greenhouse gas emissions, and have a range of other environmental impacts.

The purpose of this report is to further raise awareness and to highlight the consequences on the UK and global environments of the large amount of food wasted in the UK. One of the main objectives of this report is to quantify the water and carbon footprints of household food waste in the UK, and to present the results in the context of impacts across the supply chain. The report builds on work published by WWF-UK (Chapagain & Orr 2008) that quantified the water footprint of the UK. WRAP and WWF-UK have worked together to produce this report which, for the first time, provides an estimate of the amount of water used within the UK and abroad in food and drink which is subsequently wasted in the UK. In addition, it also analyses this information in the context of water scarcity at production regions.

The water footprint of the UK calculates the amount of water used to produce goods and services consumed in the UK, as the sum of direct (e.g. household water use) and indirect (water used along the supply chains of goods and services) water. Previous research by WWF-UK (Chapagain & Orr 2008) has found this to be 102,000 million cubic metres of water per year. Our research has found that the water footprint of avoidable food waste is 6,200 million cubic metres per year representing nearly 6% of all our water requirements. In per capita terms, this is 243 litres per person per day, approximately one and a half times the daily average household water use in the UK. A quarter of this water footprint represents water used to grow and process food here in the UK, i.e. water from the UK's rivers, lakes and aquifers.

It is estimated that avoidable food waste is responsible for greenhouse gas emissions of 20 million tonnes CO_2 equivalent per year, accounting for the whole life cycle. Avoidable food waste represents approximately 3% of the UK's domestic greenhouse gas emissions, with further emissions from overseas components of the supply chain. In contrast to the water footprint, approximately two thirds of emissions associated with food waste occur within the UK. These emissions are equivalent to those produced by over 7 million cars per year. The most significant contributors to avoidable carbon emissions are milk waste, coffee waste and wheat products (bread, cake etc.). The research also suggests that for some food and drink items, indirect emissions associated with Land Use Change caused by levels of demand for those items are greater than direct emissions.

The impact of greenhouse gas emissions is global; in terms of climate change, it does not matter where they are emitted. For water, knowing the location of the point of water use, and the relative scarcity of water resources in that location, is essential to understanding the social and ecological impacts of our footprint. This report identifies where in the world water is used to produce the part of the food being wasted in the UK and relates this to water scarcity in these production regions, with case studies for two countries. Case studies are also presented for foods for which waste has a high water footprint, and which are associated with supply chains reliant on areas where water is scarce.

The study is limited to carbon and water footprints only and doesn't include other environmental impacts associated with food production, consumption and waste. Nor does this report address issues relating to social and economic costs and benefits with water use and carbon emissions.

The findings of this research highlight that actions to reduce food waste can have a significant impact on the amount of water we use and the amount of greenhouse gases we emit. They reinforce the messages from WRAP and WWF-UK on the importance of preventing food waste at all stages of the supply chain. By reducing food waste, householders can save money and also make a significant contribution to addressing current environmental concerns in the UK and abroad. Reducing food waste will not, by itself, solve all the problems of climate change and poor water management, but it can make a positive contribution.

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Acronyms

- CF – Carbon footprint
- Defra – Department for Environment, Food and Rural Affairs
- DFID – Department for International Development
- EA – Environment Agency, UK
- EF – Ecological footprint
- EWF – External water footprint
- FAO – Food and Agriculture Organization of the United Nations, Rome
- FCRN – Food Climate Research Network
- GHG – Greenhouse gas
- GWP – Global warming potential
- ITC – International Trade Centre
- IWF – Internal water footprint
- LA – Local authority
- OPF – One Planet Food Programme, WWF-UK

- SIWI - Stockholm International Water Institute
- WBCSD – World Business Council for Sustainable Development
- WF – Water footprint
- WFN – Water Footprint Network
- WRAP – Waste & Resources Action Programme, UK
- WWF – World Wide Fund For Nature (Formerly World Wildlife Fund)

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1 Introduction

The 2010 Living Planet Report (WWF 2010) shows that we are consuming the earth's resources much faster than they can be replenished and are destroying the very systems on which our food supply depends; some two thirds of our ecosystems, including our forests, oceans, rivers and lakes, are in decline.

The food we buy accounts for 23% of our ecological footprint - a measure of our environmental impact on the world (WWF 2010). However, not all of this food is consumed. The comprehensive WRAP report *Household food and drink waste in the UK* (Quested & Johnson 2009) highlighted the importance of understanding the connection between wastage rates and resources used in the production process of these goods. The report classified household food waste in the UK based on avoidability (*avoidable, possibly avoidable, unavoidable*), disposal routes and reasons for disposal. 'Avoidable waste' is classified as the food and drink thrown away that was, at some point prior to disposal, edible, e.g. milk, lettuce, fruit juice, meat (excluding bones, skin etc.). 'Possibly avoidable waste' is classified as the food and drink that some people eat and others do not, e.g. bread crusts, or that can be eaten when a food is prepared in one way but not in another, e.g. potato skins. 'Unavoidable food waste' is classified as the waste arising from food and drink preparation that is not, and has not been, edible under normal circumstances, e.g. meat bones, egg shells, pineapple skin, tea bags.

The WRAP report estimated that the total amount of food and drink waste generated by households in the UK is 8.3 million tonnes per year (Quested & Johnson 2009). The average UK household wastes around 22% of total food and drink purchases, and the proportion of waste deemed avoidable or possibly avoidable prior to disposal amounts to 81% of the total food and drink wasted. The report concludes that reducing the considerable amount of household food and drink waste generated in the UK saves households money, while reducing our environmental impact.

With the publication of WWF-UK's report on the water footprint of the food and fibre consumption in the UK and its impact on global water resources (Chapagain & Orr 2008), quantification of water use by food consumption in the UK became possible. The WWF report, for the first time, not only quantified but also mapped where in the world water is being used to grow agricultural and industrial products consumed in the UK. The report contained recommendations for businesses, government and individuals on how they could manage the impact of their water footprint, one of the recommendations being the reduction of food waste.

Wasting food unnecessarily represents a direct waste of precious water resources, though to date there has been little quantification of water associated with food waste (Lundqvist *et al.* 2008). Recent studies have been undertaken quantifying the volume of water waste related to a single fruit industry (mango) in Australia (Ridoutt *et al.* 2009) and beef, potatoes and tomatoes in the UK (Langley *et al.* 2010, Lewis 2010). In the United States it has been reported that wasted calories account for about a quarter of the country's freshwater consumption (The Economist 2009).

In addition to water, the UK food economy is also responsible for a significant quantity of greenhouse gas emissions in the UK and abroad. Several studies have attempted to quantify the footprint of specific food and drink products, but to date no research has been published on the national impacts of UK household food waste. Given the fact that a large proportion of food is wasted, it is also relevant to assess the equivalent carbon footprint of household food waste.

The quantification of water and carbon footprints of food and drink waste is potentially of interest to a range of stakeholders such as consumers, food retailers, suppliers and producers, NGOs, environmental agencies, water managemers, national and regional governments. The information can be used in a variety of contexts such as:

- identifying foods with high and low environmental impacts;
- identifying where to focus efforts to reduce the environmental impact of food production and to improve management of natural resources;
- understanding the way in which changes to the food supply chain can contribute to wider environmental policy objectives; and
- supporting activity in preventing food waste.

WRAP and WWF-UK have therefore worked together to estimate the footprints of household food and drink waste in the UK and analyse them in the context of water and environmental resources management.

It is important to recognise that food production is, in most parts of the world, an important economic activity which provides benefits to many people. This is particularly the case in developing countries where agriculture is often the primary source of income for poor rural communities. Equally, mismanagement of natural resources such as water can have adverse impacts on the poorest people. While acknowledging these issues, WRAP and WWF-UK have not, in this report, sought to quantify them in relation to water and carbon footprints of food waste. Any policy responses stimulated by the information in this report should also be informed by analyses of the social and economic components of natural resource management.

2 One Planet Food programme at WWF-UK

In January 2009, WWF-UK launched the One Planet Food programme (OPF). Its aim is to reduce the negative environmental and social impacts of UK food consumption. It takes a holistic approach and impacts are analysed across the whole food chain, from the production of commodities through processing and on to consumption and disposal. This is a complex task, and since 2008 WWF-UK has been working in collaboration with scientists and key actors in the food system – businesses, policy makers, consumer organisations and other non-governmental organisations – to understand the impacts of the food consumed in the UK, whether grown here or imported from abroad. The OPF engages with these various stakeholders to achieve three key goals - reducing greenhouse gas emissions from food consumption in the UK, eliminating unsustainable impacts on freshwater ecosystems in relation to water scarce areas, and changing trading patterns and governance structures so that UK food is making a net positive contribution to ecosystems and the services they provide.

The OPF aims to reduce the negative environmental impacts of a number of key commodities (for example, fish, soya, beef and palm oil) through the establishment of multi-stakeholder initiatives. At the same time it also collaborates with others on some of the equally important consumption drivers including diets and food waste (WWF-UK 2009). The programme runs a number of initiatives around WWF-UK's three key strategic priorities, which are:

- to work with the food business sector to assess business risk and to reduce negative impacts throughout the value chain;
- to work with producers on a livestock dialogue programme; and
- to work with government on issues such as sustainable diets.

The OPF programme supports and works collaboratively across the food system - as exemplified through its Tasting the Future initiative (WWF-UK 2010).

3 WRAP and food waste

Preventing food waste, and managing that which arises more effectively, are among WRAP's priorities. Food is a significant proportion of household and business waste in the UK, accounting for 18% and 8% of waste arisings respectively (Resource Futures 2009, Defra 2010b).

Households throw away more food and drink (8.3 million tonnes) each year than packaging (4.9 million tonnes). Avoidable food waste adds around £600 to the average family annual grocery bill. WRAP's 2008-2011 business plan aims to help reduce household food and drink waste by 250,000 tonnes, making a significant contribution to both national efforts to reduce greenhouse gas emissions and diversion of biodegradable municipal waste from landfill as required by the 1999 EU Landfill Directive.

The WRAP campaign '*Love Food Hate Waste*' (WRAP 2010a) aims to raise awareness of the amount of avoidable food waste thrown away. It provides advice on how easy practical everyday actions in the home can help us all waste less food, which will ultimately benefit our finances and the environment.

Success in delivering food waste reduction relies on the support of the whole grocery supply chain, local government, regulatory bodies, education sectors and trade associations. WRAP brings partners together through the Courtauld Commitment, a voluntary agreement aimed at improving resource efficiency and reducing the carbon and wider environmental impacts of the grocery retail sector. The results of the first phase of the Courtauld Commitment show that action by the UK grocery sector and WRAP, in partnership with local authorities, helped consumers reduce food waste by 270,000 tonnes between 2007-08 and 2009-10 (WRAP 2010b), exceeding the Business Plan target. Courtauld Commitment 2, launched in 2010, includes a target to reduce UK household food and drink waste by 4% by 2012 from a 2009 baseline (330,000 tonnes).

4 Scope and objective

The purpose of this report is to raise awareness of the wider impacts of food wasted in the UK, and to catalyse a discussion on the implications of these and how best to address them. This is done, first, by quantifying the water footprint of food waste and its potential impacts, especially in water scarce regions; then by linking water footprint data with the greenhouse gas impacts of wasted food, accounting for the whole life cycle. The report also identifies where in the world water is used to produce the part of the food being wasted in the UK.

The specific objectives of this study are to:

- quantify the water footprint of the food wasted by UK households in total and by country of origin;
- establish the linkages of wastage to locations where water resources are used and, in doing so, shed light on potential impacts on freshwater ecosystems;
- establish the carbon footprint of food waste by UK households in total and by item;
- classify the footprints by waste categories such as avoidable food waste; and
- present case studies for specific foodstuffs and specific locations.

The report does not attempt to paint a comprehensive picture of every environmental, social or economic impact – positive and negative – of food production, consumption and waste.

5 Concept

5.1 Association between food and drink waste and environmental impacts

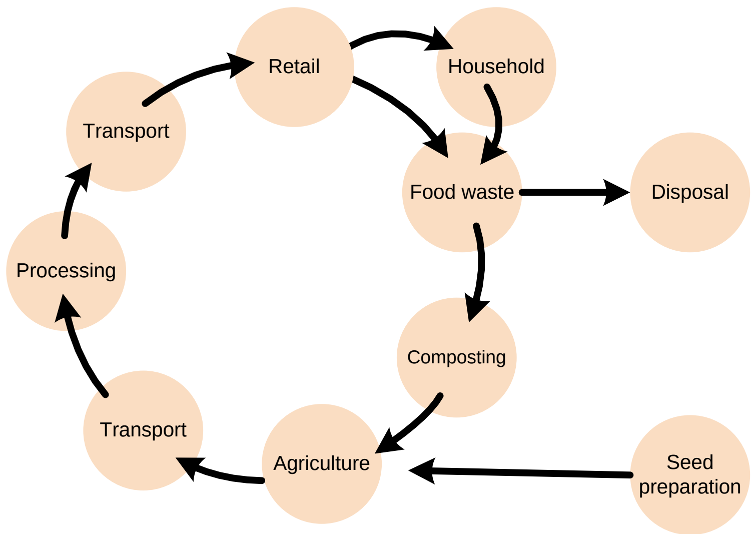
All products, including food and drink, create environmental impacts throughout their lives. Figure 1 below highlights the main stages in the life cycle of food and drink purchased by UK households. Although the diagram only shows food waste arising from retail and households, in reality it may also arise at any point within the supply chain.

The underlying hypothesis behind this report is that, if the food and drink were properly 'managed' (i.e. better decisions made during purchasing, storage, etc.), then wasted food and drink would not have had to be produced and the environmental impacts from all stages of the supply chain would be reduced. In other words, the resources employed to produce food and drink subsequently wasted would be available for other uses.

If water was not used to produce food that was subsequently wasted, it could have been used in other ways. For example, it could be used to grow the same crop for alternative markets, a different crop, or to replenish aquifers or water courses for subsequent extraction for drinking water or industrial applications.

In this study we have focused on the avoidable and possibly avoidable fraction of food waste only, as the impact associated with unavoidable food waste is allocated to food that has not been wasted (e.g. banana skins from bananas which have been eaten, tea bags used to make cups of tea), and from which unavoidable food waste is a natural consequence.

Figure 1: Simplified life cycle diagram for food.



5.2 Water footprint

The concept of footprint has been used successfully to describe the impact of production and consumption. It is most commonly applied to carbon, as in PAS2050 (BSI Group & Carbon Trust 2008) but recently it has been applied to water as well.

The founding stone of water footprint (WF) is the concept of 'virtual water'. In the early 1990s, Prof. Tony Allan coined the term 'virtual water' in an attempt to analyse the food and water security in the Middle East and Northern American countries (Allan 1996). It is defined as the volume of water required to produce a commodity or service along its whole supply chain. In its initial form, virtual water was seen as a rational means by which water-scarce countries could import water, embedded in goods, from water-abundant countries (Allan 2001).

The water footprint is an indicator of freshwater use that looks not only at the direct water use of a consumer or producer, but also at the indirect water use (Hoekstra & Chapagain 2008). It is a comprehensive indicator of freshwater resources appropriation, next to the traditional and restricted measure of water withdrawal (Hoekstra *et al.* 2011). The water footprint of a product is defined as the volume of freshwater used to produce the product, measured over the full supply chain. It shows water consumption volumes by source and polluted volumes by type of pollution. All components of a total water footprint are specified both in time and space.

The water footprint of a product comprises three colour-coded components (Hoekstra *et al*. 2011), which are green water (water evaporated from soil moisture supplemented by rainfall), blue water (water withdrawn from ground or surface water sources) and grey water (the polluted volume of blue water returned after production). Of these three components, the inclusion of green water is the most commonly debated. Whilst it is widely accepted that blue water resources are limited and their exploitation can have obvious effects, green water is often seen as water that could be exploited with limited adverse impacts on freshwater ecosystems. However, taking the use of soil moisture as granted has immensely undervalued the importance of green water in managing water resources wisely (Rockström 2001, Falkenmark 2003). Green water may also be scarce, and in the context of food waste it represents a potentially significant opportunity cost; if it was not used to grow food that was subsequently wasted, it could be used for an alternative crop which might have significant economic and/or nutritional value. In agriculture, green water can be substituted for blue water and vice versa, so both must be accounted for to obtain a full picture.

Food processing, whether it is simply washing prior to sale (e.g. carrots) or more complicated preparation (e.g. preparing a pizza with multiple toppings) uses large quantities of water. This is normally blue water which, once used, is generally discharged back to surface waters. Although most of this is 'non-evaporative use', the returned water is usually of a lower quality than the abstracted blue water, and additional blue water may be required to dilute or assimilate emissions (pollution) to the freshwater ecosystem from the production process. In the absence of accurate information on the assimilation capacity of freshwater ecosystems in the majority of places, grey water footprint accounting can be quite difficult and controversial.

In this study the scope of the water footprint is limited to the agricultural production phase, which is the stage with the largest water footprint in the whole supply chain (Figure 1). It is assumed that the quality of return flows is just enough to meet local norms and standards, although this inevitably underestimates the grey water footprints. In addition, the calculation does not include grey water footprints arising from other stages in the whole life cycle of the food.

The water footprint offers a wider perspective on how a consumer or producer relates to freshwater ecosystems. As argued by Hoekstra *et al.* (2011), it is not a measure of the severity of the local environmental impact of water consumption and pollution. The local environmental impact of a certain amount of water consumption and pollution depends on the vulnerability of the local water system and the attributes of water consumers and polluters making use of the same system. Water footprint accounts give explicit information on how water is appropriated for various human purposes for specific time and location. A water footprint can inform the discussion about sustainable and equitable water use and allocation, and also form a good basis for a local assessment of environmental, social and economic risks and impacts.

Agricultural production uses large amounts of water; for example, Chapagain and Hoekstra (2004) calculated that, in the Netherlands, it requires 1,300,000 litres of water to produce a tonne of wheat and 15,500,000 litres to produce a tonne of beef. The recent WWF report suggests that imported food and fibre account for 62% of the UK's total water footprint (Chapagain & Orr 2008). In countries where water stress is less extreme, such as the UK, the impact of water use is generally concentrated in certain areas (such as East Anglia) and is restricted to certain times of the year. Although water abstraction for agriculture is less than 1% of total blue water abstraction in the UK, in some catchments and at peak times it can exceed abstraction for domestic water supply. However, in countries where water stress is common, blue water abstraction can have much more severe impacts. For detailed water footprint accounting and impact assessment please see Appendix 6.

5.3 Carbon footprint

As with water footprint, carbon footprint accounting can be carried out at a variety of levels (e.g. national, per person, product, service etc.). Despite the high level of interest in carbon footprinting, there is a surprising lack of agreed definitions as to what a carbon footprint is. The *Guide to PAS 2050* (BSI 2008) suggests that: "The term 'product carbon footprint' refers to the greenhouse gas emissions of a product across its life cycle, from raw materials through production (or service provision), distribution, consumer use and disposal/ recycling. It includes the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), together with families of gases including hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs)."

In WWF's One Planet Economy Network Europe Project (OPEN: EU) an agreed definition of a Carbon Footprint has been developed in conjunction with a range of organisations. Here WWF suggest that *"Introduced in the scientific and public arena almost ten years ago, the Carbon Footprint is a measure of the total amount of GHG emissions that are directly and indirectly caused by an activity or are accumulated over the life stages of a product. This includes activities of individuals, populations, governments, companies, organizations, processes, industry sectors, etc. Products include goods and services. In any case, all direct (on-site, internal) and indirect emissions (off-site, external, embodied, upstream, and downstream) need to be taken into account."*

As identified in this definition, climate change is influenced by a range of greenhouse gases. Each of these has a different potential to increase atmospheric temperature. To enable them to be discussed in a common language, characterisation factors are applied to the gases against a standard radiative effect (the act of emitting or causing the emission of radiation). The characterisation model for climate change, as developed by the Intergovernmental Panel on Climate Change (IPCC), contains a series of internationally recognised characterisation factors. Factors are expressed as global warming potential (GWP) for a time horizon of 100 years (GWP100), in kg carbon dioxide equivalent (CO_2 eq)/kg emission. For a calculation of lifetimes and a full list of greenhouse gases and their global warming potentials please refer to (Solomon *et al.* 2007).

Greenhouse gas emissions arise at every point in the life of a product. Emissions may be direct (from animals, fertiliser application, fuel use) or indirect (e.g. from electricity generation). In this study all stages shown in Figure 1 have been considered in estimating the carbon footprint of food waste. The approach taken is to view emissions from a consumption perspective. This means that emissions associated with cultivating and transporting food destined for the UK but grown elsewhere are included, and in turn a proportion of emissions from UK agriculture are allocated to food exported from the UK, so not included herein. Several studies have highlighted that imports of all goods account for around a third of the UK / European greenhouse gas emissions from a consumption perspective (Wiedmann *et al.* 2008, Davis & Caldeira 2010, Brinkley & Less 2010). This approach is in line with the approach taken in water footprint accounting within this report.

Unlike a water footprint, there are no local or regional interpretations of the impact of carbon emissions; a kilogram of carbon dioxide emitted in one country contributes to climate change in the same way as a kilogram emitted elsewhere (Forster *et al.* 2007).

Carbon footprinting may be used in a variety of ways. It may be used in auditing the environmental impacts of a nation, company, individual or product; setting targets to reduce emissions; public reporting; and awareness raising. In this document, the objective is to raise awareness of the total carbon footprint of food waste and the current understanding of where most emissions occur.

As well as data gaps for processed food, we have assumed that the greenhouse gas emissions associated with growing the same crop in different countries remains constant. This is a significant limitation, as from studies by Mila i Canals *et al.* (2007) and others, it is known that the emissions associated with growing a foodstuff vary by season and location. For example, tomatoes grown in heated greenhouses in the UK will have a very different emissions profile to those grown outdoors in Spain. The use of single figures in this analysis does not allow for illustration of the varying emissions associated with wasting food at different times of the year or from different sources. There are a range of data gaps for different food products at present. In the short to medium term we anticipate that this will be filled through a wider adoption of product carbon footprinting using PAS 2050, the WRI/WBCSD GHG Protocol and the upcoming ISO Standard on product carbon footprinting. For details on carbon footprint accounting and impact assessment please see Appendix 5.

5.4 Land Use Change

Land Use Change is responsible for 18% of global greenhouse gas emissions, principally from deforestation (Herzog 2009). The FAO (2007) estimate that 58% of deforestation is due to commercial agriculture Land Use Change. Conventionally, when considering emissions from Land Use Change, accounting methods ascribe these to the products grown on the land recently converted to agriculture. However, if we consider the whole system, it is the level of demand for a product which drives expansion in agricultural land. In 2009 FCRN (Food Climate Research Network) and WWF published *How Low Can We Go?*, a study which quantified the emissions associated with Land Use Change attributable to UK demand for food stuffs (Audsley *et al.* 2010). The study estimated that 87 million tonnes CO_2 equivalent can be attributed to deforestation related to the UK food economy and provides figures for a variety of foods.

These figures have been used to report separately on Land Use Change impacts. It should be further noted that estimates of CO_2 eq from Land Use Change are still subject to large uncertainties. The IPCC 4th Assessment Report cites error ranges of up to ±2,933 million tonnes CO_2 at the global level in the 1990s (Forster *et al*. 2007).

6 Data

Household food waste data were taken from WRAP (Quested & Johnson 2009). A short summary of the household food waste, split by ability to avoid, is presented in Table 1. The full list of products selected for the study is presented in Appendix 1. In this study we have focused on the avoidable and possibly avoidable part of the food waste only. The unavoidable part in the table is presented as additional information for comparison among different categories of household food waste.

Table 1: Shares of household food waste based on ability to be avoided in the UK, million tonnes per year.

Categories	Avoidable	Possibly avoidable	Unavoidable	Total
Food	4.5	1.5	1.1	7.1
Drink	0.8	0.0	0.4	1.2
Total	5.3	1.5	1.5	8.3

Source: WRAP (Quested & Johnson 2009).

The production statistics are taken from FAO (FAOSTAT data 2008), international trade data are retrieved from International Trade Centre (ITC 2006, ITC 2009), and the water resources withdrawal data are taken from FAO (2003a, 2003b). The virtual water content data for agricultural products are taken from Chapagain and Hoekstra (2004). The various sources of other data on climate, crop coefficients and crop periods which are used in the calculations of water footprint are listed in volume 2 of the WWF-UK report (Chapagain & Orr 2008). Based on primary ingredient, the virtual water flow results are re-grouped to match with the list of household waste products in the WRAP database. Data on carbon has been drawn from various sources as listed in Appendix 6.

As the report is based on data retrieved from a variety of sources, it is inevitable that any errors in these sources can influence the result of this analysis. Every effort has been made to cross check these data sources with various other independent sources, and the selection of datasets used in this study is made based on the scope and the degree of precision achievable within the scope and limitations of this study.

7 Results of water footprint accounting

7.1 Water footprint of food consumption in the UK

Of the total UK water footprint of 102 billion cubic metres per year, agricultural products comprise 70 billion cubic metres per year (Chapagain & Orr 2008), excluding the water footprint of cotton textiles, which is a further 5 billion cubic metres per year. The UK's per capita average water footprint of agricultural products (excluding cotton textiles) is 708 cubic metres per person per year, equivalent to 3,190 litres per person per day.

Of the water footprint of agricultural products, 38% relates to water use in the UK (internal water footprint) and 62% abroad (external water footprint), as shown in Table 2. The top 12 countries in the list of the UK's external agricultural water footprint are Brazil, France, Ireland, Ghana, India, The Netherlands, Ivory Coast, Denmark, Indonesia, Spain, Germany and the USA. The top products making the external water footprint of the UK are cocoa, bovine products, cotton, swine, palm oil, soybeans, coffee, miscellaneous livestock products, milk, maize, rice and wheat (Chapagain & Orr 2008).

Table 2: Agricultural water footprint of the UK.

	Crop products (million m^3 per year)	Livestock products (million m^3 per year)	Total (million m^3 per year)	Share to the total
Internal water footprint	12,500	16,100	28,600	40%
External water footprint	28,600	13,100	41,800	60%
Total agricultural water footprint	41,100	29,200	70,400	100%
	58%	42%		

Note: The total agricultural water footprint of the UK in this table excludes the water footprint related to cotton textiles, adapted from Chapagain and Orr (2008).

7.2 Water footprint of household food waste in the UK

The total water footprint of food waste in UK households is 6,262 million cubic metres per year, of which 5,368 million cubic metres per year is attributed to avoidable food waste, and a further 894 million cubic metres to possibly avoidable waste. These figures represent 5% and 1% of the UK's total food water footprint respectively.

In per capita terms, the water footprint of total avoidable and possibly avoidable household food waste in the UK is 284 litres per person per day. By comparison, the daily average household water use in the UK (i.e. water from the tap) is about 150 litres per person per day(Defra 2008b). Out of the total household food waste, 243 litres per person per day (86%) is completely avoidable and the remainder is possibly avoidable (Table 3).

A large part (71%) of the avoidable food waste in the UK is from imported products. Please note that the table doesn't show the water footprint of unavoidable food waste, as this will be counted towards water footprint of actual food consumption. The rationale for this is that unavoidable waste (e.g. banana skins, bones) is an integral part of the food consumption.

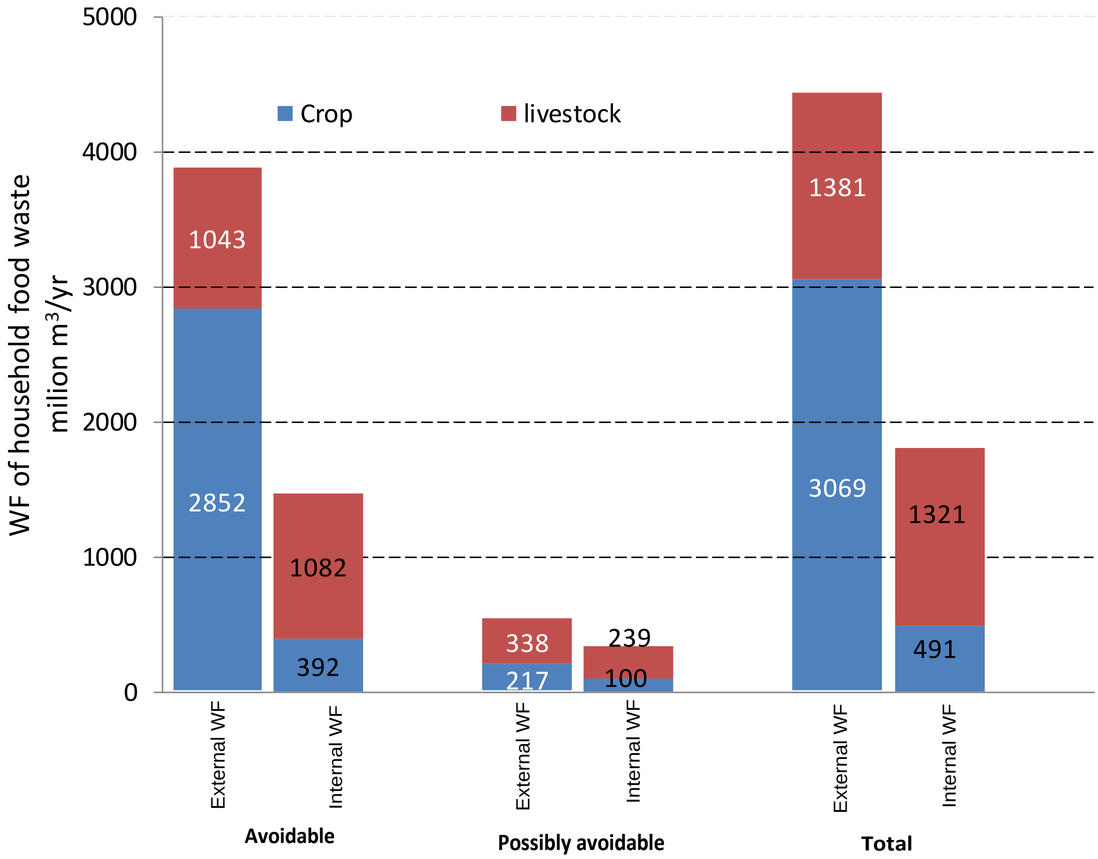
The share of the UK's External WF (EWF) for agricultural products (excluding textiles) is about 60% (Table 2), whereas the EWF of household food waste is 71% (Table 3). It shows that the imported food products are more water intensive (cubic metres per tonne) compared to the products from the UK itself.

Table 3: Total water footprint of the household food waste in the UK.

	Avoidable (million m^3 per year)	Possibly avoidable (million m^3 per year)	Total (million m^3 per year)	
Internal water footprint	1,473	339	1,812	29%
External water footprint	3,895	555	4,450	71%
Total water footprint	5,368	894	6,262	100%
	86%	14%	100%	

Though the total food waste by quantity is about 22% by weight, it is only 14% in terms of equivalent water footprint. This is because the wasted food has relatively low water content per tonne of products. The Internal Water Footprint (IWF) of wasted food is relatively bigger for livestock products (i.e. meat and dairy) compared to that for crop products. However, for imported products, it is the crop product component which has higher EWF (Figure 2).

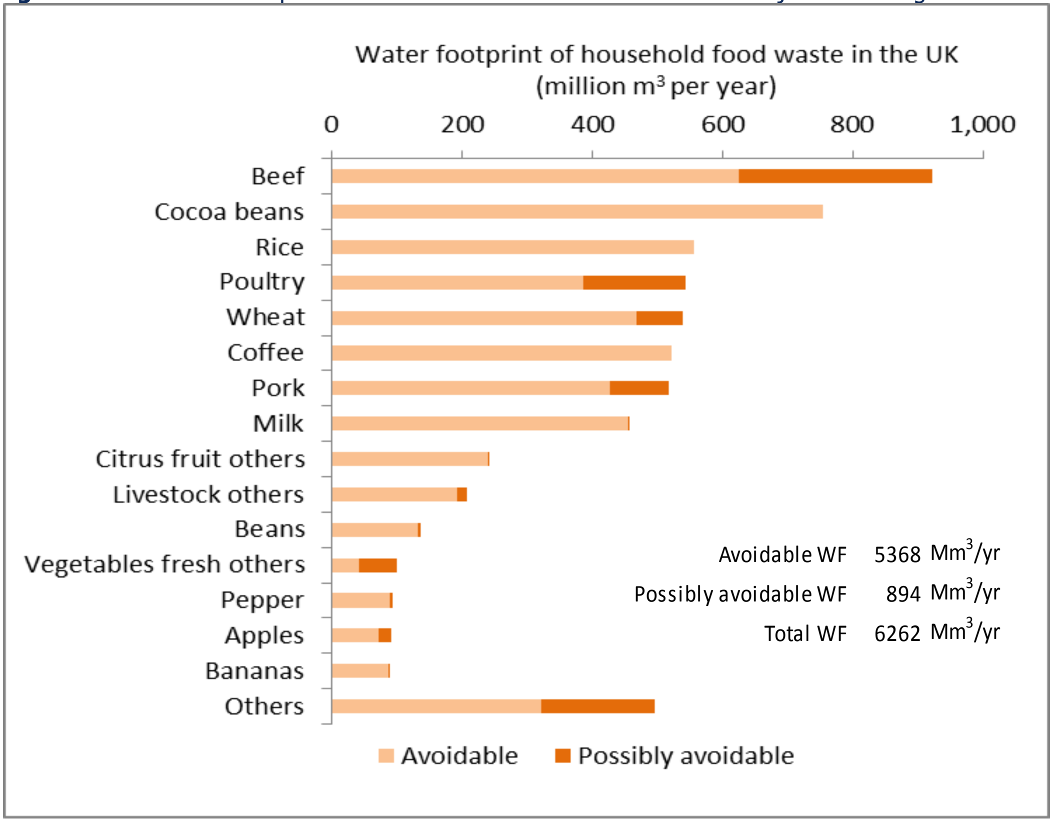
Figure 2: Internal and external water footprint of household food waste of crop and livestock products.



The products with the largest share of the water footprint of household food waste are presented in Figure 3. It is seen that beef and cocoa products are the top two products in the list of water footprint of household food waste. They also rank in the top list of products in the external water footprint of the agricultural products in the UK as reported in the WWF-UK report (Chapagain & Orr 2008). The complete list of household food waste and associated water footprint is presented in Appendix 2.

It is to be noted that for complex products with more than one ingredient, where possible an estimate of the composition has been made. Where this has not been possible, the waste has been assumed to consist of the single ingredient with the most significant share to the total water footprint of the product. For example, cakes have been assumed to be made of wheat, and the water footprint for cocoa has been used for chocolate, although other ingredients (e.g. sugar) are also used within this product.

Figure 3: Total water footprint of household food waste in the UK for major food categories.



7.3 External water footprint of household food waste in the UK

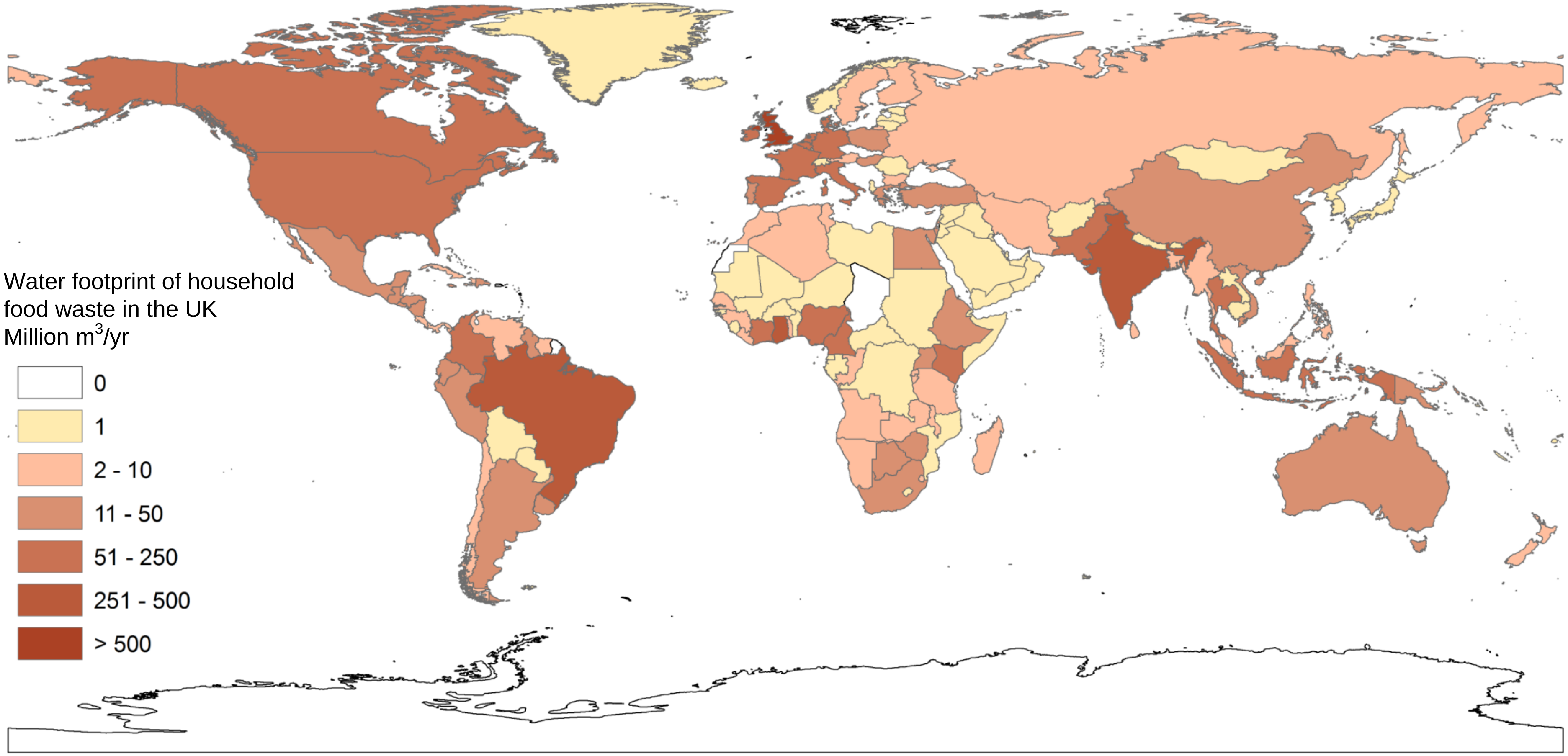
The locations where the UK has the highest water footprints related to household food waste are presented in Table 4. A complete list of these locations and the size of the UK's water footprint is presented in Appendix 3. Although Ghana, Brazil and the Ivory Coast feature at or near the top of the list of External Water Footprints, it is important to note that the products originating in these locations are mainly rain fed, and so exert limited pressure on blue water resources in these locations.

Table 4: Top 15 countries in the list of largest external water footprint of the household food waste in the UK.

Locations	EWF (million m^3/year)			Top products and EWF (million m^3/year)
	Avoidable	Possibly avoidable	Total	
Ghana	423	0	423	Cocoa beans 413, Coffee 5, Bananas 4, Pineapples 1
Brazil	271	64	336	Beef 148, Coffee 89, Poultry 47, Livestock others 35, Cocoa beans 5
India	263	22	284	Rice 165, Pepper 54, Beans dry 30, Oilseeds others 18, Coffee 5
Ireland	175	71	246	Beef 177, Poultry 27, Pork 26, Livestock others 12, Wheat 1
Netherlands	168	50	218	Pork 92, Poultry 74, Livestock others 24, Beef 15, Vegetables fresh others 6
Thailand	176	21	197	Rice 109, Poultry 62, Livestock others 14, Citrus fruit others 6, Vegetables fresh others 3
Ivory Coast	171	2	173	Cocoa beans 148, Coffee 16, Bananas 4, Stone fruit 2, Oilseeds others 2
France	129	38	166	Poultry 43, Pork 25, Wheat 25, Maize 13, Livestock others 13
Denmark	128	29	156	Pork 131, Poultry 10, Livestock others 9, Beef 3, Wheat 1
USA	128	7	135	Rice 55, Beans dry 49, Wheat 12, Apples 4, Stone fruit others fresh 3
Italy	102	15	118	Rice 37, Beef 19, Livestock others 12, Citrus fruit others 8, Wheat 7
Pakistan	114	0	115	Rice 111, Beans dry 3, Fruit fresh others 1
Nigeria	113	0	114	Cocoa beans 113
Spain	87	17	104	Rice 22, Pork 8, Poultry 8, Beef 8, Fruit fresh others 6
Canada	88	10	98	Wheat 71, Beans dry 26, Beef 1
Others	1,359	207	1,565	
Total	3,895	555	4,450	

A complete map of the water footprint of UK's household food waste is presented in Figure 4.

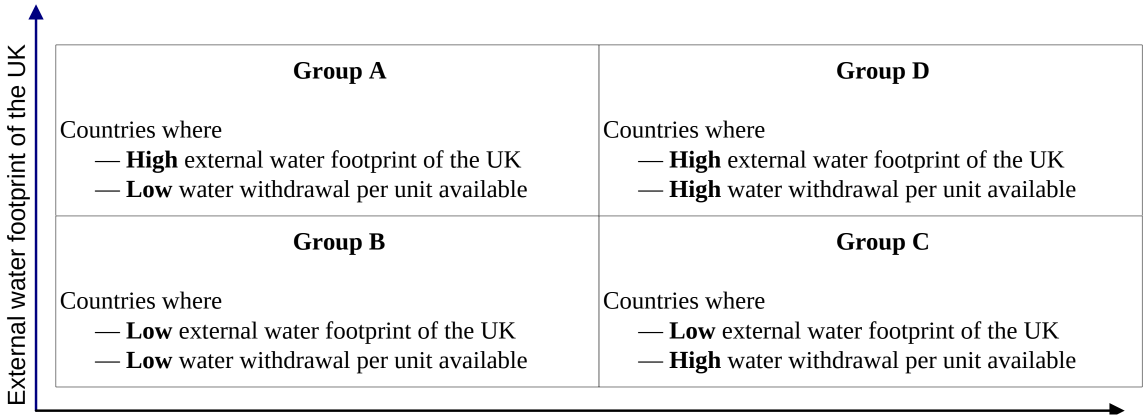
Figure 4: The UK's external water footprint of household food waste.



7.4 Impacts of the UK's water footprint from household food waste

Impact assessments of these water footprints were conducted using hydrological attributes of regions where water is used in food cultivation and processing. Water stress in these locations is calculated as the ratio of actual blue water withdrawal to the net blue water available after taking into account environmental flow requirements. Following the scheme of impact categorisation suggested in WWF-UK (Chapagain & Orr 2008), the various countries are then grouped based on the severity of the impacts using the schematic presented in Figure 5.

Figure 5: Hot-spotting impact locations based on hydrological attributes.



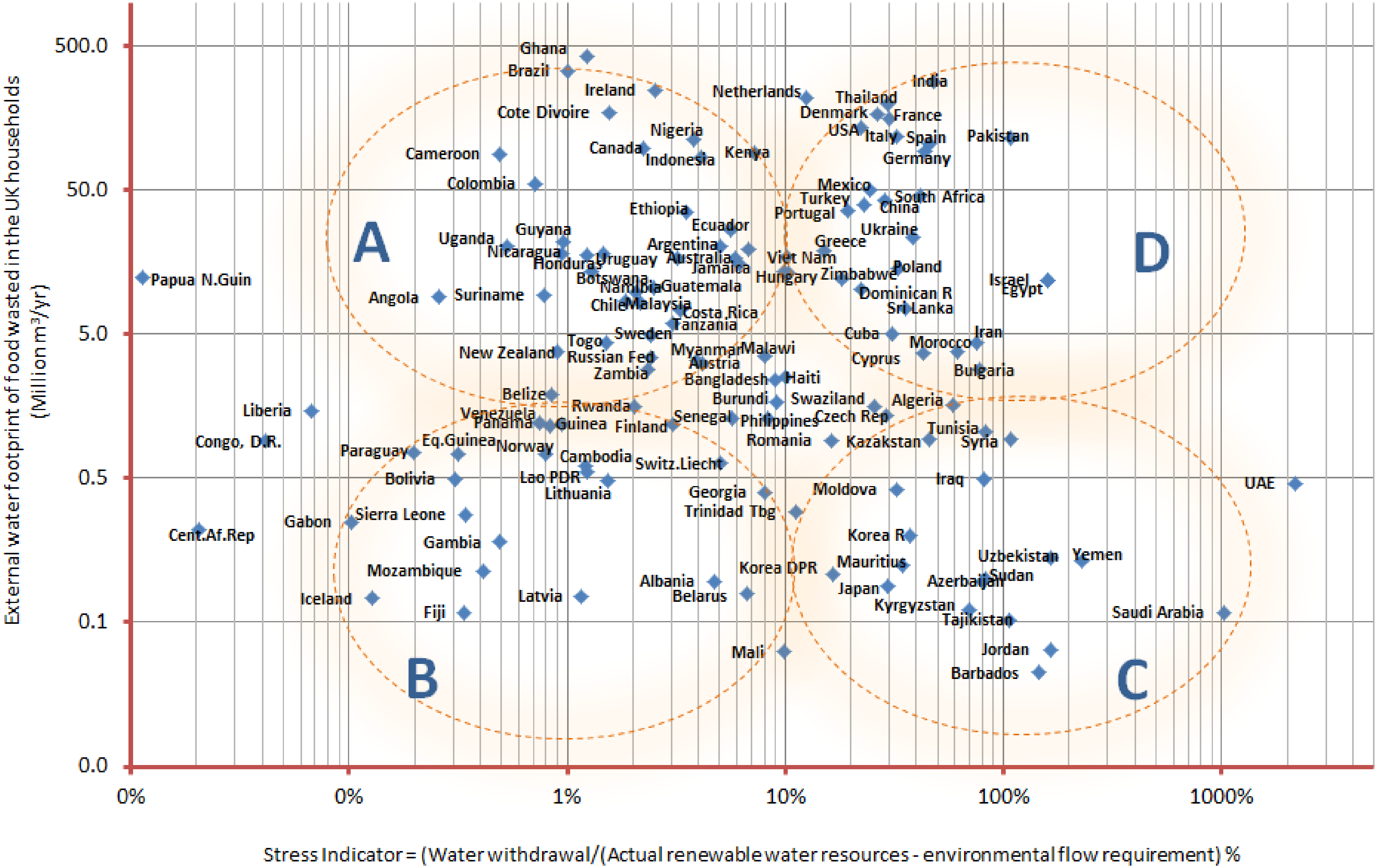
$$\text{Water stress} = \left\{ \text{Water withdrawal} \Big/ \left(\text{Actual renewable water resources} - \text{Environmental flow requirement}\right) \right\}$$

A shortcoming of this approach is that it doesn't take into account green water availability in these locations, nor the impact of grey water. Thus, calculations of stress on hydrology, based only on the blue water availability in these locations, are incomplete.

The results are presented in Figure 6. Egypt, Israel, Pakistan, India, Thailand and Spain are examples of countries falling in the Group D, where water stress is very high and the external water footprint of the UK's household food waste is also high. In contrast, countries falling in Group B have relatively lower water stress and the water footprint of UK household food waste in these countries is relatively low. Although Ghana and Brazil, both in Group A, support a large part of the external water footprint of household food waste in the UK, water stress in these countries is low.

In section 9, short case studies are set out of two countries, Spain and Brazil, to illustrate Groups D and A respectively.

Figure 6: The UK's external water footprint of household food waste versus water stress.



8 Results of carbon footprint accounting

8.1 Total carbon footprint of household food consumption in the UK

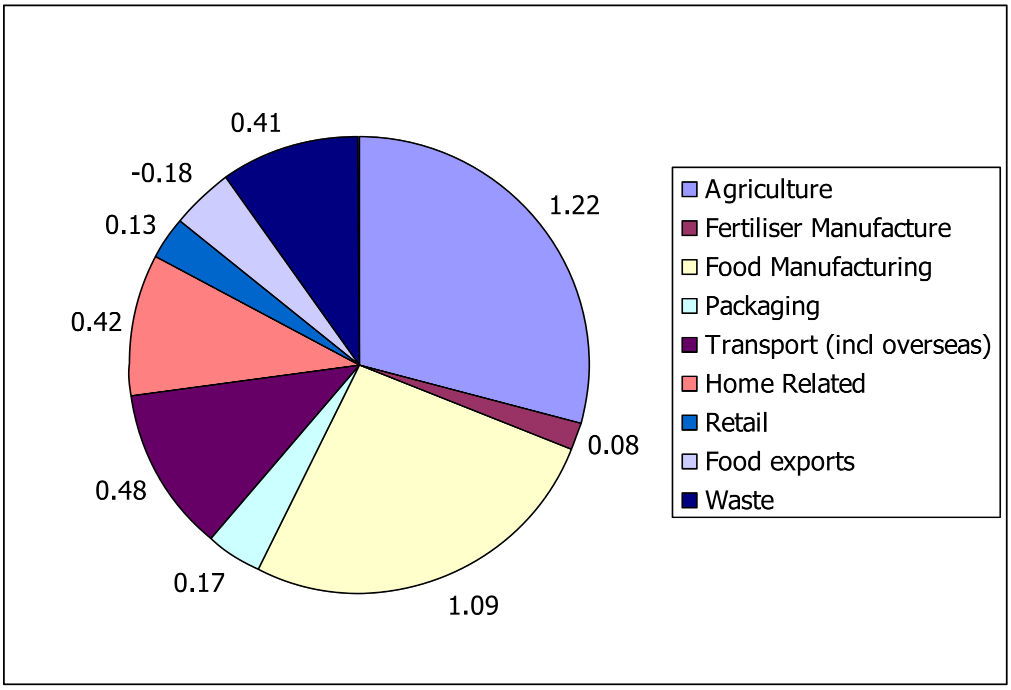
WRAP estimates that the total carbon footprint of food and drink consumed in the UK is 130 million tonnes CO_2 eq per year. This is approximately equivalent to a fifth of UK territorial emissions, or 2 tonnes of CO_2 eq per person per year. Excluding emissions from wasted items, the average impact of a tonne of food and drink purchased is 3.4 tonnes CO_2 eq, rising to 3.8 tonnes CO_2 eq per tonne of food alone.

8.2 Total carbon footprint of household food waste in the UK

This report uses two approaches to quantify the carbon footprint of food waste. The first of these is a top down approach, described in Appendix 5, attributing emissions from each life cycle stage to food and drink subsequently wasted. Using this approach, the total carbon footprint of the UK's household food and drink waste is 25.7 million tonnes CO_2 eq, of which 20 million tonnes CO_2 eq is associated with avoidable waste.

Secondly, the carbon footprint of household food and drink waste has been constructed from the bottom up, to allow allocation of emissions to country of origin. Due to data gaps for specific foods, it should be noted that the carbon emissions attributed to specific foods do not add up to the top down average. For example, no specific farm emission data was identified for approximately 10% of avoidable food waste by weight, and 20% of possibly avoidable food waste. No data to allocate specific emissions from regional distribution centres was identified for 6% of avoidable food waste by weight, and 20% of possibly avoidable food waste. Where food waste has not been identifiable, the carbon emissions associated with this have not been allocated to any specific country.

Figure 7: Contribution to the average carbon footprint of household food and drink waste using top down approach (tonnes CO_2 eq per tonne).



The top down results suggest that, on average, approximately one quarter of the impact of food is associated with growing / rearing the crops and animals which enter the food chain, one quarter is associated with food processing, and one eighth is associated with home related impacts (e.g. cooking). Waste management and degradation accounts for one tenth of emissions. This is illustrated in Figure 7.

The specific breakdown varies by food type, and this is discussed further in the case studies presented below.

8.3 Carbon footprint of the UK household food waste by source

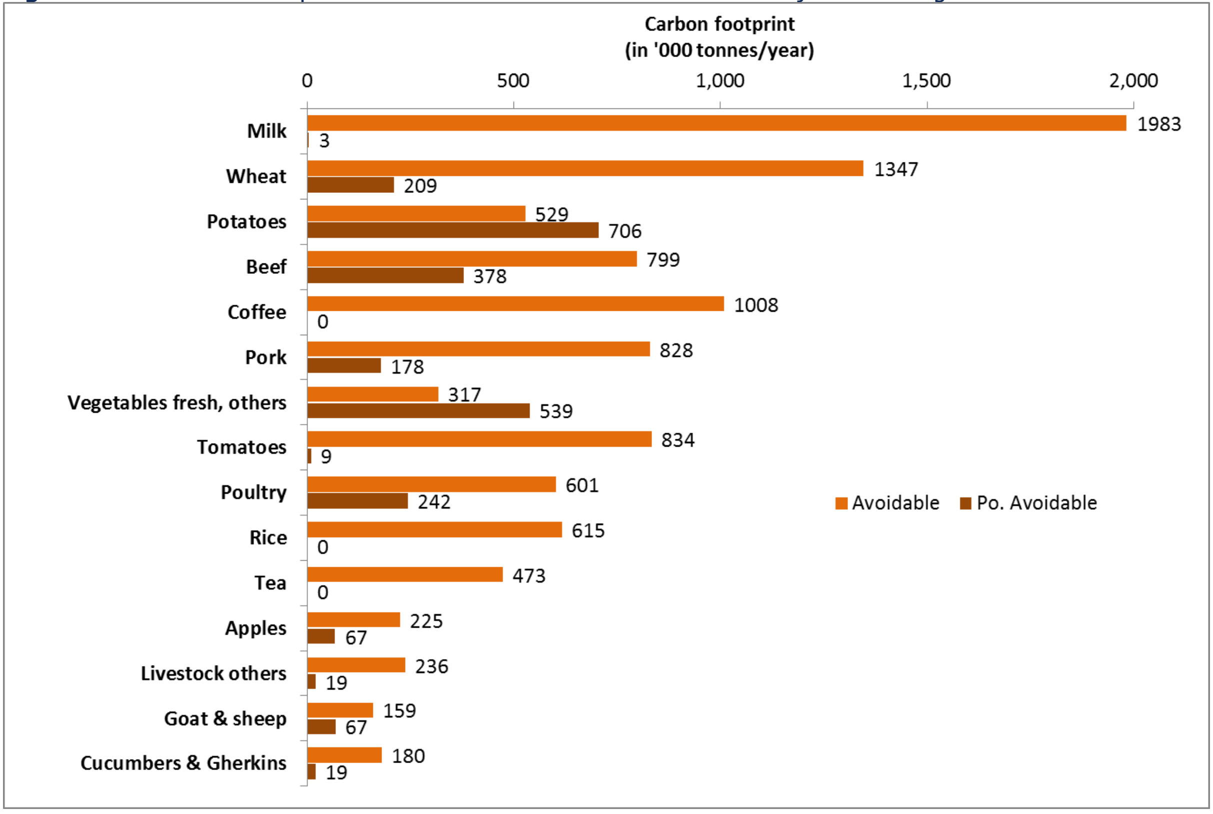
Out of the total carbon footprint of the UK's household waste of food and drink, 78% is related to waste under the 'avoidable' category and 22% under the 'possibly avoidable' category (Table 5). The average carbon footprint of avoidable household food waste is 330kg CO_2 eq per person per year. This is equivalent to approximately one third of the emissions of CO_2 (rather than CO_2 eq) associated with household electricity use per person in the UK (DECC 2010).

Table 5: Total carbon footprint of the household food waste in the UK ('000 tonnes per year).

	Avoidable waste	Possibly avoidable waste	Total
Internal emissions	14,002	3,223	17,225
External emissions	6,138	696	6,834
Unattributed emissions		1,658	1,658
Total carbon footprint	20,140	5,577	25,717

The products with the greatest share in the carbon footprint of household food waste are presented in Figure 8. Data limitations mean that few processed foods were able to be identified, and subsequently limited emissions have been attributed to these. The complete list of household food waste and associated carbon footprint is presented in Appendix 4.

Figure 8: Total carbon footprint of household food waste in the UK for major food categories.



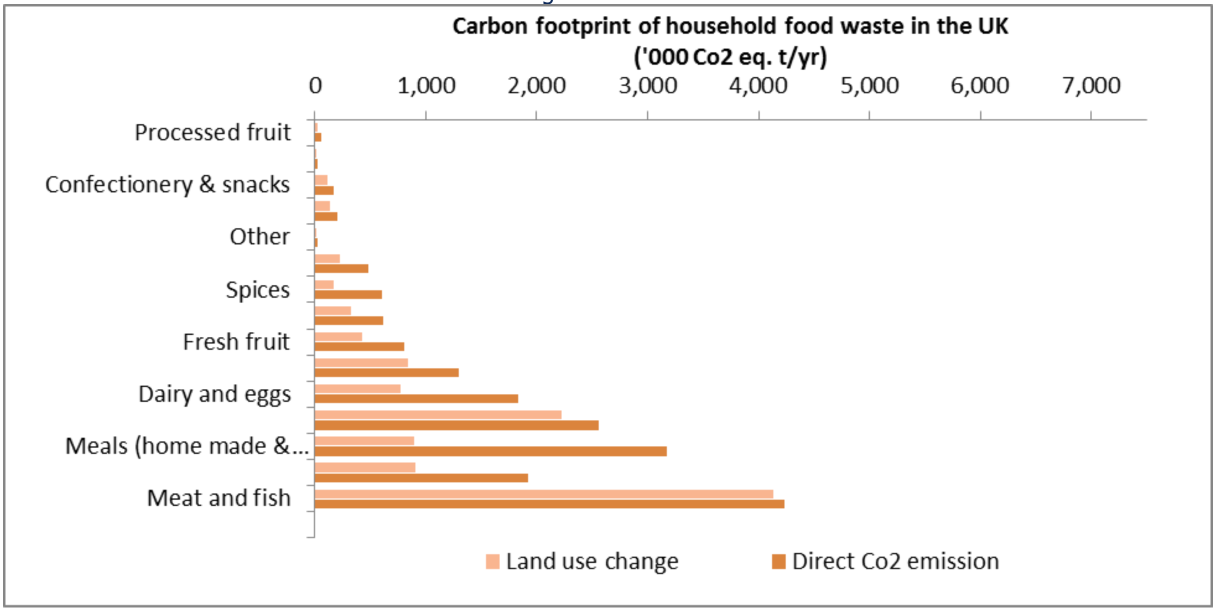
In addition to the direct emissions associated with the life cycle of food, we also estimate that avoidable food waste generated in the UK is responsible for emissions associated with Land Use Change totalling 7.6 million tonnes CO_2 eq per annum, as shown in Table 6 below. The main contributors are shown in Figure 9.

Table 6: Indirect carbon footprint of household food waste in the UK associated with Land Use Change ('000 t CO_2eq/yr).

	Avoidable	Possibly avoidable	Total
Total	6,092	1,538	7,630

The impact has not been split by external and internal Land Use Change. All figures used to calculate Land Use Change are global averages, rather than nation-specific. As such they are not necessarily representative of emissions arising within the UK as a consequence of Land Use Change.

Figure 9: Carbon footprint of avoidable and possibly avoidable household food and drink waste in the UK for direct emission and emissions from Land Use Changes.



Inclusion of emissions associated with Land Use Change would increase the average carbon footprint of avoidable food and drink waste by approximately one fifth. As a proportion of Land Use Change emissions associated with UK consumption of agricultural products it is 7%. Further discussion of the impact of Land Use Change is contained in the case studies, conclusions and recommendations of this report.

9 Case studies

In recent years there has been an increase in the UK's fruit and vegetable consumption even as production of these crops in the UK is decreasing (FAOSTAT data 2010). Major increases in agricultural product flows from the Mediterranean region, South Africa, South America, and elsewhere have made up the difference. To illustrate the connection between use of natural resources overseas with household food waste in the UK, case studies are set out below of three food products (wheat, tomato and beef) and two producing regions (Spain and Brazil).

9.1 Wheat

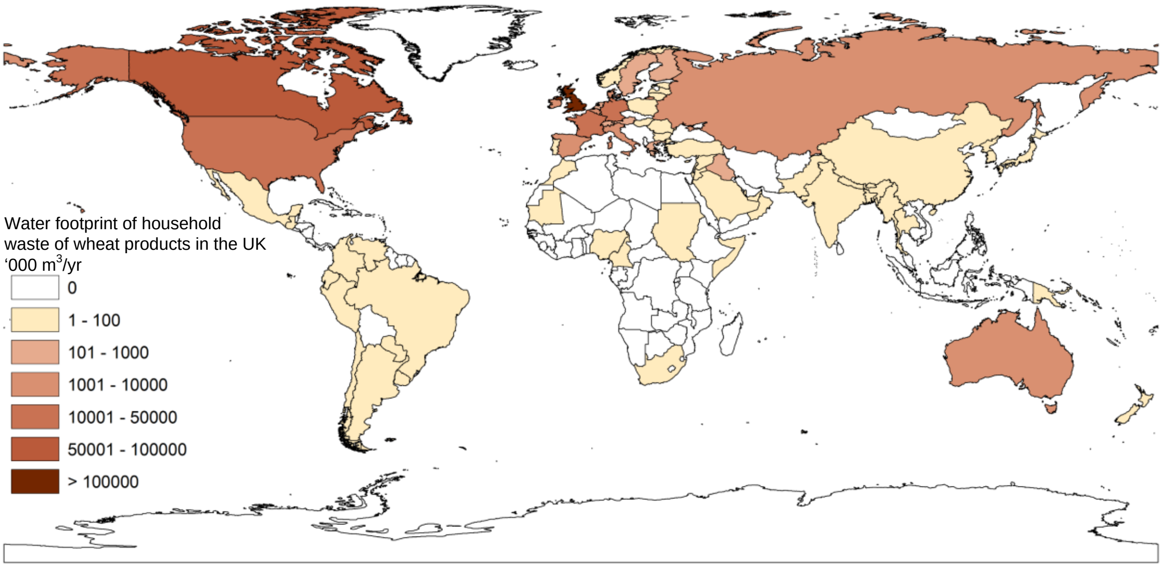
The water footprint of wheat consumption (e.g. bread, cakes) in the UK is 7,483 million cubic metres per year (Chapagain and Orr 2008). The water footprint of household waste of wheat products in the UK is equal to 143 million cubic metres per year (2% of total UK wheat water footprint), all of which is classed as avoidable. The major regions where the UK's water footprint from household waste of wheat products falls are presented in Table 7. As wheat is mostly rainfed in the UK, the impact on blue water resources in the UK is negligible. However, this does vary by region. The Environment Agency (2008) note that although farmers use less than 1% of the total amount of water abstracted in England and Wales for spray irrigation, this can reach 20% in East Anglia, and that on occasion more water is used on a hot dry day for spray irrigation than for public water supply. Nearly all of this water is lost by evaporation and can therefore represent a significant contributor to the internal water footprint of wheat production.

Table 7: Total external water footprint of UK's household wheat waste ('000 m^3/yr).

	Avoidable	Possibly avoidable	Total '000m^3/yr	Share of external water footprint of wheat waste
Canada	61,581	9,177	70,759	50%
France	22,018	3,281	25,300	18%
USA	10,739	1,600	12,340	9%
Germany	10,673	1,591	12,264	9%
Italy	6,131	914	7,045	5%
Russia	2,386	356	2,742	2%
Belgium	1,250	186	1,437	1%
Denmark	1,103	164	1,267	1%
Others	8,517	1,269	9,786	7%
Total	124,399	18,539	142,938	

The EWF of waste of wheat products in the UK is presented in Figure 10. The darker the area, the larger is the EWF of UK's household wheat waste in these areas. Note that what wheat is rainfed in some of these regions and irrigated in others.

Figure 10: Water footprint of avoidable and possibly avoidable household waste of wheat products in the UK.

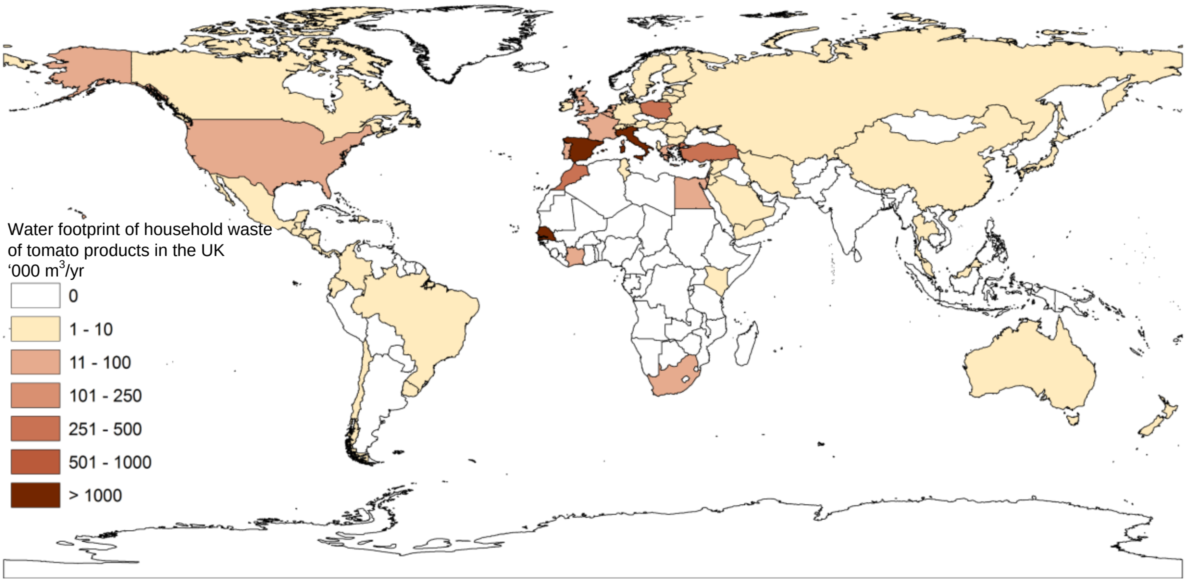


The carbon footprint of household waste of wheat products in the UK is 1,556,000 tonnes CO_2 eq per year. The internal part of the total carbon footprint is 1,448,000 tonnes CO_2 eq per year and the rest is due to activities at external locations. Almost 87% of the carbon footprint is composed of avoidable food waste, rather than possibly avoidable food waste. The greatest contribution to the footprint is made by emissions from agriculture and processing (e.g. into bread, cakes and pastries). Packaging (transit and primary) accounts for approximately 10% of the carbon footprint of the product, and the emissions from waste management is the next most significant source.

9.2 Tomato

Total water use for tomato production in the UK is only 0.8 million cubic metres per year. However as an importer of tomatoes, the UK's water footprint in relation to tomato consumption is 13.9 million cubic metres per year. Out of the total water footprint of tomato consumption in the UK (including tomatoes, cook-in sauces and ketchup), the waste at household contributes to 9.6 million cubic metres per year, of which is 9.4 million cubic metres per year is classed as avoidable. This is about 68% of the total water footprint of tomato consumption in the UK. Most of the water footprint of household tomato wastage falls overseas (Figure 11). Currently the UK imports mainly from Spain followed by Italy, the Netherlands, Morocco, Turkey and Portugal.

Figure 11: Water footprint of avoidable and possibly avoidable household waste of tomato products.



A significant share of the total waste (57%) is related to the household waste of tomatoes imported from Spain. Table 8 presents the list of countries which, taken together comprise a total share of 97% of the total external water footprint of tomato waste in the UK household. As tomatoes are mostly irrigated and grown in greenhouses in the western hemisphere, the impacts are notable from carbon as well as blue water availability perspectives.

The carbon footprint of household waste of tomato products in the UK is 853,000 tonnes per year. In contrast to wheat, it is mostly due to activities outside of the UK. The external component is 81% of the total emissions in this case. Almost 99% of the carbon footprint is composed of waste of tomato products which is avoidable. The carbon footprint of tomatoes can vary significantly depending on whether they are grown in field or in greenhouses, and upon how greenhouses are heated (Wiltshire *et al.* 2009). However, any variation in the emissions associated with the manner in which tomatoes are grown do not alter the dominant role of production in the carbon footprint

Table 8: Total external water footprint of UK's household tomato waste in the UK ('000 m^3/year).

	Avoidable	Possibly avoidable	Total water footprint '000 m^3/year	Share of the total water footprint
Spain	5414	64	5478	57%
Senegal	1284	15	1299	14%
Italy	1047	12	1059	11%
Poland	459	5	464	5%
Turkey	424	5	429	4%
Morocco	263	3	266	3%
Portugal	97	1	98	1%
Israel	64	1	64	1%
France	57	1	57	1%
Others	311	4	314	3%
Total	9,418	111	9,528	

A recent study (Chapagain & Orr 2009) shows that the EU consumes 955,000 tonnes of Spanish fresh tomatoes annually, which evaporates 71 million cubic metres of water per year and would require a further 7 million cubic metres of water per year to dilute leached nitrates in Spain. The main tomato producing regions in Spain are in the Ebro valley (Navarra, Rioja, and Zaragoza) and Guadiana valley (Extremadura), and in the south-east catchments of the Júcar, Segura and Sur (Valencia, Alicante, Murcia, Almería) and Canary Islands. The majority of fresh tomato imports to the UK originate from the southern Spanish mainland and the Canary Islands. These sites are among the most significant in Spain in terms of water stress. Other than water consumption, the main environmental issues associated with tomato cultivation are water pollution, soil pollution and erosion, with habitat loss from expanding cultivation in some areas. The over-exploitation of aquifers from horticulture exports has affected water quantity and quality, including water salinisation and declining water tables, with additional loss of biodiversity, ecological value and landscape amenity across the Mediterranean area (Martínez-Fernández & Selma 2004). Current water use, in Almeria for example, is around 4-5 times more than annual rainfall and is mainly obtained from deep wells with high salinity of water, limiting the possibilities for water reuse. Almeria also has the largest poly-tunnel concentration in the world, with around 40,000ha of greenhouse crops grown predominantly under flat-roof greenhouses. Ensuring sustainable, equitable and productive use of water resources in these regions presents a challenge to all companies and organisations with a stake in these fresh produce supply chains.

9.3 Beef

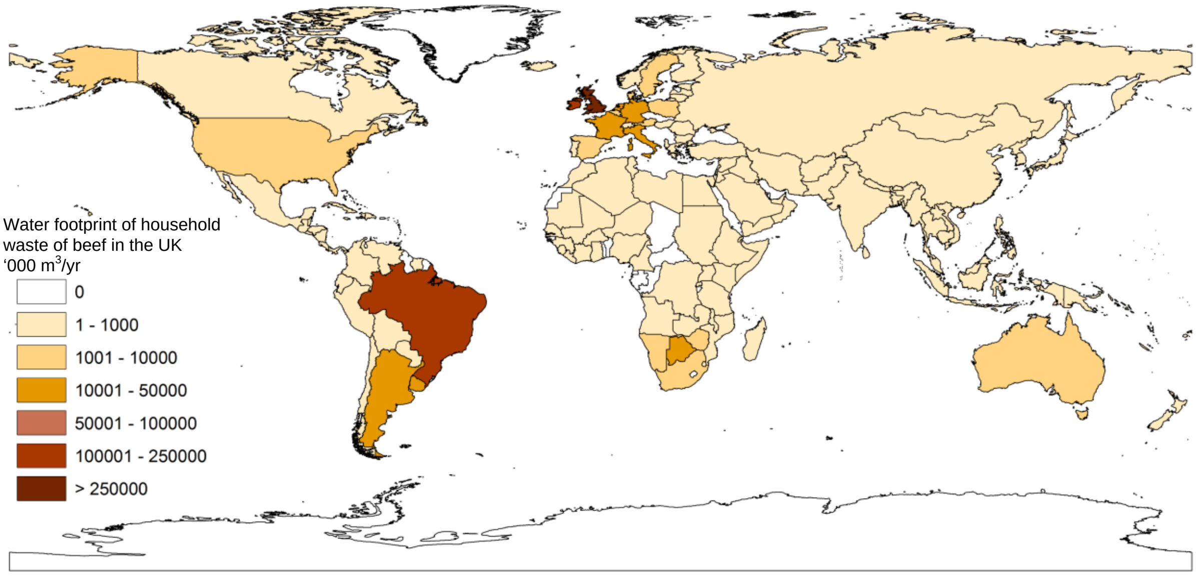
The total water footprint of the consumption of beef in the UK is estimated as 9,942 million cubic metres per year (Chapagain & Orr 2008). The total water footprint of household waste of beef product is estimated to be 921 million cubic metres per year. Nearly two third of the total water footprint of household beef waste can be avoided, and 53% of the total wasted water footprint is external to the UK (Figure 12). The major regions where the UK's wasted water footprint rests are presented in Table 9. As beef is a complex product for which to trace the final water footprint, the headline water footprint in these exporting countries does not reveal the full impact on water resources as a result of water used to grow cattle feed. As well as variation by country, the farming practices employed (e.g. extensive '*grazing'*, '*industrial'* farming) will also influence the water footprint, and a detailed location specific analysis is needed before interpreting the results. The total external water footprint per country should be further distinguished between beef from internal feed and imported feed in these locations.

Table 9: Total external water footprint of UK's household beef product waste in the UK ('000 m^3/yr).

	Avoidable	Possibly avoidable	Total '000m^3/year	Share to the total water footprint
Ireland	119,928	56,738	176,666	36%
Brazil	100,195	47,403	147,598	30%
Italy	12,749	6,032	18,780	4%
Uruguay	10,491	4,963	15,454	3%
Netherlands	10,203	4,827	15,030	3%
Germany	9,660	4,570	14,230	3%
Botswana	9,171	4,339	13,510	3%
Argentina	9,127	4,318	13,445	3%
France	7,304	3,455	10,759	2%
Others	40,927	19,363	60,289	12%
Total	329,753	156,007	485,761	

The carbon footprint of household waste of beef in the UK is 1,176,000 tonnes CO_2 eq per year. Two thirds of the total direct emissions are made up of household waste of beef that can be avoided. About 67% of the total direct emissions are due to activities outside of the UK border. However, this excludes the impact of Land Use Change. For beef, this would add 3.4 million tonnes CO_2 eq to the emissions attributed to avoidable and possibly avoidable food waste, roughly 3 times higher than direct emissions. This figure is based on average global impacts of Land Use Change to facilitate cattle farming and is discussed further in the case study on Brazil.

Figure 12: Water footprint of the UK's household waste of beef products.



9.4 Spain

Spain uses more than 70% of its water for irrigated agriculture. The main regions of Spain with some of the most pressing issues in the country in terms of their use and management of water are Almeria, Murcia and Barcelona. In the Almeria rising water demands have resulted in over abstraction of many of the province's aquifers (in some cases withdrawals exceeding recharge by 250%) leading to significant water deficits and increasing salinisation. Murcia has undergone a resort-building boom, even as many of its farmers have switched to more thirsty crops which have put new pressures on the land and on Murcia's dwindling supply of water. There is a considerable shortage of household water supplies in Barcelona, prompting a national debate about poor planning and failed governance. There are efforts to supply drinking water with tanker deliveries to homes in dry seasons.

The Spanish Government has introduced a national water plan, 'Programa Agua' calling for an increase in desalination plants. Desalination, while it may address immediate water shortages, may contribute to other environmental problems including through energy use and greenhouse gas emissions, and through marine ecosystem impacts from hyper-saline waste flows (Chapagain & Orr 2008). The most water-intensive products exported from Spain to the UK are olives, grapes, oranges, rice, and swine and bovine products (Chapagain & Orr 2008). While imports from Spain represent a small proportion of the UK's total water footprint, the impacts which arise on Spanish water resources are significant, contributing to increased competition for water resources, particularly where agricultural and tourism areas overlap.

Spain provides about 104 million cubic metres per year of the UK's water footprint from household food waste. Table 10 presents the various agricultural products imported from Spain to the UK, and their related water footprints in Spain as a result of household food waste in the UK.

Table 10: Total water footprint in Spain of the UK's household food waste.

	EWF Million m^3/year	Share of the total external water footprint
Rice	22.0	21%
Pork	8.1	8%
Poultry	8.1	8%
Beef	8.1	8%
Fruit fresh, others	6.4	6%
Cabbages	6.0	6%
Tomatoes	5.5	5%
Livestock others	5.2	5%
Carrots	4.9	5%
Oranges	4.3	4%
Olives	3.8	4%
Strawberries	3.2	3%
Apples	3.1	3%
Others	15.6	15%
Total	104.3	100%

This highlights that, although the total water footprint associated with goods imported from Spain is relatively small (only 2% of the UK's EWF), the impact of water use is relatively high due to limited water availability and over-exploitation of groundwater and surface water supplies in many parts of Spain.

9.5 Brazil

Brazil provides about 336 million cubic metres per year of the UK's water footprint from household food waste. Table 11 presents the various agricultural products imported to the UK from Brazil together with figures on the water footprint in Brazil as a result of household food waste in the UK.

Table 11: Total water footprint of the UK's household food waste in Brazil.

	EWF Million m^3/year	Share of the total external water footprint
Beef	148	44.0%
Coffee	89	26.4%
Poultry	47	14.1%
Livestock others	35	10.3%
Cocoa	5	1.4%
Oranges	4	1.3%
Bananas	4	1.1%
Pepper	2	0.6%
Apples	1	0.4%
Maize	1	0.2%
Others	1	0.2%
Total	336	100%

Since Brazil contains 12% of the world's fresh water supplies, it may not appear at first glance to be a relevant country from which to draw lessons in managing scarce water resources. North-eastern Brazil, however, is a semi-arid region characterised by water scarcity, pronounced climatic variability and social stress situations (Krol *et al.* 2001). The limited availability of water results from moderate rainfall, which is generally unreliable and seasonally distributed, and a high evaporation rate. A large portion of the UK's EWF on this region is related to beef products. It is increasingly becoming evident that rising beef consumption is a major driver of regional and global change, and warrants greater policy attention (McAlpine *et al.* 2009). Coffee and beef from Brazil has negligible blue and grey water footprints. However, the impacts are on Land Use Change and other ecosystem services as a result of deforestation etc.

As with all animal products, the manner of animal husbandry practiced will have a significant impact on the specific carbon impacts of beef. Intensive, extensive, upland, lowland and organic farming practices all alter the carbon footprint. However, they do not diminish the dominant role of agriculture in the overall carbon footprint. The case study on beef identifies that, on average, indirect emissions from Land Use Change are three times higher than direct emissions associated with beef production. However, this is a global average. Cederberg *et al.* (2011) identify carbon emissions from deforestation associated with producing beef in Brazil. Their work suggests that, averaged across all Brazilian beef production, emissions from Land Use Change are equivalent to 180 tonnes CO_2 eq per tonne of beef. If the emissions were allocated exclusively to cattle reared on newly deforested land, the figure would rise to 700 tonnes CO_2 eq per tonne of beef.

The case study of Brazil highlights the importance of considering local (i.e. sub-national) conditions when assessing how to act on water footprint data, as well as the need to clearly understand the way in which Land Use Change is accounted for in carbon footprinting.

10 Discussion

This work demonstrates the water and carbon footprint of food and drink waste generated within the UK. For the first time, the carbon and water footprint of food waste has been identified by country of origin (Appendices 4 and 5) with case studies on two countries.

Much of the produce which carries a significant water footprint is also significant in terms of carbon footprint. Milk, beef, pork products, poultry, coffee, rice and apples are identified as large contributors to both indicators. Some notable differences between the carbon and water footprint data can be seen in the cases of bananas, citrus fruit, peppers and cocoa, which have relatively high avoidable water footprint and relatively low avoidable carbon footprint; and potatoes, tea and cucumbers and gherkins, which have a relatively high avoidable carbon footprint, but low avoidable water footprint.

Chocolate is another example of contrasting impacts. The quantity of chocolate thrown away is relatively small (24,000 tonnes of chocolate bars plus 7,000 tonnes in hot chocolate). Its contribution to the carbon footprint of food and drink waste is also small (117,000 tonnes CO_2 equivalent), yet it significantly contributes to the water footprint of food waste, accounting for over 750 million cubic metres of water. Dairy and meat products comprise a relatively low proportion of food and drink waste by tonnes, but are significant both in terms of both the water and carbon footprint. This is because of the amount of feed required to support livestock, as well as enteric emissions from the animals themselves during their lives. This highlights the need to consider more than one issue when identifying priority products to be addressed by waste prevention initiatives.

The assessment of the carbon footprint excludes the impact of Land Use Change associated with demand for certain food stuffs. For some products this makes little difference. For example, Land Use Change associated with demand for mushrooms (which are subsequently wasted) contributes 9 tonnes CO_2 eq per year. However, the demand for land to grow wheat for bread is responsible for an additional 270,000 tonnes CO_2 eq per year. In the case of beef and lamb, emissions associated with Land Use Change are actually higher than direct emissions associated with avoidable waste. This highlights the need to understand the boundaries of any assessment of environmental impact and the issues which one is in a position to influence.

In using the information contained in a water or carbon footprint, a number of issues need to be considered. The amount of water used or carbon emitted does not take account of how efficiently crops are grown and food produced within the local environment. In addition, the footprint does not consider the level of competition for water resources, and local issues such as access to water. There is therefore a need also to consider scarcity of water in a given catchment area, and also how effectively it is being managed. In considering these issues from a policy perspective, it is important to take account of a range of economic, social and environmental factors, many of which have not been discussed in this report.

Egypt, Israel, Pakistan, India, Thailand and Spain are examples of countries where water stress is very high and the external water footprint of the UK's food waste is also relatively high. In such countries an appropriate policy response from UK stakeholders should include consideration of how to play a constructive role in improving information flows, stakeholder engagement, data availability and institutional capacity in order to support water management regimes which adequately balance the needs of different users and ensure the continued viability of the freshwater ecosystems.

Conversely, though Ghana and Brazil support a large part of the external water footprint of household food waste in the UK, water stress in these countries is relatively low (with local exceptions). It may be that other environmental issues are more pressing and that positive socioeconomic impacts from sourcing produce from these countries might outweigh the negative externalities related to hydrology.

The work presented here could be further developed and improved in a number of ways. Information on the water footprint of food and drink is presented herein as a total figure. This could be disaggregated to highlight the contribution of green, blue and grey water to a particular water footprint. The water footprint could also be disaggregated within a nation, to highlight particular areas of water stress and surplus to inform decisions regarding food production. At present, the impact of Land Use Change on the carbon footprint is discussed separately to the emissions directly associated with the food supply chain. Further analysis could be used to highlight particular 'hot spots' which would require further attention, as well as highlighting the interlinked nature of a range of issues, such as agriculture and forestry.

To address the water and carbon footprints of food and drink, and food and drink waste, WWF-UK (Macdiarmid J *et al.* 2011) and others (e.g. (Stehfest *et al.* 2009)) have advocated a focus on reducing, or altering patterns of consumption, which could be complementary to objectives around a healthy diet. However, a quick win in the UK would be to reduce the sheer volume of food waste at household level. It would bring positive changes in terms of impacts from the use of fertilisers and feedstuffs in the food industry overall. Another way of dealing with food waste is to reduce its creation along the full supply chain. Packaging protects food from damage during its transportation from farms and factories via warehouses to retailing, as well as preserving its freshness upon arrival. Like other waste, food waste can be sent to landfill, but some food waste can also be fed to animals (typically swine), or it can be biodegraded by composting or anaerobic digestion, and reused to enrich soil.

Demand for food is increasing, and with a projected global population of 7 billion by 2020, there is a need to ensure that the food we do produce is effectively grown, stored, distributed, prepared, and consumed, with minimal waste. Beyond this the research shows the value of considering a range of issues when tackling waste, and highlights the effect of considering water and greenhouse gas emissions in informing priorities. While it will never the answer by itself, reducing food waste could contribute toward reducing serious environmental problems associated with increasing scarcity of water resources and with climate change. Consumers, manufacturers, retailers and those in the hospitality sector can all contribute to minimising food waste, an action which is particularly relevant in the context of the global food security debate.

The way food is stored, packaged, labelled and marketed, and our expectations of what good food looks like and when we can purchase it can all influence the amount we waste. It is rather less wasteful if we align consumption to availability and adapt to the seasonal variability in supplies. A way forward to reduce waste is possible if waste generation is decoupled from economic growth as argued by Sjöström and Östblom (2010).

Reducing food waste requires action by all sectors of society. Those involved in farming can use the information contained in this and the referenced reports to reflect on the crops that they grow and their suitability given water availability and efficiency of production. Businesses can act in a number of ways, such as reviewing their supply chains and the processes and technologies they employ. Initiatives such as the Courtauld Commitment, the Federation House Commitment and WWF-UK's One Planet Food programme can help facilitate this activity on a national and international level. Businesses can also help consumers by providing information on products, altering pack sizes to reduce waste, implementing standards, or advice on how to reduce waste within the home.

Households can act to reduce food waste through a range of simple measures, as advocated through the Love Food Hate Waste campaign, supported by work undertaken by other sectors of society. Love Food Hate Waste continues to be a valuable initiative in highlighting the magnitude of household food waste, and ways in which this can be tackled.

11 Conclusion

This report identifies the water footprint of meeting the UK's food and drink needs, and the carbon footprint across the supply chain of delivering this, from farm to plate, including emissions associated with Land Use Change. Avoidable food waste represents approximately 6% of the UK water footprint, equivalent to almost twice the direct household water use of the UK. Just the internal water footprint from household food waste in the UK is equivalent to the direct household water use of 33 million people. Avoidable food waste also represents approximately 3% of the UK's domestic greenhouse gas emissions, with further emissions abroad. Excluding Land Use Change, emissions associated with avoidable food waste are equivalent to the annual greenhouse gas emissions from 7 million cars.

The case studies highlight the need to consider context when interpreting water footprint data. It is not necessarily the total volume of the water footprint which is critical; rather, it is the local context within which that water is used to produce food which determines the impacts on the environment and on other water users. The impacts in areas suffering water stress (e.g. excessive extraction of water) are normally far more significant than in areas with relatively plentiful water supplies.

The research reinforces the benefits of partnership working by organisations such as WRAP and WWF-UK to highlight issues of mutual interest. This research could be extended in future to consider the sources of water used in different countries (green, blue) and the impacts of effluent (grey water) across additional stages in the supply chain. The carbon footprint data could also be developed to provide nation-specific factors.

Even without this additional detail the key conclusion, that reducing food waste can make a significant contribution to addressing the water and carbon footprints of the UK, is clear. The research provides a framework around which to discuss how food waste could be reduced to provide the greatest environmental benefit.

Appendix 1: Household food waste in the UK

Code	Food waste description	Weight (tonne/year)			
		Avoidable	Possibly avoidable	Unavoidable	Total
A01	Cracker / crisp bread	8,968			8,968
A02	Bread sticks	259			259
A03	Dough	12,301			12,301
A04	Dumpling	769			769
A05	Morning goods	15,133			15,133
A06	Pastry	6,835			6,835
A07	Speciality bread	80,473	547		81,020
A08	Standard bread	542,023	117,291		659,314
A10	Yorkshire pudding and other batter	13,212			13,212
A11	Other bakery	1,645			1,645
B01a	Pork - bacon	13,668	4,603		18,271
B01b	Pork - carcass meat / bones	26,582	6,961	4,966	38,510
B01c	Pork - sausages	28,665	2,243		30,908
B01d	Pork - sliced ham	21,376	6,283		27,659
B01f	Pork - other	3,107			3,107
B02	Beef	43,168	20,423	8,786	72,377
B05	Fish and shellfish	32,260	3,327	7,110	42,696
B07	Lamb	8,283	3,522	19,847	31,652
B10a	Poultry - carcass meat / bones	61,075	31,749	176,740	269,565
B10b	Poultry - poultry product	17,798	1,016	10,490	29,304
B10c	Sliced Poultry	2,358			2,358
B11	Meat and fish based sandwich spread	12,124			12,124
B12	Bone (unidentifiable / mixed)		705	6,763	7,467
B13	Other meat (unidentifiable / mixed meat / offal)	11,336	2,528	1,730	15,594
B15	Game	12,830			12,830
C01	Milk	363,598			363,598
C02	Cheese	37,635	243	48	37,926
C03	Cream and crème fraiche	22,247			22,247
C04	Egg	23,627		53,724	77,351
C05	Yoghurt / yoghurt drink	79,815			79,815
C06	Other dairy	1,820			1,820
D01	Breakfast cereal	74,996			74,996
D02	Flour	19,815			19,815
D03	Pasta	41,608			41,608
D05	Rice	64,433			64,433
D06	Other staple foods	2,702			2,702
E01	Apple	175,452	53,462	31,188	260,103
E02	Banana	82,595	838	230,390	313,822
E03	Kiwi	2,972		2,799	5,771

Code	Food waste description	Weight (tonne/year)			
		Avoidable	Possibly avoidable	Unavoidable	Total
E04	Melon	29,775	27	73,649	103,451
E05	Mixed fruit	7,920	14,610	17,214	39,744
E06	Orange	49,254	564	83,660	133,478
E07	Pear	34,262	3,859	2,652	40,773
E08	Pineapple	7,650	124	20,381	28,156
E10	Soft / berry fruit	40,632	92	2,818	43,541
E11	Stone fruit	43,374	473	22,685	66,531
E12	Other citrus	18,560	1,730	24,649	44,939
E13	Other fruit	8,912	5,343	5,772	20,028
F01	Apple	4,896			4,896
F02	Banana	1,678			1,678
F05	Mixed fruit	4,961			4,961
F07	Pear	571			571
F08	Pineapple	1,675			1,675
F10	Soft / berry fruit	4,802			4,802
F11	Stone fruit	5,944			5,944
F12	Other citrus	1,432			1,432
F13	Other fruit	3,816			3,816
G01	Aubergine	1,150	249	373	1,772
G03	Bean (all varieties)	21,821	1,507	5,599	28,928
G04	Broccoli	21,389	18,230	1,262	40,881
G05	Cabbage	53,208	14,019	18,077	85,304
G06	Carrot	45,964	65,308	6,148	117,420
G07	Cauliflower	10,450	2,973	26,104	39,527
G08	Celery	20,119	1,766	1,360	23,245
G10	Courgette	4,798	2,059	1,489	8,346
G11	Cucumber	30,868	2,807	10,330	44,005
G12	Leafy salad	35,784	562	552	36,898
G13	Leek	8,491	543	11,397	20,431
G14	Lettuce	61,072	1,958	3,589	66,619
G15	Mixed vegetables	47,705	198,780	7,085	253,571
G16	Mushroom	13,529	2,598		16,126
G18	Onion	35,801	67	92,830	128,698
G19	Pea (all varieties)	2,445	832	5,500	8,777
G20	Pepper	15,760	722	7,997	24,478
G21	Potato	286,336	481,021	564	767,921
G22	Spinach	2,924	538		3,461
G24	Spring onion	5,763	451	2,118	8,331
G25	Sprout	2,085	146	4,973	7,204
G26	Sweet corn / corn on the cob	24,188	1,181	17,764	43,133
G27	Tomato	60,895	1,674	618	63,187
G28	Other vegetables and salad	21,928	6,974	4,742	33,644

Code	Food waste description	Weight (tonne/year)			
		Avoidable	Possibly avoidable	Unavoidable	Total
G29	Other root vegetables	21,885	4,390	22,935	49,210
H02	Baked beans	26,581			26,581
H03	Bean (all varieties)	3,778			3,778
H04	Broccoli	788			788
H05	Cabbage	1,164			1,164
H06	Carrot	1,095			1,095
H07	Cauliflower	130			130
H09	Coleslaw and hummus	29,887			29,887
H15	Mixed vegetables	5,348			5,348
H16	Mushroom	853			853
H17	Non-leafy salad	10,011			10,011
H18	Onion	3,031			3,031
H19	Pea (all varieties)	3,817			3,817
H20	Pepper	221			221
H21	Potato	74,160			74,160
H22	Spinach	280			280
H23	Vegetable based sandwich spread	3,981			3,981
H25	Sprout	1,811			1,811
H26	Sweet corn / corn on the cob	3,963		11	3,974
H27	Tomato	19,787			19,787
H28	Other vegetables and salad	9,323			9,323
H29	Other root vegetables	8,176			8,176
I01	Chocolate and sweets	24,325			24,325
I02	Cereal bar	1,371			1,371
I03	Savoury snacks	22,649		3,613	26,262
I04	Other confectionery and snacks	830			830
I05	Sweet biscuits	18,262	31		18,293
J01	Coffee	29,678		60,379	90,057
J02	Fruit juice and smoothies	157,357			157,357
J03	Hot chocolate	17,170			17,170
J04	Lager, beer and cider	73,788			73,788
J05	Milkshake and milk drink	33,430			33,430
J06	Carbonated soft drink	278,323			278,323
J07	Squash	52,800			52,800
J08	Tea waste	86,175		366,151	452,326
J09	Bottled water	68,607			68,607
J10	Wine	50,858			50,858
J11	Other alcohol	15,759			15,759
J12	Other drink	9,078			9,078
K01	Cook in sauce	56,994			56,994
K02	Dip	9,562			9,562
K03	Gravy	12,475			12,475

Code	Food waste description	Weight (tonne/year)			
		Avoidable	Possibly avoidable	Unavoidable	Total
K04	Herb / spice	10,220	5,712	679	16,611
K05	Honey	2,234			2,234
K06	Jam	14,710			14,710
K07	Ketchup	4,567			4,567
K08	Mayonnaise / salad cream	12,175			12,175
K09	Olives	2,148			2,148
K10	Pickle	3,830			3,830
K11	Salt	393			393
K12	Sugar	4,808			4,808
K13	Sweet spread	1,274			1,274
K14	Other condiments etc.	66,281			66,281
L01	Oil	8,634	60,805	5,089	74,528
L02	Fat	11,715	3,688		15,403
M01	Cheesecake	4,694			4,694
M02	Chocolate pudding / dessert	1,471			1,471
M03	Cakes / gateau / doughnuts / pastries	90,977			90,977
M04	Fruit pie / strudel / crumble	18,113			18,113
M05	Ice Cream	15,732			15,732
M06	Jelly	2,029			2,029
M07	Milk pudding (custard etc.)	44,703			44,703
M08	Mousse	2,632			2,632
M09	Trifle	3,480			3,480
M10	Other desserts	8,608			8,608
P01	Baby food	5,630			5,630
P02	Baby milk	8,599			8,599
P03	Gunge		136,964		136,964
P05	Mixed food	2,336	3,904		6,240
P07	Other food	3,047	1,005		4,052
P08	Draining from canned food		137,638		137,638
Q01a	Soup - pre-prepared	32,538			32,538
Q01b	Soup - homemade	46,965			46,965
Q02a	Composite meal - pre-prepared	178,485	1,314		179,799
Q02b	Composite meal - homemade	313,138	21,272		334,410
Q03a	Sandwich - pre-prepared	9,711	32		9,743
Q03b	Sandwich - homemade	37,647	1,233		38,880
Q04a	Savoury products - pre-prepared	41,425			41,425
Q04b	Savoury products - homemade	3,901			3,901
		663,810	**23,851**	**5,089**	**8,307,464**

Source: WRAP (Quested & Johnson 2009).

Appendix 2: Water footprint of household food waste by products

Products	Internal water footprint (million m³/year)			External water footprint (million m³/year)			Total water footprint (million m³/year)		
	A[1]	PA[2]	Total	A[1]	PA[2]	Total	A[1]	PA[2]	Total
Beef	295.7	139.9	435.6	329.8	156.0	485.8	625.4	295.9	921.3
Cocoa beans				753.8		753.8	753.8		753.8
Rice				556.3		556.3	556.3		556.3
Poultry	135.5	54.7	190.2	251.2	101.3	352.5	386.7	156.0	542.6
Wheat	344.0	51.3	395.2	124.4	18.5	142.9	468.4	69.8	538.2
Coffee				521.7		521.7	521.7		521.7
Pork	146.8	31.6	178.4	279.5	60.1	339.6	426.2	91.7	517.9
Milk	452.3	0.2	452.5	3.5	0.0	3.5	455.8	0.2	456.0
Citrus fruit others				238.9	2.3	241.3	238.9	2.3	241.3
Livestock others	25.6	2.3	27.8	165.9	14.8	180.7	191.5	17.1	208.6
Beans				131.7	3.8	135.5	131.7	3.8	135.5
Vegetables fresh others	14.1	19.4	33.5	27.5	37.9	65.4	41.6	57.3	98.9
Pepper				90.0	4.1	94.1	90.0	4.1	94.1
Apples	5.9	1.7	7.6	65.2	19.3	84.5	71.1	21.1	92.2
Bananas				87.3	0.9	88.2	87.3	0.9	88.2
Oilseeds others				10.4	73.0	83.3	10.4	73.0	83.3
Potatoes	20.3	27.1	47.5	12.5	16.7	29.3	32.9	43.9	76.7
Goat and sheep	25.7	10.9	36.6	13.5	5.8	19.3	39.2	16.7	55.9
Stone fruit others				51.3	0.5	51.7	51.3	0.5	51.7
Fruit fresh others				27.0	21.0	48.0	27.0	21.0	48.0
Strawberries				29.6	0.1	29.6	29.6	0.1	29.6
Oranges				25.4	0.3	25.6	25.4	0.3	25.6
Pears				18.4	2.0	20.4	18.4	2.0	20.4
Maize				15.7	0.6	16.3	15.7	0.6	16.3
Cauliflowers and broccoli				8.0	4.6	12.6	8.0	4.6	12.6
Carrots and turnips				5.2	7.2	12.4	5.2	7.2	12.4
Cabbages & other brassicas				9.2	2.4	11.6	9.2	2.4	11.6
Tomatoes	0.1	0.0	0.1	9.4	0.1	9.5	9.5	0.1	9.6
Onions and shallots	7.3	0.1	7.4	0.6	0.0	0.6	7.8	0.1	7.9
Olives				6.4		6.4	6.4		6.4
Watermelons				4.6	0.0	4.7	4.6	0.0	4.7
Lettuce and chicory				4.4	0.1	4.5	4.4	0.1	4.5
Cucumbers and gherkins				3.7	0.5	4.2	3.7	0.5	4.2
Spinach				3.9	0.1	4.0	3.9	0.1	4.0
Pineapples				3.5	0.0	3.6	3.5	0.0	3.6
Peas, green				2.1	0.3	2.4	2.1	0.3	2.4

Products	Internal water footprint (million m³/year)			External water footprint (million m³/year)			Total water footprint (million m³/year)		
	A[1]	PA[2]	Total	A[1]	PA[2]	Total	A[1]	PA[2]	Total
Roots and tubers, others				1.2	0.2	1.3	1.2	0.2	1.3
Kiwi fruit				1.3		1.3	1.3		1.3
Leeks, other alliaceous				0.6	0.0	0.7	0.6	0.0	0.7
Sugar cane				0.5		0.5	0.5		0.5
Eggplants				0.2	0.0	0.2	0.2	0.0	0.2
Grand Total	**1,473**	**339**	**1,812**	**3,895**	**555**	**4,450**	**5,368**	**894**	**6,262**

[1]Note: A=avoidable
[2]Note: PA=possibly avoidable.

Appendix 3: External water footprint of household food waste

	External water footprint (million m^3 per year)		
	Avoidable	**Possibly avoidable**	**Total**
Ghana	423	0	423
Brazil	271	64	336
India	263	22	284
Ireland	175	71	246
Netherlands	168	50	218
Thailand	176	21	197
Ivory Cost	171	2	173
France	129	38	166
Denmark	128	29	156
USA	128	7	135
Italy	102	15	118
Pakistan	114	0	115
Nigeria	113	0	114
Spain	87	17	104
Canada	88	10	98
Germany	72	20	92
Kenya	82	9	91
Cameroon	89	0	90
Indonesia	82	2	84
Belgium	53	17	71
Colombia	55	0	55
Mexico	49	1	50
South Africa	36	10	45
China	35	7	42
Turkey	34	6	40
Portugal	32	4	36
Ethiopia	8	27	35
Ecuador	25	1	27
Ukraine	6	18	23
Guyana	22	0	22
Argentina	15	5	20
Uganda	19	2	20
El Salvador	20	0	20
Greece	16	3	19
Peru	18	0	18
Nicaragua	18	0	18
Honduras	17	0	17
Viet Nam	17	0	17

	External water footprint (million m^3 per year)		
	Avoidable	**Possibly avoidable**	**Total**
Australia	13	4	17
Uruguay	12	5	17
Jamaica	15	0	15
Poland	10	5	14
Hungary	11	3	14
Botswana	9	4	14
Papua N. Guinea	12	0	12
Zimbabwe	9	3	12
Israel	8	4	12
Egypt	10	2	12
Guatemala	10	1	10
Dominican R.	10	0	10
Namibia	7	3	10
Suriname	9	0	9
Angola	9	0	9
Chile	6	2	8
Malaysia	3	5	8
Sri Lanka	7	1	8
St. Lucia	7	0	7
Costa Rica	7	0	7
Tanzania	6	0	6
Cuba	5	0	5
S. Vincent-Gr	5	0	5
Madagascar	4	1	5
Aruba	5	0	5
Sweden	4	1	5
Togo	4	0	4
Iran	4	0	4
Dominica	4	0	4
Morocco	3	0	4
New Zealand	3	1	4
Cyprus	2	2	4
Malawi	3	1	4
Russia	3	1	3
Austria	2	1	3
Myanmar	3	0	3
Bulgaria	2	1	3
Zambia	1	2	3
Others	*291*	*21*	*312*
Total	**3,895**	**555**	**4,450**

Appendix 4: Carbon footprint of the UK's household food waste

Products	Internal Carbon Footprint ('000 t/year)			External Carbon Footprint ('000 t/year)			Total Carbon Footprint ('000 t/year)		
	A[1]	PA[2]	Total	A[1]	PA[2]	Total	A[1]	PA[2]	Total
Milk	1,690	3	1,693	293	1	294	1,983	3	1,987
Wheat	1,253	195	1,448	93	15	108	1,347	209	1,556
Potatoes	491	656	1,147	38	50	88	529	706	1,234
Beef	533	252	786	265	125	391	799	378	1,176
Coffee	19		19	989		989	1,008		1,008
Pork	535	115	650	293	63	357	828	178	1,007
Vegetables fresh others	222	364	586	95	175	270	317	539	856
Tomatoes	160	2	162	674	7	682	834	9	843
Poultry	517	209	726	84	34	118	601	242	843
Rice	229		229	386		386	615		615
Tea	56		56	417		417	473		473
Apples	140	41	181	85	25	110	225	67	291
Livestock others	188	16	204	48	4	52	236	19	256
Goat and sheep	125	53	179	33	14	47	159	67	226
Cucumbers & gherkins	122	14	136	58	6	64	180	19	200
Citrus fruit others	121	1	122	71	0	71	192	1	193
Strawberries	72	0	72	115	0	115	186	0	187
Carrots	58	80	138	17	24	42	75	104	179
Lettuce	133	4	137	32	1	33	165	5	170
Cocoa beans	24		24	135		135	159		159
Bananas	58	1	59	65	1	66	123	1	124
Cabbages	69	18	87	22	6	28	91	23	115
Spinach	82	2	84	24	1	24	105	3	108
Cauliflower	41	25	66	14	9	24	56	34	90
Fruit fresh others	20	16	36	29	23	52	49	39	88
Stone fruit others, fresh	38	0	39	46	0	46	84	1	85
Oranges	34	0	34	40	0	41	74	1	75
Oilseeds others	7	50	58	2	11	13	9	61	70
Onions & shallots (green)	56	1	56	13	0	13	69	1	69
Beans, dry	42	1	43	17	0	17	59	2	60
Roots and tubers others	41	6	47	5	1	6	46	7	53
Pepper	11	0	12	39	2	40	50	2	52
Pears	26	3	29	18	2	20	43	5	48
Mushrooms	25	5	30	12	2	14	37	7	44
Maize	25	1	26	13	0	13	38	1	39
Citrus fruit others	21	0	21	10	0	10	30	0	30

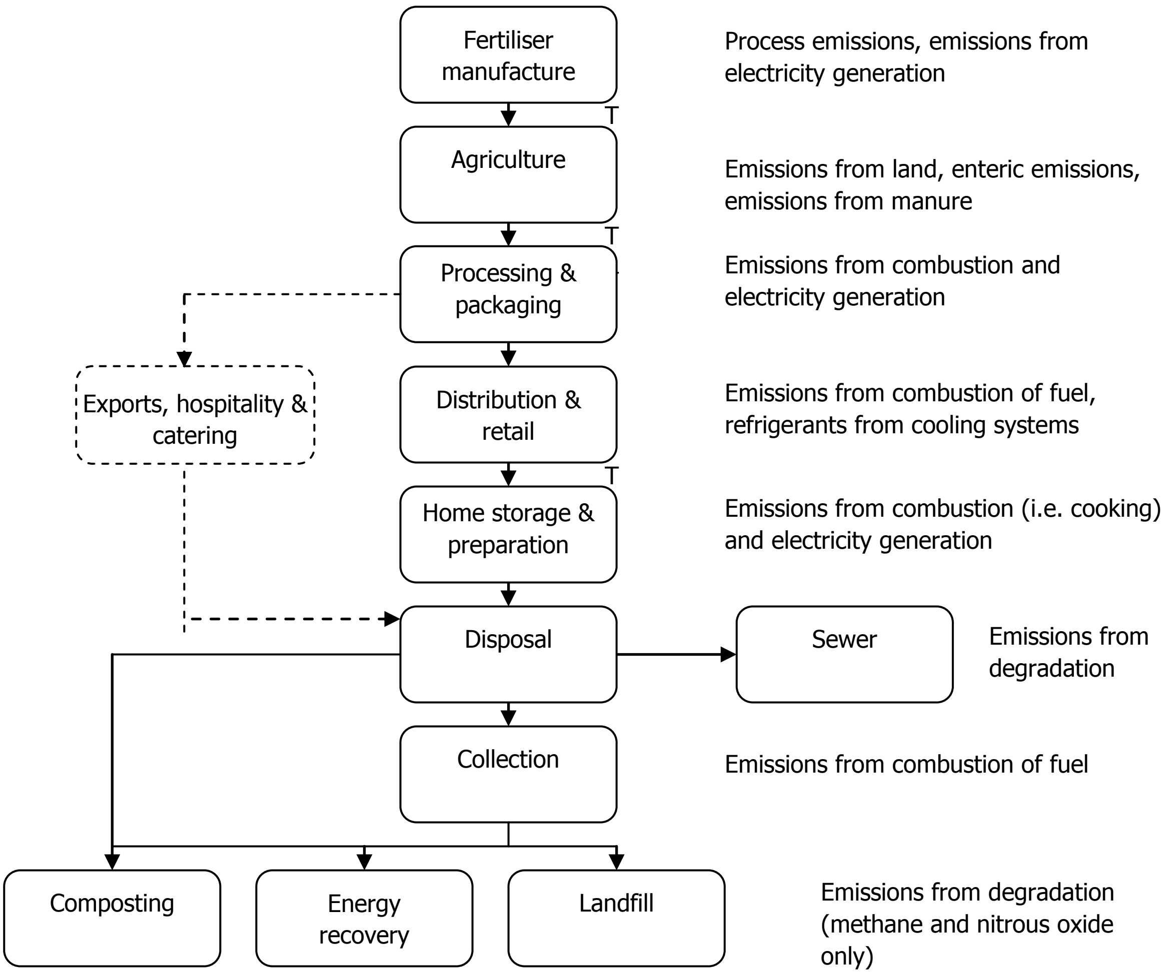
Pineapples	6	0	7	12	0	12	19	0	19
Peas, green	14	2	16	0	0	0	14	2	16
Leeks & oth.alliac.veg	10	1	11	3	0	3	13	1	14
Sugar cane	3		3	4		4	8		8
Citrus fruit others	2		2	3		3	6		6
Olives	1		1	3		3	5		5
Eggplants	1	0	1	0	0	0	1	0	2
Others	2,989	320	3,308	1,520	92	1,612	4,509	412	4,921
Unallocated	2,694	767							
Total	**13,007**	**3,223**	**16,230**	**6,138**	**696**	**6,833**	**19,145**	**3,919**	**23,064**

[1]Note: A=avoidable
[2]Note: PA=possibly avoidable.

Appendix 5: Background on carbon footprint accounting

Greenhouse gas emissions have been calculated in two ways in this report. Firstly, estimates have been made at a national level based on emissions from whole sectors (e.g. agriculture, food and drink manufacturing) and other top level sources. Greenhouse gas emissions data has been taken from a variety of sources to derive an overview of the impact of food and drink across a range of sectors from agriculture to households and waste management. The stages and sources of emissions covered are summarised in Figure 13.

Figure 13: Schematic to calculate the various components of the carbon footprint of an agricultural product.



T = transportation, including overseas.

The emissions associated with food have been allocated to the final quantity which is consumed by UK households, net of exports and food and drink which is sold via the hospitality / catering sector. The factors therefore account for waste along the supply chain associated with the production of food for household consumption, although they exclude emissions from managing this waste. Secondly, as part of this report, individual carbon factors for different products have been identified. The available figures centre on unprocessed (fruit, vegetables, raw meat) rather than processed foods (e.g. ready meals, sauces, prepared sandwiches, carbonated drinks), and do not cover all food products wasted. These are significant gaps, and means that the sum of the figures outlined herein will not add up to the average of all foods.

Several sources have been used to derive the emissions associated with growing food items of interest. In order to be selected for use in this study, the information must meet specific criteria. These are:

- The study must be a life cycle analysis or life cycle analysis-like study.
- It must have been critically reviewed (e.g. in a scientific journal or in line with ISO 14040 or other relevant standards such as PAS 2050).
- The study must be representative of the UK supply chain for food.
- The report must clearly outline the scope of the emissions reported (e.g. clear system boundary).
- The assumptions made must be transparent.
- Clearly identify data from primary and secondary research.
- No ambiguity in the way impacts are ascribed to materials (e.g. co-products).

Data which complies with either the International Standard on life cycle assessment, ISO14040, or the standard on carbon footprinting, PAS 2050 has been used wherever possible. Where this is not available, data from scientific journals has also been used. A full list of studies used is provided within the references for this report.

Information on emissions associated with processing food for consumption within the UK are limited. Defra (2009a) and DECC (2010) publish data on emissions associated with the food, drink and tobacco sector in the UK and associated with food imported. However, whilst applicable at a top down level, this information cannot be used at a product level. In lieu of this, product specific reports have been used where possible. One study (ERM 2009) has been identified which contains information on processing pork. In this report, the figures associated with pork have been applied to all meats. Processing data from Yoshikawa (Yoshikawa *et al.* 2008) have been used for stoned fruit, broccoli, cabbage, carrots, potatoes, spinach and sprouts, Beccali (Beccali *et al.* 2009) for citrus fruit, Ruini and Marino (2009) for pasta, Kasmaprapruet *et al.* (2009) for rice, Zespri *et al.* (2009) for Kiwi fruit, Cadbury (2008) for chocolate, and Tesco (2008) for orange juice.

Watkiss *et al.* (2005) identify that approximately 9 million tonnes of CO_2 emissions were associated with the import of 28 million tonnes of food to the UK. Although this figure is CO_2 only, it has been used in this study as a rough approximation for the impact of importing one tonne of food, with an emission factor of 0.320 tonnes CO_2 per tonne of imported food used for emissions which occur abroad in transporting food to the UK. An average packaging emission factor has been applied to all food items, based on data collected for the Courtauld Commitment. This includes primary and secondary packaging. The emissions factors used are identified in James (2010).

Tassou *et al.* (2009) identified emissions associated with storage, distribution and retail of 11 specimen food products in a study to test and inform the development of PAS 2050. The emissions derived accounted for the time products spend on shelf, the temperature at which they are kept and the volume of the product. In this report, these emissions factors have been applied to similar food items. For example, emissions factors for bread have been applied to crackers, pastries and flour. Most fruit have been classified as fresh apples. Soft berries, cucumbers, leafy salad and lettuce have been allocated the same Retail Distribution Centre (RDC), transport and retail emissions as strawberries. Emissions associated with drink products have been estimated based on WRAP estimates in discussion with industry.

Pretty *et al.* (2005) calculated that UK household food shopping involves around 8km of car travel per household per week (in addition to travel by bus, bicycle and on foot). The food expenditure survey suggests that food consumption is about 12kg per person per week. With an average UK household size of 2.32 persons, this equates to 28kg per household per week. Defra (2010a) provide emissions factors for a range of vehicles. Based on a lower medium size passenger car, and assuming that the sole purpose of the journey is food shopping, this equates to 0.228kg CO_2 eq per km. This equates to 0.07kg CO_2 eq per kilogram of food transported home, or 0.07 tonnes CO_2 eq per tonne of food.

As with processing, limited food-specific emission factors are available for home storage and preparation of food. Information on drink storage is based upon WRAP estimates in discussion with industry, squash has been taken from Tesco (2008), peas have been taken from Defra (2009b) pasta from Ruini and Marino (2009) and meat from ERM (2009). At waste stage, an average emission factor for all foods has been applied as per Table 12. To provide an average estimate several data sources have been used. These have been sense checked against a separate top down calculation outlined below. Table 12 identifies the carbon factors used to estimate the average impact of food. Information on agriculture and fertiliser manufacture is based upon UK agriculture and fertiliser use only.

Data on food and drink brought into the home (from retail, takeaways and sources of free food) come from Defra's Family Food Survey for the calendar year 2007 (Defra 2008a). The food types used in this report were aligned as closely as possible with the classification of food and drink in the Family Food dataset and then estimates for amounts of purchases at the food group level were obtained. The information from the Family Food dataset was converted from grams per person per week into tonnes in the UK each year. From this, we estimate that UK households purchase approximately 38.5 million tonnes of food and drink per annum, with a further 4.8 million tonnes consumed outside of the home (e.g. restaurants).

Of the 5.3 million tonnes of avoidable food and drink waste, 17% is drink and 83% food. The bottom-up calculation takes these relative proportions into account in obtaining the overall carbon factor for food and drink (3.8). Defra estimates that greenhouse gas emissions from the UK food chain are equivalent to about 180 million tonnes CO_2 eq, excluding waste (Defra figure 4). This suggests an average figure of 4.2 tonnes CO_2 eq per tonne of food, excluding waste management impacts. The results from both assessments are similar in the magnitude of impact.

Table 12: CO_2 Emission data, metric tonnes CO_2 eq .

Life Cycle Stage	Total million tonnes CO_2 eq)	Per tonne food waste (tonnes CO_2 eq)*	Data source
Agriculture	52.7	1.22	Defra (2006)
Fertiliser manufacture	3.5	0.08	Composition (AIC 2008) Impacts (Davis & Haglund 1999)
Food and drink manufacturing	13.3 (UK), 47.2 (non-UK)	1.09	DTI (2002) Defra (2009a)
Packaging	6.6	0.17	WRAP**
Transport (including overseas)	18.4	0.48	Defra (2005)
Food exports	-8.0	-0.18	Defra (2009a)
Retail	5.0	0.13	Tassou *et al.* (2009)
Home related	16.1	0.42	Brook Lyndhurst (2008)
Waste emissions (avoidable food only)	2.4	0.41	WRAP***
Total	**130***	**3.8**	

* Note: Total and per tonne factor is for food purchased by households only
** Note: WRAP calculation based on Courtauld Methodology and packaging data
**Note: Calculation based upon 62% to landfill, 8% to Energy from Waste, 22% to sewer and 8% to home composting

Appendix 6: Background on water footprint accounting

The total water footprint of a product/nation is made up of two components; the direct water footprint and indirect water footprint. The direct water footprint is calculated as the sum of volume of water either evaporated or polluted at the point of operation. For a nation, it is also called as the internal water footprint (IWF) of the nation. The indirect water footprint is equal to the sum of total water footprints of the predecessor suppliers in the product supply chain. In the national context, it also referred as the external water footprint (EWF) of the nation.

$$WF = IWF + EWF$$

For detailed methods and data used in calculating the water footprint of the UK, please refer to the volume 2 of the WWF report on water footprint (Chapagain & Orr 2008). In gist, first the water footprint of the products (also called virtual water content of the products) imported in the UK is calculated based on the climate and production statistics of the producing regions.

The internal water footprint of the UK, IWF, is calculated as:

$$IWF = Total\ domestic\ water\ use - Export\ of\ domestic\ virtual\ water$$

The external water footprint of the UK, EWF, is calculated as:

$$EWF = Total\ import - Export\ of\ imported\ virtual\ water$$

However, international trade is more complicated and a substantial volume of trade originates in countries which are not directly exporting to the country where the final consumption takes place. Hence, tracking the products of origin is not straight forward. We've followed the method used in WWF report (Chapagain & Orr 2008) to trace the origin of the virtual water imports. The virtual water flow calculations and footprint estimates are made at product category level. The product level information is aggregated only at the final stage in the calculations, allowing us to analyse individual products as a case study in this report. Based on international trade data (tonne/year) and the water footprint of these products (cubic metres/tonne), the virtual water flows (cubic metres/year) are estimated. Using crop production data (tonne/year) and the water footprint of crops in the UK (cubic metres/tonne), the total domestic water use is calculated. To avoid double accounting, the part of the crops used as feed has been separated from crop water use based on Food Balance Sheets produced by FAO (FAOSTAT data 2010). Water use in livestock products is calculated using the water footprint of livestock products (cubic metres/tonne) and the production volumes in the UK (tonne/year).

A schematic on estimating the water footprint of product is presented in Figure 14 with a short discussion on each of these components in the following paragraphs.

Green water footprint
This is soil water derived from rainfall. Green water supports all non-irrigated agricultural production (rain fed cropping) and is normally assumed to be the volume of water that is lost through evapotranspiration during crop growth. As evapotranspiration is a function of climate, crop location has a major impact on the volumetric water footprint. Consequently, a key issue for water footprint accounting of agricultural products is the treatment of green water. Green water is often seen as 'free' and its use unproblematic but this is not necessarily always the case. In the majority of situations, interception of rainfall by the plant canopy of cash crops is less than that of natural vegetation; this leads to the scenario where replacing natural vegetation by cash crops can increase ground water and river flows (Scanlon *et al.* 2007). However where rainfall is limited and there are concerns over low levels of ground water or river flows, it may be economically, environmentally and socially preferable to grow an irrigated high value crop like strawberry or flowers rather than a rain fed high water requirement crop, like maize.

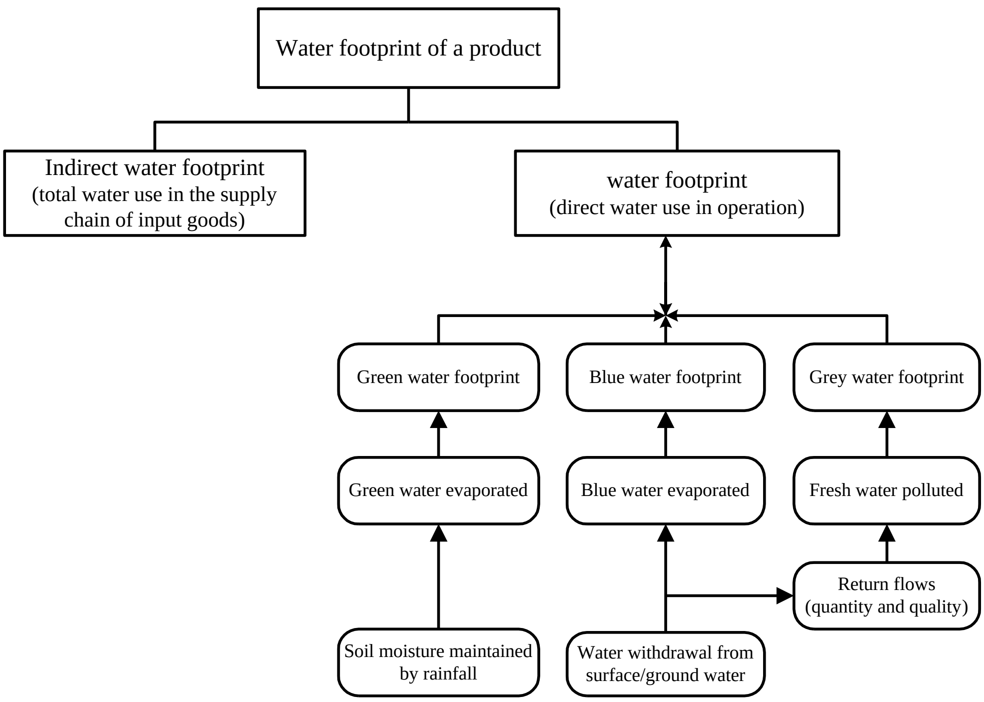
More recent works on green water has shown that it is an important dimension in the global food and water security (Chapagain & Orr 2009, Aldaya *et al.* 2009, Chapagain & Hoekstra 2010, Mekonnen & Hoekstra 2010, Chapagain *et al.* 2006). The inclusion of green water is again being questioned since some workers contend that "green water (and other resources) is only accessible through access to and occupation of land" and that "the consumption of green water in agri-food product life cycles is better considered in the context of land use"

(SABMiller & WWF 2009, Ridoutt & Pfister 2009). The inclusion of green water within the volumetric water footprint is a useful auditing tool but the need to consider water use within the wider context of land use and environmental impact has exposed its limitations.

Blue water footprint

The blue water footprint is an indicator of consumptive use of so-called blue water, i.e. fresh surface (lakes and rivers) or groundwater (Hoekstra *et al.* 2011). The term consumptive refers to the volume that meets any of the three conditions of either being evaporated, or incorporated into the product, or water diverted into another catchment (not available in the same place and time). Generally, this is the part of the water abstracted by farmers for irrigation or by water companies to supply the general population that meet either of the above three conditions of being consumptive use. The blue water footprint can be further refined based on different kinds of blue water e.g. surface water (rivers and lakes), renewable ground water (residence time in the order of months and a few years), fossil ground water (residence time in the order of thousands of years. As such distinction is very data and time demanding, it is often limited to specific examples where such refined information is needed. The green water footprint has a relatively low opportunity cost compared to the blue water footprint. The environmental impact of the blue water footprint in crop production depends on the timing and location of the water use. It would need a dedicated analysis to estimate where and when blue water footprints in crop production constitute significant environmental problems.

Figure 14: The various components of the water footprint of an agricultural product.



Grey water footprint

The existing definition of grey water in water supply literatures defines it as the total volume of polluted return flows. Based on this definition, the grey water use can be easily quantified as most businesses will have a discharge licence which states the volume of water that they may discharge but the second definition can create difficulties. However, it doesn't explicitly show the quality of the return flow and the assimilating capacity of the receiving water bodies. Later on grey water footprint has been introduced in an attempt to account the degree of pollution of fresh water system from pollution arising in the production process such as residual fertilisers and pesticides in the return flows from the agricultural fields, or various contaminants from an industrial effluent (Hoekstra & Chapagain 2008, 2006, Chapagain 2006). The grey water footprint is defined as the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards (Hoekstra *et al.* 2011). The definition of grey water in water footprint accounting is more holistic. It is based on the quality and quantity of the polluted return flows (effluent), and is quantified based on the size and existing water quality standards of the receiving water bodies. In this report, we've used the second definition of grey water footprint.

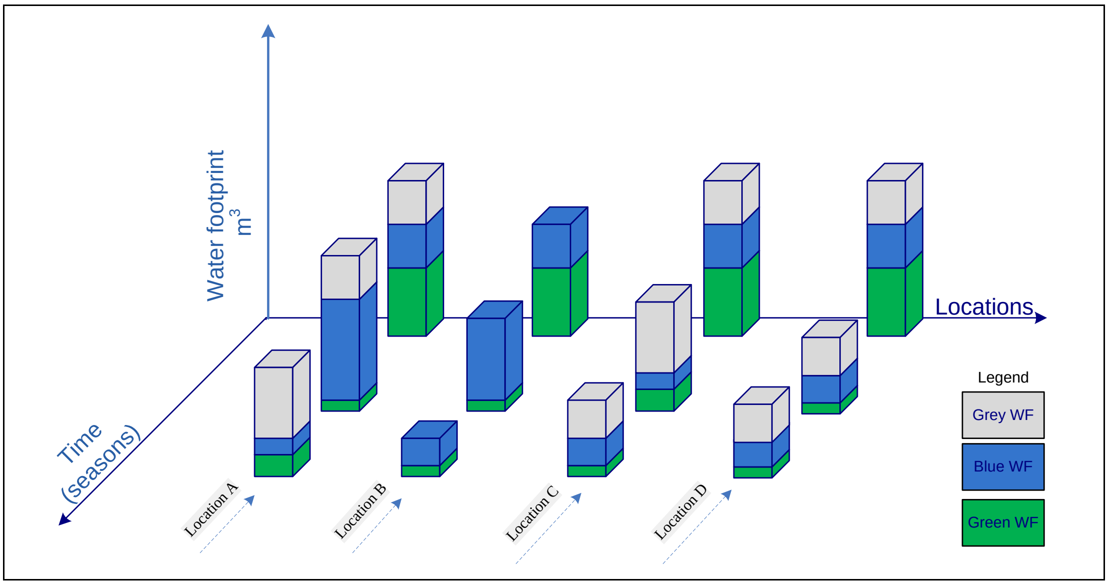
The idea of expressing water pollution in terms of a water volume needed to dilute the waste is not new. Falkenmark and Lindh (1974) proposed as a rule of thumb to reckon with a dilution factor of 10 to 50 times the wastewater flow. Postel *et al.* (1996) applied a dilution factor for waste absorption of 28 litres per second per 1,000 population. These generic dilution factors do not account for the sort of pollution and the level of treatment before disposal, but implicitly assume some average characteristics of human waste flows. Chapagain *et al.* (2006) proposed to make the dilution factor dependent on the type of pollutant and to use the ambient water quality standard for a certain pollutant as the criterion to quantify the dilution requirement. The grey water footprint concept has grown out of the recognition that the size of water pollution can be expressed in terms of the volume of water that is required to dilute pollutants such that they become harmless. The requirement to calculate a volume of water required to dilute another volume of water to an agreed discharge standard involves knowing the concentration of pollutants in return flows as well as in the receiving water bodies, and the exact volumes required achieving a set discharge concentration. Not all grey water is derived from blue water. Rain fed agriculture will have a grey water footprint due to leaching by rainfall. In fact good irrigation management can reduce the grey water footprint compared to rain fed agriculture in a place like the UK. These reasons illustrate why grey water calculations are difficult to make and why grey water is often excluded from water footprint calculations.

Assessing the impacts of water footprint

A volumetric water footprint accounting exercise produces a 3-dimensional matrix of information where the water footprint of a product/service/business/nation is disaggregated both in time and space with a clear distinction on kinds of water evaporated (blue and green) or polluted (grey) (Chapagain *et al.* 2011). The volumetric water footprint is useful mostly in awareness raising and in auditing process, but for a complete impact assessment, it needs to be analysed in the right context of local economic, environmental or social attributes. The impact and sustainability of the water footprint depends on its various attributes (e.g. size, time, location and kinds of water use) and the local conditions in those places where the footprints are located. The impact assessment can be done both quantitatively as well as qualitatively. Furthermore, the quantitative assessment can be carried out from different perspectives using either hydrological attributes, ecological attributes, social attributes, or any combination of these attributes (Chapagain *et al.* 2011).

Figure 15 shows a full chain of food supply. For example, at location A tomatoes are grown in the farm, stored at B, processed at C and consumed at D. As these activities can take place at any time of the year, the water use can be presented along the time axis as well. The variation can either be presented as a continuous curve or lumped into different columns of information depending upon the scope of the study. The figure breaks down the information into blue, green and grey water footprints for three different periods in a year for all these four locations. Though the total water footprint of a product is the sum of all the columns in the whole supply chain of a product, it is vital to remember the granularity of the background information while interpreting the impacts.

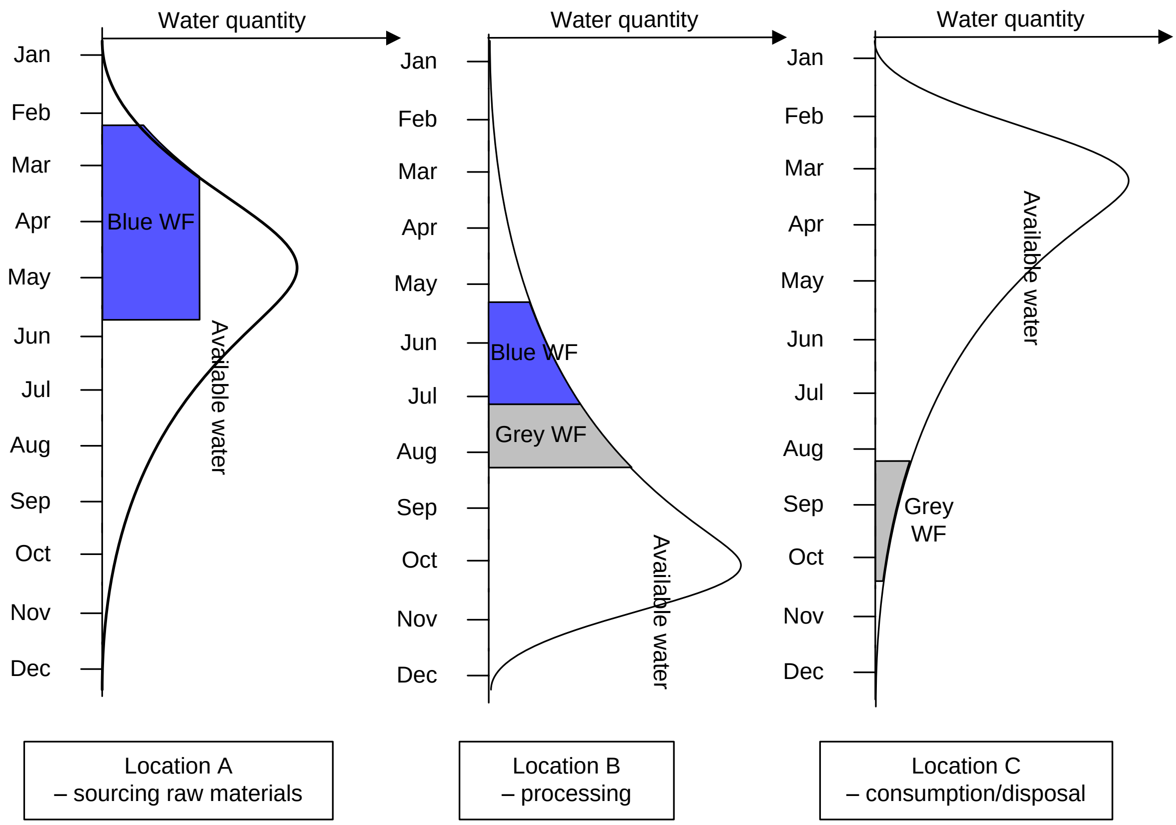
Figure 15: Matrix of water footprint accounts along the value chain of a product.



Source: Chapagain *et al.* (2011)

Figure 16 presents an illustration of water footprint accounting along the supply chain of a product where the largest water footprint occurs at the sourcing of raw material phase. As 100% of water footprint is blue at this stage, it is analysed in the context of blue water availability at sourcing region. As it is seen that most of the water footprint is below the available water quantity curve, the resulting negative impacts might be lower compared to the one at consumption stage. At consumption stage, the water footprint is entirely grey in this case, meaning that there is no evaporation or losses of blue water from the immediate hydrology. However, as it would take almost all the blue water available to assimilate the emitted pollution at consumption at this time of the year at this location, the impacts will be severe from the hydrological perspectives.

Figure 16: Water footprint and water availability along the value chain of a product



The use of water always has an environmental impact. In water rich countries, like the UK, this is generally small and is concentrated in certain areas of the country (such as East Anglia) and is restricted to certain times of the year. Although blue water abstraction for agriculture is less than 1% of the total, in some catchments and at peak times it can exceed abstraction for domestic water supply. However, in water poor countries, water use can have severe impacts, for example, in Morocco, where water demand for horticultural irrigation has lowered the water table to the detriment of future supplies for all sectors. The impact of the UK's water footprint, both domestically and overseas, has environmental and social consequences.

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Why we are here
To stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature.

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