Environmental Sustainability Assessment of the Primary School Catering Sector

By

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Abstract

Current food production and consumption practices are depleting natural resources and polluting ecosystems at a rate that is unsustainable, and they are also one of the main causes of anthropogenic climate change. If this trend does not change, externalities of food production will be exacerbated in future decades due to population growth and increasing living standards. A shift towards low impact diets has been proposed as part of the solution to overcome these challenges. The public food sector offers tremendous potential for influencing such a shift; however currently in the UK this potential is only partially exploited as national guidelines for public food procurement and sustainability schemes for the catering sector generally avoid promoting the adoption of low impact menus.

This doctoral research aims at addressing this shortfall by creating a procedure for the design of low impact primary school menus. This is informed by a life-cycle based tool (the Environmental Assessment Tool of School meals, EATS) that enables catering companies and local authorities to self-assess the environmental impact of a meal in terms of its carbon and water footprint, with the purpose of identifying *hotspot* meals and comparing alternatives in the design of new menus. The data underlying EATS includes the results of a meta-analysis of the existing literature on the carbon footprint of 110 food products commonly used in the preparation of primary school meals in the UK.

To validate EATS, a statistical analysis of the underlying data was performed, feedback from its potential users was collected through a questionnaire, three case study analyses were developed, and the results provided were compared with existing studies. Finally, by providing an example of application of the procedural assessment, the potential impact arising from the implementation of the reduction measures suggested in this work is discussed.

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Abbreviations

BFM	Bone Free Meat
CF	Carbon Footprint
CW	Carcass Weight
DECC	Department of Energy and Climate Change
DEFRA	Department of Environment Food and Rural Affairs
EATS	Environmental Assessment Tool of School meals
EPD	Environmental Product Declaration
EWFN	Energy Water Food Nexus
FAO	Food and Agriculture Organization
GHG	Greenhouse Gases
GWP	Global Warming Potential
HG	Heated Greenhouse
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LW	Live Weight
MIPS	Material Input Per unit of Service
PSFS	Primary School Food Survey
RDC	Regional Distribution Centre
UN	United Nations
UNEP	United Nations Environment Programme
WF	Water Footprint
WRAP	Waste and Resources Action Programme
WSI	Water Stress Index
ρ	waste coefficient

Glossary

Food category: food products are grouped into six categories (dairy and eggs, fish, fruit and nuts, vegetables and pulses, meat, processed agricultural products)

Food product: ingredient (e.g. carrots, salmon) used in the preparation of school meals that the user can find in EATS

Fish items: the items recorded in the PSFS that contain fish (e.g. cod in tomato sauce)

Item code: in the PSFS an item code is associated to each item name

Item group: in the PSFS all the food and drink items on offer are grouped into 19 item groups (e.g. salad, fruit, protein-meat)

Item name: in the PSFS each food and drink item on offer is attributed an item name (e.g. mashed potatoes)

Meat items: the items recorded in the PSFS that contain meat (e.g. lamb stew)

School meal: one serving of a school meal according to primary school servings size, this generally includes a main dish, a side dish and a dessert

Vegan items: the items recorded in the PSFS that do not contain meat, fish, dairy nor eggs (e.g. fruit salad)

Vegetarian items: the items recorded in the PSFS that do not contain meat or fish but contain dairy or eggs (e.g. cheesy jacket potato, chocolate cake)

1 Introduction

1.1 Background

During the World Food Summit (World Food Summit, 1996), food security was defined as a situation "when all people at all times have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life". This definition stressed the importance of elements that go beyond the availability of food which are: access (individual entitlement for obtaining food), food safety, nutritional value, and stability through time.

In the last century the primary focus of the research community has been on enhancing food productivity and during the "Green Revolution" (1966–1985) research and technological improvements led to significant increases in yields, which meant that overall global production kept ahead of the overall demand (Ingram et al., 2013). These increased yields were mainly achieved due to radical improvements in the use of fertilizers, pesticides, agricultural machinery, and irrigation systems. However, this was accompanied with higher resource intensity, land degradation, loss of biodiversity and changes in climate (Ericksen et al., 2009).

Between 1990 and 2010 the production of food (+56%) grew at a faster rate than the world population (+30%) and yet significant inequalities now exist with regard to access (DEFRA, 2012, FAO et al., 2013). For example, whilst in 2008 an estimated two billion people worldwide were overweight or obese (FAO et al., 2013, Swinburn et al., 2011), in 2011–2013 the Food and Agriculture Organization of the United Nations (FAO et al., 2013) estimated that 842 million people suffered chronic undernourishment.

The prevalent food production systems deplete natural resources and pollute ecosystems at a rate that is unsustainable, and this will compromise the capacity for nations to produce food for future generations. Food consumption is the main purpose of land use (38% of the terrestrial surface is used for agriculture and 70% of land suitable for growing food is already in use) and of water use (70% of freshwater withdrawals are used for irrigation) (Foley et al., 2011, Giovanucci et al., 2012). Agriculture damages productive land through soil erosion and degradation and affects the ecosystems, representing a threat to biodiversity (Verhulst et al., 2010). The increased use of fertilizers has caused the crucial disruption of global nitrogen and phosphorus cycles, with negative consequences on water quality, aquatic ecosystems and marine fisheries (Diaz and Rosenberg, 2008, Canfield et al., 2010). Furthermore, agriculture is responsible for 30-35% of anthropogenic greenhouse gas emissions globally, mainly due to deforestation, direct emissions from fertilised soils, livestock rearing and rice cultivation (Foley et al., 2011).

Without a change to current trends, externalities of food production will be exacerbated in future decades by further pressures that will be applied as a consequence of: growing population (expected to reach 9.2 billion people by 2050) (United Nations Department of Economic and Social Affairs, 2007), economic growth and consequent changing lifestyles. Increasing living standards in developing countries and consequent changing lifestyles are considered to be causing a global transition towards less environmentally sustainable diets (inspired by the western world) rich in meat, processed foods, refined sugars, refined fats, and oils (Tilman and Clark, 2014, Hoff, 2011, Khan and Hanjra, 2009, Foresight, 2011). Based on projected increases in greenhouse gas emissions from income-dependent global dietary shifts and population growth, Tilman and Clark (2014) have estimated that by 2050 emissions driven by food consumption will soar by 80% compared to the emissions released in 2009. In addition, climate change is adding further pressures on water supplies and agricultural productivity. This is a consequence of rising temperatures, significant changes to normal weather patterns that potentially influence crop yields (e.g. changes in rainfall patterns), rising seawater levels, shrinking glaciers and the increase in extreme weather events, like droughts and floods. Adaptation measures to maintain yields in response to extreme weather events and different growing conditions will in return influence levels of greenhouse gas emissions (as more inputs will be required to maintain productivity) (Bows et al., 2012). Ultimately in a context of a world of limited resources exacerbated by the effects of climate change, the achievement of food security is one of the biggest challenges of the 21st century (Godfray et al., 2010a).

However, not all food types carry the same environmental burden. In terms of greenhouse gas (GHG) emissions for instance, it is well-known that meat and dairy products present higher emissions than plant-based products. At the same time, diets that exclude an adequate intake of fruit, vegetables, nuts and seeds coupled with a high consumption of red and processed meat, have been shown to be one of the major causes of non-communicable diseases (Aleksandrowicz et al., 2016). For these reasons there is widespread agreement across the academic community that there is a major potential for dietary changes to reduce the environmental impacts of food production whilst improving health (Aleksandrowicz et al., 2016, Whitmee et al., 2015, Garnett, 2016) or as Tilman and Clark (2014, p. 518) phrased it:

> *“The implementation of dietary solutions to the tightly linked diet-environment-health trilemma is a global challenge, and opportunity, of great environmental and public health importance.”*

Governments can use a range of instruments to promote dietary change; these include but are not limited to: removing subsidies for animal-sourced foods that cause distorted food prices in high income countries; introducing carbon taxes on food products; integrating environmental priorities into dietary recommendations (as has already happened in Brazil and Sweden (Röös, 2015, Ministry of Health of Brazil, 2014)); and providing information-oriented tools (Popkin, 2009, Aleksandrowicz et al., 2016, Joyce et al., 2014, Heller and Keoleian, 2015). One of the means by which governments can enhance sustainable consumption is by using the leverage of the public food sector (schools, hospitals, universities, care homes, etc.) in setting a "best-practice" example for consumers and citizens and therefore operating as a driver of change (Sonnino and McWilliam, 2011). The nudging power of such a strategy is particularly strong within the education sector, where issues on food and nutrition can also be included in the curriculum, using the school meal as a system of social learning (Morgan and Sonnino, 2007).

In order to do so it is crucial to adopt a robust scientific approach in defining what is meant by "*sustainable food*". This can be achieved through adopting an Energy/Water/Food Nexus approach, which, essentially highlights the interconnections between energy, water and food systems, thereby stressing the importance of identifying and then quantifying water and energy (and more generally greenhouse gas emissions) embedded in food production (Hoff, 2011). This approach is crucially complemented by the application of life-cycle thinking, which makes it possible to calculate the actual embedded impacts of a product throughout the whole supply chain (i.e. from cradle to grave), as opposed to their apparent ones, thus dismantling "common sense" assumptions, such as for instance the concept of food miles (Garnett, 2008).

It is argued within this thesis that in the UK the potential offered by the public food sector in promoting a shift towards more sustainable consumption patterns is only partially exploited. National guidelines for the catering sector and sustainability schemes generally avoid suggesting a dietary shift towards low resource intensive products and, in promoting the provision of a sustainable service, they do not adopt a full life cycle perspective (which sometimes results in focusing on stages of the supply chain that only have a minor significance compared to the overall picture). In terms of climate change mitigation measures, this focus on selected stages of the supply chain (e.g. energy efficiency of kitchen appliances, reduction of transport distances), can be interpreted as a consequence of two main factors. Firstly, due to a widespread attitude towards considering territorial-based rather than consumption-based emissions when defining national or regional carbon reduction targets, that leads to emissions embedded in imported products being generally omitted (Wood et al., 2014). Secondly, due the predominant role of CO_2 reduction measures (particularly from fossil fuels combustion) linked to climate change mitigation. This subsequently fails to acknowledge that (in the case of food systems) non-CO_2 emissions are in actuality relatively more impacting (and therefore important) than CO_2 emissions. This is particularly true when looking at global GHG emissions from agriculture, where, if land use change is not taken into account, the emissions contributions are only 1% for CO_2, 53% for CH_4 (a greenhouse gas 25 times more polluting than CO_2 over a 100 year period) and 46% for N_2O (a greenhouse gas 298 times more polluting than CO_2 over a 100 year period) (Bows et al., 2012, Bows-Larkin et al., 2014).

The purpose of this doctoral research work is therefore to fill this gap in knowledge, by combining nexus thinking with a life-cycle perspective to develop a procedural assessment to advise caterers and local authorities on how to reduce the environmental impact of the food service they provide, with a specific focus on primary school meals.

1.2 Aim and Objectives of the study

The aim of the research is:

'To develop a procedure for the assessment of the environmental impact of primary school menus and the design of low impact alternative menus'.

The objectives of the research are listed below and presented together with the methodology and the research outputs in Table 1-1:

1. To select the best method(s) to use to assess the environmental impact of food production and consumption choices.
2. To collect secondary data on the carbon footprint (CF) and water footprint (WF) of a range of food products that comprehensively covers most ingredients used in the preparation of primary school meals in the UK.
3. Based on the findings of objective 2 to develop a tool that can be used for the self-assessment of a primary school meal from *cradle to plate*.
4. To validate the tool through case studies, user(s) feedback, and by testing it against existing studies.
5. To develop a procedural assessment informed by the tool, to create environmentally sustainable menus.

Table 1-1: Objectives of research

Objective No.	Objectives of the Research	Methodology No.	Methodology to achieve the Objectives	Research Output
O1	To critically review existing methods to assess the environmental impact of food production and consumption choices. (See M1 in Section 3.1)	M1	Review current literature on environmental impact assessment of food production and consumption	Literature review and identification of research gap
O2	To collect secondary data on the CF and WF of a range of food products that comprehensively covers most ingredients used in the preparation of primary school meals in the UK. (See M2 in Section 3.1)	M2	Selecting a list of food products of interest and performing a systematic review of literature for each element on the list to create a CF and WF database	Database of carbon and water footprints from *cradle to gate*

O3	To develop a tool that can be used for the self-assessment of a primary school meal from *cradle to plate.* (See M3 in Section 3.1)	M3	Collection of the factors to calculate the impacts of a primary school meal from *gate to plate* and creation of a user interface to enable users to perform the overall calculation	Environmental Assessment Tool of School meals (EATS)
O4	To validate the tool through statistical analysis, case studies, users' feedback and by testing it against existing studies. (See M4a and M4b in Section 3.1)	M4a & M4b	Validate the methodology and the tool, using statistical analysis of the data, case study analysis, feedback from users, and by comparing the results with existing ones. Develop the final version of the tool	EATS (final version) Results from meta-analysis, case studies and comparison with literature
O5	To develop a procedural assessment to create environmentally sustainable menus. (See M5 in Section 3.1)	M5	Development of a procedural assessment informed by the tool, that enables the creation of environmentally sustainable menus	Sustainability procedural assessment Example of application of the procedure

2 Literature review

This chapter provides a critical review of the literature base related to the following areas:

- The Energy/Water/Food nexus (Section 2.1);
- Key pathways to achieve food security (Section 2.2);
- Existing methods to assess the environmental impact of food production and provide the evidence base to promote each pathway (Section 2.3).

An overview of the current regulatory landscape in the UK public food sector together with existing sustainability schemes is provided, in order to assess whether the key pathways identified to achieve food security are reflected therein.

2.1 The Energy/Water/Food nexus

The word “nexus” derives from the Latin verb *nectere* which means “to connect”, and expresses the study of the interactions and connections between two or more things, often termed dependencies or interdependencies. The water, energy and food nexus (EWFN) is therefore the study of the interactions between these three resources, the synergies and trade-offs that arise from the way they are managed, and the potential areas of conflict (Bazilian et al., 2011, Keairns et al., 2016). This nexus approach is based on the idea that it is not possible to address water, energy or food security in isolation in an effective way without considering the implications on the other two, in other words the broader consequences caused by the interdependencies between them (Bazilian et al., 2011, Olsson, 2013, Hoff, 2011). For example, the basis of food production requires water directly to grow crops, and this water usually requires pumping and treating which requires energy; in turn electricity production is dependent on water for cooling and steam generation etc.

Energy and water are further required for processing, packaging, transport and storage, preparation by the end-user and ultimately final disposal of food waste. The use of energy in each phase of the food chain, for the case of the UK, is illustrated in Figure 2-1.

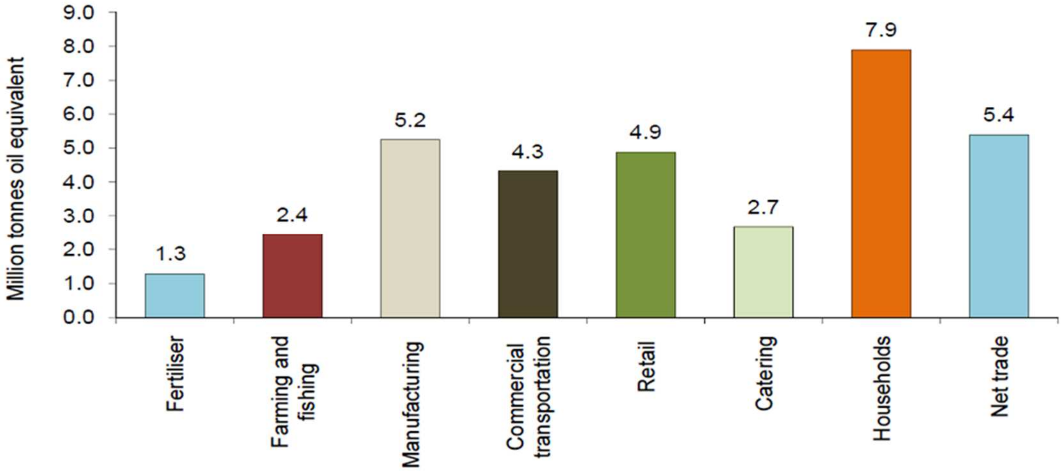


Figure 2-1: Energy use in the UK food supply chain in 2011 (DEFRA, 2013b p. 35).

Figure 2-2 shows just how closely interconnected the elements of the nexus are by showing the correlation between food and energy prices. This close connection is a consequence of the reliance of modern agriculture on fossil fuels and of first generation bio-fuel expansion, which has made energy and food production become competitors for land and water (Bazilian et al., 2011, Olsson, 2013, FAO, 2010). This tension between energy and food represents a case in which a trade-off can be made considering all aspects of the nexus.

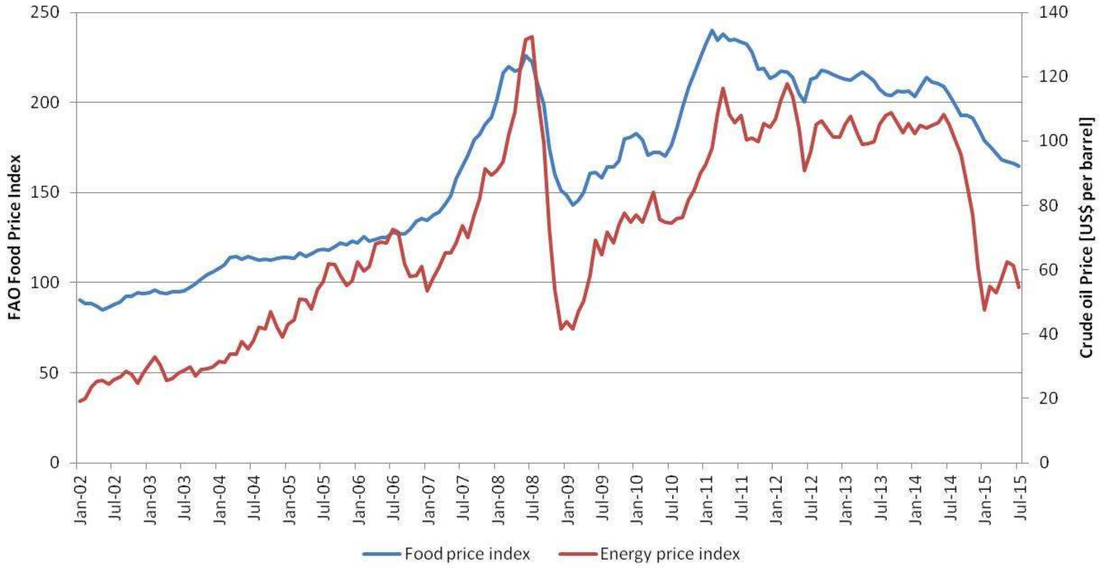


Figure 2-2: World food and oil prices. January 2002 to July 2015 (The World Bank, FAO, 2015)

The water, energy and food nexus has been identified as one of the three greatest threats to the global economy (Van der Elst and Dave, 2011). It has also been defined a “security” nexus, as access to all three elements must be ensured in order to have prosperity and peace (Lawford et al., 2013).

The ultimate goal for analysing the connections between water, energy and food, and highlighting the potential areas for conflict, trade-offs and synergies, is to guide policy-making towards integrated solutions and approaches to resource use (Lawford et al., 2013, Bazilian et al., 2011, Hoff, 2011, Ringler et al., 2013, Howells et al., 2013).

In this work, the nexus is approached from a food security standpoint, and provides the rationale behind the choice of investigating embedded water and energy inputs (and related greenhouse gas emissions) of food consumption and production patterns.

2.2 Pathways to achieve Food Security

Throughout the literature two key goals relating to the concept of food security can be identified (Dogliotti et al., 2014, Foresight, 2011, Godfray et al., 2010a). These are:

- Sustainably balancing the growing demand for food with supply streams;
- Ensuring universal access to food, nutritional security and stability through time.

Both are extremely ambitious and multi-disciplinary; however this review of the literature is focused on the first goal, as its achievement is ultimately a necessary condition for achieving the second goal. Numerous pathways have been suggested to reach this primary goal. On the supply-side of the equation, the pathways mainly focus on developing food production methods that make more efficient use of resources and replenish, rather than deplete, biodiversity and related ecosystems. Whilst on the demand side they focus on the promotion of a shift towards more sustainable consumption patterns (Foresight, 2011, Garnett, 2014, Godfray et al., 2010a, Godfray et al., 2010b).

These include:

- Pathway 1—Employing sustainable production methods (Beddington, 2010, OECD, 2013, BMU and BMZ, 2011, Foresight, 2011, Foley et al., 2011);
- Pathway 2—Changing diets (Garnett, 2008, Godfray et al., 2010a, BMU and BMZ, 2011, Foresight, 2011, Garnett, 2011, Foley et al., 2011, Tilman and Clark, 2014, Heller and Keoleian, 2015, Bows et al., 2012);
- Pathway 3—Reducing wastage (Kummu et al., 2012, Garrone et al., 2014, Parfitt et al., 2010, FAO, 2011a, BMU and BMZ, 2011, Godfray et al., 2010a, Foresight, 2011, Foley et al., 2011, Quested et al., 2012).

This three-pathway approach is now analysed in more detail and their respective connection(s) with the nexus approach are underlined.

2.2.1 Pathway 1: Employing Sustainable Production Methods

There is common agreement that in the coming decades more food will have to be produced at a lower environmental cost in a resource constrained environment (Foresight, 2011, Foley et al., 2011).

In terms of water resource availability, in 2000, 10 countries used more than 40% of their water resources for irrigation, and were therefore defined as suffering critical water scarcity (Khan and Hanjra, 2009). Water scarcity is defined as the situation in which the aggregated impact of all users compromises the supply and/or the quality of water, to the extent that demand by all sectors (including the environment) cannot be fully satisfied (UN Water, 2006). Besides over consumption of water, a threat is presented by salinization and pollution of water courses and bodies and degradation of water related ecosystems (FAO, 2011b). This is not the only resource whose limited availability is critical for increasing agricultural production. For example allied to this is phosphorus, which is used in the production of chemical fertilizers. (The price of phosphate rock increased by 700% in 14 months between 2007 and 2008 (Cordell et al., 2009)). Land represents another critical resource. Stiff competition ensues for land use as a consequence of other human activities (e.g. urbanization and the cultivation of crops for biofuels) and where land is available, it may no longer be productive because of unsustainable land management, which leads to desertification, salinization, soil erosion and other consequences. Alternatively it may simply be because land banks that exist for the protection of biodiversity and ecosystems services (such as carbon storage) must be given priority (Godfray et al., 2010a, FAO, 2013b, Fazeni and Steinmüller, 2011, Howells et al., 2013). Furthermore, agriculture is responsible for 30-35% of GHG emissions globally, mainly due to carbon dioxide emissions caused by deforestation, nitrous oxide emissions from fertilized soils and methane emissions from livestock rearing and rice cultivation (Foley et al., 2011).

It is, therefore, extremely important to optimize the use of inputs in agricultural production. The EWFN approach can assist in such an aim through informing policies and regulations that promote the implementation of more efficient production technologies. Some examples are solutions for water conservation (like rainwater harvesting) and efficient water use technologies (on time water delivery and micro irrigation), increased fertilizer use efficiency (through more precise application of fertilizers), increased yields to input ratio, improved feed quality for better digestibility, improved manure management, and reduced carbon intensity of fuel inputs (by using alternative sources for energy production such as wind and solar power or anaerobic digestion) (Garnett, 2011, Ringler et al., 2013, Godfray et al., 2010a, Vergé et al., 2007). Notwithstanding these requirements, existing policies created using a silo approach have traditionally focused only on food security, while heavily subsidising water and energy requirements for food production (e.g. in India farmers have access to free electricity in order to use it for groundwater extraction for irrigation (Hoff, 2011)). These are explicitly in conflict, dis-incentivizing farmers to invest in new technologies (Olsson, 2013).

2.2.2 Pathway 2: Changing Diets

About one third of global cereal production is fed directly to animals (Alexandratos et al., 2006). Even though the efficiency of the conversion of feedstock into animal matter is considerably variable among different species (e.g., in developed countries the cereal necessary to produce a weight increase of one kilogram is approximately: 7 kg for cattle, 4 kg for pork and 2 kg for chicken (Rosegrant et al., 1999)), in most cases meat consumption represents a sub-optimal use of land, water and energy resources involved in the agricultural production (Godfray et al., 2010a, Garnett, 2011). In addition, according to the FAO's *Livestock Long Shadow* report (FAO, 2006) and many other LCA analyses (e.g. Head et al., 2014, Baldwin et al., 2010, Mogensen et al., 2009, Gössling et al., 2011), livestock has a strong impact on water pollution (caused by manure and wastewater), land use and biodiversity, and heavily contributes to greenhouse gases emissions (contributing to 18% of global emissions over its lifecycle (Gerber et al., 2013).

Amongst researchers aiming at identifying dietary patterns that have a lower environmental impact, the great majority of academics agree on the net benefits of reducing meat consumption (Baroni et al., 2007, Davis et al., 2010, Saxe et al., 2012, Hoolohan et al., 2013, Aston et al., 2012, Pathak et al., 2010, Vieux et al., 2012, Audsley et al., 2010, Macdiarmid et al., 2011, Davis et al., 2016, Aleksandrowicz et al., 2016, Jalava et al., 2014, Scarborough et al., 2014). For instance, Vanham et al.

(2016) quantified the water resources related to food consumption in thirteen Mediterranean cities and calculated that a shift to a healthy Mediterranean diet, a pesco-vegetarian diet and a vegetarian diet would lead to reductions in water consumption of 19% to 43%, 28% to 52% and 30% to 53% respectively. Tilman and Clark (2014) performed a similar analysis focusing on GHG emissions, and estimated that a global dietary shift to a Mediterranean, pesco-vegetarian and vegetarian diet would lead to reductions in GHG emissions respectively of 6%, 30% and 43%.

Often this argument has been supported by medical professionals for health reasons, asserting that a shift towards a more plant based diet would improve health, as proven by a number of dietary guidelines promoting a lower meat consumption compared to the current one in western countries (Food Standards Agency, 2007, Mäkelä, 2005, National Health and Medical Research Council, 2013). However, taking the attitude that meat rearing and consumption is always negative is over simplistic: in developing countries meat represents an important source of some vitamins and minerals which are crucial for children’s development (Neumann et al., 2002, Garnett, 2009).

There is a vast range of literature focused on finding synergies between a shift towards both healthier diets and environmentally friendly ones; some examples can be found in (Reynolds et al., 2014, van Dooren et al., 2014, Saxe et al., 2012, Meier and Christen, 2013, Berners-Lee et al., 2012, Macdiarmid et al., 2011, Tukker et al., 2011, Risku-Norja et al., 2009, Scarborough et al., 2012). However, it has been discussed therein that this might not always be the case. For instance Macdiarmid et al. (2011) discussed some examples of trade-offs between health and the environment such as fish intake, low fat dairy and lean meat. Oily fish, for instance, is considered a good source of protein and omega-3 fatty acids, however a global increase in fish consumption would put further pressure on the already declining wild fish stocks. Other researchers have discussed a number of parallel solutions for dietary shifts that would lower our impact on the environment such as: the consumption of seasonal products (Foster et al., 2014), seeking a balance between energy intake and expenditure (Vieux et al., 2012) and a lower consumption of products such as coffee, tea, cocoa and alcohol that usually come with a high environmental burden and are not necessary from a nutritional perspective (Saxe et al., 2012).

The benefits that a EWFN approach brings to this discussion is that it serves to emphasize the importance of considering embedded water, energy and GHG emissions in food production when supporting and guiding a shift towards less intensive consumption dietary choices. Such a mentality stands behind the application of a range of methodologies (e.g. LCA, water footprinting, carbon footprinting) that can quantitatively assess the performance on diets. The results of these studies can be used to facilitate transparently informed consumer choices. As an example, an App called SuperWijzer (www.thequestionmark.org/en/ accessed June 2017) has been developed by the Dutch organization *Varkens in Nood*, which enables purchasers to scan a product and obtain information on its environmental impact (obtained through the application of LCA) and to receive suggestions for similar products which have a better score (Head et al., 2014). Such innovations are an integral part of a EWFN approach.

2.2.3 Pathway 3: Reducing Wastage

It has been estimated throughout the global food chain that approximately 30% of food produced for human consumption is lost or wasted (FAO, 2013b, FAO, 2011a). The stages of the food system that experience most wastage can vary significantly when comparing developing and developed countries. For example, in developing countries most of the food loss occurs in the field (as a consequence of pests and pathogens (Kader, 2005)) and at post-harvest stages, as a consequence of poor infrastructure, technical limitations in harvesting techniques, storage and cooling technologies, packaging and lack of connection to markets (FAO, 2011a). Conversely, in the developed world most of the waste occurs at the retail, food service and household level(s). A study conducted by WRAP (WRAP, 2008) estimated that in the UK, household food waste corresponds to one third of the amount of food purchased. The U.S. Department of Agriculture estimated that in 2008 food wasted at retail and consumer levels was equal to 124 kg per capita per year, corresponding to a purchasing value of US$ 165.6 billion (Buzby and Hyman, 2012). There are many reasons reported for this, these include: low prices of food - which encourages wasteful behaviours; extreme reliance on “use by” dates, which often underestimate the shelf life of the product for safety reasons; aesthetic criteria as a result of which retailers throw away perfectly edible fruits and vegetables; offers, which encourage consumers to buy more than they can consume; and oversized portions proposed by the food service sector (Godfray et al., 2010a, FAO, 2011a, WRAP, 2008, Parfitt et al., 2010, O’Donnell et al., 2015).

The impact of food waste and losses on the environment, in terms of the resources involved in the production, processing, transport and consumption stages was highlighted by the FAO in its Food Wastage Footprint report (FAO, 2013b), in which for the first time the impact of food wastage on climate change, biodiversity, water and land was assessed at a global level. Figure 2-3 and Figure 2-4, extracted from this report, illustrate the impact on climate change deriving from food wasted at each phase of the supply chain, highlighting how the later in the supply chain food is wasted, the higher the impact will be, due to the accumulating impacts of the previous phases.

Similarly, in a study by Kummu et al. (2012), it was assessed that the production of lost and wasted food crops accounts for 24% of total freshwater used in food crop production, in addition to 23% of total global cropland area and global fertilizer use. As pointed out by the United Nations Environment Programme - UNEP (Nellemann, 2009), food wastage not only represents an inefficient use of resources and ecosystem services, but also a large source of methane emissions at the landfill stage.

It is estimated that if the minimum loss and waste percentages in each food supply chain step were to be applied everywhere, approximately half of the food supply (and associated resources) losses could be saved (Kummu et al., 2012). It is, therefore, evident that the application of a EWFN approach could be crucial in serving to underline the opportunity for improving overall resource efficiency offered by reducing wastage at all stages of the food supply chain (FAO, 2013b, HLPE, 2014, Garnett, 2008). In addition it could foster productive recycling of food no longer fit for consumption as animal feed or as a source of energy (Foresight, 2011).

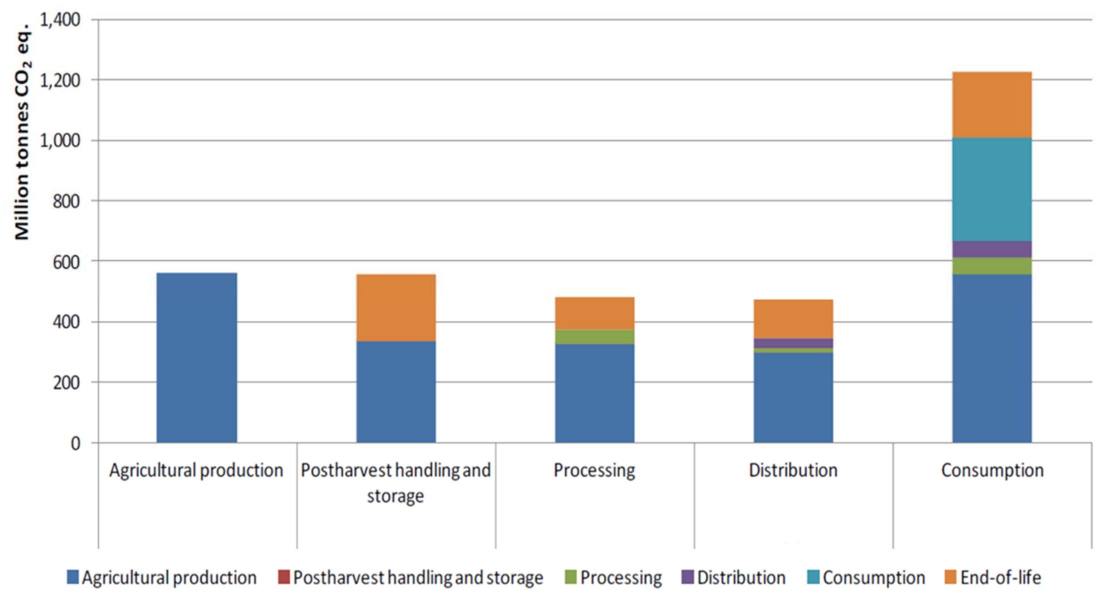


Figure 2-3: Carbon footprint of food wastage, by phase of the food supply chain with respective contribution of embedded life cycle phases (FAO, 2013b)

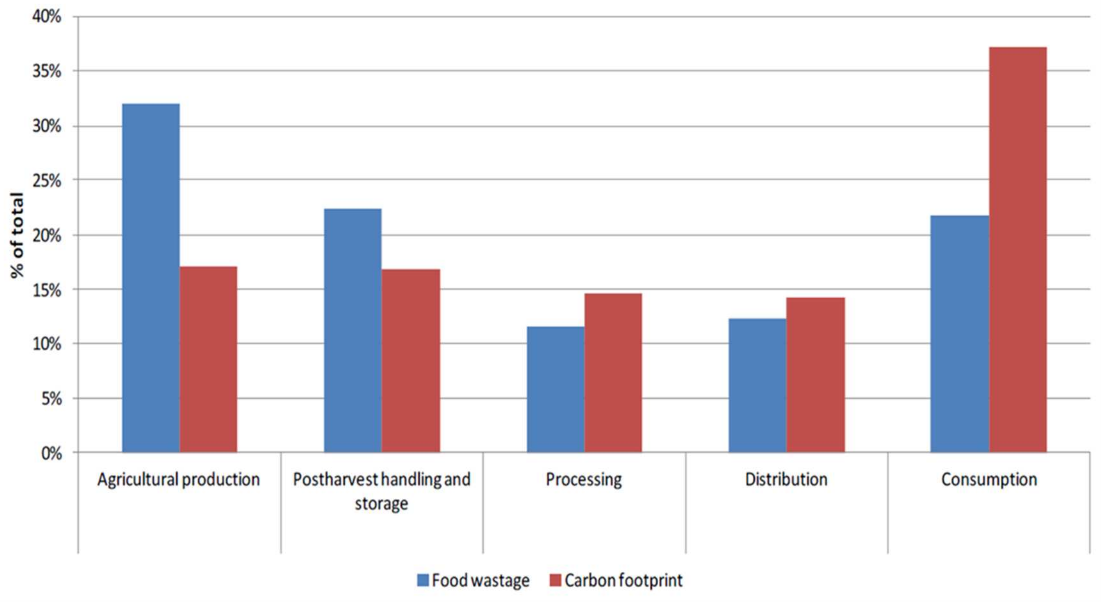


Figure 2-4: Contribution of each phase of the food supply chain to food wastage and carbon footprint (FAO, 2013b)

2.3 Review of existing methods to assess the resource use and/or the environmental impact of products

In order to adopt an EWFN approach to achieve food security, analysis of the literature base suggests that it is necessary to develop methods of analysis that can supply information on the complex relationships between water, energy and food (Pacetti et al., 2015, Bazilian et al., 2011). A number of analytical tools and methods were developed in the last decades to enable the assessment of the resource use and/or the environmental impact of products. Such methods can be applied to food products in order to provide the necessary information to promote the three pathways mentioned in the previous sections.

Energy Analysis measures the energy required to manufacture a product or a service, including both direct and indirect energy flows. There are different types of energy measures, including: exergy, a measure of the maximum amount of work that can be theoretically obtained from a system (Jeswani et al., 2010) and emergy, a measure of the total inputs to a system (e.g. energy, materials, labour and information) calculated using a common unit of measure (Finnveden and Moberg, 2005).

The Material Intensity Per Unit Service (MIPS) calculates the material inputs to a system aggregating them in five categories: abiotic materials, biotic materials, water, air and soil (Spangenberg et al., 1999). In this analysis, all the materials required for the production process minus the final weight of the products are quantified and represent the material intensity of a product (Ness et al., 2007).

The Ecological Footprint estimates the corresponding area of land required to produce the resources consumed and assimilate the waste produced by a nation, a region, a project or a product (Wackernagel and Rees, 1996), although it has mainly been used for regions and nations (Finnveden and Moberg, 2005).

Life Cycle Costing (LCC) enables the assessment of the cost of a product or a service including all stages of the life cycle. In principle it is not associated with environmental impacts, being essentially an economic tool. Nevertheless, in some cases the costs associated with environmental impacts are also accounted for (Gluch and Baumann, 2004).

Also based on life cycle thinking, the tool of Life Cycle Assessment is considered to be the most well established and developed tool in this category (Ness et al., 2007). This tool enables to evaluate the environmental impacts of a product or a service throughout its life cycle. Being ISO regulated, this tool allows for wide applicability and potential comparability of the results (Sala et al., 2012).

Amongst the tools presented, the first three (Energy Analysis, MIPS and Ecological Footprint) are focused on the consumption of natural resources (e.g. energy, land, materials) while the last two include both an assessment of the natural resources used and the environmental impacts (Finnveden and Moberg, 2005). Furthermore, in the context of the nexus the application of life-cycle thinking is of crucial importance, as it makes it possible to account for the increasing globalisation of an array of supply chains - with the production and consumption of products often occurring in different locations and affecting the nexus in different ways (Jeswani et al., 2015).

Between LCC and LCA, the former was excluded as the economic analysis was not the primary aim of this work. Therefore, Life Cycle Assessment was selected as the most appropriate method on which to base the research work conducted in this doctoral project. It is for this reason that the review presented in the next section focuses on the applications of the tool of Life Cycle Assessment (LCA) to the agri-food sector.

2.3.1 Definition of LCA and Its Historical Development as a Tool Applied within the Agri-Food Sector

Life Cycle Assessment is a tool to assess the potential environmental impacts, such as the extraction and use of resources and the emission of hazardous substances, throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (ISO, 2006b). The term "product" includes both goods and services. The "life cycle thinking" approach differentiates this tool from other environmental management approaches and enables users to better consider problem shifting—in other words, movement of resources from one phase of the life cycle to another or geographically from one place to another (Finnveden et al., 2009). Furthermore the environmental impacts are assessed through a wide range of environmental indicators, which avoids shifting from one environmental problem to another (Ridoutt et al., 2014, McLaren, 2010).

LCA is considered to be the main tool to guide a shift towards sustainable food systems (van der Werf et al., 2014) primarily for three reasons:

(1) It enables the identification of the stage where the main impacts lie (within the life cycle of a product);

(2) It highlights where the introduction of alternative operations (within a particular stage) would be more effective;

(3) Since it presents clear numerical results, it enables users to dismantle common sense assumptions, such as *food miles*, and create information to guide consumers' choices (Garnett, 2008).

Figure 2-5 shows that within the last decade there has been a steady increase in the number of journal articles where LCA has been applied to the agri-food sector (Blue indicators). The other three series of indicators refer to a selection of those publications that are respectively aligned with pathways 1, 2 and 3 identified in Section 2.2. A predominance of publications focusing on production methods can be seen; this will be further discussed in the following section.

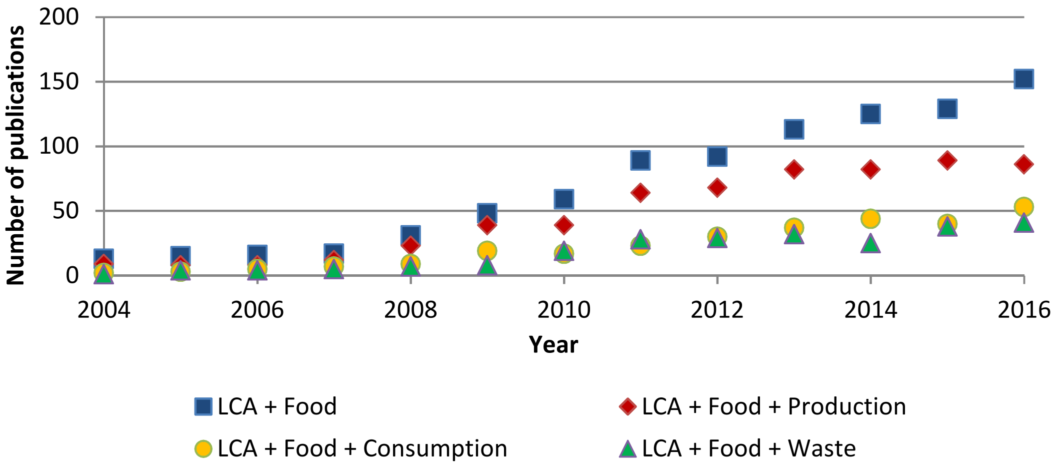


Figure 2-5: Number of peer reviewed articles published between 2004 and 2014 related to LCA and food
(These results came from Scopus when using "LCA" OR "Life Cycle Assessment" AND "Food" as "Title, abstract, keywords" respectively, and subsequently refining the search adding the words "Production", "Consumption" and "Waste")

The use of LCA in the agri-food sector has gained momentum in the last two decades because of an increased awareness on the pressures posed by food production and consumption on the environment (Saarinen et al., 2012, Heller et al., 2013, Hallström et al., 2015). The first "International Conference on LCA in the Agri-Food Sector" was held in 1996 in Brussels, and since then nine other editions have taken place, the last in 2016, bringing together the world experts in this interdisciplinary research field, which includes agronomic, food and nutrition science and environmental system analysis disciplines (van der Werf et al., 2014).

2.3.2 Categorizing Applications of LCA within the Food Sector

The literature base identified in Section 2.3.1 was interrogated in order to identify how LCA had been applied, which stakeholders were involved and how these mapped onto the three pathways identified. The database consisted of peer reviewed journal articles, which present the results of applying the LCA methodology to a product/group of products in the agri-food sector. This resulted in the identification of five different applications of LCA considering five overarching goals. The relevance to the three pathways is shown in Table 2-1 followed by a more detailed discussion.

Table 2-1: Grouping of LCA literature according to five overarching goals

Type (of Application)	References	Pathway	Applicable Instruments	Stakeholders
A—Assessment of the environmental impact of production processes and products	(Vázquez-Rowe et al., 2012, Dalgaard et al., 2014, Hospido et al., 2006, Romero-Gámez et al., 2014, Ridoutt et al., 2014, Ziegler et al., 2003, Del Borghi et al., 2014, Espinoza-Orias et al., 2011, Vazquez-Rowe et al., 2014, Williams et al., 2010, Vinyes et al., 2015, van Middelaar et al., 2011, Torrellas et al., 2012, Thrane, 2006, Basset-Mens and van der Werf, 2005, de Backer et al., 2009, De Menna et al., 2015, Pashaei Kamali et al., 2016)	1: Employing sustainable production methods	Environmental Product Declarations (ISO 14025) Regulations and fiscal measures to foster resource efficient production	Public procurers, producers, consumers, food service providers, policy makers
B—Comparison of alternative consumption choices (products/meals) for communication purposes	(Davis et al., 2010, Espinoza-Orias et al., 2011, Foster et al., 2014, Hassard et al., 2014, Head et al., 2014, Röös et al., 2014, Saarinen et al., 2012, Schmidt Rivera et al., 2014, Carlsson-Kanyama, 1998, Carlsson-Kanyama et al., 2003, Sonesson et al., 2005, Davis and Sonesson, 2008, Carlsson-Kanyama and Gonzalez, 2009, Virtanen et al., 2011, Sanfilippo et al., 2012, Ribal et al., 2016, Benvenuti et al., 2016)	2: Changing diets	Information/education campaigns	Consumers, food service providers, policy makers, third sector (e.g., Sustain[*])
C—Assessment of the environmental performance of diets	(Saxe et al., 2012, van Dooren et al., 2014, Fazeni and Steinmüller, 2011, Baroni et al., 2007, Carlsson-Kanyama et al., 2003, Berners-Lee et al., 2012, Vieux et al., 2012, Hoolohan et al., 2013, Meier and Christen, 2013, Macdiarmid et al., 2012, Aston et al., 2012, Tukker et al., 2011, Pathak et al., 2010, Risku-Norja et al., 2009, Davis et al., 2016, Tilman and Clark, 2014, Donati et al., 2016, Springmann et al., 2016, Heller and Keoleian, 2015)		Fiscal measures to influence consumers' choices Integrate environmental priorities in dietary recommendations	
D—Assessment of potential environmental savings of food wastage reduction	(Scholz et al., 2015, Eberle and Fels, 2015, Gruber et al., 2015, Sonesson et al., 2015, Berlin et al., 2008, Davis and Sonesson, 2008, Bernstad Saraiva Schott and Andersson, 2015, Gentil et al., 2011, Matsuda et al., 2012, Venkat, 2011, Davis et al., 2016, Willersinn et al., 2017, Heller and Keoleian, 2015)	3: Reducing waste	Awareness raising campaigns	Consumers, third sector (e.g., WRAP**)
			Fiscal measures (incentivizing redistribution and increasing levies on landfill)	Policy makers, producers, retailers, food service provides
			Quality standards revision	
E—Investigation of the role of packaging in food waste reduction	(Williams and Wikström, 2011, Wikström et al., 2014, Williams et al., 2008, Wikström and Williams, 2010, Zhang et al., 2015, Grant et al., 2015, Manfredi et al., 2015, Silvenius et al., 2014)		Packaging innovation	Producers, policy makers
			Regulations on packaging	

[*] www.sustainweb.org

[**] www.wrap.org.uk

2.3.2.1 Pathway 1—Employing Sustainable Production Methods—Type A

LCA has been extensively used as both a tool for decision making and learning (Tillman, 2010). Type A studies, by assessing the environmental impact of a product through its life cycle and identify "hot spots" (i.e., potential areas for improvement), can fall in both categories. The system boundaries are from cradle to farm gate, or cradle to factory gate (in the case of processed food products). The functional unit adopted is usually mass based (e.g., 1 kg of beef cattle live weight at farm gate (Ridoutt et al., 2014)).

The results of these types of study, which are aligned with aspirational shifts towards more sustainable production processes, can lead to the creation of Environmental Product Declaration (EPD), defined as Type III environmental declarations by the ISO 14025 (ISO, 2006a). As explained in this standard, potential applications of EPDs are:

- Influencing Green Public Procurement;
- Product development (Ecodesign) and improvement;
- Business-to-consumer communication.

Furthermore LCA studies have created the evidence-base to inform a number of environmental policies that aim at both increasing resource efficiency and lowering environmental impacts of current food production methods (e.g. European Commission, 2011), or reports that inform policy (DEFRA, 2006, Foster et al., 2007b, Guinée et al., 2006).

Historically, food related LCA studies have been conducted with the scope of identifying opportunities to improve the environmental efficiency in food production (Heller et al., 2013) (feeding into what Garnett (Garnett, 2014) defined the *efficiency oriented* perspective). For this reason, most of the literature applying LCA to the agri-food sector belongs to this group.

2.3.2.2 Pathway 2—Changing Diets—Type B and C

Amongst studies where LCA is applied with the purpose of fostering a shift towards more sustainable consumption patterns, two main groups were identified, Type B and Type C.

Type B studies compare alternative consumption choices such as products or full meals (e.g., a traditional burger *versus* a vegetarian one, or a seasonal *versus* a non-seasonal raspberry, see (Davis et al., 2010) and (Foster et al., 2014)). The system boundaries are usually from *cradle to retail*, *cradle to plate*, and in some cases from *cradle to grave*, including the end-of-life stage (household waste management). The functional unit chosen varies according to the goal of the LCA. In studies that aim at comparing different food items to guide consumers purchasing choices, the functional unit is usually 1 kg of product (e.g. Head et al., 2014, Röös et al., 2014), whilst in studies aiming at comparing a range of alternative meals, the functional unit is usually one portion of each (e.g. Saarinen et al., 2012, Davis and Sonesson, 2008, Davis et al., 2010).

Type C studies have a similar aim to Type B; however they are conducted on a different scale. Instead of focusing on food items or meals, they are focused on the assessment of the environmental performance of overall diets. In order to identify optimized low impact diets, they usually compare a number of diets (e.g. Mediterranean diet, vegetarian diet, vegan diet) with a baseline scenario, based on the current food consumption of a country (e.g. Saxe et al., 2012). System boundaries are usually the same as in the first group (Types A) as these studies often use secondary data from LCA studies of food products as a starting point. Functional units used to compare the impacts of different diets are usually measured as the consumption of one person in a timeframe (e.g. one year).

The results of both types of studies can be used in communication and education campaigns to increase the awareness of consumers of the impact of their choices on the environment. Examples of this are: the *Double Pyramid* (Figure 2-6), a communication tool developed in Italy that aims at promoting a Mediterranean diet, the *Livewell plate* (Figure 2-7), a list of dietary recommendations that was developed in the UK with the purpose of meeting at the same time the existing dietary guidelines (Food Standards Agency, 2007) and the 2020 target reduction in greenhouse gases emissions (Macdiarmid et al., 2011) and the *Meat Guide* (Figure 2-8), a consumer guide using a traffic light system to assist consumers in making less environmentally harmful meat choices (Röös et al., 2013). Furthermore, such studies can inform policy interventions that aim at favouring certain dietary choices, such as fiscal measures, as suggested by Wirsenius et al. (2010).

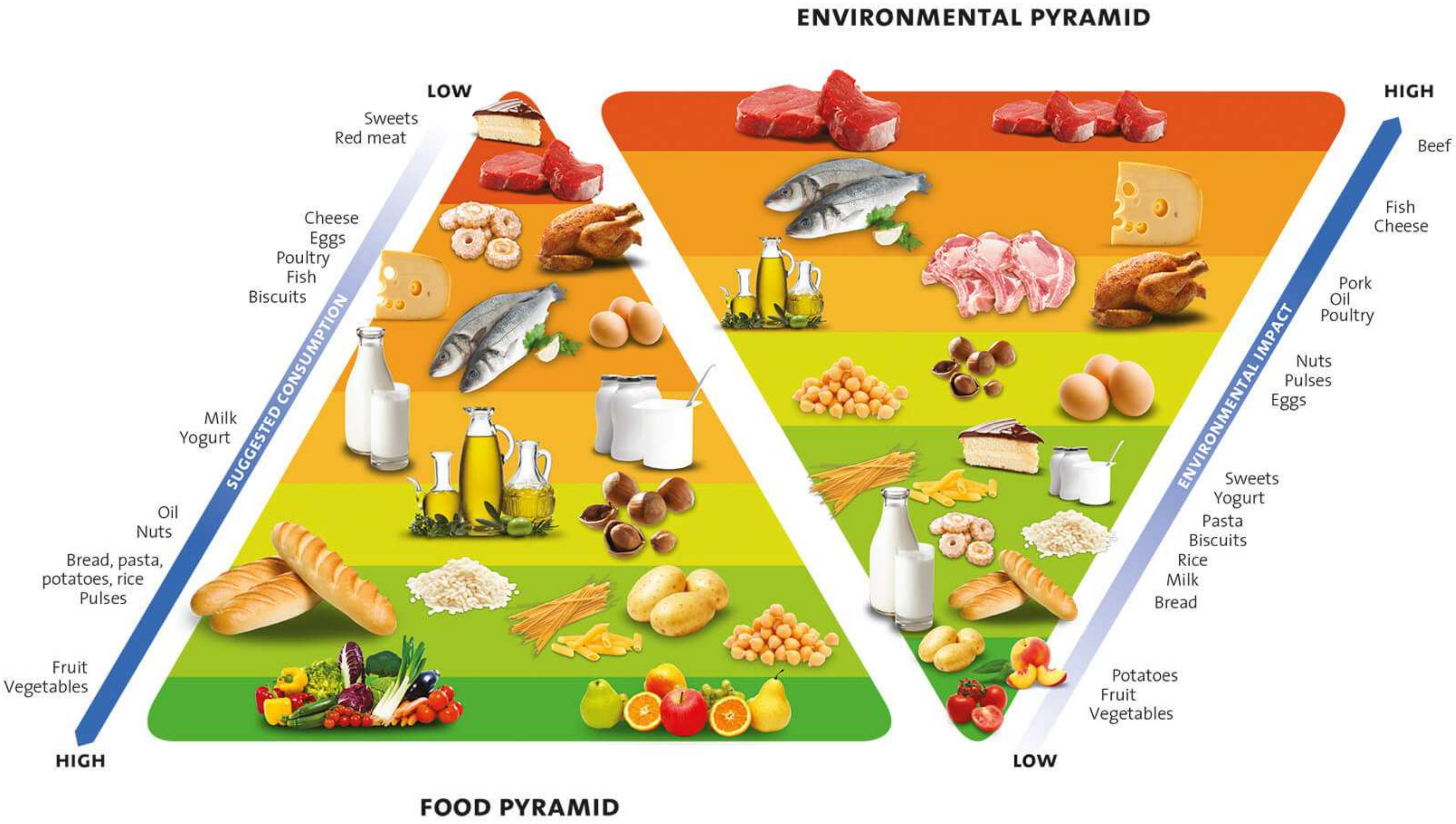


Figure 2-6: Double Pyramid: a communication tool developed by the Barilla Centre for Food and Nutrition (BFCN, 2015)

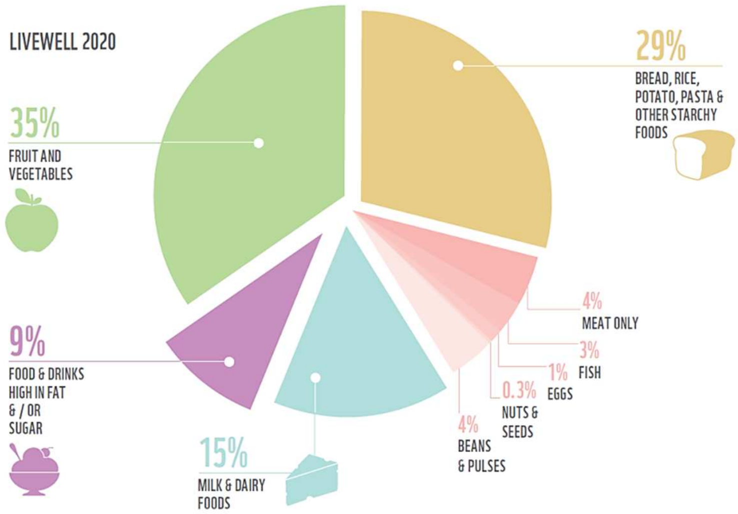
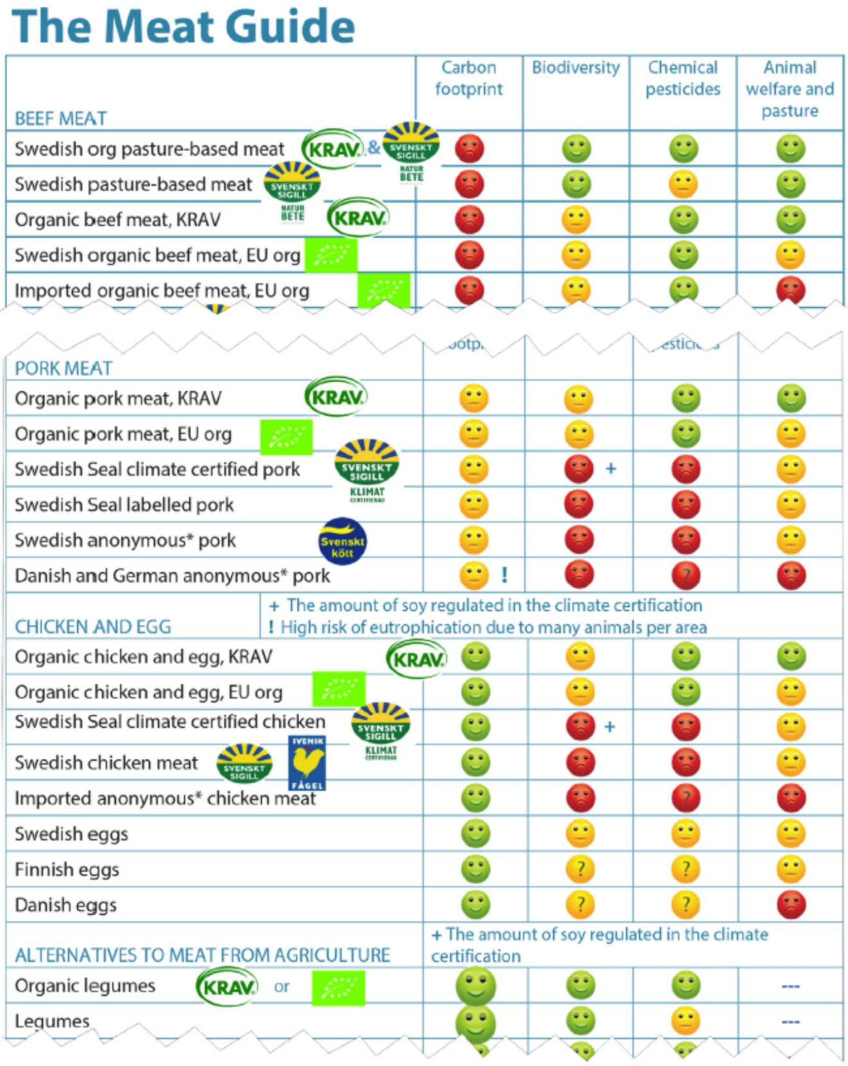


Figure 2-7: Livewell plate: recommended consumption of each food group (Macdiarmid et al., 2011)



The Meat Guide

BEEF MEAT	Carbon footprint	Biodiversity	Chemical pesticides	Animal welfare and pasture
Swedish org pasture-based meat	🔴	🟢	🟢	🟢
Swedish pasture-based meat	🔴	🟢	🟡	🟢
Organic beef meat, KRAV	🔴	🟡	🟢	🟢
Swedish organic beef meat, EU org	🔴	🟡	🟢	🟡
Imported organic beef meat, EU org	🔴	🟡	🟢	🔴
PORK MEAT				
Organic pork meat, KRAV	🟡	🟡	🟢	🟢
Organic pork meat, EU org	🟡	🟡	🟢	🟡
Swedish Seal climate certified pork	🟡	🔴 +	🔴	🟡
Swedish Seal labelled pork	🟡	🔴	🔴	🟡
Swedish anonymous* pork	🟡	🔴	🔴	🟡
Danish and German anonymous* pork	🟡 !	🔴	🔴 ?	🔴
CHICKEN AND EGG	+ The amount of soy regulated in the climate certification ! High risk of eutrophication due to many animals per area			
Organic chicken and egg, KRAV	🟢	🟡	🟢	🟢
Organic chicken and egg, EU org	🟢	🟡	🟢	🟡
Swedish Seal climate certified chicken	🟢	🔴 +	🔴	🟡
Swedish chicken meat	🟢	🔴	🔴	🟡
Imported anonymous* chicken meat	🟢	🔴	🔴 ?	🔴
Swedish eggs	🟢	🟡	🟡	🟡
Finnish eggs	🟢	🟡 ?	🟡 ?	🟡
Danish eggs	🟢	🟡 ?	🟡 ?	🔴
ALTERNATIVES TO MEAT FROM AGRICULTURE	+ The amount of soy regulated in the climate certification			
Organic legumes	🟢	🟢	🟢	---
Legumes	🟢	🟢	🟡	---

Figure 2-8: The meat guide (Röös et al., 2014)

2.3.2.3 Pathway 3—Reducing Waste—Type D and E

Two main groups were identified in the literature for studies that share the aim of fostering a reduction in food waste. In both cases the functional unit is mass based and the system boundaries are from cradle to grave (e.g., 1 kg of potato waste at household level (Gruber et al., 2015)).

In Type D studies LCA is applied to the full life cycle of a waste product, or a group of products, with the purpose of quantifying the potential environmental savings that would have occurred if that waste had been avoided. This can lead to the development of campaigns that aim at raising awareness on the environmental burden of food waste (for example the *Love Food Hate Waste* program conducted by WRAP in the UK (WRAP)). Additionally LCA studies can provide the evidence base to put in place a number of policy instruments for tackling the problem of food wastage. Some examples are: incentives for redistribution to farmers, food manufacturers, retailers and the food service sector, increased levies on bio-waste sent to landfill and the revision of quality standards that lead to the wastage of significant amounts of products for aesthetic reasons(FAO, 2013b).

Type E studies centre on the role of packaging on food waste, where LCA is used to analyse trade-offs between employing packaging solutions that have a higher environmental impact but foster food waste reduction. Such studies can influence food manufacturers in developing improved types of packaging (e.g. active packaging (Zhang et al., 2015)) and policy makers to stipulate or update regulations on packaging and packaging waste (Williams, 2011).

2.3.3 Summary

This section identified three pathways to tackle food security: (1) employing sustainable production methods, (2) changing diets and (3) reducing waste. All three foster the potential for making a more efficient use of the resources involved in food system activities combined with a reduction in their impact on the environment. A nexus mentality, using the EWFN approach, that involves thinking of resource streams/flows of energy, water, land and food in an interconnected way with the overarching aim of improving the overall efficiency of the food system, underlies each pathway.

In the last few decades, LCA has emerged as a dominant methodological framework in the assessment of the environmental impacts of consumer products thanks to its holistic and comprehensive approach, as it accounts for all stages of the life cycle of a product, thereby avoiding “problem shifting”, and specifically because it takes into account the globalization of the food supply chain (McLaren, 2010, Heller et al., 2013, Curran, 2012). Through the provision of clear numerical results, LCA studies can provide the evidence base necessary to foster beneficial change in terms of production methods (pathway 1—through assessing the impact of production methods and technologies), consumption patterns (pathway 2—through the comparison of alternative products that can enable the identification of those that are most resource intensive and guide consumers towards more sustainable food choices and diets) and food wastage reduction at all levels (both at production and consumption stage, pathway 3).

Table 2-1 provides for each type of application a number of potential instruments (and related stakeholders) that could be informed by the results of the studies belonging to that group. Studies of type A can influence the introduction of regulations and fiscal measures that foster resource efficient production, and can directly influence consumer choices through EPDs and eco-labelling. Studies of type B and C represent the starting point for government policy tools (in the form of regulations, economic incentives/disincentives and information oriented tools) that promote dietary shifts (Joyce et al., 2014). Studies of type D create the evidence base for awareness raising campaigns and fiscal measures to promote a reduction of wastage across the food supply chain. Finally, studies of type E can influence regulation on packaging and therefore promote innovation.

Governments play a significant role in the promotion of each of the three pathways described. One of the means by which governments can enhance sustainable consumption and production practices is through the public food sector (e.g. schools, hospitals, universities, care homes). There are two main reasons for this. Firstly the purchasing power of the public sector, which is often a prominent economic actor in national economies (around 16% of the European Union’s gross national product is spent on public purchases of products and services (PWC sustainability, 2009)), translates into the possibility of influencing the behaviour of the private sector towards sustainable practices (Wahlen et al., 2011, Lehtinen, 2012). Secondly, the public sector has the power to set a good example for consumers and citizens, and therefore to operate as a driver of change in setting environmental, economic and socio-cultural trends (Sonnino and McWilliam, 2011, Morgan, 2008, Walker and Brammer, 2009).

Within the context of public catering, the school catering sector occupies a privileged position in delivering this change. This occurs for a number of reasons. For example, school meals tend to be a sensitive issue among public opinion, as there is a general awareness of the influence of children’s diets on their physical and mental development, especially in countries that are facing the problem of growing rates of child obesity (Galli et al., 2014, Shaw, 2012). Additionally, the nudging power of such a strategy is particularly strong within the education sector, where issues of food and nutrition can also be included in the curriculum, using the school meal as a system of social learning (Morgan and Sonnino, 2007).

Only a handful of examples can be found in the literature where the LCA tool has been used to assess the environmental performance of meals served in schools. For example, the work conducted by:

- Benvenuti et al. (2016), who used an LCA-based approach to assess menus served in public schools in Rome and to design optimized menus;

- Saarinen et al. (2012), who used LCA to assess the impact of a set of meals served by a school in Finland;
- Ribal et al. (2016), who developed a model to design optimized menus and subsequently tested it a school catering company in Spain;
- Wickramasinghe et al. (2016), who investigated the correlation between healthy and environmentally sustainable (in terms of having low GHG emissions) school meals served in England.

In short, this represents a field of application of LCA where very little work has been conducted so far and, to the best knowledge of the author, no work has been conducted with the purpose of creating a framework that enables a direct comparison between the environmental impacts of school meal options with the purpose of providing the necessary information to catering companies and local authorities to design low impact menus.

The following section 2.4 provides an overview of the current regulatory landscape of public food procurement in the UK and of a number of existing sustainability schemes, in order to assess whether all three pathways identified through this literature review are reflected therein.

2.4 Guidelines and initiatives for sustainable public food procurement in the UK

2.4.1 National guidelines for public procurement

The government buying standards for food and catering services (DEFRA, 2014a) cover a wide range of aspects, including animal welfare, seasonality, environmental production standards, traceability, nutrition, resource efficiency and social sustainability. Central government procurers are required to apply these standards either directly or indirectly through catering contractors. The government buying standards for food and catering have been translated into a “balanced scorecard” in order to support catering services in procurement decisions, as illustrated in Figure 2-9 (DEFRA, 2014b). The scorecard, which can be applied by contractors bidding for contracts in the public sector on a voluntary basis, presents a range of aspects synthesised under the headings of cost and service. Where service relates to five key aspects: production, health and wellbeing, resource efficiency, socio-economic and quality of service. Environmental sustainability is targeted specifically in two sections. The first is under “Production”, where it is required that all the food supplied has been produced to acceptable standards of environmental management. For example all wild fish procured meets the FAO code of conduct for responsible fisheries (FAO, 1995) and all palm oil is sustainably produced. The second is under “Resource efficiency”, where it focuses on encouraging best practice energy management of catering operations, promoting the efficient use of water in catering services and the reduced consumption of bottled water, and minimising food and packaging waste.

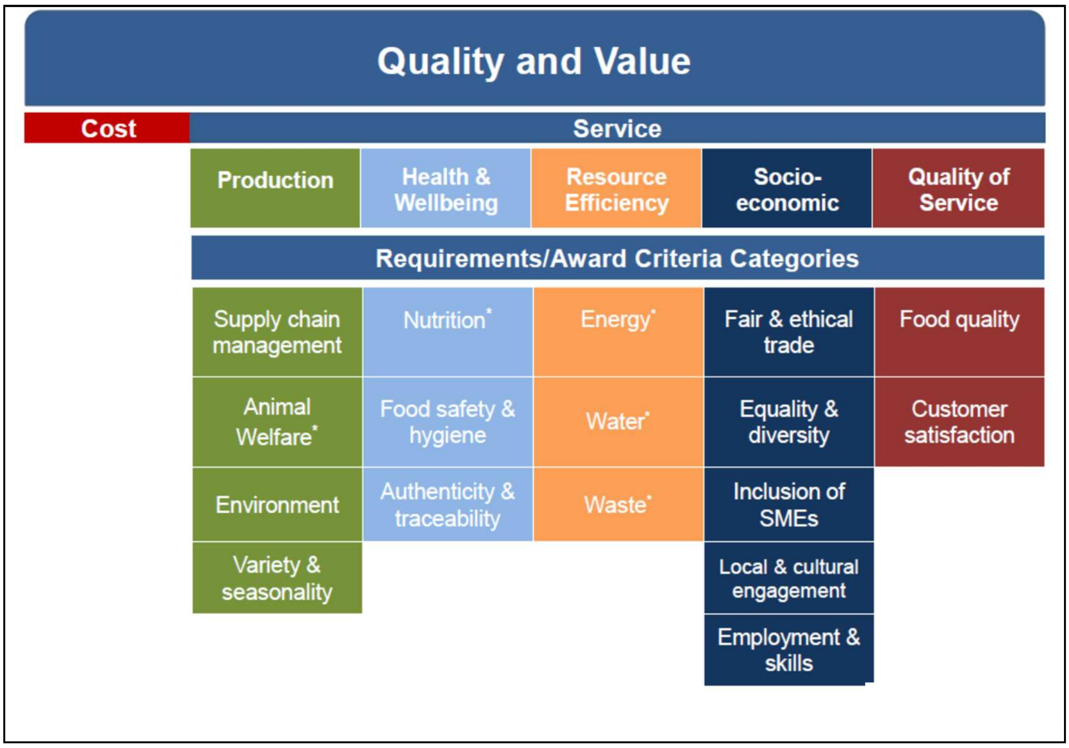


Figure 2-9: The Balanced Scorecard (DEFRA, 2014b)

The Sustainable Development Commission published the report "Setting the table: advice to government on priority elements of sustainable diets" (Sustainable Development Commission, 2009) which highlighted the importance of an evidence based policy that promoted sustainable diets in order to minimise a number of critical sustainability issues such as climate change, energy, land and water use, public health, social inequality and biodiversity. The report identified three key dietary changes that are likely to have the most significant impact on making diets more sustainable and in which health, environmental, economic and social aspects are likely to complement each other. Those are:

- Reducing consumption of meat and dairy products;
- Reducing consumption of food and drinks of low nutritional value;
- Reducing food waste.

The overarching opinion expressed in this report was that the government's approach in addressing these priorities had in the past been mixed: food waste had received significant attention whilst the other two priority areas had not. This can be clearly seen in the approach of the "balanced scorecard", which fails to mention the environmental impact of dietary choices and the power of the public sector in promoting a shift to sustainable diets through setting a good example by providing low impact food. Furthermore, the suggestions of the "balanced scorecard" lack a life cycle approach, as it can be seen that the "Resource efficiency" measures, are only focused on the resources directly used during the catering operations, and do not consider embedded resources used over the full life cycle.

2.4.2 Sustainability schemes for the catering sector

This section presents the key schemes, guidelines and tools developed to support the UK catering sector in the provision of a more sustainable service.

The Food for Life Catering Mark is a certification scheme run by the Food for Life Partnership (a multi-NGO-led partnership funded by the Big Lottery), that provides schools with an award scheme for transforming their food culture (Sustainable Development Commission, 2009). This scheme benefits from a whole school approach to food, in which school food nutrition is connected to education, both in terms of cooking skills and by including food related issues in various subjects on the curriculum. The requirements are primarily focused on the promotion of healthy dishes, procurement choices that take into account animal welfare, seasonal, local and organic food and avoiding endangered fish species. This scheme also incentivises the promotion of low-meat diets, through adopting a meat-free day in the menu, reducing the total amount of meat used or actively promoting non-meat dishes.

The Sustainable food guide for hospitals was developed by the Department of Health (DH/NHS PASA, 2009) to help the NHS to refine its approach to food procurement in order to achieve improvements in the health of patients and staff, while reducing environmental impacts. Similarly to the Food for Life Catering Mark, it promotes the procurement of seasonal, local, organic and ethical food, and the exclusion of fish species at risk of extinction. It promotes the use of energy efficient kitchen equipment and introduces food waste recycling programmes.

The Healthier Food Mark is a scheme led by the Department of Health (2010), which aims at improving the nutrition and sustainability of food served in the public sector (including care homes, general government departments and agencies, hospitals, local authorities, prisons, police and schools). Factors covered include health and nutritional considerations, environmental standards of production, energy efficient kitchen equipment, initiatives to recycle food waste, fair trade, welfare standards, seasonality of products.

The Carbon Trust Calculator (www.carbontrust.com/resources/tools/cut-costs-and-carbon-calculator-catering/ accessed June 2017) was developed by the Carbon Trust and aims at reducing the energy use of food service operations (Carbon Trust, 2014).

The Hospitality and Food Service Agreement was an initiative run by the charity Waste and Resources Action Programme (WRAP, 2012). This initiative, which was concluded in January 2015, aimed at reducing food and associated packaging waste and increase the proportion that is either recycled, sent to anaerobic digestion or composted. It applied to any food service institution (both private and public).

Of the five sustainability schemes and initiatives, the last two are focused on one specific aspect of sustainability (and adopt a more quantitative approach) whilst the first three are quite broad and all encompassing, being based mainly on qualitative criteria and existing certification schemes (e.g. the FAO code for responsible fisheries (FAO, 1995)). The advantage of adopting a qualitative approach in assessing the environmental sustainability of a food service is that it is easy to communicate. However, the drawback is that it can lead to decision making based on subjective, common sense principles rather than on scientific evidence, especially when a life cycle approach is not adopted. For instance, all schemes provide awards for sourcing food locally, as, they claim, it will reduce the environmental impact of the service. However, the literature demonstrates that from a life cycle perspective, the contribution of transport to greenhouse gas emissions is small, and that sometimes the reduction in emissions caused by sourcing a product locally may be counterbalanced by the higher emissions of production (Schmidt Rivera et al., 2014). It is therefore not clear to what extent caterers can reduce the life cycle impacts of their service by following the fore mentioned schemes and standards. Finally, as identified for national guidelines, there seems to be little focus on menu choices and the promotion of sustainable diets (with the exception of the Food for Life Catering Mark that awards point for reducing the meat content of menus).

2.5 Literature gap addressed by this research

In order to find a balance between a growing demand for food and the planet’s limited capacity to support its production, solutions need to focus both on the production side of the equation and on the consumption side, which, it is argued, is often overlooked (Wood et al., 2010). A water, energy and food nexus (EWFN) mentality can support this endeavour by identifying opportunities for efficient resource use and reduced environmental impact in both food production practices and consumption choices. Such an approach can be enabled by applying an EWFN approach to food systems using the LCA tool, in which the quantitative environmental assessment of a product over its life cycle can provide valuable information for decision making, education and communication purposes.

The public food sector offers a tremendous potential for influencing a shift towards more sustainable practices, both amongst producers (through sustainable procurement) and consumers (thanks to its nudging power). It therefore represents an area of study where the application of a robust methodology, such as LCA, within a EWFN approach, can ensure that the most effective efficiency measures are applied and the correct information on sustainable food choices is delivered. From the review of LCA studies conducted, it appears that the majority of studies undertaken have been orientated towards assessing the resource efficiency and environmental impact of current food production methods, whilst very few studies have explored the potential of LCA in assessing the environmental performance of the public food service.

In the UK, this gap in the literature is reflected in the current national guidelines for public food procurement and in existing sustainability schemes for the catering sector. Both the first and the second would benefit from the adoption of a life cycle approach to environmental sustainability, which would crucially result in the dismantling of “common sense myths” on sustainable food. Furthermore, of the three pathways identified in Section 2.2, the second, suggesting the promotion of a shift towards sustainable diets, does not appear in the national guidelines and is mentioned in only one of the initiatives presented.

This doctoral research project proposes to address this significant shortfall by creating an LCA-based procedural assessment that can be used to assess the environmental impact of menus, identify *hotspot* meals and ingredients and design improved menus. The procedural assessment presented herein was specifically designed in order to be applied to the UK school catering sector as this represents the largest sector of public food procurement in the UK (Bonfield, 2014). In addition and due to the potential provided by school meals, this will allow for the education of a new generation of sustainable food consumers.

3 Methodology of Research

The literature review demonstrated that there was no existing assessment framework for the quantification of the environmental impact of school menus and the suggestion of alternative, low impact menus. This chapter presents the overall methodology developed to address this shortfall and create a tool for the assessment of the environmental impact of a primary school meal and a procedural assessment, informed by the tool, for the development of environmentally improved menus. The chapter consists of two main parts:

Methodology overview (Section 3.1), which outlines the methodological steps used to conduct the research; and

Research methods (Section 3.2), which introduces the background to existing research methods (in general terms) which have been applied to create the tool.

The way in which elements of each have been applied (in specific terms) is outlined throughout Section 4.

3.1 Methodology overview

The aforementioned step-wise stages of the methodology are outlined briefly below and shown in Figure 3-1 (for the code of each stage see Table 1-1):

M1. Stage 1 - Review of the literature on the energy/water/food nexus, the food security challenge and on the applications of LCA to inform a shift to sustainable food production and consumption patterns. The literature review enabled the identification of the research gap: no previous framework had been developed which used a life cycle approach to inform the provision of sustainable school food in the United Kingdom. This is fully described in Chapter 2.

M2. Stage 2 - Analysis of the Primary School Food Survey to create a list of the ingredients commonly used to prepare primary school meals in the UK. Systematic review of the literature to create a database of carbon and water footprints of food products from cradle to gate. Literature review to collect factors for the calculation of emissions associated with a school meal calculated from gate to plate. The research methods used are described in detail in Chapter 3.

M3. Stage 3 - Development of a tool to calculate the CF and WF associated with a primary school meal from cradle to plate. The tool development is described in detail in Sections 4.1-4.3.

M4a. Stage 4 - Collection of data for the development of three case study analyses. Collection of feedback from users through a questionnaire. This process is described in Section 4.4.

M4b. Stage 5 - Tool validation and improvement based on statistical analysis of the data, case study analyses, users' feedback and by testing it against existing studies. This process is described in Section 4.4.

M5. Stage 6 - Development of a procedural assessment informed by the tool for the creation of low carbon/water menus. An application of the procedural assessment is provided through an example. This process is described in Section 4.5

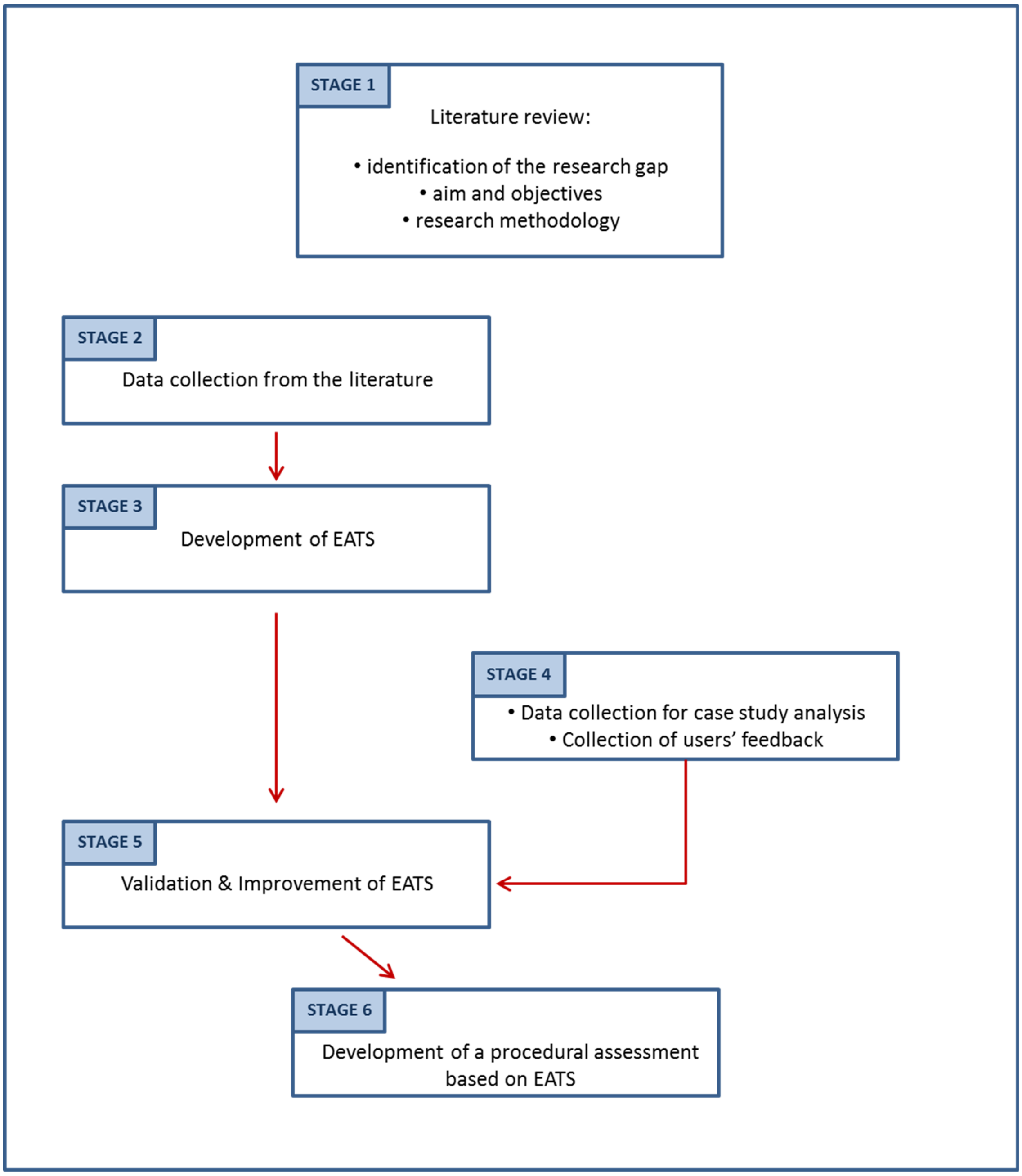


Figure 3-1: Research Methodology

EATS, developed in Stage 3, needed to satisfy seven main requirements (Table 3-1). Of these, requirements 3 to 5 are based on the GHG protocol review (WRI and WBCSD, 2011).

Table 3-1: Rationale behind the requirements of the tool

	Requirement	Description
1	Contextual applicability	In order to enable potential users to assess the environmental impact of a meal served in a generic primary school kitchen in the UK, the tool needs to include a comprehensive list of food products from which the user can select the ingredients. This has been tailored to the current composition of primary school meals served in the UK.
2	Usability	The tool needs to have a user friendly interface in order that the intended users (e.g. catering companies and school governors) with assumed basic to average computer literacy skills can easily engage with it. Furthermore, to make sure that the tool is used successfully, it should require the user to provide only information that he/she would already have or could easily obtain.
3	Meaningfulness	The results provided by the tool need to be readily understandable by the intended users, therefore the indicators of environmental impact used are those frequently used in communications with the general public (explained in Section 3.2.3).
4	Adequate completeness	In the assessment of the environmental impacts of a meal all the relevant life cycle phases need to be considered within the specified boundaries (i.e. from cradle to plate) and justification needs to be provided when a life cycle phase is not included (e.g. if the impact associated with that phase is negligible compared to the remaining ones or if current methodologies do not allow to quantify those impacts).
5	Validity	To ensure the validity of the results provided by the tool, the calculations performed (and associated methods) need to be consistently applied and this requires the use of robust data underlying the results. Therefore, a rigorous approach needs to be applied in the data collection to ensure uncertainties are reduced as far as practicable.
6	Transparency	The information recorded within the tool, including the various data sources and the respective calculations performed need to be transparent and should be recorded in a clear way to enable external reviewers to assess its credibility.
7	Adaptability	The tool needs to be adaptable, so that it can be easily updated over time (e.g. when new data is published, or emission coefficients are updated).

The methodological choices presented in Section 4.2 and Section 4.3 are driven by the need to meet this set of requirements, whilst the process of validating the tool (Section 4.4) aims at verifying whether the first five requirements have been met. Requirements 6 and 7 are considered to be automatically met after the decision of developing the tool as an Excel spreadsheet, and recording the information in a clear and understandable way, easy to both review and update. Furthermore, in order to meet the requirement of transparency, it was decided that all the data sources used to build the tool would be available in the public domain; in this way all the data collected could be freely reproduced.

3.2 Research methods

In the following, the research methods used in the development of the tool are explained in detail.

3.2.1 Life Cycle Assessment and definition of carbon footprint

The tool of Life Cycle Assessment, introduced in Section 2.3.1, has emerged in recent decades as a dominant methodological framework in the evaluation of the environmental impact of food products

(Heller et al., 2013, van der Werf et al., 2014, Schau and Fet, 2007). Through an LCA, it is possible to quantify the inputs to a system, in terms of natural resources such as minerals, water and energy, and the outputs, such as products, by-products, emissions and waste for all stages of the life cycle of a product (ISO, 2006b). A large body of research has been published on the methodology of LCA applied to the agri-food sector (e.g. Finnveden et al., 2009, Tillman, 2010). In this section a brief overview of this methodology is provided based on its role in the development of this research work.

There are two main ways of performing an LCA: attributional and consequential. The first is focused on the assessment of the environmental impact related to a particular product, whilst the second is aimed at describing the consequential change in environmental impacts in response to possible decisions and actions (Nguyen et al., 2010, Finnveden et al., 2009). Some authors argue that consequential LCA is more relevant for decision-making (Lundie et al., 2007, Weidema, 2003), on the other hand attributional LCA is more appropriate when the scope is to identify *hotspots* in the production of a product in order to reduce its impact (Lundie et al., 2007).

As described in the ISO 14040 (2006b), the main phases of LCA are: goal and scope definition, inventory analysis, impact assessment and interpretation (Figure 3-2). In the first phase the intended use of the results of the analysis is described. Based on this, critical modelling choices are defined, including but not limited to: the system boundaries, the functional unit and allocation procedures. In the second phase a life cycle inventory (LCI) analysis is performed, i.e. data is collected to quantify the inputs and outputs crossing the system boundaries. In the third phase, named life cycle impact assessment (LCIA) the overall impacts (expressed in the form of a numerical value for each impact category) are calculated from the results of the inventory analysis. In the last phase the results are interpreted and tested through a sensitivity analysis, subsequently conclusions are drawn and recommendations made (ISO, 2006b).

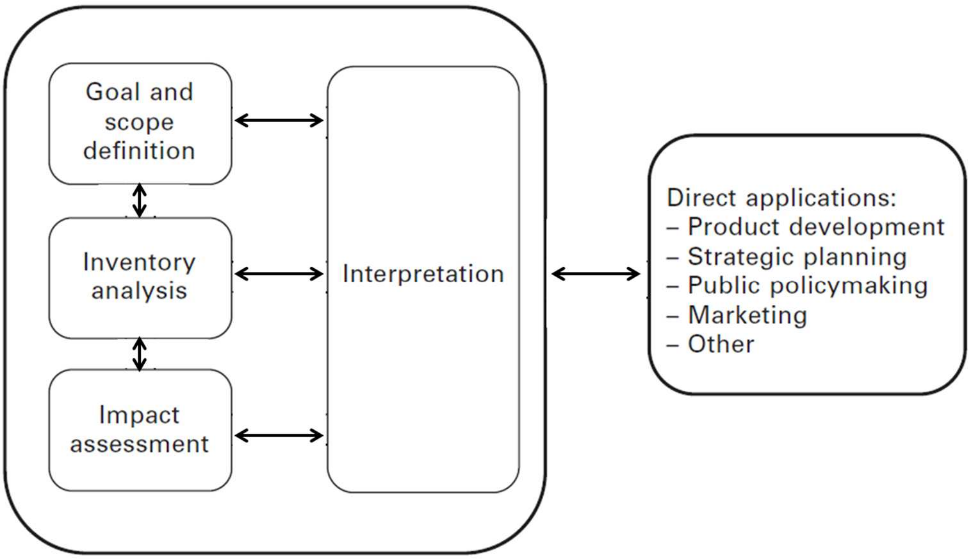


Figure 3-2: Phases of LCA(ISO, 2006b)

The choice of the functional unit and of the system boundaries are crucial when comparing the results of the LCA of different products. The system boundaries define all the stages in the life cycle of a product or a service that are taken into account in the analysis. In food LCA they usually include pre farm processes (e.g. production and transport of feed and fertilizers) and on farm processes (e.g. livestock management, manure management) but less often post farm emissions (e.g. processing and packaging, transport, distribution and consumption). In particular, the consumption phase (including refrigeration, cooking, digestion and waste disposal) is rarely included as it depends largely on personal behaviour and preferences and is therefore very challenging to predict (Heller et al., 2013). Nevertheless, the consumption phase can have a significant contribution in the overall assessment of the impact of food consumption. For instance, in a study by Berlin and Sund (2010) it contributed to 10% of the total global warming potential of the meals analysed.

The functional unit is the reference to which all system inputs and outputs are related and it is the unit to which the results of the LCA refer (Heller et al., 2013, Schau and Fet, 2007). In food LCA, the functional unit represents a methodological challenge and has been the subject of debate for several years (van der Werf et al., 2014). The most common functional units used for food are mass, measured in kg, or volume, measured in m^3 or litres (Schau and Fet, 2007). Some authors argue that when the nutritional aspect is taken into account within the comparison of different dietary patterns, this should be reflected in the choice of the functional unit and have therefore suggested calculating the impacts per g of protein, kcal of food energy, or using more complex nutrient density scores as functional unit (Heller et al., 2013).

When a production system has more than one economic output (as in the case of dairy products and beef), it is important to clearly define the procedure followed for the allocation of emissions and resources used, to each one of the co-products. Having a variety of co-products deriving from closely interlinked sub-systems is often the case for food products (Schau and Fet, 2007). Co-product allocation is generally performed according to economic or physical relationships for attributional LCA and through system expansion for consequential LCA. An example of this last case was given by Cederberg and Stadig (2003), who assessed the environmental impact of milk alone within a combined milk and beef production system. The process started by making an LCA of the combined system, and then subtracting from it the results of an LCA of an alternative meat-only production system. This approach is considered preferable in the ISO standards but is less recurrent for reasons of complexity and data intensive requirements (Schau and Fet, 2007).

At the life cycle impact assessment (LCIA) stage, characterization methods are used to convert the outputs of the life cycle inventory (emissions to – and/or resource flow from – the environment) in their related potential impact (expressed in the common unit of a category indicator). One of the most common impact categories is *Climate Change* calculated according to the characterization method suggested by the Intergovernmental Panel on Climate Change (IPCC, 2007). According to this methodology, it is possible to calculate the category indicator defined as the global warming potential (GWP) of the greenhouse gases released during a product's life cycle. The GWP is measured in $kgCO_2$ equivalent, and can be calculated through a set of conversion factors (presented in Table 3-2) quantifying how much heat each greenhouse gas (GHG) traps in the atmosphere when compared to the amount of heat trapped by CO_2 for three different time horizons (20, 100 and 500 years). A time horizon of 100 years is usually used, as required by the ISO standard (ISO, 2013).

Table 3-2: GWP of carbon dioxide, methane and nitrous oxide for different time horizons (IPCC, 2007)

GHG*	GWP_{20}	GWP_{100}	GWP_{500}
Carbon dioxide (CO_2)	1	1	1
Methane (CH_4)	72	25	7.6
Nitrous oxide (N_2O)	289	298	153

* Additional GHG are considered in the characterization method, but are not reported here as their generation from food production is very rare

Therefore within the example shown in Table 3-2 the total GWP is calculated as follows:

$$GWP_{tot}\,[kgCO_{2e}] = \text{Mass of } CO_2 * 1 + \text{Mass of } CH_4 * GWP(CH_4) + \text{Mass } N_2O * GWP(N_2O)$$

Therefore considering a 20 year horizon the total GWP of 1 kg of CO_2, 1 kg of CH_4 and 1 kg of N_2O would be:

$$GWP_{20}\,[kgCO_{2e}] = 1+72+289 = 362$$

There is no universally accepted definition of the concept of carbon footprint (CF); however the CF of a process or product is often quantified using the GWP indicator (Čuček et al., 2012). This is the definition of CF used in this work.

3.2.2 Simplified LCA

The application of a fully compliant LCA is highly resource intensive and time-consuming, as a consequence of the large amount of primary data that are required (and therefore need to be collected) in order to create the life cycle inventories (Teixeira, 2015, Cooper and Fava, 2006). For this reason a number of simplified approaches have been adopted in the literature, classified as simplified LCA. Some examples are:

- The adoption of only one impact category;
- The use of existing life cycle inventory (LCI) databases and software which include those databases;
- The use of life cycle impact assessment (LCIA) databases: collection of LCIA measurements determined in previous studies that associate for instance a value of GWP to a product (measured in $kgCO_{2e}$ per kg of product) (Teixeira, 2015).

A large body of literature has adopted this last approach when aiming at making comparisons between different food choices or different dietary patterns (e.g. Röös et al., 2014, Sanfilippo et al., 2012, Saxe et al., 2012, Hoolohan et al., 2013, e.g. Aston et al., 2012, Vieux et al., 2012, González et al., 2011, Scholz et al., 2015). In order to establish how the accuracy of the results is affected when using secondary data of food products LCA, Teixeira (2015) analysed a dataset of 2276 values of GWP for agri-food products, concluding that such an approach can provide reliable estimates for most food products.

As one of the objectives of this current research work is the assessment of the environmental impact of school meals commonly served in primary schools in the UK (see objective 3), it was clear from the start that a simplified approach would be appropriate in order to include a large enough number of food products within the analysis (see Requirement 1, Section 3.1). In other words it was not feasible within the time constrains of a PhD to calculate a supply-chain specific LCA for each ingredient used by a generic school kitchen in the UK (a similar simplified approach was adopted by Pulkkinen et al. (2015) and Röös et al. (2014)). Therefore, two main simplifications were made:

- Only two indicators of environmental impacts were selected;
- Secondary data from previous studies and databases was gathered and used as a surrogate for primary data.

Each of these methodological choices is explained in detail in the following sections.

3.2.3 Choice of impact categories

As described in Section 1.1, the food sector has been identified as a major contributor to anthropogenic climate change. In the UK, a breakdown of the consumption-based emissions for 2004 presented by Bows-Larkin et al. (2014), shows that the food sector is the third contributor to climate change, after manufactured goods and public services, and the largest contributor to non-CO_2 GHG emissions. This is presented in Figure 3-3.

An illustration of the different GHGs emitted by the food supply chain is provided in Figure 3-4. At *farm stage* (or up to farm gate - left hand side of Figure 3-4), the main contributors are nitrous oxide (N_20) emissions from the use of fertilizers and soil management, methane emissions (CH_4) from rice cultivation, enteric fermentation in livestock rearing and manure and to a lesser extent carbon dioxide emissions (CO_2) caused by the use of fossil fuels in agricultural machinery and in the manufacture of synthetic fertilizers (Vergé et al., 2007, Garnett, 2011). Despite these aspects being hard to quantify, emissions of CO_2 caused by land use change for agricultural purposes are considered to be highly significant.

At *post farm stage* (or beyond farm gate - right hand side of Figure 3-4), emissions are dominated by CO_2, caused by fossil fuel use and refrigerant gases (Garnett, 2011).

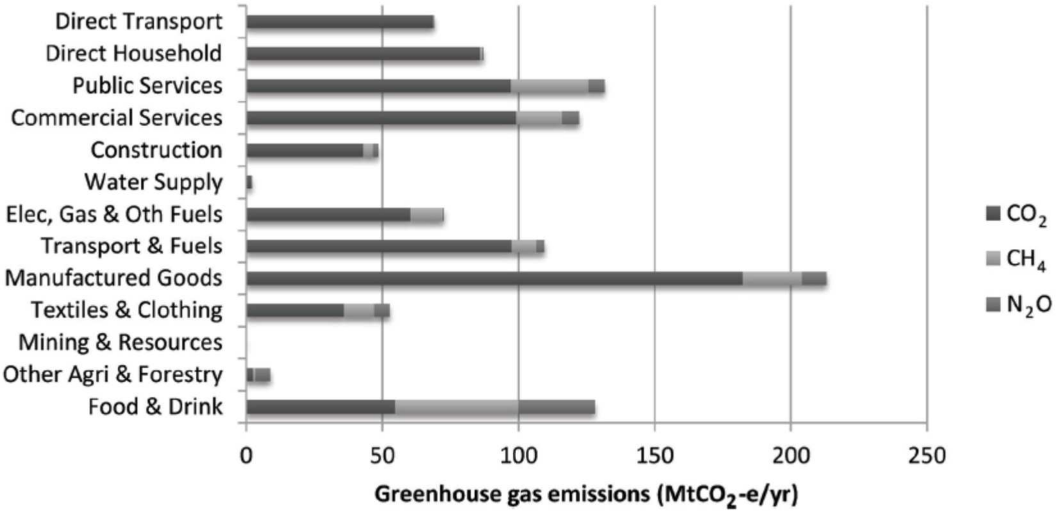


Figure 3-3: Consumption-based GHG emissions in the UK in 2004 by sector (Bows-Larkin et al., 2014)

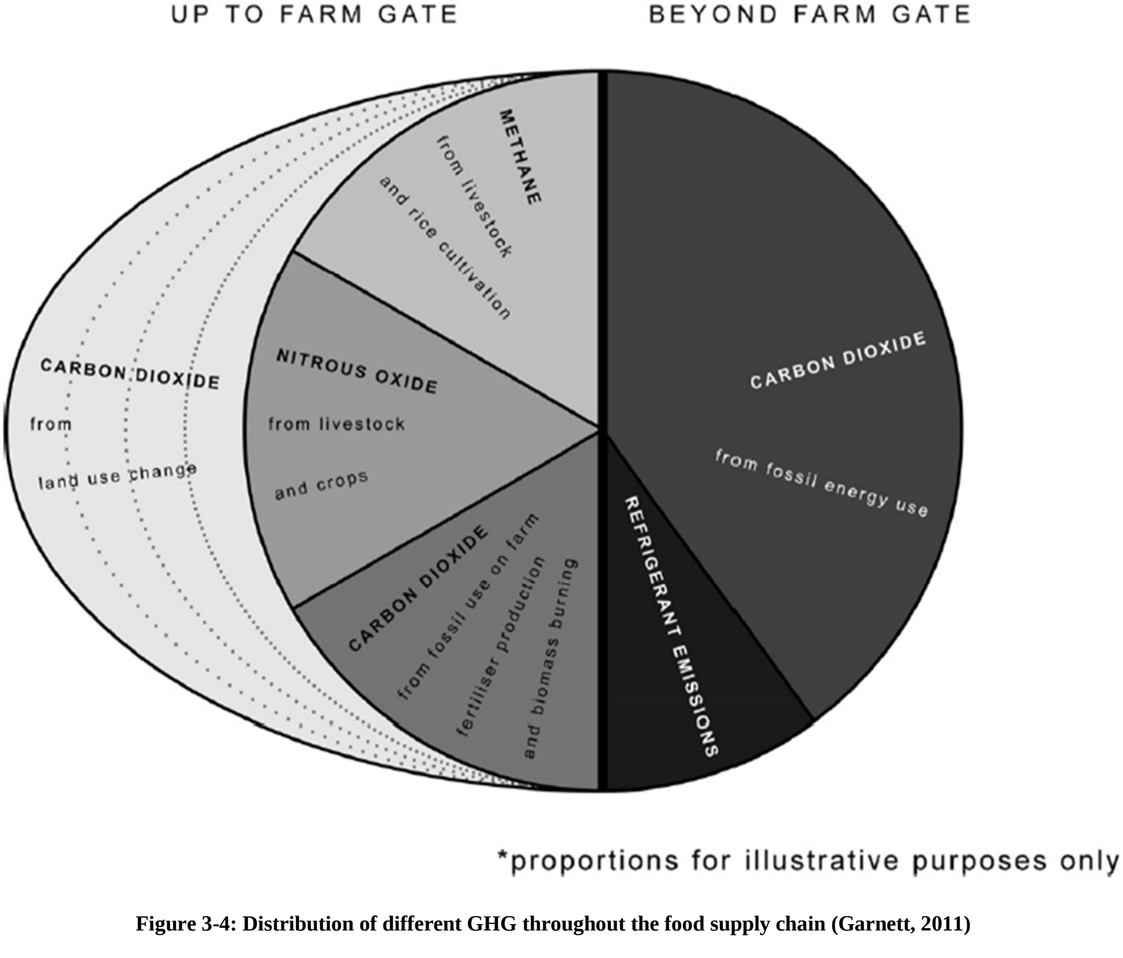


Figure 3-4: Distribution of different GHG throughout the food supply chain (Garnett, 2011)

Large volumes of water are necessary to produce food: is has been estimated that agriculture is responsible for around 70% of global freshwater withdrawals for irrigation and livestock production (Foley et al., 2011) and, if green water use (water absorbed in soil) is also included, the estimated contribution of food consumption to total water use is 86% (Hoekstra and Chapagain, 2006).

Agriculture occupies about 38% of the terrestrial surface, making it the activity associated with the largest use of land on the planet (Foley et al., 2011). On top of this Giovanucci et al. (2012) have estimated that 70% of land suitable for growing food worldwide is already in use. Furthermore, agriculture damages productive land through soil erosion and degradation and affects the ecosystems, representing a threat to biodiversity (Verhulst et al., 2010). Finally, the increased use of fertilizers has caused the crucial disruption of global nitrogen and phosphorus cycles, causing eutrophication of water bodies, which compromises aquatic ecosystems and marine fisheries (Diaz and Rosenberg, 2008, Canfield et al., 2010).

Despite the awareness of the author that a restriction of the impact categories considered reduces the breadth of the study (Schmidt, 2009, Ridoutt et al., 2014), only two indicators of the environmental impacts were considered in this research analysis: GWP and water use. The rationale behind this choice is explained as follows.

Firstly, one of the objectives of this current research is the creation of a tool that could be used for the self-assessment of a school meal. Given that such a tool is intended for use by the members of staff of catering companies, schools and those in charge of choosing school menus within local authorities, the results it provides should be easy to interpret for non-LCA experts (see requirement 3, Section 3.1). Due to its popularity, the concept of carbon footprint (used here as a synonym of GWP, as explained in Section 3.2.1) is an accepted metric for communicating the contribution of a product or an activity to climate change (Weidema et al., 2008, Čuček et al., 2012). Similarly, the concept of water footprint (used to measure water use, see Section 3.2.4) can be easily explained to non-scientific audiences (as shown in the work of Sabmiller and WWF (2009)). Furthermore these two concepts benefit from the fact that they are easy to explain to students, enabling the results provided by the tool to be used not only for decision making purposes (i.e. menu choices) but also for educational purposes (similar to work done by Saarinen et al. (2012)).

Secondly, as the tool will utilise a database of secondary data collected from the literature, the indicators of GWP and water use were chosen due to their recurrence within the literature. Given the popularity of carbon footprinting, it can be seen that within the literature most of the studies of LCA of food products include (or are limited to) an assessment of the contribution to climate change (Teixeira, 2015). As for the assessment of water use, an extensive collection of values of the water footprint for most food products has been published by leading organizations in this field, (i.e. the Water Footprint

Network) and therefore this is used as the principal source in this current study (Mekonnen and Hoekstra, 2010a, Mekonnen and Hoekstra, 2010b).

The remaining impact categories relevant when assessing the environmental impacts of food systems (e.g. land use, eutrophication potential, acidification potential, loss of biodiversity), were omitted from the analysis mainly for reasons of lack of data. The reason for this may be due to the lack of a commonly accepted methodology (meaning that results of different studies cannot be compared), as is the case for land use (Gabel et al., 2016, Taelman et al., 2016), or simply because of the larger traction carbon footprinting has gained recently within the research community. As a consequence a much greater proportion of studies have been solely focused on this aspect.

3.2.4 Water Footprint

The concept of Water Footprint (WF) was first introduced in 2002 to provide a consumption-based indicator of freshwater use (Hoekstra, 2003, Hoekstra, 2016). A WF is calculated as the total volume of direct and indirect water used, in other words the process must include that which is consumed but also that which is polluted. As illustrated in Figure 3-5, the three components of a WF are: blue, green and grey water footprints, representing respectively the consumption of surface and ground water, the consumption of rain water stored in soil and the volume of water necessary to dilute the pollutants to water quality standards (Hoekstra et al., 2009a).

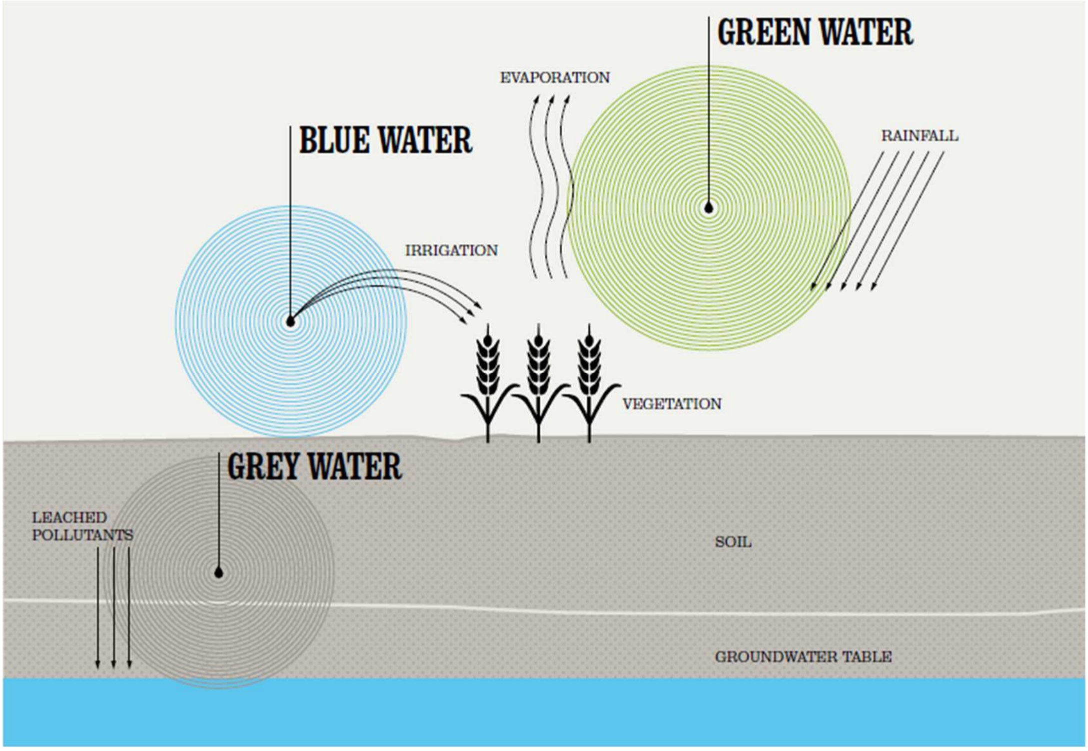


Figure 3-5: Different *colours* of Water Footprint (Sabmiller and WWF, 2009)

Some argue that a weakness of this metric is that it is limited to the representation of the quantity of water used without estimating the related environmental impacts (Jeswani and Azapagic, 2011). In this way, it fails to stress the consumption of *”virtual water”* in other words the water use which arises as part of the production process but occurs in regions that are more water scarce due to a range of climatic conditions (Chen et al., 2016, Ridoutt et al., 2009). Furthermore, concerns have been expressed on the calculation of the grey water footprint, as it suffers from the absence of a clear definition of common standards for water quality and an agreed method for the quantification of dilution volumes (Jeswani and Azapagic, 2011, Čuček et al., 2012, Berger and Finkbeiner, 2010). Some authors argue that this component should not be included as the environmental impacts of grey water are already assessed in other impact categories of traditional LCA, such as eutrophication and toxicity (Milà i Canals et al., 2009). Another controversial aspect is the inclusion of the green water in the assessment, as some authors state that green water use does not affect the availability of blue water (Jeswani and Azapagic, 2011, Ridoutt and Pfister, 2010). Therefore, some authors have suggested that green water use is better assessed as a consequence of land use change (Milà i Canals et al., 2009). Finally, this method has been criticised for adding together two different physical quantities: on one side measures of water consumption (blue and green water) and on the other a measure of the impact related to water pollution (grey water). Additionally it has been criticised for giving the same importance to the consumption of ground water and surface water (blue water) and of rain water absorbed in soils (green water), which have significantly different opportunity costs (i.e. surface and ground water can be used for other activities such as drinking or energy production whilst rain water absorbed in soil can only be used by vegetation) (Ridoutt et al., 2009, Hess et al., 2015).

Consequently, a number of alternative methods have been proposed to account for the environmental impact related to water use (e.g. Frischknecht et al. (2009), Milà i Canals et al. (2009), Pfister et al. (2009)), in order to align the concept of WF to the one of the impact categories within LCA. Amongst these, the method suggested by Pfister and colleagues (Pfister et al., 2009) has gained significant attention and has been partially adopted in the ISO’s LCA based WF standard (ISO, 2014). It enables the assessment of a “water scarcity weighed WF” based on two main factors: the blue water consumption and the regional “water stress index” (WSI) which is used as a characterization factor to assess water deprivation. The WSI can be applied at any spatial scale, however it is recommended by the authors to assess the impacts related to water use at a watershed level, as the national level data would not be truly representative of the actual impact (Pfister et al., 2009, Jeswani and Azapagic, 2011). The developers of the original definition of WF expressed their disagreement with this method as they believe that given the limited global availability of freshwater, it is crucial to measure water consumption *per se*, when adopting an allocation and depletion point of view on a global scale (Hoekstra, 2016). Furthermore, by using a characterization method that weighs the volumetric water use, the results obtained have no physical meaning and depend largely on the weighing choice (Hoekstra et al., 2009b).

Therefore it can be seen that there is much debate and agreement on the subject has still to be reached. Thus methodologies that are used to assess the impacts of water use will continue to evolve (Chenoweth et al., 2014, Jeswani and Azapagic, 2011). In order to choose the most appropriate methodology within this study three main considerations were made.

Consideration One: As the purpose of the tool is to communicate to non-scientific audiences the impacts of different menu choices, in order to enable the identification of (negative) *hotspot* meals and ingredients, the metric used had to be simple to understand (requirement 3, Section 3.1). The idea of presenting the WF as defined by Hoekstra in a disaggregated form (blue, green and grey components) was therefore excluded.

Consideration Two: Catering companies can sometimes trace the origin of the food products they purchase back to the regional level (especially if they use local products) or more often to the national level; however for certain food products (mainly processed) this information can be hard to obtain due to the complexity of the supply chain. Therefore, in the vast majority of cases it would be impossible to assess the impact of each food product based on the location of production at the watershed scale. Hence, the method suggested by Pfister et al. (2009) would lead to results that are not representative of the real impacts.

Consideration Three: Because of the decision to select only two indicators of environmental impact (Section 3.2.3), the other impact categories of a traditional LCA have not been included in the analysis. This implies that if the method suggested by Pfister et al. (2009) was adopted and the WF was calculated only based on blue water consumption, the impact of products on water quality (which a traditional LCA assesses through eutrophication and toxicity) and on green water depletion (which in LCA could be assessed together with land use change), would be neglected.

It was therefore decided to use the definition of WF suggested by Hoekstra et al. (2009a), in an aggregated form (blue + green + grey WF) using as a source the two comprehensive databases published by the Water Footprint Network (Mekonnen and Hoekstra, 2010a, Mekonnen and Hoekstra, 2010b). However, in order to investigate the contribution of the three different *colours* of WF to the total impacts, the results presented in this doctoral research show both the aggregated impacts and the blue, green and grey components.

3.2.5 Systematic review of the LCA literature

As mentioned previously, for the assessment of water use it was possible to extract from an existing database the values of WF of the food products of interest. Instead, for the assessment of GHG emissions, a large number of sources were consulted to gather the data required to create a database of values of GWP of food products. The details of this process are outlined in the following.

A systematic review of the LCA literature was conducted in order to collate published values of GWP for a list of food products into a CF database. The reason for applying a systematic approach was to ensure the adequate completeness and validity of the data collected (requirements 4 and 5 Section 3.1). A meta-analysis was then performed to assess the reliability and meaningfulness of the database when using its values as proxies for context specific LCAs. The systematic review and meta-analysis were completed following the PRISMA statement protocol to minimize the risk of bias and increase scientific validity (Liberati et al., 2009, Moher et al., 2009). This protocol, developed in the field of health care, suggests a rigorous approach to systematic reviews centred on:

- The clear definition and rationale of the eligibility criteria;
- Description of all information sources used and the search strategy used;
- Description of the process followed for selecting studies and collecting the data;
- List all the variables recorded, and any assumptions and simplifications made;
- Description of the methods for handling data;
- Specification of any assessment of the risk of bias that may affect the cumulative evidence;
- Description of methods of additional analysis, such as sensitivity or subgroup analysis.

In this specific case, particular attention had to be given to the handling of the data collected, in order to minimize the risk of collating and comparing values that could not (and should not) be compared due to methodological differences in the way they were obtained (Röös et al., 2013, Foster et al., 2007b). Even though the LCA methodology has been standardised through the publication of the ISO14040, there is still a range of different methodological choices that can be taken and therefore the existing literature appears to be significantly heterogeneous. This was addressed in two main ways within this study using a systematic review of the LCA literature, through:

- The clear definition of the eligibility criteria that would exclude from a start studies that adopted a methodological choices different from the selected ones (e.g. attributional LCA, 100 years time horizon, mass based functional unit);
- Data handling to limit these variations.

The detailed description of how the systematic review and the meta-analysis were conducted is provided in respectively in Section 4.2.2 and Section 4.4.1 of Chapter 4, whilst the results of the literature review and the meta-analysis are provided in Section 5.2, together with the implications that can be derived and the consequent limitations of the study.

Part of the meta-analysis is aimed at assessing the risk of bias in the final values provided by the database. In line with the findings of Clune et al. (2016) and Teixeira (2015), the studies identified in the literature were mainly Eurocentric. This suggests that the values of GWP provided by the database are more likely to provide a meaningful proxy for products sourced from European countries rather than the rest of the world. Even though this presents a limitation to the study, it is considered acceptable for two main reasons. Firstly, because most of the ingredients used in the preparation of primary school meals in the UK are likely to be either home produced or imported from European countries (in line with general food consumption trends for the UK, as illustrated in Figure 3-6). Secondly because findings from Teixeira (2015) have shown how the geographical origin and production method have a limited influence on the value of GWP of most food types.

The meta-analysis involved calculating for each food product the following:

- Number of values of GWP recorded;
- Average value of GWP;
- Standard deviation;
- Minimum, maximum and 95% confidence intervals.

Those values were then compared across the different food products to identify food types that were underrepresented in the literature and assess the level of confidence when using the average values of GWP in the analysis.

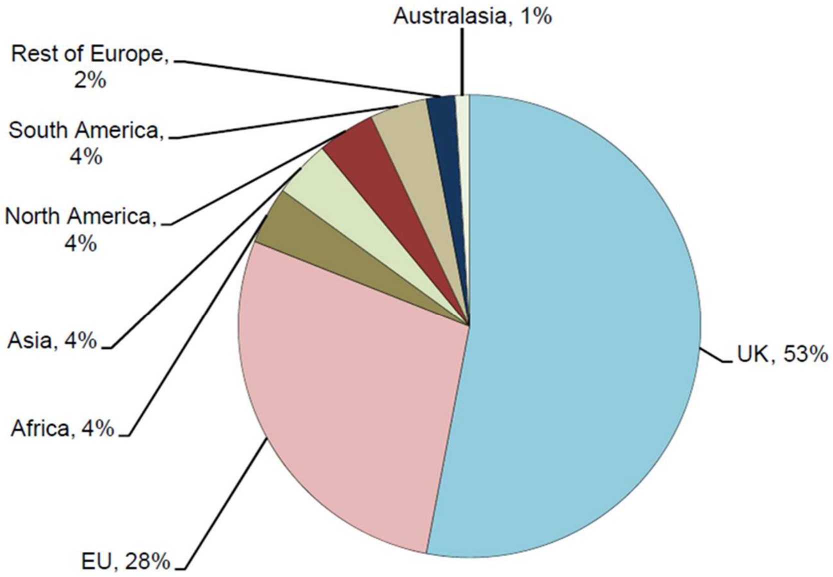


Figure 3-6: Origin of foods consumed in the UK in 2012 (DEFRA, 2013b)

3.3 Summary

In this section an overview of the methods used to carry out the research within this study were presented. In order to meet objectives 2 and 3, and develop a tool for the self-assessment of the environmental impact of a school meal by a catering provider or a local authority, the tool had to meet two main requirements:

- It had to be as inclusive as possible in terms of the list of ingredients it contained (requirement 1, Section 3.1);

- The results provided had to be meaningful and easy to understand (requirement 3, Section 3.1).

This led to the choice of adopting a simplified LCA approach, utilising as a starting point secondary data from existing published studies. The indicators of environmental impact selected were therefore chosen to comply with two main requisites: data availability and ease of communication. After briefly introducing the concept of LCA, a description of simplified LCA is provided followed by the rationale behind the selection of the impact categories and the method chosen to assess water use. Finally the procedure followed in the development of the CF database – a systematic review of the literature and a meta-analysis - is introduced. The details of the application of these research methods to this study will be the core of the following section.

4 Design and Development of EATS and the procedural assessment

The Environmental Assessment Tool of School meals (EATS) was created in order to be able to assess the environmental impact of a primary school meal. In this chapter, the processes that led to the creation of both EATS and the procedural assessment which supports its use are explained in detail.

4.1 Introduction

In this study, the environmental impact of a school meal is described by:

The Carbon Footprint and the Water Footprint of one portion of a meal produced in a generic school kitchen.

The functional unit at this stage of the analysis (and within EATS) is therefore: one portion of a primary school meal at the consumption stage. The system boundaries of the system analysed are from *cradle to plate* and therefore the following phases of the life cycle are considered (Figure 4-1):

1. Production;
2. Transport;
3. Storage at regional distribution centre (RDC);
4. Meal Preparation.

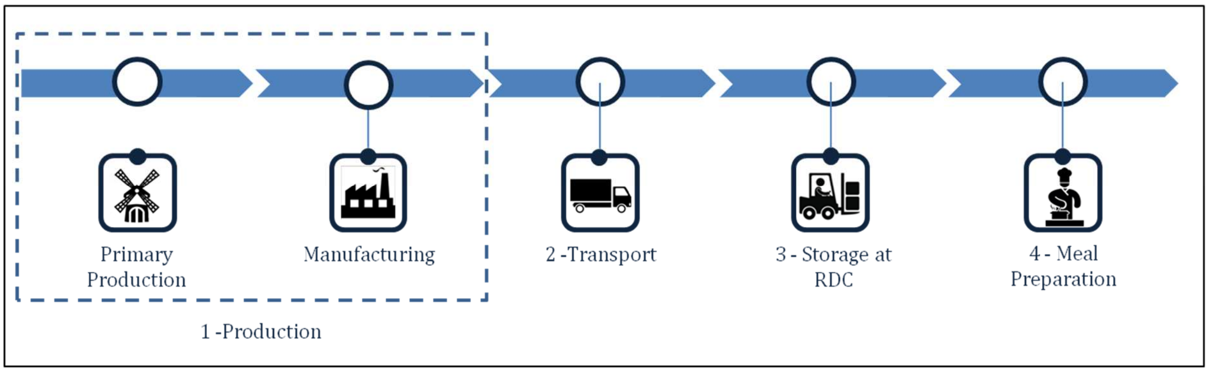


Figure 4-1: System boundaries and life cycle phases

In calculating the CF of a school meal within EATS, three phases (i.e. Phase 1, 2 and 4 in Figure 4-1) of the life cycle are assumed to contribute to the final CF value. The storage phase (i.e. Phase 3), is excluded as emissions can be assumed negligible. This will be further explained in Section 4.2.2.

In the calculation of the WF within EATS the methodology by Hoekstra (2003) has been adopted, where blue, green and grey water are taken into account. As a result the only phase of the life cycle that is considered is the production phase (i.e. Phase 1). In comparison the other phases are assumed to have a negligible WF. This assumption is in line with similar research undertaken by Jefferies et al. (2012) and Strasburg and Jahno (2015).

The process followed in the creation of EATS (Figure 4-2) was comprised of 3 stages.

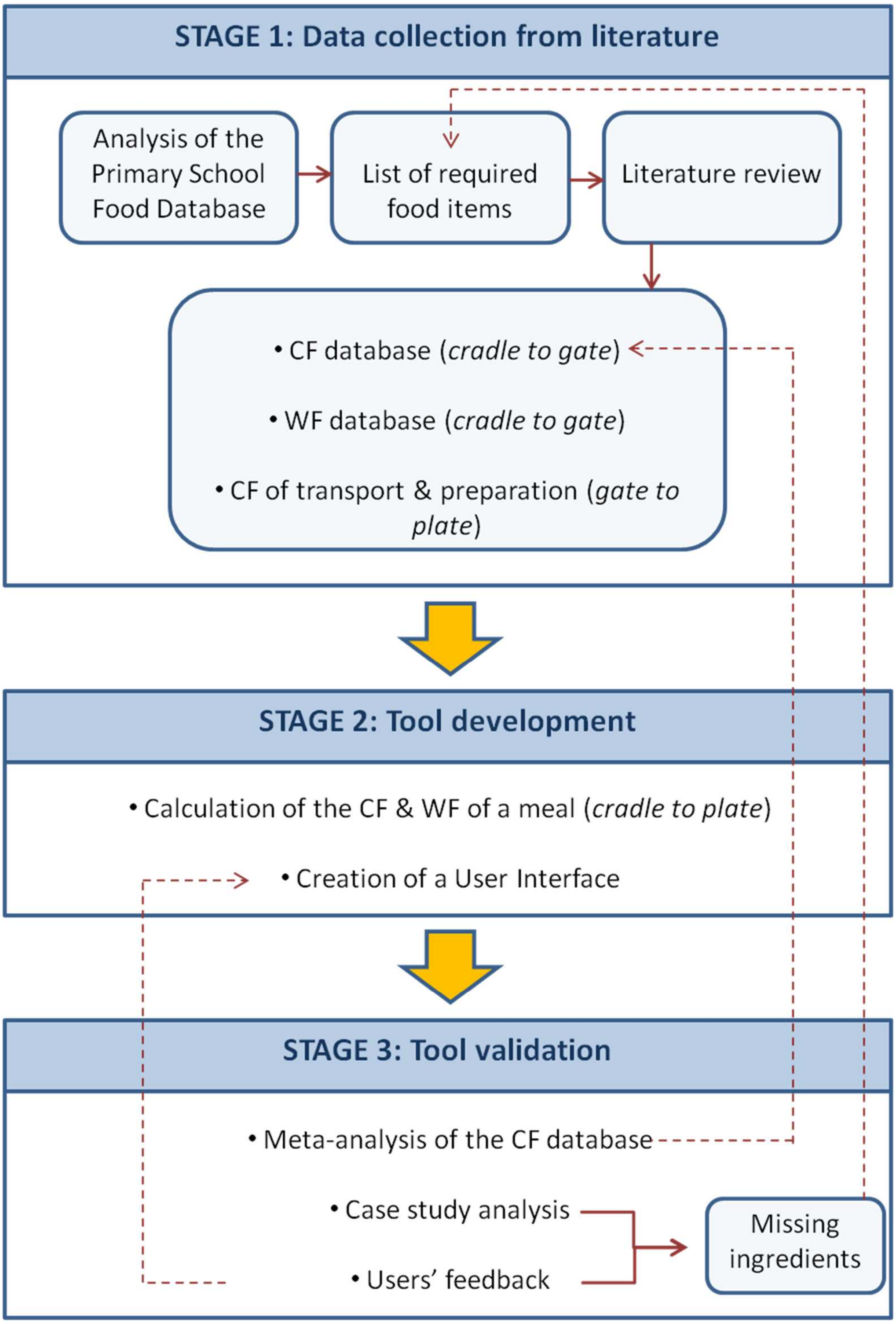


Figure 4-2: Stages of the design of EATS (dashed arrows represent iterations)

In the first stage (Section 4.2) the literature was consulted to collect data of existing LCA studies and water footprint studies in order to create a database of carbon footprints and water footprints for the production phase (i.e. Phase 1 in Figure 4-1) of a number of food products. Additionally, information was collected from the literature to calculate the contribution of the remaining phases (i.e. Phase 2 and Phase 4 in Figure 4-1) to the CF of a meal.

In the second stage (Section 4.3) EATS was developed in order to perform the calculation of the total CF and WF of one portion of a primary school meal, and a user interface was created to enable users to perform the analysis with ease.

In the third and final stage (Section 4.4) the tool was validated and improved through

- A statistical analysis of the data;
- A case study analysis;
- The collection of feedback from its potential users.

Once the tool was completed, a procedural assessment (informed by the tool) was created. The purpose of the procedural assessment associated to EATS is to define a procedure to create new menus that meet a set of targets in terms of carbon (CF) and water (WF) savings. This is presented in detail in Section 4.5.

4.2 Stage 1: Data collection from the literature

The purpose of this stage was the collection of data from the literature for the calculation of the CF and WF of a school meal from *cradle to plate*. This required three steps.

The first step was the identification of those food products that had to be included in the database in order to make it as comprehensive as possible according to its scope (see requirement 1, Section 3.1). In other words, the purpose was to minimize the possibility that when a user would enter the recipe of a school meal, they would be unable to find some of its ingredients in the ingredients list. As the final purpose of the tool is to enable the assessment of the impacts associated with a generic primary school meal prepared in a school kitchen in the UK, in order to find the list of food products that needed to be included, a thorough analysis of the 2009 Primary School Food Survey (carried out in England) was conducted (Haroun et al., 2009). This step is presented in Section 4.2.1.

In the second step two separate databases were created. The first database, presented in Section 4.2.2, was a collection of values of GWP (calculated from *cradle to gate*) associated with the food products identified in the Step 1. It was obtained by carrying out a systematic review of the published literature on food LCA (Section 3.2.5). To create the second database (presented in Section 4.2.3), the value of WF of the food products identified was extracted from the databases published by the Water Footprint Network (Mekonnen and Hoekstra, 2010a, Mekonnen and Hoekstra, 2010b). These values are also calculated from *cradle to gate*. The CF and WF databases are provided respectively in Part 2 and Part 3 of Appendix D (electronic material). In the two databases, the functional unit of the food products recorded is 1 kg of product weight.

In the third step information was collected from the literature to take into account the remaining life cycle phases (i.e. the *gate to plate* phase) in the assessment of the environmental impact of a meal. In this step only the GHG emissions were included in the analysis, as for water use the production phase is the predominant one, and the others (i.e. transport, storage and preparation) can be considered negligible when compared to it (Jefferies et al., 2012). Therefore, the literature was consulted to extract values of emissions associated with transporting goods via road and via sea, and emissions associated with the energy used during the cooking phase. This step and associated sub-steps are described in detail in Sections 4.2.4 to 4.2.6.

The data recorded are collated in an Excel spreadsheet. The reason for choosing Excel was in order to meet requirements 6 and 7 (Section 3.1) of transparency and versatility. In this way all of the data recorded can be easily accessed, reviewed and subsequently updated.

4.2.1 Analysis of the *Primary School Food Survey*

In order to identify those food products that would need to be included in the database the researcher performed an analysis of the Primary School Food Survey (PSFS), a national survey conducted in 2009 to collect information on school dinners across the country (Haroun et al., 2009).

This survey was carried out by the School Food Trust in order to assess the impact of the new food standards (introduced in 2008 in England) on catering provision and food consumption of pupils eating a school lunch. A nationally representative sample of 139 schools in England took part in the survey (Haroun et al., 2011). The participants were asked to create a food inventory where they recorded all food and drink items on offer each day in the school canteen for a period of two weeks. Each item was attributed a name (item name) and a code (item code) and all the data collected was recorded in a datasheet. Additionally, food and drink items were grouped into 19 item groups, as can be seen in Table 4-1.

Table 4-1: Item group classification in the PSFS

Number	Item Group
1	Protein - meat
2	Carbohydrate
3	Protein and carbohydrate
4	Vegetable
5	Salad
6	Protein and vegetable
7	Carbohydrate and vegetable
8	Protein, carbohydrate and vegetable
9	Condiments
10	Fruit
11	Fruit Dessert
12	Dessert
13	Water
14	Fruit juice
15	Sandwiches

16	Milk, yogurt and milky drinks
17	Baked beans
18	Protein-other
19	Starchy in oil

The total number of item codes recorded was 1556; in order to have a list of food products that was as inclusive as possible it was necessary to select those items that were more frequently occurring. Using the SPSS software (version 21.0, SPSS Inc.), it was possible to extract the most frequently occurring items for each of the nineteen groups. The following criteria were used within this selection process: *The 15 most frequent item codes in each group were chosen.*

For example, within Group 2 (carbohydrates) the 15 most frequently occurring item codes are highlighted in Figure 4-3 and listed in Table 4-2.

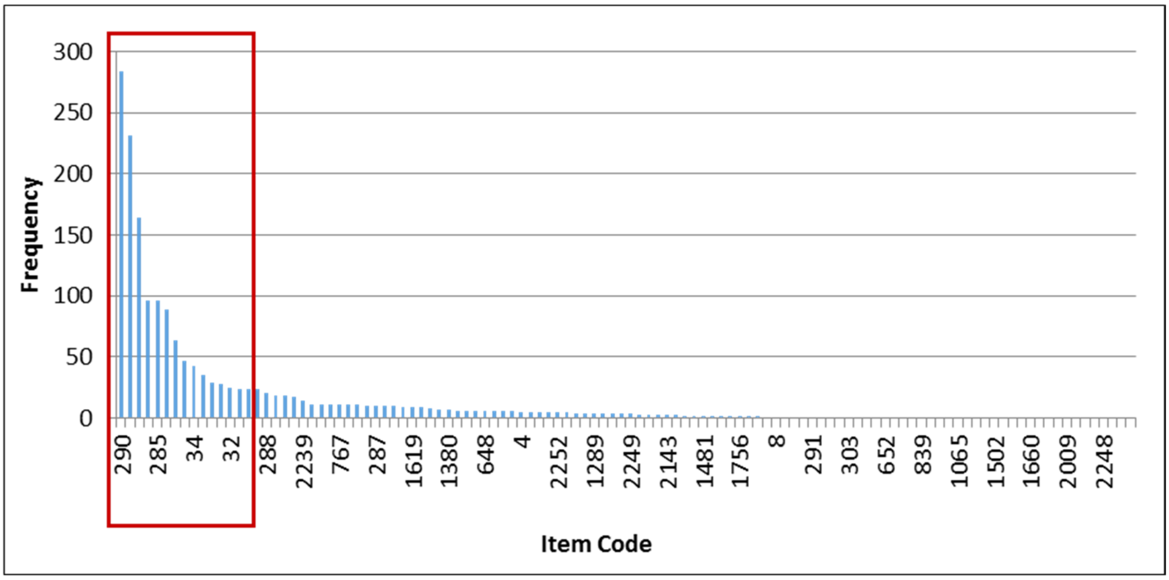


Figure 4-3: Group 2 – Frequency of item codes and items selected (15 most frequent)

Table 4-2: Items selected from Group 2

Item Name	Item Code	Frequency
Jacket potato	290	284
Wholemeal bread	26	231
White sliced bread	21	164
Rice	10	96
Mashed potatoes	285	96
Pasta	3	89
White sliced bread	22	64

Table continues on the following page

White bread	24	47
Wholemeal bun	34	43
Boiled potatoes	286	35
Brown bread	15	29
Sage and onion stuffing	452	28
French bread	32	25
White bread rolls	33	24
Nan bread	650	24

Following this process, the total number of item codes was reduced to 160, which covered 65% of the total frequency of items. Each element of this list of items was classified as type A, B or C as follows:

- Type A - items that can be described as single ingredients, usually purchased in their unprocessed / natural state (e.g. carrots, strawberries);
- Type B - items that are usually purchased after being processed (e.g. bread, dried pasta, canned tuna);
- Type C - meals (e.g. lamb curry with rice) prepared on site, by combining items type A and B.

A list of food products (or ingredients) was then created based on the following criteria:

This includes all type A and B items, and the ingredients necessary to prepare type C items that were not already on the list. This list was then used as a starting point for the creation of the CF and WF databases. Nevertheless, this was not the final list of food products; in subsequent iterations it was expanded to include those ingredients that were missing. These were identified through the case study analysis and the respective feedback of users (as shown in Figure 4-2). This will be further explained in Section 4.4. Additionally, the PSFS was used as the starting point of the third case study, this is presented in Sections 4.4.2.3 and 5.6.

4.2.2 Carbon Footprints (CF) Database

In order to create the CF database, in line with requirement 5 (Section 3.1), a systematic literature review was performed following the PRISMA statement protocol (Moher et al., 2009, Liberati et al., 2009) as explained in Section 3.2.5.

4.2.2.1 Information sources and search strategy

The review was performed across a range of sources available in the public domain: peer reviewed journal papers, conference proceedings, open access LCA databases, reports and Environmental Product Declarations (EPDs). Initially, for each food product belonging to the list extracted from the

PSFS, a targeted search was performed in Scopus using the key words “[FOOD PRODUCT] AND [LCA] OR [Carbon] OR [CO_2]”. This led to a number of peer reviewed journal papers that either presented a case study LCA of the food product in question (e.g. Espinoza-Orias et al., 2011), or collated and reviewed a number of publications presenting food LCA studies (e.g. González et al., 2011). In the second case, it was possible to retrieve the studies referenced and add them to the list. Through the screening of the reference list of the articles found and of those articles that had cited the ones identified, more articles were selected. This enabled the identification of “grey literature” such as reports issued by a variety of stakeholders amongst which research bodies, government departments, sectoral organizations, food companies and LCA consultancies (e.g. English Beef and Lamb Executive, 2009, Fuentes and Carlsson-Kanyama, 2006).

A separate search for key words was performed through the proceedings of the editions of the international conference “Life Cycle Assessment in the Agri-Food Sector” between 2008 and 2014. In this case the key word used was the name of the food product in question. To search across EPDs, a Google search was performed using as keywords “[EPD] AND [FOOD PRODUCT]”.

A number of open access databases of LCA of food products were found in the literature. Amongst those, some presented original work (e.g. Nielsen et al. (2003), PROBAS database (2013)), whilst others were created by collating secondary data from other sources (e.g. CCaLC (2011), Barilla Centre for Food and Nutrition (2015)). The first group of databases was used directly to search for additional values of CF, whilst the second group of databases was used to identify more sources, but the values were never extracted directly from those databases. The researcher went back to the original source in order to extract the data following the rigorous method explained in the next sections (Section 4.2.2.2 and 4.2.2.3).

The CF of some of the food products extracted from the PSFS, could not be found anywhere within the literature. When those missing elements belonged to items type A, no additional search was performed. When no information was found for a processed food product (i.e. type B), the ingredients necessary to make it were retrieved from a traditional homemade recipe and a separate search was performed for each ingredient. For instance one of the food codes extracted was “Pesto”. This is made of: basil, walnuts, olive oil, garlic and cheese. All the ingredients mentioned were already recorded with exception of basil and walnuts, which were then added to the list.

4.2.2.2 Eligibility criteria and study selection

In order to ensure the validity of the results provided (requirement number 5, Section 3.1), a selection criterion was defined according to which studies would be included in the analysis if they:

- Provided a value of GWP calculated according to the IPCC methodology (IPCC, 2007, IPCC, 1996) for a period of time corresponding to 100 years [2];
- Calculated the value of GWP for a mass based functional unit;
- Clearly specified the system boundaries included in the study, and whenever the system boundaries included phases *post farm gate* the contribution of each phase was clearly defined (providing either figures of GWP for each phase, percentage of the contribution of each phase or a graph showing the contribution of each phase);
- Clearly specified the location of production;
- Performed an attributional rather than consequential LCA.

For four food products (i.e. beef, pork, chicken and milk) a very large body of literature met the selection criteria. Due to the time constraints of this research work, it was decided (only for these four food products) to further refine the selection of literature by adding one element to the selection criteria.

To this end, import trade statistics were consulted to evaluate what percentage of each product consumed in the UK was imported from the rest of the EU and from the rest of the world. This information was reported by DEFRA for 2013 (DEFRA, 2013a) and is presented in Table 4-3. In the case of milk it can be seen that only 1% of the product consumed is imported from outside the UK, therefore only those studies which assessed milk produced in the UK were consulted. For beef, pork and chicken, the quota of product coming from outside the EU is relatively low (respectively 8, 1 and 2 percent) and therefore only studies which assessed European livestock products were consulted. The table reports also lamb and sheep products. In this specific case a higher share (i.e. 20 percent) of the products consumed in the UK in 2013 was imported from outside the EU. Therefore no additional criterion was added and all LCA studies of lamb aligned to the initial criteria were included directly. For each study identified, a screening of the abstract and methodology was performed to assess whether it met the inclusion criteria.

Table 4-3: Quotas of consumed milk, beef, pork, chicken and lamb imported from outside the UK and outside the EU (DEFRA, 2013a)

Product name	% imported from outside the UK	% imported from outside the EU	Additional selection criterion
Milk	1%	N/A	UK production
Beef	30%	8%	European production
Pork	55%	1%	European production
Chicken	26%	2%	European production
Lamb and sheep	24%	20%	-

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[2] The conversion factors presented in Table 3-2, are taken from the IPCC 2007 guidelines, which present an updated version of earlier 1996 values. This means that the publications prior to 2007 present values of GWP calculated with slightly different conversion factors.

4.2.2.3 Data extraction

The following data was subsequently extracted for each food product mentioned in the selected sources:

- Product name;
- Food category;
- Reference;
- System Boundaries included;
- Geographic location of study;
- Year of publication;
- Additional information (e.g. production method and additional processing);
- Total CF [gCO_{2e}/kg of food product];
- *Cradle to gate* CF.

The data extracted were reported systematically in a separate Excel sheet, in line with requirement 6 (Section 3.1).

In order to minimize the heterogeneity of the data (and ensure the validity of the results provided, requirement number 5, Section 3.1), a number of measures were taken when extracting the values of CF and if necessary, those values were adapted as explained in the following sections.

4.2.2.4 Data Handling: Functional Unit

The functional unit is the unit by which all the environmental results are reported. Across the studies of meat products included in the review a number of different functional units were considered, such as:

- Kilogram Live Weight (LW);
- Kilogram Carcass Weight (CW);
- Kilogram edible meat, also referred to as bone free meat (BFM).

Similarly, for fish products some studies used as functional unit one kilogram of live weight, and some one kilogram of product (which does not consider the weight of head and guts).

Whenever this was not the case in the original publications it was decided to convert all the values of GWP to the functional unit of 1 kg of edible product. This choice was made when considering the final use of the tool, which is to calculate the CF associated with a meal, based on the weight of each ingredient as expressed by the recipe. Table 4-4 presents the factors extracted from the literature that were used to convert all values of GWP to a common functional unit of 1 kg of BFM.

Table 4-4: Conversion of alternative functional units to bone free meat (BFM)

	Beef	Lamb	Pork	Chicken	Fish
CW/LW	0.55[a]	0.47 [a]	0.75 [a]	0.70 [a]	
BFM/CW	0.70 [c]	0.75 [c]	0.59 [d]	0.77 [d]	
BFM/LW	0.38	0.35	0.44	0.54	0.62 [b]

Sources:
a: Williams et al. (2006)
b: FAO (2013c)
c: Blonk and Luske (2008)
d: Sonesson et al. (2010)

4.2.2.5 Data Handling: System Boundaries

A range of different system boundaries were found in the studies analysed, such as:

- Cradle to farm gate;
- Cradle to slaughterhouse gate;
- Cradle to factory gate;
- Cradle to port;
- Cradle to regional distribution centre;
- Cradle to retail;
- Cradle to plate (home consumption or food service);
- Cradle to grave.

In order to homogenize the data, the value of GWP corresponding to the production phase only was extracted. In other words when the original study included phases other than the production phase, the contribution of those additional phases was subtracted. In this study, "production phase" is defined differently according to different food types, as illustrated in Table 4-5.

Table 4-5: System boundaries of the production phase for different food types

Food type	**System boundaries corresponding to production phase**
Unprocessed cereals, fruits, legumes, vegetables, eggs, fish (aquaculture)	Cradle to farm gate
Meat	Cradle to slaughterhouse gate
Fish (wild-caught)	Cradle to port
Processed food products (canned legumes, canned fish, bread, dairy etc.)	Cradle to factory gate

In some cases, the system boundaries in the original study included fewer phases than those shown in Table 4-5. For instance, this was the case for studies of meat production that did not consider the slaughterhouse phase, and studies of processed food products that did not include the processing phase. In these cases the values of GWP were modified to include these additional phases, based on values of related emissions extracted from the literature, as illustrated in Table 4-6. Some of the studies considered included packaging, others did not. When data on packaging were not available for non-processed products, its contribution was considered to be negligible. This is acceptable as packaging is generally not included in studies of food products that are packed in cardboard or plastic, which have a relatively low GWP (Ribal et al., 2016). However, certain processed products (e.g. tuna, tomato sauce, olives, and canned beans) are usually packed in carbon intensive packaging (e.g. tin cans and glass bottles). In this case the studies used to create the database generally took this packaging into account. When they did not, the contribution of packaging was added manually as illustrated in Table 4-6.

Table 4-6: Post farm gate emissions identified in the literature

Life cycle phase	GPW [gCO_{2eq}/kg]	Source
Slaughterhouse - Beef	800	Mieleitner et al. (2012)
Slaughterhouse - Pork	373	Reckmann et al. (2013)
Slaughterhouse - Lamb	1440	Peters et al. (2010)
Slaughterhouse - Chicken	359	Nielsen et al. (2011)
Canning of fruit and vegetables	295	Carlsson-Kanyama and Faist (2001)
Processing and packaging of milk	100	Foster et al. (2007a)
Packaging – plastic bottle	287	Andersson and Ohlsson (1999)
Packaging - can	700	Del Borghi et al. (2014)

Therefore the impact of packaging production is taken into account (either in the original study or added manually) for all of the following food products:

- Canned beans, lentils and chickpeas;
- Chopped tomatoes (glass bottle and tin);
- Honey;
- Jam;
- Olive oil;
- Canned sardines;
- Tomato ketchup;
- Tomatoes passata (carton, glass and tin);
- Canned tuna;
- Vegetable oil;
- Olives;
- Milk;
- Fruit juices.

Figure 4-4 presents an overview of the system boundaries included in the study. The green line represents the system boundaries considered at the stage described in this section, i.e. the creation of the database. The blue line shows the overall system boundaries of the tool; the two additional phases included therein (transport to regional distribution centre and meal preparation in school kitchen) are presented in Sections 4.2.4 to 4.2.6. Part of the inputs and outputs lie outside the system boundaries, this will be further examined in Section 5.10.3 within the discussion of the limitations of this work.

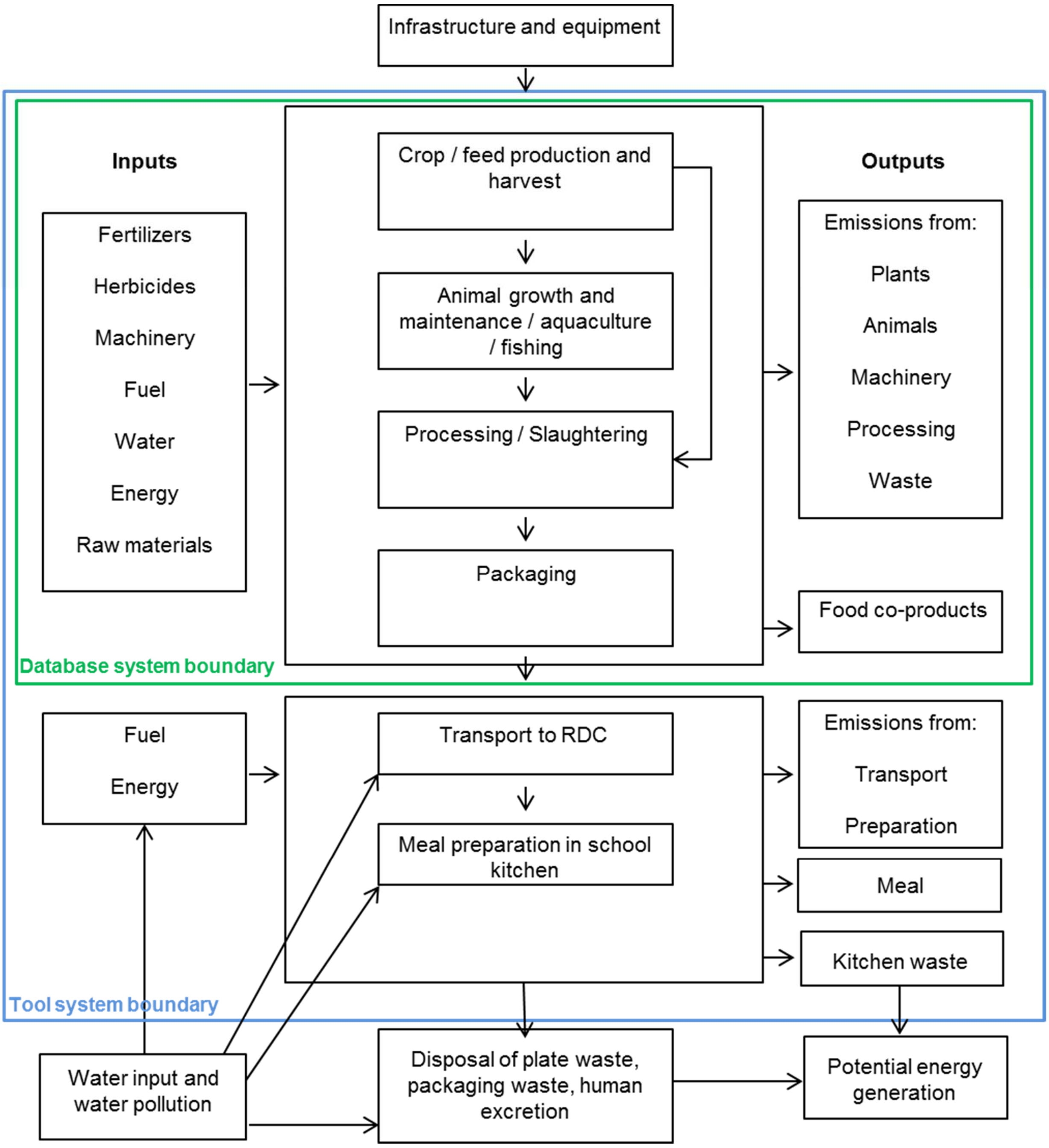

Figure 4-4: Life cycle phases and system boundaries of database and tool (adapted from Clune et al. (2016)

4.2.2.6 Calculation of average values of GWP

For each food product, the average of the values of GWP collated in the database, was calculated. This is the main output of the database.

As for the majority of products only a handful of values of GWP were found throughout the literature, therefore it was clear that it would not be possible to take into account the country of origin or the production method on top of the product name when calculating the average value of GWP. This is only a partial limitation, as the reviews from Teixeira (2015) and Clune et al. (2016) have demonstrated that the GWP of a product is actually strongly correlated with the food type and much less so with its origin and production method. This will be further discussed in Section 5.2. It is however important to stress that within this study the average values of GWP are calculated across different countries and production methods (with the only exception of horticultural products, where heated greenhouse products are differentiated from the others, as is explained in Section 4.4.1).

The CF database is provided in Appendix D (electronic material), Part 2 and the list of references of the CF database is provided in Appendix E.

4.2.3 Water Footprints (WF) Database

The creation of the WF database differed significantly from the creation of the CF database. In this case one existing source (Mekonnen and Hoekstra, 2010a, Mekonnen and Hoekstra, 2010b) provided the values of WF for a large range of food products at a high spatial resolution (regional level, country averages and world averages). This included livestock products, agricultural products and some processed agricultural products. Therein the green, blue and grey components of the WF are provided separately, therefore the three values were extracted, and additionally the total value (sum of green, blue and grey component) was calculated.

The process followed in creating the WF database was different from the CF database for three main reasons:

- Most of the data were collected from the same source, hence no data harmonization was required in terms of system boundaries (*cradle to gate*) or functional unit (1 kg product weight)[3];
- There is one single value of WF for each combination food product and country of origin, therefore no statistical analysis was performed;
- As there was availability of data at different geographical locations, it was possible to include this level of detail in the WF database (unlike what done in the CF database, where values of GWP of the same food product were grouped together regardless the country of production).

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[3] The only exception being the case of poultry, where the value provided was calculated using a functional unit of 1kg of live weight. In this case a correction was applied as explained in Section 4.2.2 for the CF database.

As with the CF database a handful of products did not appear in previously cited reports. Hence, a search was performed through the literature to find values of WF from other sources. When no information was found in the literature, proxies were used (for instance to include the WF of leek, onions were used as a proxy, as both species belong to the same *genus* and therefore it is assumed that they have similar irrigation requirements).

The databases published by the Water Footprint Network provide the values of WF for each food product at a high spatial resolution. However, for simplicity of use of the tool, the values extracted were the country average value, for each country of the EU28, and the world average value (to be used when the product is imported from outside Europe or when the origin is unknown).

To summarize, for each food product the following information was extracted and inserted in a separate excel sheet:

- Product name;
- Food category;
- Reference;
- Blue, green, grey and total WF (for each country of the EU28 + global average value).

The WF database is provided in Appendix D (electronic material), Part 3, whilst an analysis of the results collected is presented in Section 5.3.

4.2.4 Transport

At this step, transport emissions were calculated taking into account the transport of food products from their respective country of origin to a generic school kitchen located in Birmingham, UK. The contribution of this life cycle phase to the WF is negligible when adopting the approach by Hoekstra (2003), as the *pre farm gate* phases are predominant. Therefore, only the contribution to climate change was assessed at this stage. In order to do this, a number of assumptions were made.

For food products produced in the UK three different options were considered:

- A “UK generic” option, assuming road freight for a conservative distance of 250 km;
- A “UK less than 100 miles option”, assuming road freight for a distance of 160 km (100 miles);
- A “UK less than 30 miles option”, assuming road freight for a distance of 50 km.

For all food products imported from outside the UK and inside the EU28, the transport route was assumed to be from the capital city of the country of origin to Birmingham. [European countries that are not part of the EU28 were excluded at this stage after checking that the imports of food (for the year 2013) from those countries to the UK were small (HMRC, 2013)]. Two alternative routes were considered, the first prioritised sea freight and the second prioritised road freight. Rail freight was not considered as transport statistics show that in 2012 it accounted for less than 10% of the total inland freight transport of agricultural products in the EU (Directorate General for Internal Policies, 2015).

This could be included within the tool should rail freight distribution of food stock increase significantly.

Finally, for food products imported from outside the EU, a forfeit transport route was considered: this was calculated assuming that the food product would be transported by ship to the UK from Sydney. This was chosen as it is the longest sea route that connects a country in the world to the UK. This last option applies also when the origin of the product is unknown. The reason for including this broad assumption is to ensure the user friendliness of the tool: as the user can choose the country of origin from a drop down menu, it was decided that including all the existing countries would make the list too long, and therefore it would be better to include only EU countries and a generic option for all the other cases.

Sea freight transport routes were taken from the website http://www.cargorouter.com/ (accessed November 2016) which provides the fastest route when prioritizing sea freight. For example, if Copenhagen was entered as the origin and Birmingham as the destination, this resulted in:

- Sea freight from Copenhagen port to Manchester port;
- Road freight from Manchester port to Birmingham.

Sea distances between the two ports were then calculated from the website http://www.sea-distances.org/ (accessed November 2016) and road distances were calculated from Google Maps. This website was also used to calculate transport routes and distances in the "road freight prioritised" option. The result of this process is illustrated in Table 4-7.

Table 4-7: Transport routes and distances

	SEA FREIGHT PRIORITISED			ROAD FREIGHT PRIORITISED
Origin of food products	Sea route	Road distances [km]	Sea distance [km]	Road distance [km]
United Kingdom	-	-	-	250
< 30 miles	-	-	-	50
< 100 miles	-	-	-	160
Austria	Trieste - Manchester	628	2954	1700
Belgium	Antwerp - Manchester	157	1366	583
Bulgaria	Aliaga - Southampton	1027	5152	2696
Croatia	Rijeka-Manchester	317	5396	1865
Cyprus	Mersin-Southampton	228	6070	3406
Czech Republic	Szczecin-Manchester	657	1781	1482
Denmark	Copenhagen-Manchester	157	2018	1466
Estonia	Tallin-Manchester	157	2998	2725
Finland	Helsinki-Manchester	157	3037	2893
France	Le havre-Manchester	353	1001	680
Germany	Szczecin-Manchester	307	1781	1311

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Greece	Aliaga - Southampton	1468	5152	3406
Hungary	Rijeka-Manchester	660	5396	1936
Ireland	Dublin-Manchester	157	290	-
Italy	Bagnoli-Manchester	390	4224	2085
Latvia	Riga-Manchester	157	2887	2500
Lithuania	Riga-Manchester	451	2887	2297
Luxembourg	Antwerp-Manchester	414	1366	802
Malta	Malta-Tilbury	231	4228	3126
Netherlands	Amsterdam-Manchester	157	1409	750
Poland	Szczecin-Manchester	732	1781	1716
Portugal	Lisbon-Manchester	157	1909	2400
Romania	Gebze - Southampton	930	5446	2765
Slovakia	Rijeka-Manchester	1299	5396	2042
Slovenia	Trieste - Manchester	244	2954	1733
Spain	Valencia-Manchester	514	3135	1932
Sweden	Stockholm-Manchester	157	2800	2100
World	Sydney-Felixstowe	265	21300	-

Subsequently, the GHG emissions associated with the each of these transport routes were calculated. This was done considering as transport vehicles:

- A generic HGV, refrigerated and with average load (based on the average load for a freighting vehicle in the UK);
- A generic cargo ship, average size.

The emissions associated with these vehicles were obtained from a dataset provided by DECC (Department of Energy & Climate Change, 2015). This includes both the direct emissions deriving from the vehicle and the upstream emissions, referred to as *Well-to-Tank*. This component, classified as Scope 3 according to the GHG protocol, includes the full lifecycle of the fuel up to the point of use of the fuel, resulting from the extraction, transport, refining, purification or conversion of primary fuels to produce and then distribute end-user fuels.

The emission coefficients extracted from the DECC dataset are:

- Road freight emission coefficient: 0.1625 gCO_{2e}/Kg*Km;
- Sea freight emission coefficient: 0.0156 gCO_{2e}/Kg*Km.

The final values of transport emissions were calculated by multiplying the transport distance (for each country of origin and transport mode) by the emission coefficient, and are reported in Table 4-8.

Table 4-8: Transport emissions for each country of origin and transport mode

	SEA FREIGHT PRIORITISED	ROAD FREIGHT ONLY
Origin of food products	Emissions [gCO_{2e}/kg]	Emissions [gCO_{2e}/kg]
United Kingdom	-	41
< 30 miles	-	8
< 100 miles	-	26
Austria	148	276
Belgium	47	95
Bulgaria	247	438
Croatia	136	303
Cyprus	132	553
Czech Republic	135	241
Denmark	57	238
Estonia	72	443
Finland	73	470
France	73	110
Germany	78	213
Greece	319	553
Hungary	192	315
Ireland	30	30
Italy	129	339
Latvia	71	406
Lithuania	118	373
Luxembourg	89	130
Malta	104	508
Netherlands	48	122
Poland	147	279
Portugal	55	390
Romania	236	449
Slovakia	295	332
Slovenia	86	282
Spain	132	314
Sweden	69	341
World	376	-

4.2.5 Storage

In traditional LCA, when the storage phase is included in the system boundaries, the impacts of refrigerated storage are assessed at three stages: regional distribution centre, retail and household level (e.g. Schmidt Rivera et al., 2014). In the study here presented, food products are assumed to be transported directly from the regional distribution centre to a school kitchen, therefore the retail stage is not included (similarly to work done by Saarinen et al. (2012)).

As the transport phase, the storage phase has a negligible contribution to the water footprint, and therefore only GHG emissions were considered in the following.

In order to account for emissions associated with refrigerated storage at regional distribution centre, the work from Brunel University (2008) was consulted. Here, the GHG emissions caused by the storage of food products in refrigerated regional distribution centres is calculated based on the energy consumption of refrigerators and the average time for which the different products are usually stored. As shown in Table 4-9, the contribution of this phase to the GWP is very small. The highest value of GWP is 0.1 gCO2e, associated with the storage of 1 kilogram of fresh potatoes. The average value of GWP associated with the production of potatoes (see Section 5.2) is 153 gCO2e/kg, which is more than 1000 times higher. Therefore, it was decided to neglect the contribution of storage at regional distribution centre to the total GWP. However, this phase of the life cycle was taken into account when assessing the levels of waste, as explained in section 4.2.7.

Table 4-9: GHG emissions of storage at regional distribution centre for the average time of storage (adapted from Brunel University (2008))

Product	GHG emissions [gCO2e/kg]
Packed fresh meat	0.1
Ready meals	0.1
Milk	0.0
Cheese	0.038
Frozen peas	0.0
Frozen potatoes	0.0
Fresh apples	0.0
Fresh potatoes	0.1
Strawberries	0.0
Bread	0.0
Beef cottage pie	0.1

When it comes to accounting for refrigerated storage at household level, or in a food service kitchen, traditional LCA allocates to a product a share of refrigeration emissions based on the quota of the overall volume it occupies and the time for which it is stored. However, as Garnett (2008) points out when discussing the weaknesses of LCA, keeping a product in the refrigerator for a longer period of time has an insignificant impact on the overall energy consumption of the refrigerator throughout one year, in other words, in a household (or a commercial kitchen) the refrigerator and the freezer will still be continuously on, even when they are not full.

It is true that a larger consumption of chilled or frozen food products could drive in the long term a demand for larger refrigerators, or freezers, which will consume more energy and therefore cause more emissions. However, it is unclear how to account for this aspect in LCA.

As the aim of this work is the assessment of the environmental impact of alternative menu options, the burden of refrigerating and freezing the ingredients prior to consumption is considered as a baseline for all of the different meals compared, and therefore there is no need to include this within the system boundaries. If a different functional unit had been adopted, such as one day of operation of the catering service (as in the work by Clune and Lockrey (2014)), the overall emissions associated with the energy use of refrigerators in that time could have been taken into account. However, as the functional unit chosen is one portion of each meal, in order to enable comparisons across different meals, it is more appropriate to omit the contribution of refrigerated storage to climate change.

A criticism to this approach could be that radically changing the menus served would lead to an increased or decreased need for refrigeration, and therefore a variation in the associated energy consumption. However the impact of designing new menus on the levels of energy consumption of the refrigerators is here considered to be negligible.

4.2.6 Preparation

The preparation of a meal contributes to the overall GWP due to the use of cooking appliances run on either by electricity or natural gas. The contribution of the preparation phase to the WF is considered to be negligible when compared to the production phase (Strasburg and Jahno, 2015), and therefore the only impact category considered at this stage was GWP.

Average values of energy consumption for a range of cooking appliances were taken from the literature - (Carlsson-Kanyama and Faist, 2001) . Corresponding emissions were then calculated based on the emissions coefficients for the UK electricity grid and natural gas reported in Table 4-10 (Department of Energy & Climate Change, 2015) for the year 2015.

Table 4-10: Emissions coefficients for the UK electricity grid and natural gas (extracted from Department of Energy & Climate Change (2015))

Emission coefficients	kgCO_{2e}/kWh	gCO_{2e}/MJ
Electricity	0.5311	147.52
Natural gas	0.2093	58.13

The final values of emissions for a range of cooking appliances and processes are reported in Table 4-11.

Table 4-11: Energy consumption and corresponding GHG emissions for a range of cooking appliances and processes (adapted from Carlsson-Kanyama and Faist (2001)).

Cooking appliance and process	Comment	Energy consumption (minimum) [MJ/minute]	Energy consumption (maximum) [MJ/minute]	GHG emissions (average) [gCO$_{2e}$/minute]
Microwave, heating	Min/max: 650W/800W	0.039	0.048	6.42
Microwave, cooking	Min/max: 250W/700W	0.015	0.042	4.20
Microwave, defrosting	Min/max: 150W/190W	0.009	0.011	1.48
Hob, electric	Min/max: 1000W/2800W	0.060	0.117	13.06
Hob, gas	Min/max: 1000W/2600W	0.060	0.108	4.88
Oven, electric	Min/max: 2200W/3900W	0.092	0.163	18.81
Oven, electric, (warm up)	Min/max: 400W/1200W	0.024	0.072	7.08
Oven, gas	Min/max: 1500W/2500W	0.090	0.150	6.98

4.2.7 Waste and losses along the supply chain

The functional unit of this study has been defined as: *one serving of a primary school meal calculated from cradle to plate*. When allocating to a meal the environmental impact it has caused during its life cycle, it is important to take into consideration losses and waste along the supply chain. Due to wastage levels at post farm stages, a larger amount of each ingredient will have to be produced than the quantity expressed by the recipe, as illustrated in Figure 4-5.

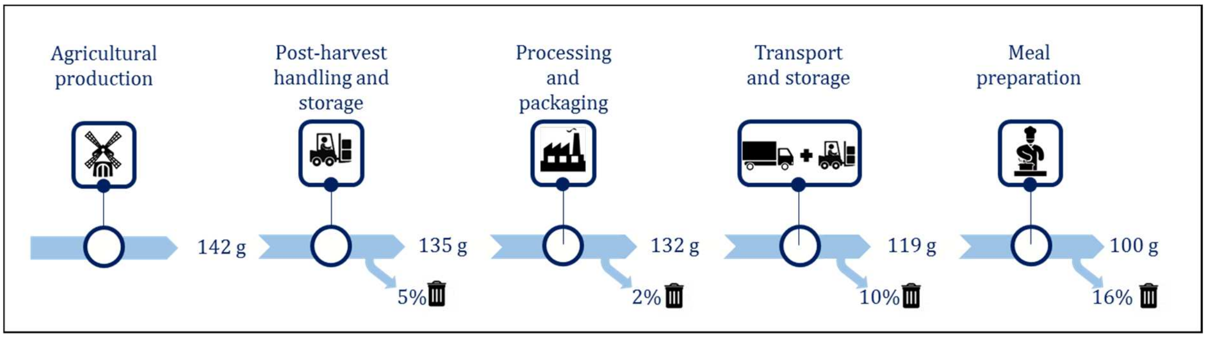


Figure 4-5: Food and wastage flows throughout the life cycle of fruit and vegetable products

In this example, the recipe considers 100 g of broccoli; this means that a larger amount (i.e. 119 g) will need to enter the school kitchen, due to waste at preparation stage (due to the inedible component of fruit and vegetables). Furthermore, as a consequence of losses during distribution, an even larger quantity will have to leave the packaging facility (i.e. 132 g). When adding considerations on losses during processing and packaging and at post-harvest handling stage (which include quality checks and damage to crops during grading and sorting), the amount of broccoli that needs to be harvested is 142 g. Considerations on losses during the agricultural production were not included, due to the assumption that wastage happening at this stage had already been taken into account in the literature sources consulted to extract the environmental impacts relative to the production phase.

Levels of wastage at each phase of the life cycle were collected from the literature for seven groups of food products (i.e. cereals, roots and tubers, oilseeds and pulses, fruits and vegetables, meat, fish, and dairy) from two sources:

- FAO (2011a) was used to extract the percentage of waste generated at post-harvest, processing and distribution stage. This source only considered edible waste generation.
- For certain types of food inedible waste (e.g. vegetable peelings) is generated at preparation stage. Amongst the groups considered, this is the case for fruit, vegetables, tubers, eggs, meat and fish. However, as the CF and WF of meat and fish had been calculated using one kg of product weight as a functional unit (and therefore excluding bones and other inedible parts), a coefficient of inedible waste was assumed only for the remaining groups. These coefficients were taken from DEFRA (2010).

The levels of wastage used for each group at the different stages of the life cycle and the overall waste coefficients (ρ) calculated as the ratio between the quantity of each food product that is harvested and the corresponding quantity used in the meal, are presented in Table 4-12.

Table 4-12: Levels of wastage at each stage of the life cycle collected from the literature and overall waste coefficients

Group	Post-harvest	Processing and packaging	Distribution	Preparation	waste coefficient (ϱ)
Cereals	4%	10%	2%	-	1.18
Roots and tubers	9%	15%	7%	27%	1.90
Oilseed and pulses	1%	5%	1%	-	1.07
Fruit and vegetables	5%	2%	10%	16%	1.42
Meat	1%	5%	4%	-	1.10
Fish and seafood	1%	6%	9%	-	1.17
Dairy and eggs	1%	1%	1%	1%	1.03

4.3 Stage 2: Tool development

The ethos behind EATS is that it should provide the user(s) with a simple-to-use interface (Figure 4-6) that allows them to input information on an individual recipe and be provided with respective outputs on the impact of each portion served (requirement 2, Section 3.1).

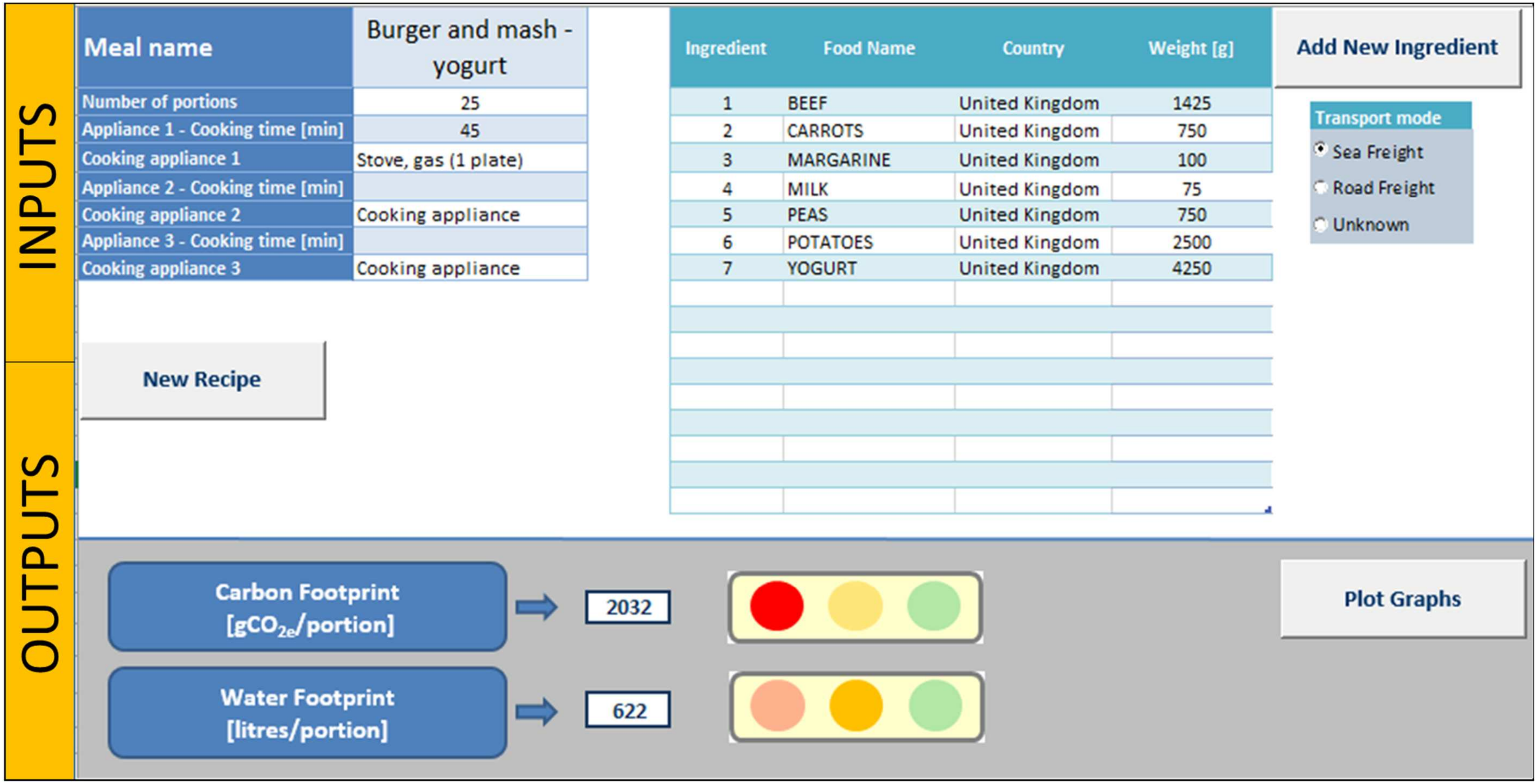
As such the following *inputs* are required from the user:

- Product name, weight and country of production of each ingredient;
- Transport mode;
- Number of portions required;
- Cooking appliance(s) used and for how long.

The respective *outputs* are given for one portion:

- Carbon Footprint: absolute value and score (green, amber, red);
- Water Footprint: absolute value and score (green, amber, red);
- Plots showing the contribution of each ingredient to the CF and the WF and the contribution of each phase of the life cycle to the CF.

The tool was developed in the form of an Excel spreadsheet. Excel was chosen for its simplicity of use and in order to meet the requirements 6 and 7 (Section 3.1) of transparency and adaptability of the tool.



Meal name	Burger and mash - yogurt
Number of portions	25
Appliance 1 - Cooking time [min]	45
Cooking appliance 1	Stove, gas (1 plate)
Appliance 2 - Cooking time [min]	
Cooking appliance 2	Cooking appliance
Appliance 3 - Cooking time [min]	
Cooking appliance 3	Cooking appliance

Ingredient	Food Name	Country	Weight [g]
1	BEEF	United Kingdom	1425
2	CARROTS	United Kingdom	750
3	MARGARINE	United Kingdom	100
4	MILK	United Kingdom	75
5	PEAS	United Kingdom	750
6	POTATOES	United Kingdom	2500
7	YOGURT	United Kingdom	4250

Transport mode
● Sea Freight
○ Road Freight
○ Unknown

Carbon Footprint [gCO_{2e}/portion] → 2032

Water Footprint [litres/portion] → 622

Figure 4-6: Interface for EATS

4.3.1 Calculation of impacts

The calculation of the CF and WF is based on the data collected in Stage 1 (Section 4.2) and is explained in detail in the following text.

Considering a generic ingredient (x), the user selects the food product (F_x), the weight (W_x) and the country of origin (C_x). Then a transport mode is chosen (M) (this should apply to all ingredients imported from outside the UK, whilst for ingredients produced in Britain it is implicit that the transport mode is by HGV). The user can choose up to three cooking appliances (y) used in the preparation phase, and for each select the time of use (T_y). Finally the number of portions (N) needs to be defined. This represents both the number of portions to which the quantity of each ingredient refers and the number of portions being prepared at the same time. It is important to highlight that the functional unit, which in the database is 1 kg of each food product, at this stage becomes one portion of each meal.

The total values of CF and WF are calculated according to:

$$\mathrm{CF_{tot}} = \left(\sum_{x=1}^{Z} \mathrm{CFPx} + \mathrm{CFTx} + \sum_{y=1}^{K} \mathrm{CFCy}\right)/N \tag{1}$$

$$\mathrm{WF_{tot}} = \left(\sum_{x=1}^{Z} \mathrm{WFPx}\right)/N \tag{2}$$

Where:

CF_{tot}= Total Carbon Footprint of one portion of the meal analysed [gCO_{2e}]

WF_{tot}= Total Water Footprint of one portion of the meal analysed [liters]

N = number of portions

Z = total number of ingredients

K= total number of cooking appliances

The Carbon Footprint associated with the production of the ingredient (x) is calculated according to Equation (1a)

$$CFP_x = CFP_{F(x)} \text{ x } W_x \text{ x } \rho_x /1000 \tag{1a}$$

Where:

CFP_x= Carbon Footprint associated with the production of the ingredient x [gCO_{2e}]

$CFP_{F(x)}$= Carbon Footprint associated with the production of 1 kg of food product F(x) [gCO_{2e}/kg] – (average value associated with food product F(x) in the CF database, see Section 5.2)

W_x=quantity of ingredient x [g]

ρ_x= waste coefficient of ingredient x (defined in Section 4.2.7) [no unit]

The Carbon Footprint associated with transporting ingredient (x) is calculated according to Equation (1b).

$$CFT_x=CFT_{M(x),C(x)} \text{ x } W_x \text{ x } \rho_x /1000 \tag{1b}$$

Where:

CFT_x = Carbon Footprint associated with transporting ingredient x [gCO2e]

$CFT_{M(x),C(x)}$ = Carbon Footprint associated with transporting 1 kg of goods from country C(x) to Birmingham, according to transport mode M(x) (see Table 4-8) [gCO2e/kg]

W_x and ρ_x as above.

The Carbon Footprint associated with cooking with appliance (y) is calculated according to Equation (1c).

$$CFC_y = CFC_{A(y)} \text{ x } T_y \tag{1c}$$

Where:

CFC_y = Carbon Footprint associated with cooking with appliance y [gCO_{2e}]

$CFC_{A(y)}$ = Carbon Footprint associated with the use of cooking appliance A(y) for one minute (see Table 4-11) [gCO2e/minute]

T_y= time of use of appliance y [minutes]

The Water Footprint associated with the production of ingredient (x) is calculated according to Equation (2a).

$$WFP_x = WF_{F(x),C(x)} \text{ x } W_x \text{ x } \rho_x /1000 \tag{2a}$$

Where:

WF_x= Water Footprint associated with the production of ingredient x [liters]

$WF_{F(x),C(x)}$ = Water Footprint associated with the production of 1 kg of food product F(x) in country C(x) (see WF database, appendix D, Part 3) [liters/kg]

W_x and ρ_x as above.

Once the CF and WF are calculated, in order to increase the user friendliness of the tool, a score is assigned to both impacts. This was defined in the following way. Taken CF_{av} and WF_{av} as the average values of CF and WF of a meal served in the UK (which are calculated in the third case study of this work), the following criteria was set:

- Green CF, when $CF \leq 0.7 \text{ x } CF_{av}$
- Amber CF, when $0.7 \text{ x } CF_{av} < CF < 1.3 \text{ x } CF_{av}$
- Red CF, when $CF \geq 1.3 \text{ x } CF_{av}$

The same considerations apply to the WF.

4.3.2 User interface

The user interface was created using VBA (Visual Basic for Applications) for Excel 2007 and provides the user with the following input controls (Table 4-13).

Table 4-13: Graphic user interface input controls

Label	Element type	Action
New recipe	Button	Resets the tool (cancelling previous recipe)
Add new ingredient	Button	Adds a new row to the ingredients table
Choose ingredient	Dropdown list	Select one ingredient from a list
Choose country	Dropdown list	Select the country of origin from a list
Transport mode	Radio Button	Select the transport mode (from 3 options)
Meal name	Text Field	Type info required
Number of portions	Text Field	Type info required
Cooking time	Text Field	Type info required
Cooking appliance	Dropdown list	Select the cooking appliance from a list
Plot graphs	Button	Plots 3 graphs

After inserting all the required inputs and clicking on “Plot Graphs” the user is provided with: a value for the Carbon Footprint (calculated according to one portion served), a score for Carbon Footprint (using a *traffic light* symbol), a value for the Water Footprint and a score (similarly to the one reported for CF), and three graphs. The first graph shows the contribution of each ingredient to the total CF, the second shows the contribution of each ingredient to the total WF and the third shows the contribution of each phase of the life cycle to the total CF of a meal. An example of each is provided in Figure 4-7, Figure 4-8 and Figure 4-9 respectively.

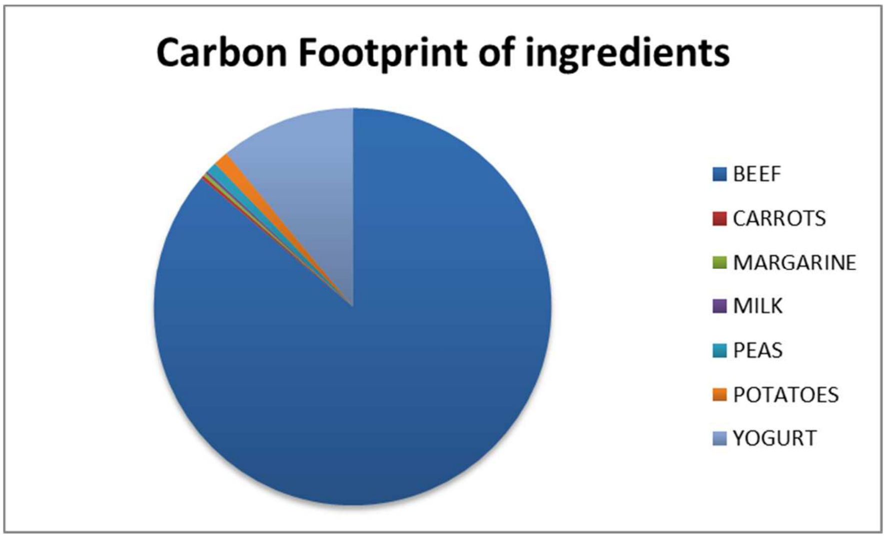


Figure 4-7: Graph 1 – Carbon Footprint of ingredients

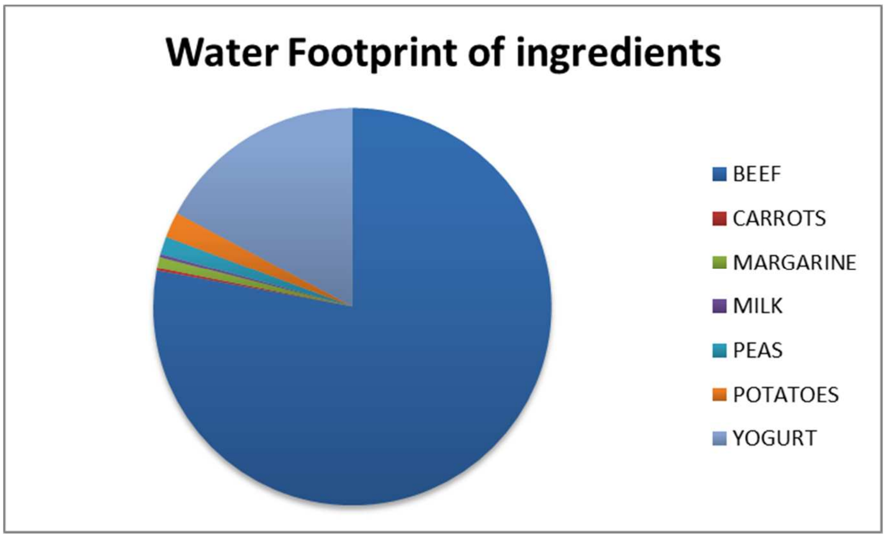


Figure 4-8: Graph 2 – Water Footprint of ingredients

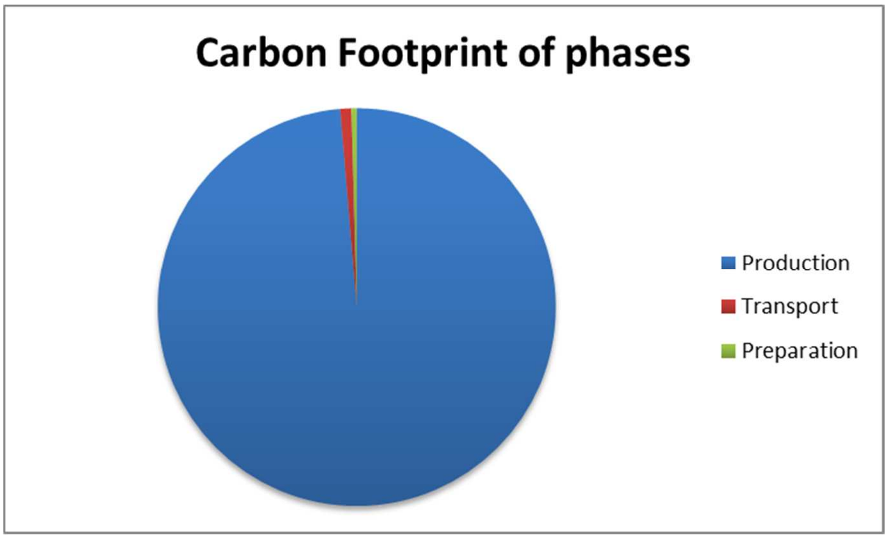


Figure 4-9: Graph 3 – Carbon Footprint of phases

As stated previously the purpose of the interface is to provide an easy to use platform for non-scientific audiences to engage with (requirement 2, Section 3.1), and therefore it was created with the aim of maximising its user friendliness. To this purpose a user-manual was produced, which explains how to use the tool in 5 easy steps. This is attached in Appendix B, while the tool is attached in Appendix D, Part 1.

A number of assumptions are made in the calculations for the following specific cases:

Case 1: When the users do not know the country of origin of some or all the ingredients, they are told to select the option “World” from the drop down list. This is also the option they are told to choose when the food product is imported from a non-EU country. In this case the WF is calculated based on the global average value for that specific food product, and the calculation of the transport emissions is made considering a forfeit transport route, from the port of Sydney to Birmingham.

Case 2: When the users do not know the transport mode, they can select the option "Unknown". In this case the transport mode will automatically be assumed as road freight for food products produced in the UK, and sea freight for food products imported from outside the UK.

Case 3: When the users cannot find an ingredient in the drop down list, they will have to look for a similar ingredient to use as a proxy. This is more likely to happen for processed rather than for fresh food products, due to a lack of LCA studies of processed food (e.g. industrial custard). For those processed foods that could also be made from scratch, the users are advised to use instead the corresponding ingredients and quantities in the homemade version of that product (for instance the traditional recipe for custard). This leads to a level of approximation of the results and represents a limitation of the study. For this reason it is important to highlight that the tool presented here may lead to more accurate results when being used to assess recipes made from unprocessed ingredients (i.e. a cake made from scratch rather than a cake made using a prepared mix).

4.4 Stage 3: Tool validation

In this last stage of the methodology, the tool was validated in four ways.

Firstly, in order to assess the adequate completeness and validity of the data collated in the CF database (requirements 4 and 5), a meta-analysis of the data was performed (Section 4.4.1), according to the PRISMA protocol for systematic reviews (Moher et al., 2009), as outlined in Section 3.2.5.

Secondly, through the development of three case studies (Section 4.4.2), it was possible to assess whether requirement 1 (contextual applicability, Section 3.1) had been met.

Thirdly, by asking to a number of potential users of EATS to trial it and provide some feedback (forty-two catering companies were contacted out of which five responded); this enabled to further assess the contextual applicability of the tool (requirement 1) and its usability (requirement 2) and meaningfulness (requirement 3). The validation stage was an iterative process which means that based on the results of the meta-analysis, the case study analysis and the users' feedback, the tool was improved and developed into its final version (as illustrated in Figure 4-2).

Finally, in order to test the requirement of validity of the results (requirement 5), the tool was tested by comparing the results of the case study analysis with existing literature and by using EATS to re-calculate the CF of the meals analysed by one literature source (Ribal et al. 2016) and compare the set of results thus obtained with the original one.

4.4.1 Meta-analysis of the CF database

In order to assess the validity of the results provided by the tool, each of the components of the calculation of the overall carbon and water footprint of a recipe was assessed separately.

The calculation of the CF is performed by summing three components (see Eq. 1, 4.3.1): the CF of production (CFP, Eq. 1a), of transport (CFT, Eq. 1b) and of preparation (CFC, Eq. 1c). The calculation of the WF (shown in Eq.2) is based only on the WF of production (WFP, Eq. 2a). The reasons for not including any other phase of the life cycle of a meal are presented in Section 4.1.

The calculation of the CF of the transport and of the preparation phases, as presented in Sections 4.2.4 and 4.2.6 respectively, are based on data extracted from either peer reviewed scientific articles or datasets published by the UK government. All of these sources are considered reliable and no further quality assessment is required.

Similar considerations apply to the data used for calculating the WF of production. The source used in this case are two databases published by the leading organization in this sector, the Water Footprint Network (Mekonnen and Hoekstra, 2010a, Mekonnen and Hoekstra, 2010b). These databases have been used as a starting point in a number of peer reviewed journal articles (e.g. Capone et al., 2013, Chen et al., 2016, Hess et al., 2015, Hess et al., 2016, Meier and Christen, 2013, Vanham et al., 2013) and therefore no additional assessment of their quality is considered necessary.

This is not the case for the CF of the production phase. This is calculated as the average of the values of GWP collected in the CF database for each food product. In order to ensure the meaningfulness of these average values, a number of measures were taken (see Section 4.2.2). However, it was decided to assess the accuracy of the values obtained through a meta-analysis.

The database of values of GWP of food products was analysed statistically with the software SPSS (version 21.0, SPSS Inc.) in order to assess the accuracy of the average values extracted from it. For each food product for which more than three values of GWP were recorded, the following statistical measures were calculated:

- Number of values of GWP recorded;
- Average;
- Standard deviation (of the sample);
- Minimum;
- Maximum;
- Lower and upper interval of a 95% confidence interval.

As the sample size is in most cases smaller than 30, the confidence interval was calculated by assuming that the population of values of GWP had a *t*-distribution. This distribution is preferable to the Normal distribution when the sample size is small and the standard deviation of the population is unknown (Sachs, 2012).

For those food products for which three or less values of GWP were recorded, only average value, minimum and maximum were calculated. The large number of food products with a sample size equal or smaller to three highlights the need for LCA research that covers a wider range of products, as suggested by other authors (Clune et al., 2016, Teixeira, 2015, Pulkkinen et al., 2015).

Through the statistical analysis, it was possible to identify food products that had a significant spread, and further refine the methodology of data collection and handling. For instance, a number of horticultural products presented a particularly large spread of values. When looking at the additional information recorded for each study the reason for this was identified: studies that assessed the GWP of products cultivated in heated greenhouses reported significantly higher values than those considering either unheated greenhouses or open field cultivation. It was therefore decided to divide these studies into two different groups (e.g. strawberries – heated greenhouse / strawberries - other). The statistical analysis was then performed again and the spread of values for each food product was significantly lower.

The same statistical analysis was then performed at food group level (after dividing the food products in fifteen groups), in order to compare the results obtained with those of the only existing publication that (to the author’s knowledge) performed a similar analysis.

The results of the meta-analysis applied to the final version of the CF database and of the comparison with existing literature are presented in Section 5.2 together with a thorough discussion of the overall accuracy of the results and the meaningfulness of using the average values.

4.4.2 Case study analyses: introduction

The three case studies presented in the following sections were developed in order to test the tool and provide three different examples of application of the tool, these are:

- Assessing the environmental impact of an existing menu, in order to design low impact menus (case study 1 – CS1 – Section 4.4.2.1);
- Assessing the environmental impact of a set of *best practice* recipes, in order to include environmental considerations when promoting healthy school meals (case study 2 – CS2 – Section 4.4.2.2);
- Assessing the environmental impact of the school catering sector in England, in order to estimate potential carbon and water savings that could be achieved at national level by implementing reduction measures (case study 3 – CS3 – Section 4.4.2.3).

In the three case studies, the following assumptions were made on the origin of the ingredients and transport mode:

- *Assumption 1*: For all food products that are produced in the UK (even if only during part of the year - shown in Table 4-14), this was assumed to be the chosen point of origin (valid in CS1, CS2 and only partly in CS3);
- *Assumption 2*: In all the other cases (e.g. fruits that cannot grow in the UK in any season) the country of origin was chosen as the country that is the first supplier of that food product to the UK (shown in Table 4-15);

- *Assumption 3*: The transport mode was assumed to be via truck and road for food products produced in the UK and cargo ship for food products imported from overseas.

In order to verify whether a food product can be produced in the UK, the FAOSTAT database for 2013 was consulted (FAO, 2013a). For those food products that could not be found in this database, other sources were consulted (e.g. Ellis et al., 2012). To identify the main supplier of the food products that were assumed to be imported from abroad, the overseas trade statistics for the UK were consulted (HMRC, 2013).

Table 4-14 shows a list of all the ingredients selected in the three case studies that are produced in the UK and the quantities produced in 2013, when this information is available from the FAOSTAT database. Additionally it lists the references used to verify that the food products that could not be found in the FAOSTAT database are produced in the UK. Table 4-15 shows the ingredients that are not produced in the UK (FAO, 2013a), and the main supplier of each to the UK (HMRC, 2013).

Table 4-14: List of ingredients produced in the UK and quantities (FAO, 2013a)

Food Product	UK production 2013 [tonnes]
Apples	217240
Beans, green	14540
Bread	N/A[a]
Butter, cow milk	145000
Cabbages and other brassicas	271800
Carrots and turnips	696200
Cauliflowers and broccoli	155700
Cheese, whole cow milk	380000
Chillies and peppers, green	23500
Cod	N/A[b]
Cream fresh	37000
Cucumbers and gherkins	57900
Currants	16300
Eggs, hen, in shell	672000
Grapes	817
Haddock	N/A[b]
Honey, natural	6400
Leeks, other alliaceous vegetables	35220
Lettuce and chicory	125500
Margarine, short	330000
Meat, cattle[5]	847000

Table continues on the following page

Meat, chicken	1443000
Meat, pig	833000
Meat, turkey	187000
Meat, sheep	289000
Milk, skimmed cow	3233106
Milk, whole fresh cow	13941000
Mushrooms and truffles	79500
Oats	964000
Oil, rapeseed	749900
Onions, shallots, green	13700
Pears	22630
Peas, green	152570
Plums and sloes	12375
Pollak	N/A[b]
Potatoes	5685000
Quorn™	N/A[c]
Raspberries	13800
Roots and Tubers,Total	5685000
Rye	35000
Sardines	N/A[b]
Salmon	N/A[d]
Strawberries	94373
Sugar Raw Centrifugal	1319000
Tomatoes	93600
Vinegar	N/A[e]
Wheat	11921000
Yeast	N/A[f]
Yogurt	N/A[g]

Sources proving the UK production of food products not found in the FAOSTAT database:
a: http://www.bakersfederation.org.uk/
b: http://www.fao.org/fishery/species/search/en
c: http://www.quorn.co.uk/
d: (Ellis et al., 2012)
e: http://www.aspall.co.uk/
f: http://www.dclyeast.co.uk/
g: https://www.muller.co.uk/about-mueller/muller-uk-ireland.html

Table 4-15: List of ingredients not produced in the UK and main supplier of each (FAO, 2013a, HMRC, 2013)

Food Product	Main supplier
Apricots	Spain
Bananas	Colombia
Beans, dry	Canada
Beetroot	Spain
Blueberries	Chile
Celery	Spain
Chickpeas	Italy
Chopped tomatoes	Italy
Cocoa Beans and products	Ivory Coast
Coconut	India
Cranberries	Chile
Dates	Iran
Aubergine	Netherlands
Garlic	Spain
Kiwi	Italy
Lemons and limes	Spain
Lentils	Canada
Maize	Senegal
Mandarins	Spain
Mango	Brazil
Melons	Brazil
Olive oil	Spain
Olives	Spain
Oranges	Spain
Pasta	Italy
Peaches and nectarines	Spain
Pineapples	Costa Rica
Pumpkins, squash and gourds	Portugal
Raisins	Turkey
Rice	India
Spinach	Spain
Sweet corn	India
Tomato ketchup	Netherland
Tomato passata	Italy
Tuna	Thailand
Walnuts	China

4.4.2.1 Case Study 1 (CS1)

The first case study was developed in order to assess the environmental impact of an existing menu. To this purpose, a catering company that serves several primary schools in the West Midlands (which desires to remain anonymous) was contacted in order to collect the necessary data for the development of the case study.

The catering company was contacted via email and answered by providing the following information:

- Menus to be served in the winter term of 2017 (within a Pdf file);
- Recipe(s) for each of the dishes on the menu (including the list of ingredients, quantities and cooking procedure) (within an Excel file);
- Food procurement information where available (i.e. name of suppliers and origin of ingredients for each recipe) (through email exchange).

The following step was then used to verify whether all of the ingredients being used by the catering company were already recorded within the tool. A number of missing ingredients were identified, and therefore the processes described in Sections 4.2.2 and 4.2.3 were repeated to enlarge the ingredients list of the tool. Whenever it was not possible to find the required data, assumptions were made in order to replace those ingredients with similar ingredients available from the tool, and the recipes were adapted accordingly.

The number of portions and cooking time were provided as part of the recipes. It is important to highlight that the emissions of the preparation phase are calculated according to the time that a cooking appliance will be switched on and by using the cooking time expressed in the recipe it is likely to underestimate the time the hob or oven will be on (for instance the time necessary to preheat the oven will not be considered). As it is not possible to predict precisely for how long each cooking appliance will be turned on by looking at the recipe, this represents a limitation of the tool, however as it will affect different recipes in similar ways, it will not affect the comparisons between alternative recipes.

As the suppliers used by the catering company are often changing, and due to the complexity of the supply chain in the case of processed ingredients, it was not possible to obtain a comprehensive overview of the origin of all the ingredients used to prepare the meals analysed, and therefore for most ingredients the origin had to be assumed (according to the approach outlined in the previous section). In the case of meat products, the catering company confirmed that these were always nationally sourced (which is in line with the assumption made). All the ingredients used in the menu provided are seasonal (and therefore assumption 1 from the previous section is valid). The cooking appliances used in the kitchen are assumed to be run on natural gas (AEA, 2012).

Once all the relevant information was collected, each recipe was tested with EATS and for each the values of CF and WF of one portion were recorded. The results of this case study are shown in detail in Section 5.4.

4.4.2.2 Case Study 2 (CS2)

The second case study was developed in order to assess the environmental impact of a set of *best practice* recipes. Those were taken from the online Recipe Hub (http://whatworkswell.schoolfoodplan.com/articles/category/52/recipes-menus accessed November 2016), published by the School Food Plan (2015) to provide schools and catering companies with a set of healthy and nutritionally compliant recipes.

As in CS1, the first step was the identification of those ingredients used in CS2 recipes that were missing from the tool, and when possible the enlargement of the tool to include those ingredients. Then, the recipes were adapted to replace the ingredients that could not be found with proxies. All the ingredients are assumed to be seasonal (therefore assumption 1 is valid) and the cooking appliances were assumed to be run on natural gas.

The same procedure adopted for CS1 was then implemented and the values of CF and WF for each recipe were recorded. The results are shown in detail in Section 5.5.

4.4.2.3 Case study 3 (CS3)

The third case study was developed in order to assess the average environmental impact of a primary school meal served in England and therefore the impacts of primary school meals at national level. Additionally, this enabled to define the intervals against which to assign a score to the CF and WF of a meal, as explained in Section 4.3.1. This was decided in order to increase the user friendliness of the tool.

The baseline data used to analyse school meals in England was the Primary School Food Survey (PSFS), presented in Section 4.2.1. A nationally representative sample of 139 schools in England took part in this survey, which was conducted between February and April of 2009. Table 4-16 provides the geographical distribution of the primary schools that took part in the survey.

Table 4-16: Geographical distribution of primary schools that participated to the PSFS (Haroun et al., 2009)

Government Office Region	Number of schools
East Midlands	10
East of England	14
London	26
North East	14
North West	10

Table continues on the following page

South East	22
South West	14
West Midlands	15
Yorks & Humber	14
Total	139

The participants were asked to create a food inventory where they recorded all food and drink items on offer each day in the school canteen for a period of two weeks. Each item is described by a name and a unique code. For each item code, the nutritional information and the weight of two typical portions (hence cooked weight) were recorded. Additionally, participants were asked to record all food and drink items chosen by 10 pupils for 5 days. A total number of 6690 school meals was recorded.

In the PSFS data set, 1556 unique item codes were identified. Each of them was associated to a value of CF and a value of WF calculated using EATS. In this case study, when calculating the CF, only two phases of the life cycle were considered: the production phase and the transport phase. No additional considerations were made to include the CF of the preparation phase of the meals. The reason for this is that greenhouse gas emissions arising from cooking can be significantly variable depending on cooking appliances used, number of portions and cooking methods and therefore are expected to change across different school kitchens (Chen et al., 2016).

For all the ingredients that can be produced in the UK only in a specific season, it was verified whether or not this season overlapped with the window of time in which the survey was conducted (between February and April). Of the ingredients presented in Table 4-14 and used in the preparation of the items analysed, six were out of season in the months considered. Therefore instead of assuming the UK as their country of origin (according to assumption 1), this was assumed as the country that was the main supplier of that product to the UK during that period of time. This information was obtained from the UK trade statistics (HMRC, 2013). In this case study the origin of the ingredients was therefore assumed according to Table 4-14 and Table 4-15, with exception for the ingredients reported in the Table 4-17.

Table 4-17: List of ingredients non-seasonal for the UK between February and April and main supplier of each (HMRC, 2013)

Ingredient	Main supplier
Broccoli	Spain
Carrots	Netherlands
Pears	Netherlands
Raspberries	Spain
Strawberries	Spain
Tomatoes	Spain

The methodology followed to calculate the CF and WF of each food code was:

- Each item was associated with its main ingredients (up to a maximum of five ingredients) and the proportion of each ingredient was assumed based on existing recipes;
- The cooked weight of each ingredient was then calculated based on the average cooked weight of the food code;
- The cooked weight of each ingredient was transformed into the corresponding weight before cooking based on conversion factors from the literature (Chappell, 1954);
- For each item, the name, raw weight and country of production of its ingredients were inserted in EATS and the corresponding values of CF and WF were obtained.

Each of the 6690 school meals recorded in the PSFS data set is set is composed of a combination of items that belong to the 1556 unique item codes (for a total number of 38148 items). Therefore, based on the impacts calculated for each item code, it was possible to calculate the CF and WF of each school meal recorded, and hence the average impacts. As the PSFS is considered to be representative of primary school meals consumed in England (Haroun et al., 2011), from the average values of CF and of WF it was possible to calculate the total impacts at national level, based on the number of primary school meals served each day in England.

In order to investigate the contribution of different types of food to the total impacts, the items analysed were divided into four groups:

- Group A - *Meat items*: including all items containing meat (e.g. lamb stew, Bolognese pasta, etc.);
- Group B - *Fish items*: including all items containing fish (e.g. cod in tomato sauce);
- Group C - *Vegetarian items*: including all items which had no meat or fish, but contained eggs or dairy ingredients (i.e. vegetarian main dishes, vegetarian sandwiches, side dishes containing dairy, and most desserts);
- Group D - *Vegan items*: including all the items which did not contain meat, fish, eggs or dairy (i.e. most vegetable and starchy side dishes, fruit salads etc.).

Based on this, it was possible to calculate the contribution of each group to the total CF and WF of the 6690 meals analysed. These results are presented in detail in Section 5.6.1.

4.4.3 Users' feedback

An important step of the tool validation was collecting feedback from its potential users. The purpose of this process was threefold:

- To identify additional missing ingredients from the tool (in order to test requirement 1, contextual applicability);
- To gain an understanding of how a potential user of the tool might find it in terms of user friendliness and where there was still room for improvement (requirement 2, usability);

- To investigate the general usefulness that professionals in the school catering sector see in such a tool (requirement 3, meaningfulness).

In order to do so, a short video was recorded that introduced the tool in its context and explained how to use it, in the style of a tutorial. The video was sent to a 42 catering companies across the UK, together with a demo version of EATS, a user manual (attached in Appendix B) and a survey. Figure 4-10 provides an overview of the geographical distribution on the catering companies contacted. Based on the results of the survey a number of amendments were made to the tool. This was the final step in the creation of the tool. An overview of the users' feedback is presented in Section 5.8 together with the amendments that were applied to the tool as a result.

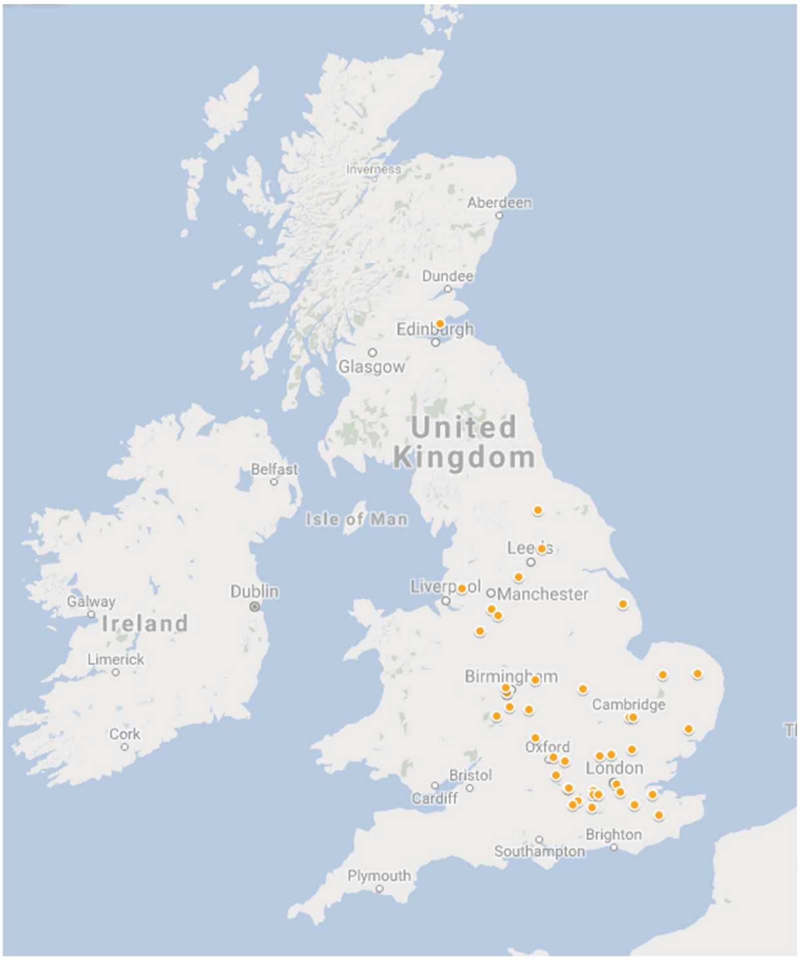


Figure 4-10: Geographical distribution of the 42 catering companies contacted

4.4.4 Testing the tool against existing literature

A crucial step of the tool validation was testing it against existing literature. To this purpose a literature review was conducted and four relevant studies were identified that adopted a similar approach to the one adopted in this work to assess the environmental impact of school meals. Three studies (Benvenuti et al., 2016, Ribal et al., 2016, Saarinen et al., 2012) performed an analysis similar to the first case study of this work, and therefore the results presented in those studies were directly compared with the results of CS1. Additionally the study by Ribal et al. (2016) provided the necessary information to enable a direct comparison of the CF of the recipes analysed therein with the corresponding results obtained by performing the calculations with EATS. The fourth study (Wickramasinghe et al. 2016) presented an analysis similar to the third case study of this work by assessing the CF of school meals in England based on the data recorded in the PSFS. Hence, a direct comparison between the results of this work and the ones obtained in the third case study of this thesis is provided. These results are presented in detail in Section 5.10.1.

4.5 Development of the procedural assessment

A procedure to follow in order to generate new and more sustainable menus, which have a lower carbon and water footprint compared to the current menu, was developed. This is informed by the results provided by EATS. The target savings are selected by the user (e.g. 20% for both CF and WF). As illustrated in Figure 4-11 the procedural assessment is an iterative process consisting of three main steps.

Step 1 is done only once, whilst steps 2 and 3 will need to be repeated until the CF and WF target savings are met.

Step 1: Firstly the data necessary to analyse the current menu (MENU 1) is collected, similarly to what described in Section 4.4.2.1 for the first case study. Then, using EATS, the CF and WF of each recipe in MENU 1 are calculated. Finally, the overall carbon and water footprints, corresponding to the functional unit of one portion per day for one week (or more, as the menus usually consists of a three to four week cycle), are calculated.

Step 2: In the second step a new menu (MENU 2) is created, which needs to be in line with the national nutritional guidelines (Public Health England, 2014). The nutritional assessment of the new menu lies outside the scope of this research and therefore it is not further analysed. Once MENU 2 has been created, it is analysed with EATS and all the calculations performed in Step 1 are repeated.

Step 3: The total carbon and water footprint of the menus are compared and the overall savings are calculated. If those meet the prefixed target, MENU 2 is accepted and there is no further iteration. If the target savings are not met, the user proceeds to identify the main *hotspots* amongst the ingredients (i.e. ingredients characterised by a particularly high value of CF and/or WF) of each recipe (using the results of EATS) and changes the menu accordingly. Then, the analysis is repeated and the new savings are calculated. This process continues until the desired savings are met.

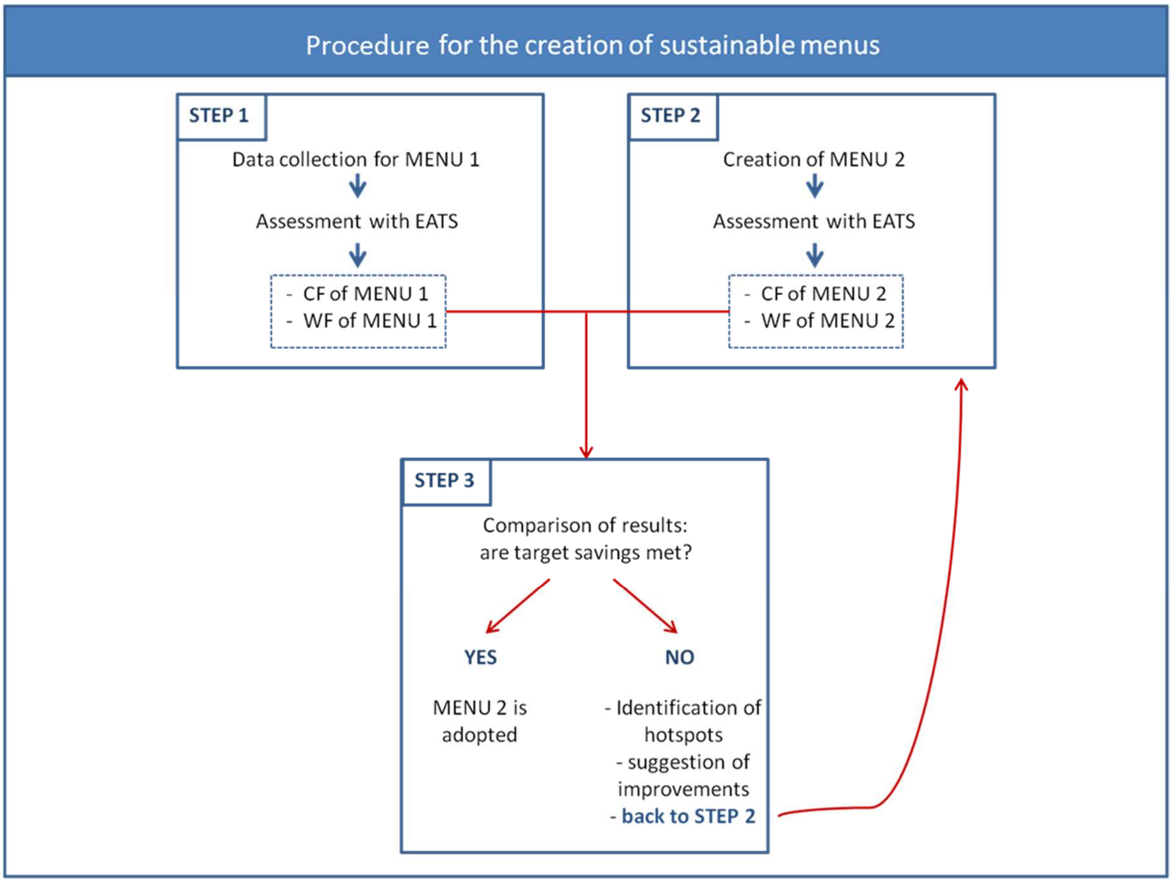


Figure 4-11: Flowchart of the procedural assessment

A practical example of an application of the procedural assessment is provided in Section 5.9, using as a starting point the menu of CS1, and as an improved menu, one generated from a combination of the meals analysed in CS1 and in CS2. In the discussion section (Section 5.10.2), a calculation is performed to quantify the impact of implementing this measure at a national scale based on the impacts at national level calculated in CS3 (assuming that similar savings could be achieved in all primary schools in England). This exercise has the purpose of showing the potential implications of adopting the procedure suggested in this work on a large scale.

4.6 Summary

The EATS tool and the associated procedure proposed by this research represent a unique and novel way to assess the environmental impact of school meals and create low impact menus. Existing sustainability schemes in the catering sector in the UK are generally based on qualitative, common sense, criteria rather than on scientific evidence. On the other hand, a number of LCA based methodologies have been suggested to quantify the environmental impacts of catering services (e.g. Ribal et al., 2016, Jungbluth et al., 2015), but have not been developed into a tool that catering companies can use to self-assess their performance. Therefore, the research presented herein is, as far as the author is aware, the first attempt at bridging this gap.

This chapter provided the detailed methodology that led to the creation of EATS and the related procedural assessment. The tool creation followed three steps: data collection from literature, tool development and tool validation. This was an iterative process, which meant that based on the outcome of the tool validation the first two steps were repeated to improve the tool.

The tool needed to fulfil a number of requirements, as presented in Table 4-18. Against each requirement were a number of methodological choices and validation processes.

Table 4-18: Requirements of the tool and related methodological choices and validation process

	Requirement	Methodological choices	Validation process
1	Contextual applicability	Use of the Primary School Food Survey as a starting point in the development of the databases	Case study analysis (identification and inclusion of missing ingredients) Survey to users
2	Usability	Interface design Choice of inputs required for the calculation	Survey to users
3	Meaningfulness	Choice of impact categories	Survey to users
4	Adequate completeness	Choice of system boundaries Data handling in the creation of the CF database	Meta-analysis of the data Comparison with existing literature Testing the tool against other options
5	Validity	Selection criteria in the systematic review of literature Data handling in the creation of the CF database	
6	Transparency	Choice of developing the tool as an Excel spreadsheet Choice of using only data available in the public domain	No validation required
7	Adaptability	Development of an Excel spreadsheet	

Data collection (Section 4.2) was designed to meet requirements 1, 4 and 5 (contextual applicability, adequate completeness, validity). In the validation process the first three requirements (contextual applicability, usability and meaningfulness) were tested using case study analysis and users’ feedback, and a statistical analysis of the CF database was performed to verify the validity of the results provided by the tool. Furthermore, the results of the meta-analysis of the CF database were compared with existing literature. Finally, to ensure that requirements 6 and 7 (transparency and adaptability) were achieved an Excel-based spreadsheet tool was developed.

Section 5 provides the results of the creation of the CF database and related statistical analysis, an analysis of the WF database, an application of EATS with the help of three case studies and an example of application of the informed procedural assessment. It then discusses the associated findings and observations.

5 Research findings and discussion

5.1 Introduction

This section describes the results obtained during the development, application and validation of the tool (and associated procedural assessment). In other words:

- Creation of the CF database (Section 5.2);
- Creation of the WF database (Section 5.3);
- Application of the tool to three case studies (Sections 5.4 to 5.6);
- Sensitivity analysis of the results (Section 5.7);
- Validation (through user feedback) of the tool (Section 5.8);
- Application of the developed procedural assessment (Section 5.9);
- Validation by comparing the results with existing literature (Section 5.10.1)

Sections 5.10.2 and 5.10.35.10 then discuss the potential impact and the limitations of the research presented.

5.2 Carbon Footprint database: results from systematic literature review and meta-analysis

In this section, the results from the systematic review of the literature and meta-analysis, performed to create the CF database, are presented in detail. Based on the results of the meta-analysis it is possible to make some general considerations on the GWP of different food groups, the level of accuracy of the tool, and the related limitations. Finally a comparison with existing literature is provided in order to demonstrate the rigorousness of the approach followed in the systematic review and the consequent quality of the results obtained.

5.2.1 Overview of available literature

The CF database comprises 783 values of GWP extracted from 215 sources published between 1998 and 2015 (for the full list of references see Appendix E). These belong to the following types of publications: EPDs, scientific reports, journal and conference papers and existing databases. An overview of the spread of values of GWP across the different types of publication is provided in Figure 5-1. It is possible to see how the vast majority of values (68%) were collected from journal and conference papers. These types of publication guarantee a rigorous approach and certain degree of data quality. As for EPDs, these are performed based on the standard ISO 14025 (2006a) and verified by a third party, guaranteeing the quality of the results provided. However, the low number of values collected from EPDs reflects the novelty of this certification and the fact that only a small number of food producers have engaged in performing this type of analysis at the time of writing. Finally, reports and LCA datasets are generally produced by LCA consultancies, governmental departments and research bodies, and the quality varies on a case-to-case.

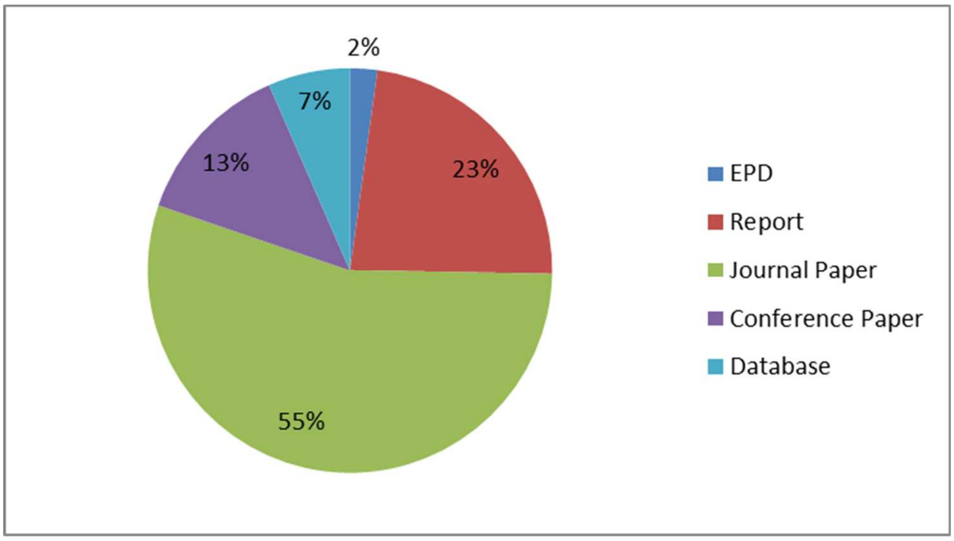


Figure 5-1: Spread of values across different publication types

As explained in Section 4.2.2.5, a variety of different choices of system boundaries was applied in the various studies considered. Figure 5-2 presents the distribution of the values of GWP across the different types of system boundaries. The most common choice is *cradle to farm gate*: in this case the value extracted from the study could be directly added to the database with the exception of meat products (adapted to include the slaughterhouse phase) and processed products (where the value of GWP was adapted in order to be calculated from *cradle to factory gate*). For the studies that presented the results calculated from *cradle to factory gate, cradle to port* and from *cradle to slaughterhouse gate* the values of GWP were extracted without further data handling. Finally, in the remaining cases (studies that considered as system boundaries either *cradle to RDC*, *cradle to retail*, *cradle to plate* or *cradle to grave*) the contribution of the *post gate* phases was removed.

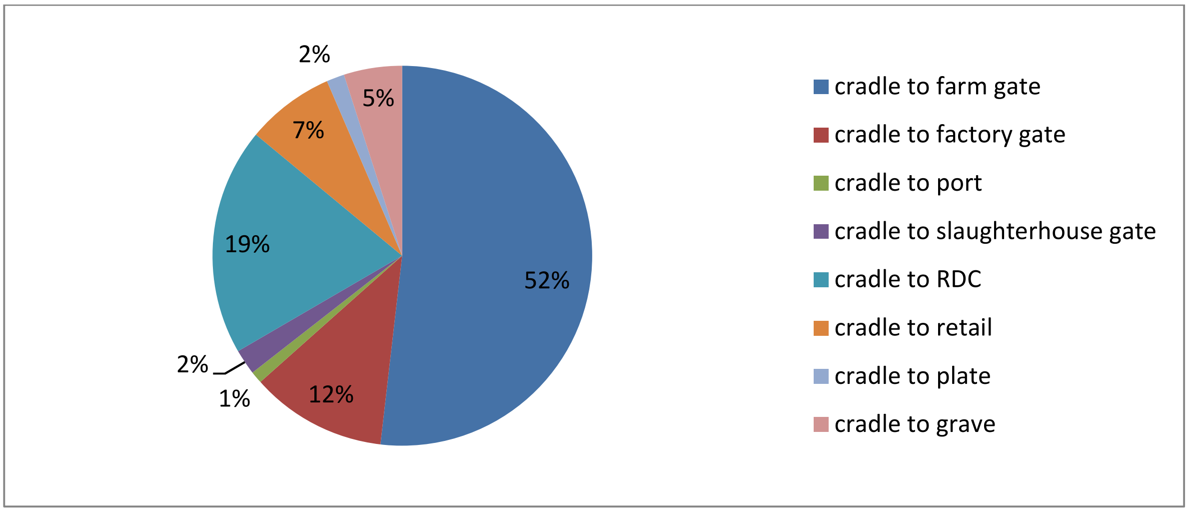


Figure 5-2: Spread of values across different choices of system boundaries

As identified in previous literature (Teixeira, 2015, Clune et al., 2016) most of the available literature on food LCA has been calculated for food products produced in Europe (with the exception of North American and Australian studies). This trend is also reflected in the CF database, when looking at the geographical origin of the values of GWP collected, as illustrated in Figure 5-3. The recognised Eurocentric bias of the literature is amplified in this case by the fact that for a number of food products, the selection of studies was restricted to those that assessed European products (see Table 4-3). However, as the database was built as part of a tool to be used in the UK context, rather than to provide a general overview of the GWP of food products on a global scale, this is considered to be acceptable.

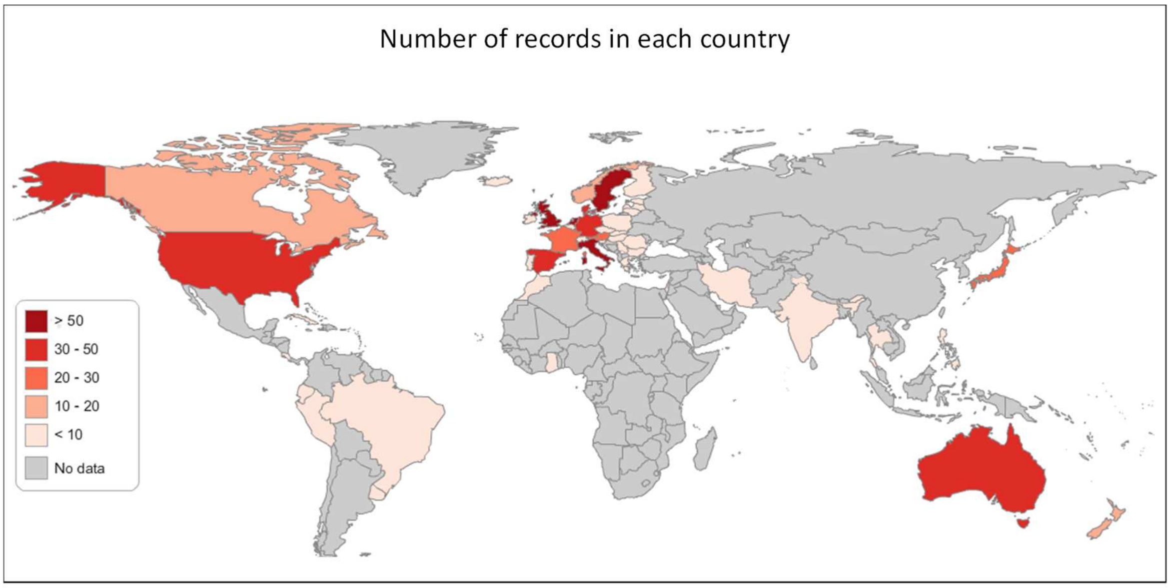


Figure 5-3: Location and number of GWP values recorded in the database

As explained in Section 4.2.2.1, a targeted search was performed for each entry on the list of food products commonly served in primary school meals in England. For some of them (e.g. beef, chicken and potatoes) a large number of values of GWP were found in the literature, whilst for others no values were found (e.g. basil and parsnips) or a very small number (e.g. garlic and pears). In total, 783 values of GWP were recorded for 110 different food products.

The different availability of data that was found across food types is aligned with the findings of broadly similar studies (i.e. Clune et al., 2016, Teixeira, 2015), which have observed how the LCA literature is clearly biased towards certain types (e.g. milk and beef). This bias is illustrated in Table 5-1 and Figure 5-4.

The food products analysed are here divided into five categories: dairy and eggs, fish, fruits and nuts, meat, processed agricultural products, vegetable and pulses. Table 5-1 shows the total number of values of GWP recorded in the database for the food products belonging to each category (R), the number of food products in each group (I), and the ratio between the first and the second value. This is the average number of records of the food products belonging to each category. Figure 5-4 provides a visual representation of Table 5-1: on the y-axis it shows the total number of values of GWP recorded in each category (first column of the table), whilst the size of the blue circles is proportional to the average number of records per food product in each category (third column of the table). Therefore it is possible to see that some food products (i.e. those belonging to the meat and dairy category) are highly represented in the database (bigger circles), whilst the remaining ones are less represented (smaller circles).

Table 5-1: Number of records and number of food products for five different categories

Food category	Records in each group - R	Food products in each group - I	R/I
Dairy and eggs	86	7	12
Fish	46	8	6
Fruits and nuts	110	24	5
Meat	221	6	37
Processed agricultural products	117	29	4
Vegetables and pulses	203	36	6
Total	783	110	-

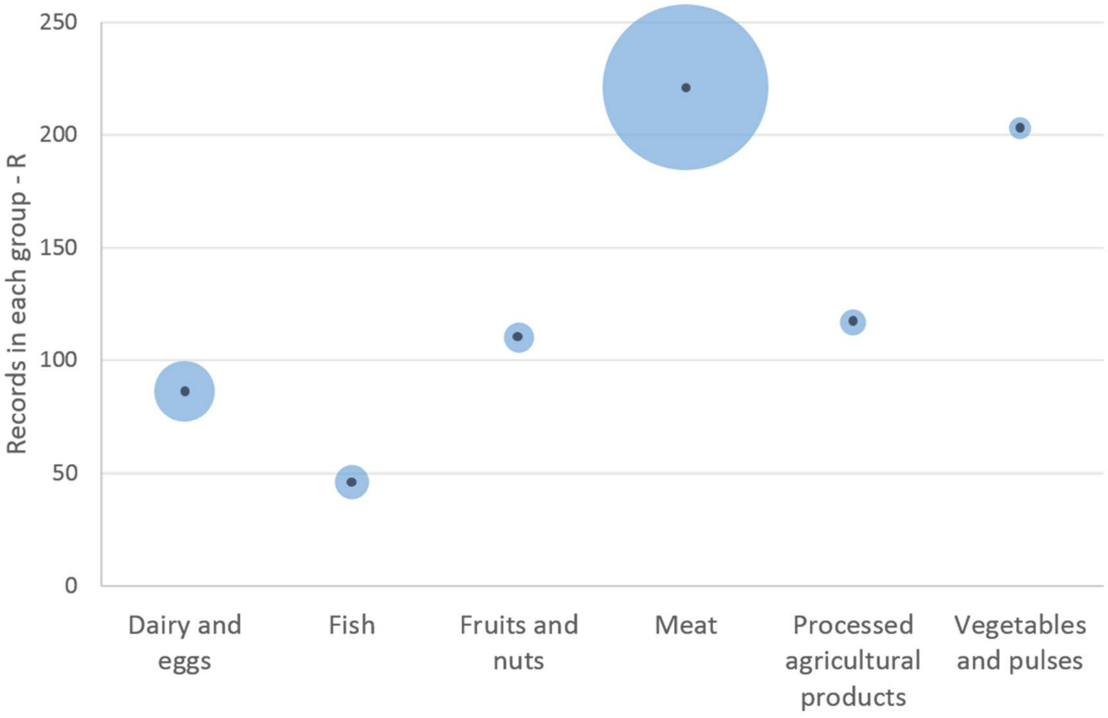


Figure 5-4: Number of records of GWP in each food category, the size of the circles is proportional to R/I from Table 5-1.

Overall, this analysis confirms that the data available in the public domain of values of GWP of food products is significantly biased towards European products, and a larger number of studies can be found for certain food categories (meat and dairy) compared to others (e.g. nuts and pulses). Furthermore, the records collected in the CF database were sourced from a varied range of sources and are characterised by a significant heterogeneity in methodological choices (such as the choice of the system boundaries) highlighting the importance of the data handling process.

5.2.2 Results of the meta-analysis

As explained in Section 4.4.1, a statistical analysis of the CF database was performed in order to assess the accuracy of the average values of GWP used by the tool in the calculation of the CF of a recipe. For those food products for which only one value of GWP was identified in the literature (N=1), no statistical analysis was performed. For those associated with either two or three values of GWP (N=2÷3), the average value was compared with the minimum and maximum value. Finally, for all the other food products (N>3), the upper and lower limits of a 95% confidence interval were calculated assuming that the values had a *t*-distribution. The results of the statistical analysis are presented in the following table and figures.

Table 5-2: Results of the meta-analysis of the GWP of food products [gCO$_{2e}$/kg]

Food product	Average	SD	N	Min	Max	Lower limit	Upper limit
APPLE JUICE	1600		1	1600	1600		
APPLES	186	152	27	36	762	126	246
APRICOTS	430		1	430	430		
AUBERGINE	31		1	31	31		
BACON	3950	1485	2	2900	5000		
BANANAS	334	64	9	228	463	284	383
BEANS - CANNED	1050		1	1050	1050		
BEANS - DRY	625	281	6	320	1000	331	920
BEEF	26573	9291	79	8031	50151	24492	28654
BEETROOT	163	109	2	86	240		
BISCUITS	1668	104	2	1595	1741		
BLUEBERRIES	776	75	2	723	829		
BREAD	820	138	11	495	1013	727	913
BREAKFAST CEREALS	1000		1	1000	1000		
BROCCOLI	617	547	6	346	1730	43	1191
BUTTER	8085	1001	6	7200	9600	7035	9135

Table continues on the following page

BUTTERNUT SQUASH	66		1	66	66		
CABBAGE	176	163	7	30	500	26	327
CARROTS	95	40	13	50	200	70	119
CAULIFLOWER	326	47	3	291	380		
CELERY	340	226	2	180	500		
CHEESE	8298	2311	24	2900	14339	7322	9274
CHICKEN	4037	1702	42	1433	9049	3507	4567
CHICKPEAS - CANNED	900	198	2	760	1040		
CHICKPEAS - DRY	650	636	2	200	1100		
CHOCOLATE	2949	1041	3	1782	3782		
CHOPPED TOMATOES	1516	60	2	1473	1558		
COCOA	3804		1	3804	3804		
COCONUT MILK	415	35	2	390	440		
CODFISH	2903	1381	14	1200	5960	2106	3700
COTTAGE CHEESE	1800		1	1800	1800		
COURGETTE	712	578	6	120	1386	106	1319
CRACKERS	2075	799	2	1510	2640		
CRANBERRIES	790		1	790	790		
CREAM	6386	2871	7	2100	10500	3731	9040
CUCUMBER	118	45	4	56	164	46	190
CUCUMBER (HG)*	2200	953	3	1648	3300		
DATES	320		1	320	320		
EGGS	3015	1548	26	1300	7000	2390	3640
FISH FINGERS	2238		1	2238	2238		
GARLIC	570		1	570	570		
GRAPES	164	79	4	62	239	39	289
GREEN BEANS	268	182	3	136	476		
GREEN BEANS - CANNED	1353	131	2	1260	1445		
HADDOCK	3339	40	2	3310	3367		
HAM	4453	1271	4	2900	6000	2430	6475
HONEY	4467		1	4467	4467		
JAM	1097		1	1097	1097		
KIWI	214	74	3	146	292		
LAMB	28782	13825	38	3400	53140	24238	33326

LEEK	119	72	2	69	170		
LEMONS	80	57	2	40	120		
LENTILS - CANNED	900		1	900	900		
LENTILS - DRY	1233	801	2	667	1800		
LETTUCE	348	288	15	106	1282	188	507
LETTUCE (HG)*	3038	1188	3	2172	4392		
MANDARINES	388	238	2	220	556		
MANGO	139		1	139	139		
MARGARINE	1224	613	6	497	2120	581	1867
MELONS	733	492	3	304	1270		
MILK	1316	233	11	984	1800	1159	1472
MUSHROOMS	60		1	60	60		
MUSHROOMS (HG)*	3493	1311	2	2566	4420		
OAT FLAKES	830	240	2	660	1000		
OLIVE OIL	3803	2806	3	1447	6906		
OLIVES	1374	226	7	1075	1702	1165	1583
ONIONS	211	178	15	42	590	113	310
ORANGE JUICE	839	196	2	700	978		
ORANGES	172	86	11	70	330	115	230
PASTA	906	323	8	495	1433	635	1176
PEACHES	399	222	4	180	591	45	753
PEARS	376		1	376	376		
PEAS	503	86	6	390	627	413	593
PEPPERS	579	55	4	510	644	491	667
PEPPERS (HG)*	7659	3527	3	3600	9976		
PINEAPPLE JUICE	1035		1	1035	1035		
PINEAPPLES	253	110	6	127	429	137	368
POLLOCK	1477		1	1477	1477		
PORK	6329	2111	52	2585	11312	5729	6929
POTATOES	153	78	30	65	380	124	182
QUORN™ - MINCE	3133	737	3	2300	3700		
QUORN™ - PIECES	3300	141	2	3200	3400		
RAISINS	684	23	2	667	700		
RASPBERRIES	790		1	790	790		
RICE	2445	1344	25	857	5978	1890	3000
RYE FLOUR	611	335	3	325	980		

Table continues on the following page

SALMON	3101	1040	13	1935	5610	2473	3730
SALT	300		1	300	300		
SARDINES - CANNED	5250	3466	2	2799	7700		
SPICES	300		1	300	300		
SPINACH	327	306	3	136	680		
SPRING ONIONS	230		1	230	230		
STRAWBERRIES	422	256	13	80	854	267	577
STRAWBERRIES (HG)*	2663	2115	3	695	4900		
SUGAR	754	474	6	214	1370	256	1251
SWEDE	500		1	500	500		
SWEET CORN	1135	267	3	850	1380		
TOMATO KETCHUP	747	0	2	747	747		
TOMATOES	502	383	24	149	1440	340	664
TOMATOES (HG)*	2935	1440	24	850	5782	2327	3543
TOMATOES PASSATA	1099	186	3	981	1314		
TUNA	2780	461	6	2242	3548	2296	3263
TUNA – CANNED	3864	1398	7	2850	6641	2571	5156
TURKEY	6633	2225	6	3760	8409	4298	8967
VEGETABLE OIL	3740	2644	18	1083	9107	2425	5055
VINEGAR	1327		1	1327	1327		
WALNUTS	695	276	2	499	890		
WHEAT FLOUR	650	258	4	399	1010	239	1061
YEAST	960		1	960	960		
YOGURT	1200	180	11	1018	1545	1079	1322

* HG: heated greenhouse

The results collected in Table 5-2 are illustrated in the following figures: Figure 5-5 and Figure 5-6 show the food products characterised by N>3, having respectively an average value of GWP lower than 2000 gCO_{2e}/kg and higher than 2000 gCO_{2e}/kg. The error bars show the lower and upper values of a 95% confidence interval.

Figure 5-7 and Figure 5-8 show the food products characterised by N smaller or equal to 3, respectively for an average value of GWP lower and higher than 1000 gCO_{2e}/kg. In this case the error bars represent the minimum and maximum values recorded.

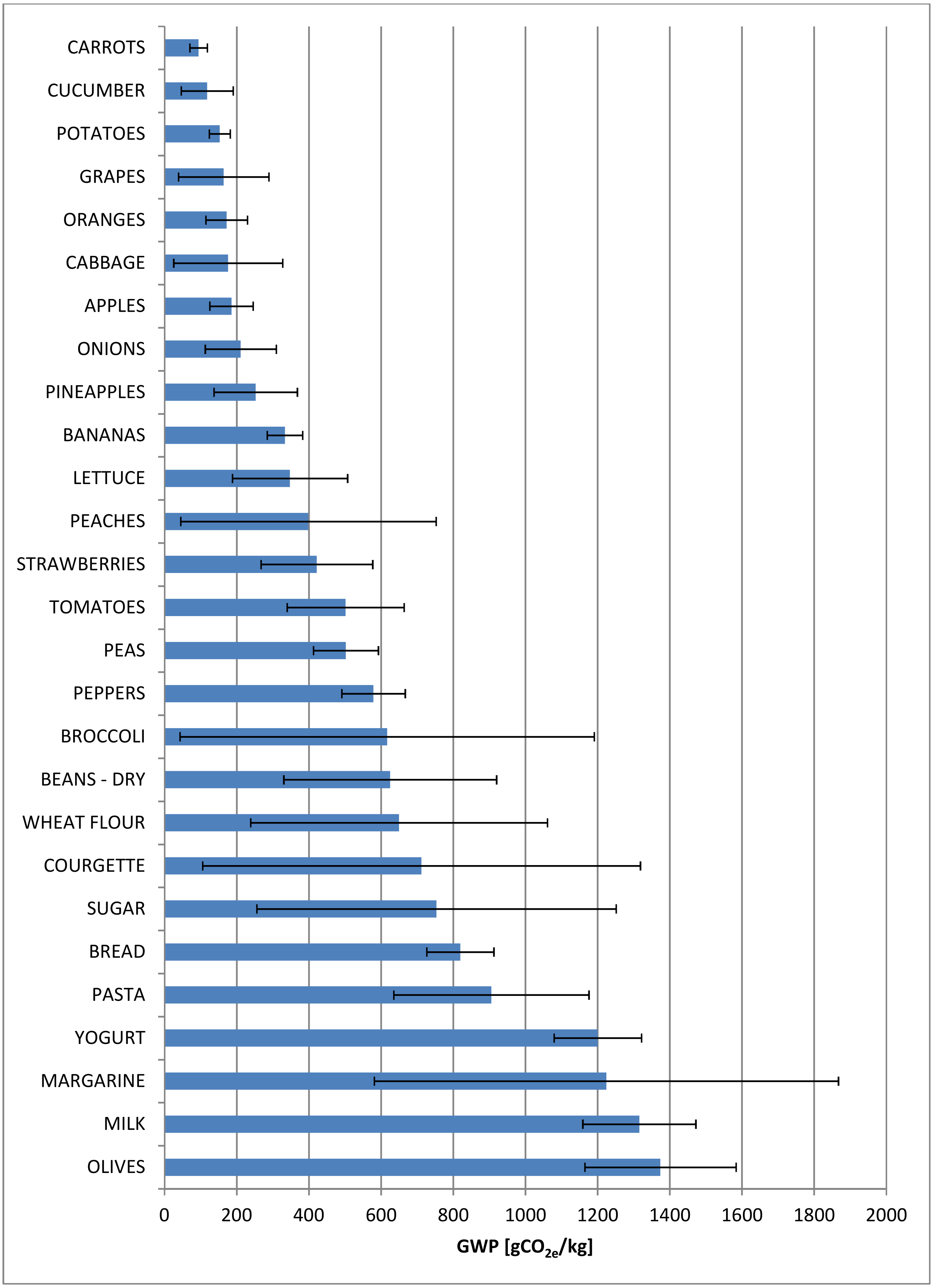


Figure 5-5: Average value of GWP and 95% confidence interval for food products with N>3 and average GWP<2000 gCO_{2e}/kg

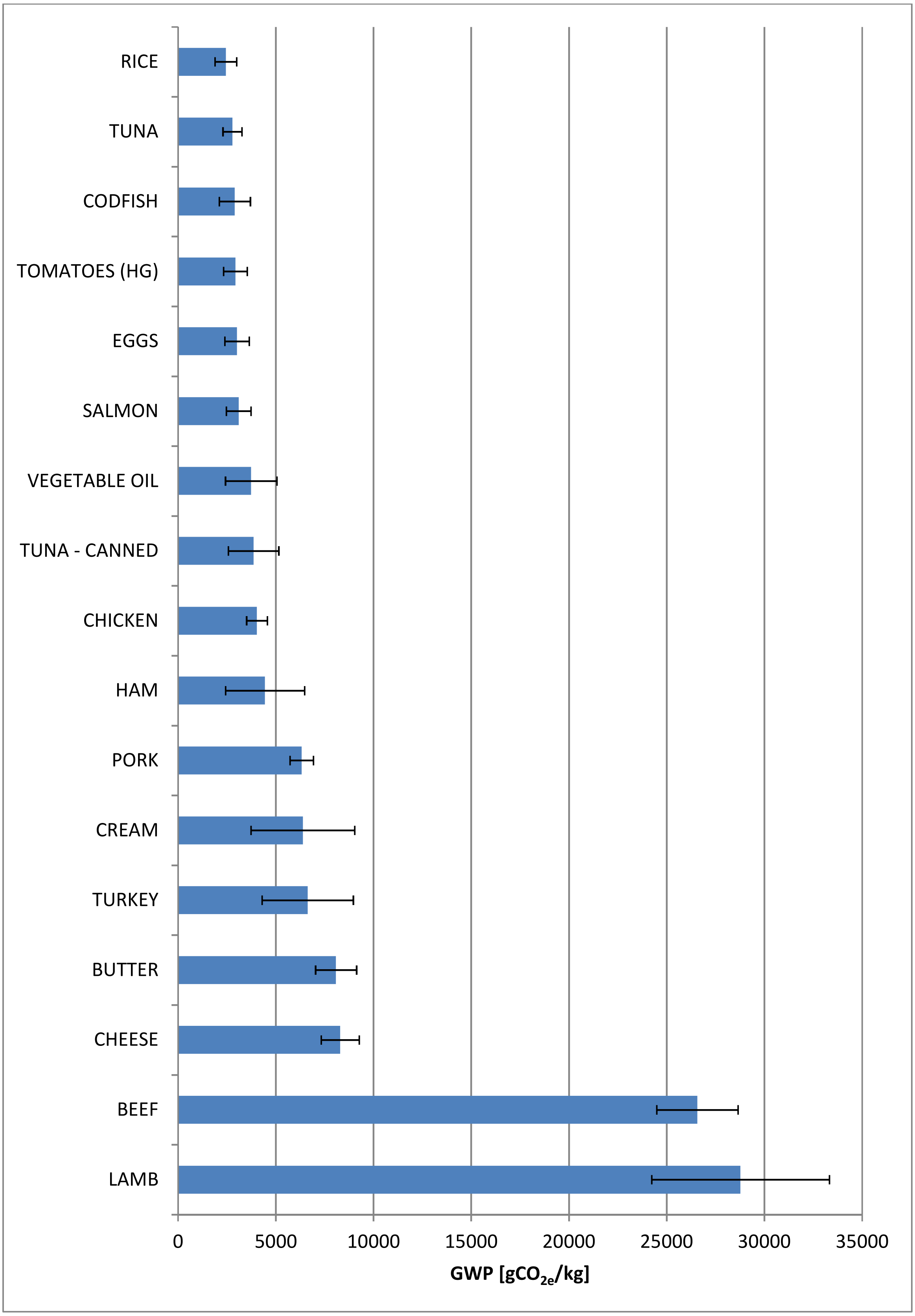


Figure 5-6: Average value of GWP and 95% confidence interval for food products with N>3 and average GWP>2000 gCO_{2e}/kg

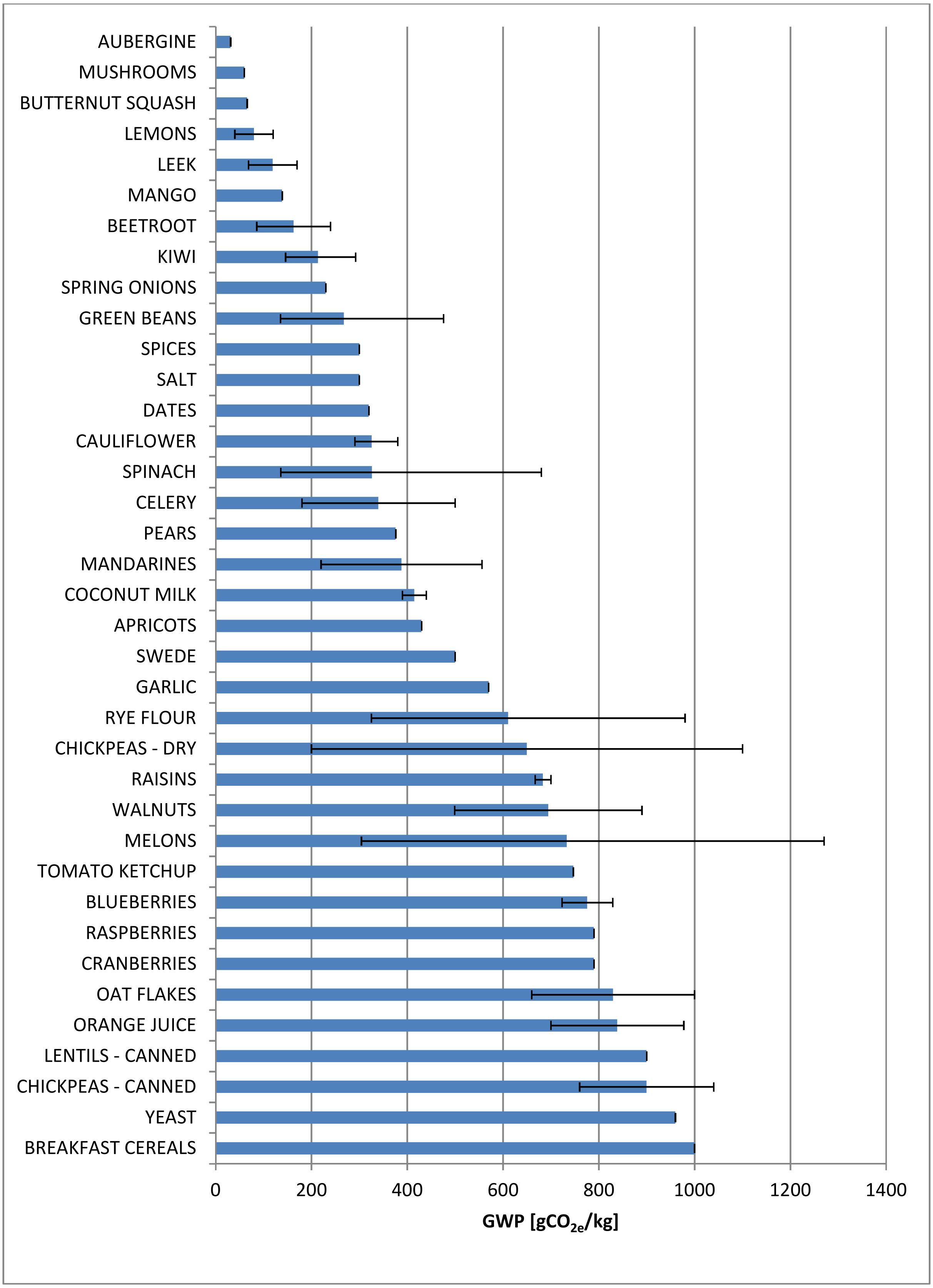


Figure 5-7: Average value of GWP and minimum and maximum values (error bars) for food products with N≤3 and average GWP<1000 gCO_{2e}/kg

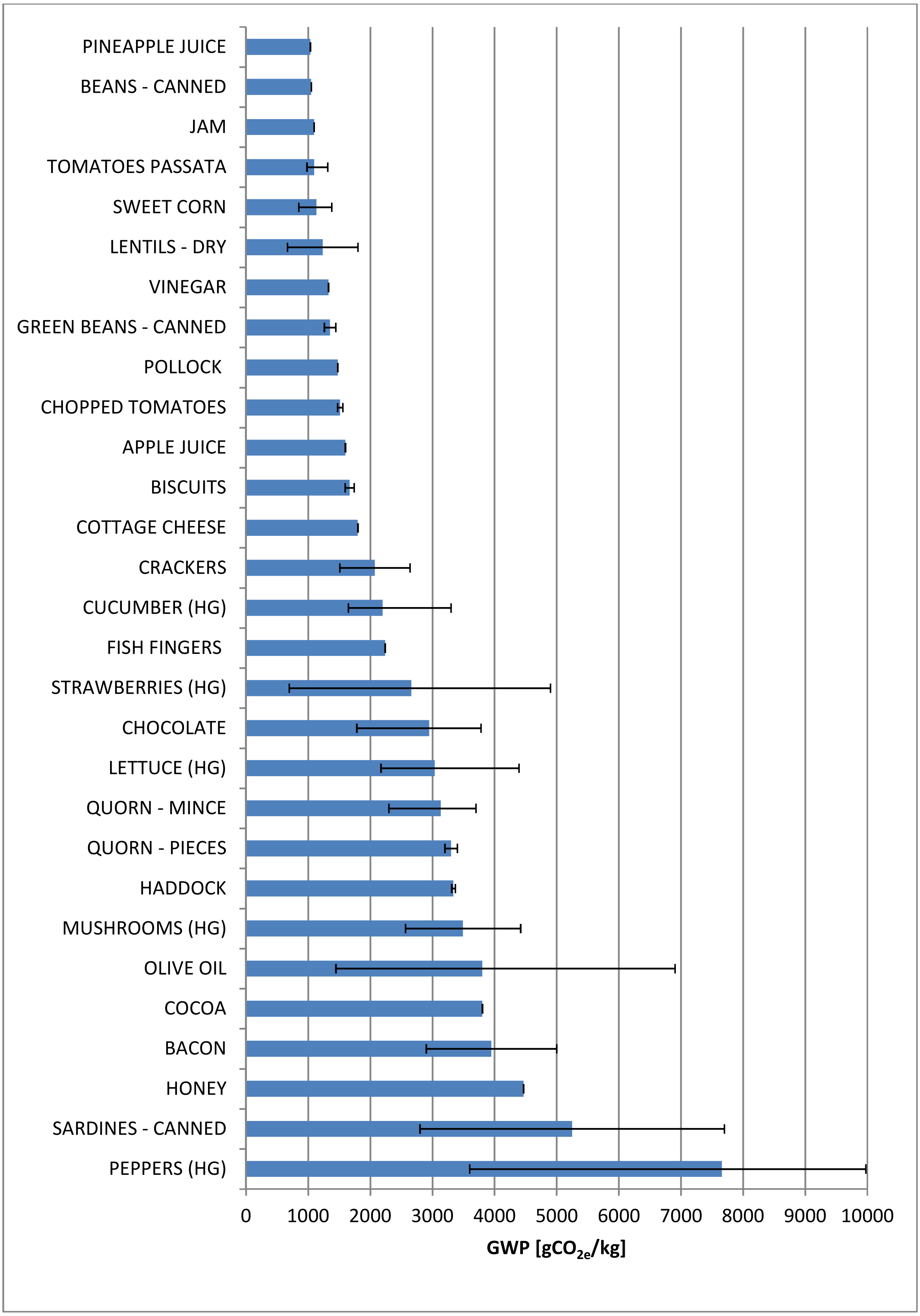


Figure 5-8: Average value of GWP and minimum and maximum values (error bars) for food products with N≤3 and average GWP>1000 gCO_{2e}/kg

In order to compare the results obtained with the existing literature a similar analysis was performed at food group level. Fifteen food groups were chosen in a similar fashion to those presented by Clune et al. (2016), in order to enable a comparison with the results presented in their publication. The values of the database attached to the article above were analysed using a *t*-distribution and 95% confidence intervals were calculated as also for the database presented in this work. Figure 5-9 presents a comparison between the average value of GWP for each food group in both the EATS database and the database presented by Clune et al. (2016).

It is important to stress that there are a number of methodological differences in the ways the two databases were created (both in the selection criteria and in the process of data handling), and furthermore the list of food products included in the two databases is not identical as they serve different purposes (the database created by Clune et al. (2016) aimed at presenting a global overview of existing data on the GWP of fresh food products), therefore the food groups do not have exactly the same composition. This explains the differences between the values obtained in the two studies; however it is possible to see that overall the results presented are relatively close.

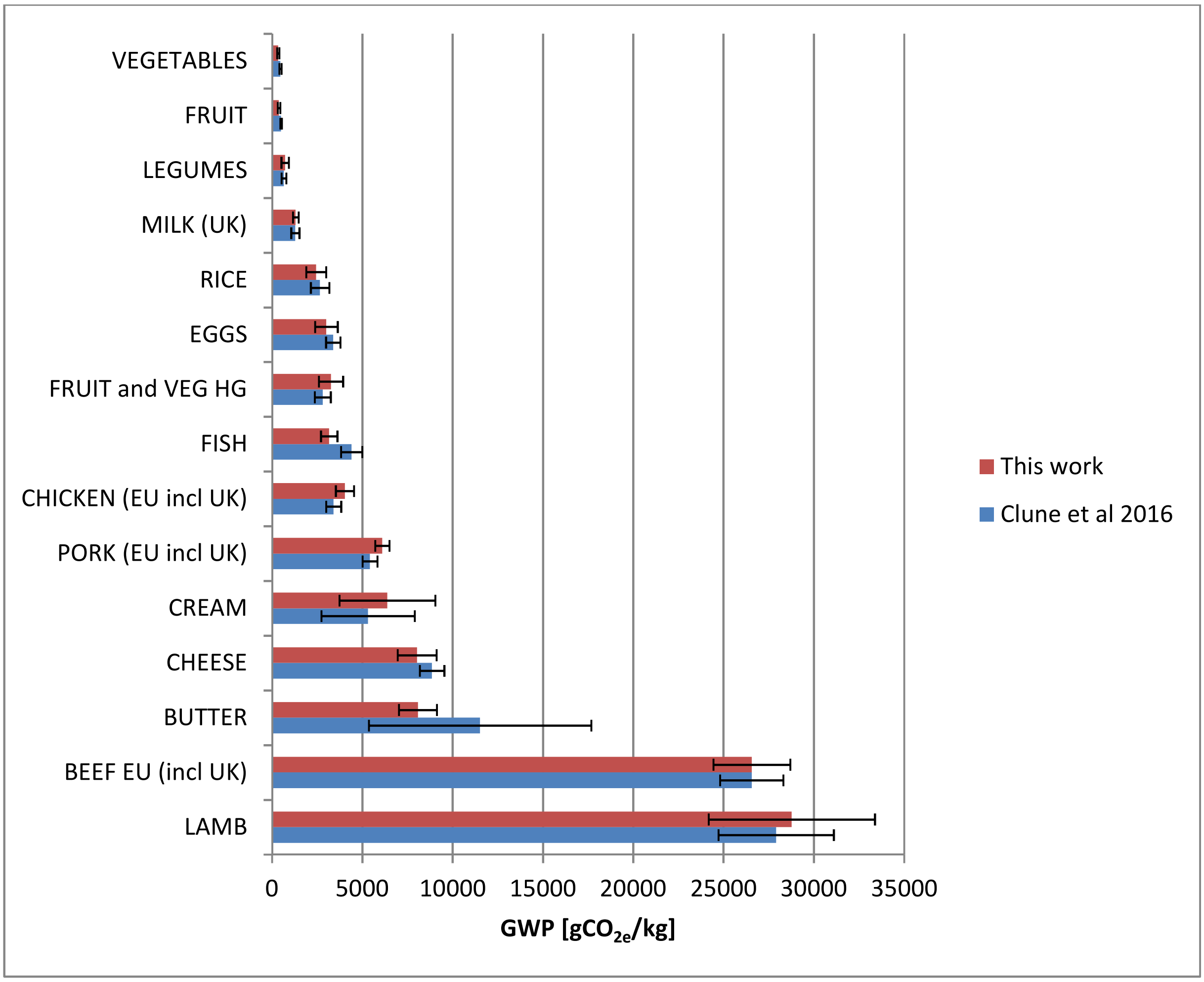


Figure 5-9: Average GWP and confidence intervals for food groups, comparison of results

This figure illustrates the hierarchy of food types identified in previous literature (e.g. González et al., 2011, Carlsson-Kanyama and Gonzalez, 2009), showing how meat from ruminant livestock (beef and lamb) is characterised by significantly higher values of GWP than other types of meat and how food products of vegetable origin have a lower impact than those of animal origin (ruminant describes animals that have a complex three or four-chambered stomach, to differentiate them from monogastric livestock, such as pigs and poultry, that have a single-chambered stomach). It is also interesting to note the difference between the GWP of fruit and vegetables grown in heated greenhouses compared to that of those grown either in open fields or non-heated greenhouses. For instance, for tomatoes grown in heated greenhouses, the average value of GWP is 2935 gCO_{2e}/kg, while for those grown in open fields this value is 502 gCO_{2e}/kg, therefore 83% smaller. For this reason, even though the tool does not generally give the user the possibility of choosing a production method, it was decided in this case to differentiate horticultural products based on whether or not they had been produced in a heated greenhouse. If this had not been done, the average value utilised (calculated across all the values recorded for a specific horticultural product, e.g. tomatoes), would not have been truly representative of the real value.

As explained in Section 4.2.2.6, the country of origin is not taken into account when performing the statistical analysis (this means that for each food product the average value of GWP is calculated across different countries). However, geographical variations exist in the values of GWP of food products, due to variations in meteorological conditions and production practices between countries. As an example, a study by Pelletier et al. (2009) compares the production of salmon in four different countries (Canada, Norway, UK and Chile), identifying as the main cause for the variation in the final value of GWP the different composition of the feedstock provided to the salmon.

Due to constraints in data availability, it was not possible to perform a statistical analysis to assess the geographical variation of the GWP of production for each food product. This is a limitation of this current study, but as previously mentioned it is attenuated by the fact that the origin only plays a small role in defining the contribution of a product to climate change (Teixeira, 2015).

5.3 Water Footprint database

The Water Footprint database was created as explained in Section 4.2.3, by collecting for most food products the values of WF published by Mekonnen and Hoekstra (2010a), Mekonnen and Hoekstra (2010b). For those food products not included in this publication a search was performed in the literature to identify other studies that presented the associated values of WF. Some of those studies used a different methodology to calculate the WF and instead of including blue, green and grey WF, they neglected either green or grey or both components. Table 5-3 presents the food products for which different sources were used, together with the components of the WF included in each case. When no information was found in the literature, proxies were used to calculate the WF. This was for instance the case of leeks; as no published work reports its WF, this was assumed to be equal to that of onions. This represents a limitation to the accuracy of the results presented by the tool. Table 5-4 presents a list of the food products for which a proxy was used, together with the proxy itself.

Traditional WF studies do not account for fish species (Vanham et al., 2013). This is due to the fact that no water is directly used in the production of wild fish. However a recent study (Pahlow et al., 2015) calculated the WF of a number of farmed fish species (as in this case there is a WF embedded in the production of feedstock provided to fish). Therefore in the WF database only the farmed fish species (Atlantic cod and salmon) are included.

Table 5-3: Other sources consulted for the extraction of values of WF [L/kg] and *colours* included

Food product	Source	Blue WF	Green WF	Grey WF	Total WF
BISCUITS	(BFCN, 2015)	1950			1950
BREAKFAST CEREALS	(Jeswani et al., 2015)	672	1100		1772
CRACKERS	(BFCN, 2015)	1171			1171
MARGARINE	(Jefferies et al., 2012)	218	1106		1324
CODFISH	(Pahlow et al., 2015)	100	450	50	600
SALMON	(Pahlow et al., 2015)	150	1550	250	1950

Table 5-4: List of proxies used in the WF database

Food product	Proxy
QUORN™ - MINCE	Eggs
QUORN™ - PIECES	Eggs
COURGETTE	Butternut squash
LEEK	Onions
COTTAGE CHEESE	Cheese

In all the remaining cases, it was possible to extract from Mekonnen and Hoekstra (2010a), Mekonnen and Hoekstra (2010b) the values of WF associated with the production of 1 kg of a food product. The following values were extracted: one for each of the EU28 countries and one value representing the global average WF.

In order to investigate the geographical variation of the WF of different food products, three values were compared for each food product in the database: the UK WF, the average European WF and the average global WF. Table 5-5 and Figure 5-10 present the results of this analysis. The blank cells in the second column of Table 5-5 correspond to food products that are not produced in the UK. The same applies to the third column for products that are not produced in any country in Europe. In Figure 5-10 only a selection of 20 food products is represented (based on the food products of the WF database that see the highest production in the UK, according to the FAOSTAT database (FAO, 2013a)).

Table 5-5: UK, European and Global average of the total WF of each food product in the WF database extracted from the Water Footprint Network databases (for the breakdown of blue, green and grey components see Appendix D, Part 3)

Food product	UK WF [L/kg]	European WF [L/kg]	Global WF [L/kg]
APPLE JUICE	400	842	1141
APPLES	288	606	822
APRICOTS		1197	1287
AUBERGINE		215	362
BACON	5119	6499	6457
BANANAS		371	790
BEANS - DRY		1849	5053
BEEF	7388	13532	15415
BEETROOT		120	385
BLUEBERRIES		694	845
BREAD	497	1114	1608
BROCCOLI	289	276	285
BUTTER	2801	5137	5553
BUTTERNUT SQUASH		168	336
CABBAGE	160	180	280
CARROTS	38	129	195
CAULIFLOWER	289	276	285
CELERY	38	129	195
CHEESE	2560	4682	5060
CHICKEN	3034	5267	6241
CHICKPEAS - CANNED		997	1649
CHICKPEAS - DRY		2525	4177
CHOCOLATE			17196
CHOPPED TOMATOES	15	156	267
COCOA			15636

CRANBERRIES		424	276
CREAM	957	1756	1898
CUCUMBER	8	138	353
DATES		904	2277
EGGS	1488	2629	3265
GARLIC		685	589
GRAPES	1911	818	608
GREEN BEANS	232	571	561
HAM	5119	6499	6457
KIWI		1134	514
LAMB	6275	11233	10412
LEMONS		876	642
LENTILS - CANNED		1337	1599
LENTILS - DRY		4912	5874
LETTUCE	124	237	237
MANDARINES		522	748
MANGO		5282	1828
MELONS		347	221
MILK	515	944	1020
OAT FLAKES	568	1763	2416
OLIVE OIL		92388	14431
OLIVES		19300	3015
ONIONS	399	253	272
ORANGE JUICE		3601	1018
ORANGES		1980	560
PASTA	571	1281	1849
PEACHES		884	910
PEARS	373	625	922
PEAS	275	630	595

Table continues on the following page

PEPPERS	17	205	379
PINEAPPLE JUICE		1468	1273
PINEAPPLES		294	255
PORK	4747	5964	5988
POTATOES	102	230	287
RAISINS	7644	3274	2433
RASPBERRIES	340	544	413
RICE		2199	2497
RYE FLOUR	915	1414	1930
SALT		3105	3367
SPICES		3105	3367
SPINACH		189	292
SPRING ONIONS	399	253	272
STRAWBERRIES	251	613	347
SUGAR		1318	1782
SWEDE	38	129	195
SWEET CORN		479	700
TOMATO KETCHUP	30	312	534
TOMATOES	12	125	214
TOMATOES PASSATA	41	416	713
TURKEY	2920	5069	6007
VEGETABLE OIL	2486	4405	4301
WALNUTS		8234	9280
WHEAT FLOUR	571	1281	1849
YOGURT	598	1097	1186

As illustrated by Figure 5-10, the WF associated with the production of the food products selected in the UK is generally lower than the corresponding value calculated for Europe, which again is usually lower than the global average value (with the exception of lamb meat and strawberries). Variations in the values of WF are caused by differences in climate and agricultural practices between countries and for livestock products also by differences in feed conversion efficiencies (Mekonnen and Hoekstra, 2012).

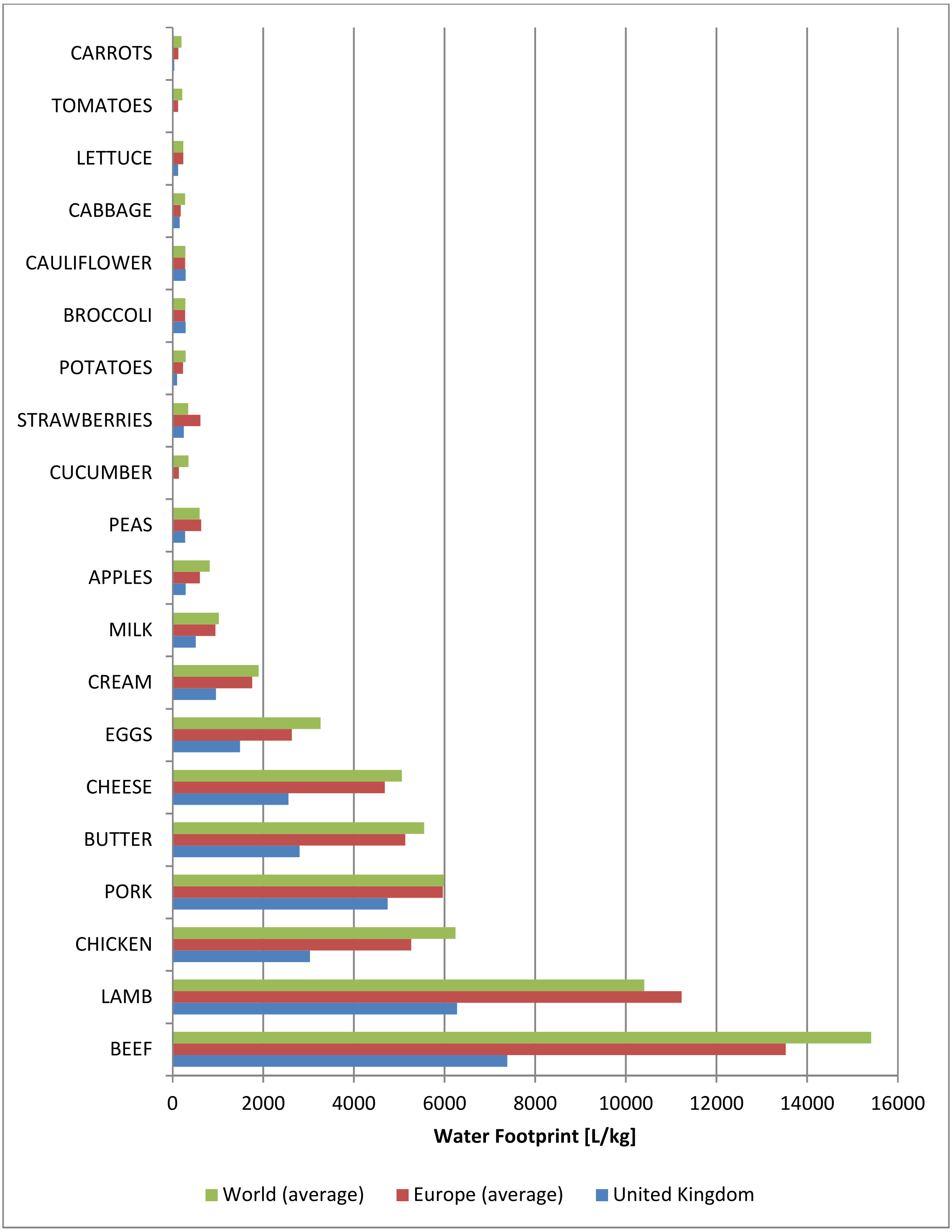


Figure 5-10: UK, European and Global average WF for a selection of food products

As in the case of GWP, it is possible to identify a clear water intensity hierarchy emerging across food products, illustrated in Figure 5-11, in which cocoa and meat products are the most water intensive and fruit and vegetables the least (with the exception of nuts). In Figure 5-11 the values of the blue, green and grey components of the WF are presented separately. This shows the prevalence of the green component and that, if only the blue component was taken into account, the hierarchy identified would differ significantly (with nuts presenting the highest value and cocoa the lowest and less differences between animal and vegetable products).

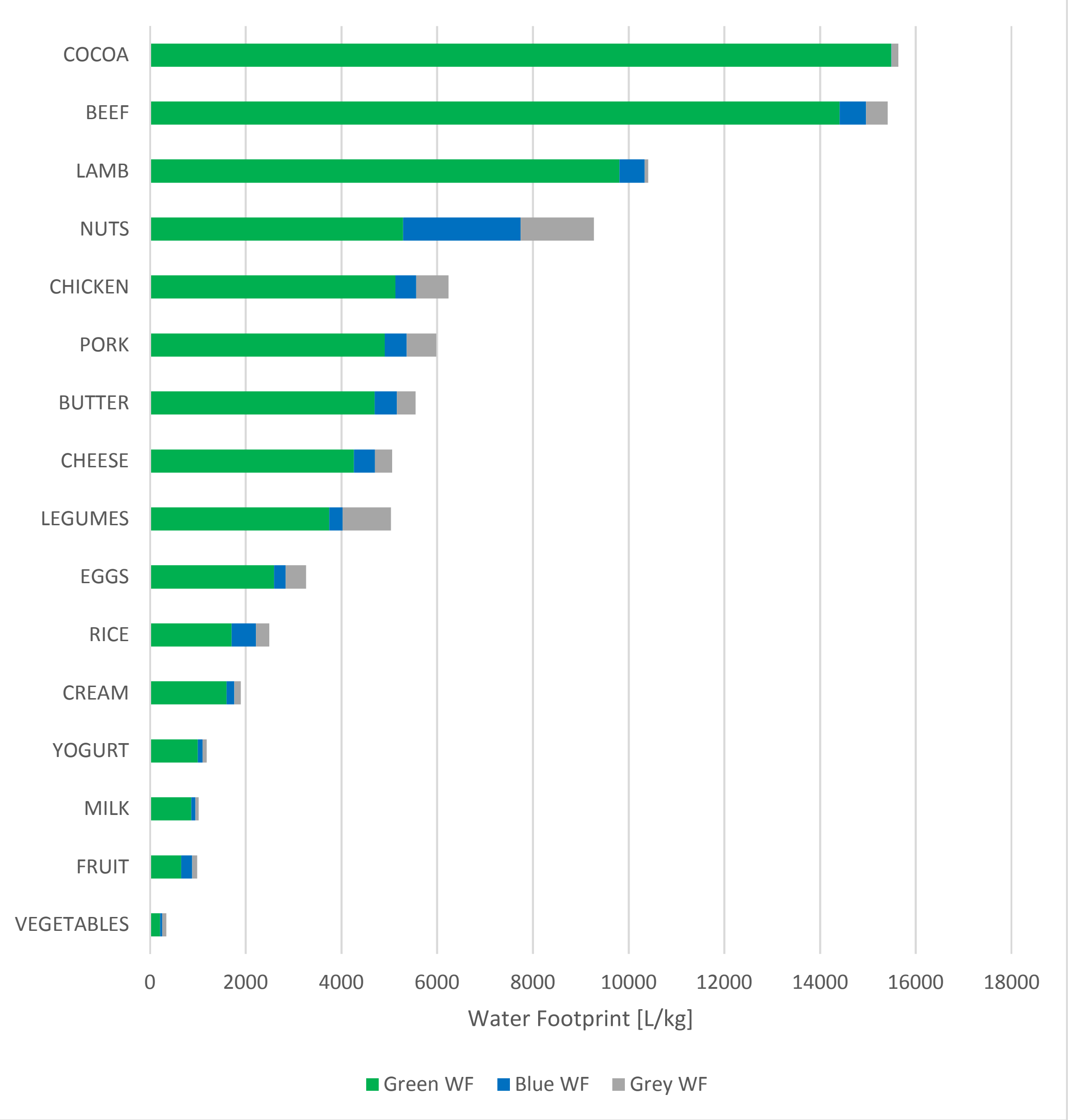


Figure 5-11: Global average blue, green and grey WF of food products (for legumes, fruit and vegetables the average value is provided)

In order to directly compare the variations of carbon and water footprints across food products, Figure 5-12 represents them together. For clarity of representation in this graph all the values are normalised against the maximum value (respectively the CF of lamb, 28728 gCO_{2e}/kg and the WF of cocoa, 15636 L/kg), and are therefore directly comparable. A number of similarities can be identified between the two sets of impacts, for instance beef and lamb feature amongst the highest carbon and water intensity. However, there are a number of differences, which result in trade-offs between low carbon and low water food choices. For instance, nuts present a high value of WF and legumes have a WF comparable to eggs, whilst they are both characterised by a low CF. This result has to be kept in mind as both food items are often presented as a sustainable alternative protein source to meat. Cocoa (and therefore derived products) presents the highest value of WF and a relatively low value of CF. Nevertheless, Figure 5-12 clearly supports the thesis that a shift to a less meat and dairy intensive diet carries significant benefits both in terms of carbon and water footprint reduction.

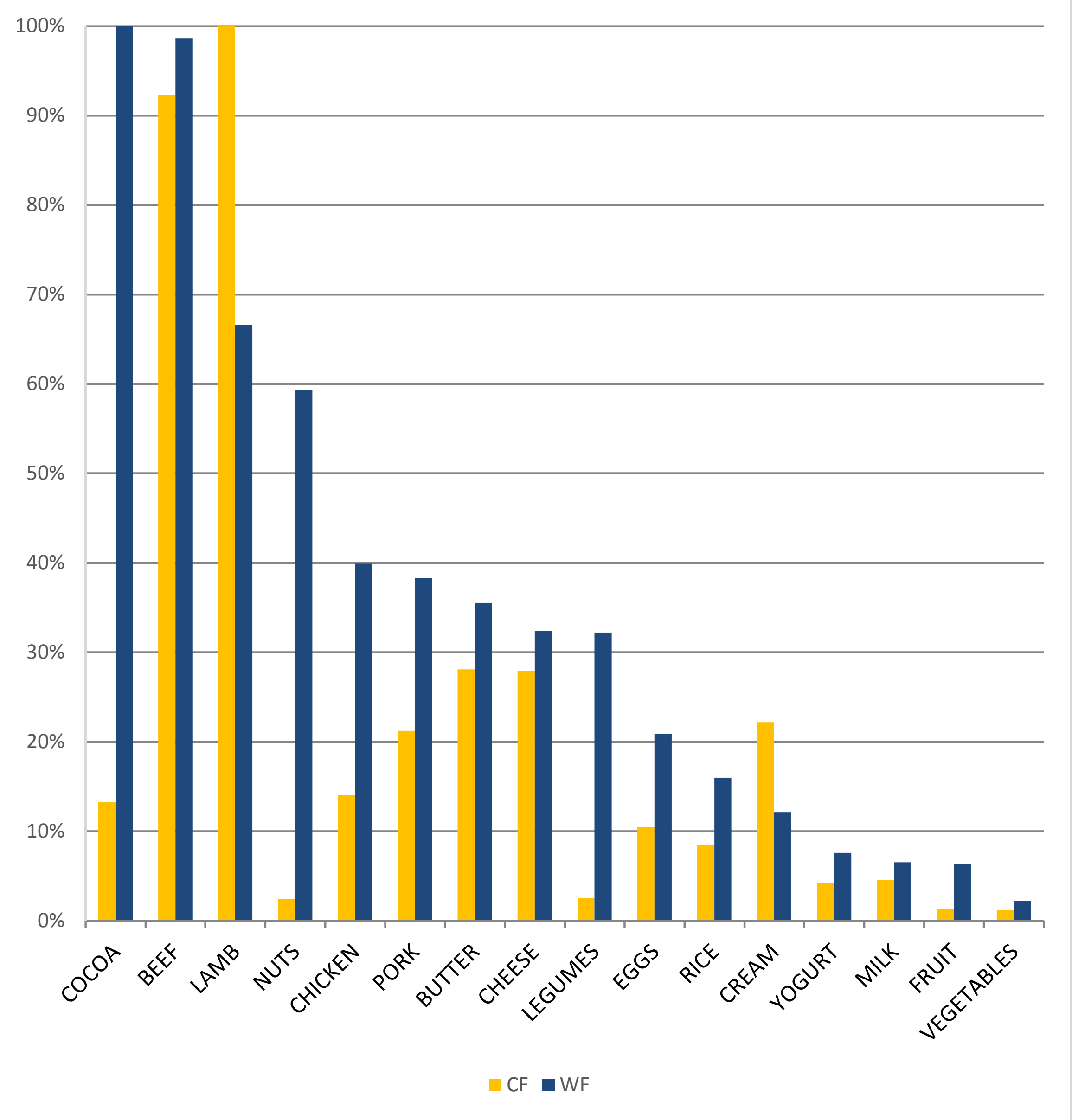


Figure 5-12: Comparison between normalised CF and WF of food products (for legumes, fruit and vegetables the average values are provided)

5.4 Case Study 1 (CS1): assessment of an existing menu

The purpose of the first case study (CS1) was to apply EATS to an existing menu, in order to assess the carbon and water footprint of the meals served by a catering company operating in Birmingham. This company, whilst wishing to remain anonymous, provided the researcher with the menus due to be served up to the winter term of 2017. The company also supplied the recipes of each meal within the menus and supplementary information such as procurement choices.

A number of the ingredients required to prepare the meals within these recipes were not recorded in the tool; in this case whenever possible the ingredients were added (retrospectively) to the tool. This was the case for walnuts and canned tomatoes. Other ingredients could not be found (e.g. garlic puree and gravy), and were therefore replaced by proxies or omitted from the recipes when no suitable proxy was found. Table 5-6 presents an overview of all the proxies used and of the ingredients that were omitted from the recipes. The full set of recipes used to develop the analysis is presented in Appendix D, Part 4.

Table 5-6: List of proxies used and omitted ingredients in CS1(numerical values in brackets show the weight conversion applied)

Ingredient	Proxy
1/2 fat crème fraiche	Cream
Apple (tinned)	Apples
Coleslaw	Carrots (x 0.5) + Cabbage (x 0.5)
Garlic puree	Garlic (x 2)
Golden syrup	Sugar
Gravy	*No proxy found - omitted*
Mixed dried herbs	*No proxy found - omitted*
Pesto	Olive oil (x 0.4) + Cheese (x 0.15) + Walnuts (x 0.15) + Basil (x 0.3)
Tumeric	Spices
Tortilla wrap	Bread
Vegetable stock	*No proxy found - omitted*

The results of the analysis performed in the first case study are presented in Tables 5-7 to 5-10. The menus are for four weeks (five days per week). For each day a meal is reported, this includes a Main and side dish (code M) and a Dessert (code D). The CF and the WF (green, blue, grey and total) are shown. Additionally, for each meal two coloured circles are presented, according to the colour code assigned to the CF and WF of the meals, as explained in Section 4.3.1. Figure 5-13 shows graphically the CF for all meals over all four weeks. Figure 5-14 and 5-15 show the WF for main and side dishes and desserts respectively over the same time period. A discussion follows the figures.

In addition, the results presented for CS1 are used in Section 5.9 to create an improved version of this menu set with lower CF and WF values.

Table 5-7: CF and WF of the meals served in Week 1(all values refer to one portion, the WF components may not add up to the total WF due to rounding)

Day	Dish name	Dish code	CF [gCO$_{2e}$]	WF [L]				CF	WF
				green	blue	grey	total		
Monday	Organic beef burgers with creamy mash	M_1M	1812	437	16	61	515	🔴	🟡
	Yogurt	D_1M	222	88	5	14	107		
Tuesday	Tomato and herb pork Bolognese	M_1Tu	735	387	33	73	492	🟡	🟡
	Blueberry and apple crumble	D_1Tu	249	62	12	9	83		
Wednesday	Ham roast dinner	M_1W	550	288	23	54	365	🟢	🟡
	Pineapple upside down cake	D_1W	85	43	8	5	56		
Thursday	Chicken pesto pasta	M_1Th	341	380	64	42	486	🟢	🟡
	Fruity sponge cake	D_1Th	99	46	9	5	60		
Friday	Salmon gougons and savoury rice	M_1F	570	281	50	46	377	🟢	🟡
	Mixed fruit flapjacks	D_1F	45	20	4	3	27		

Table 5-8: CF and WF of the meals served in Week 2 (all values refer to one portion, the WF components may not add up to the total WF due to rounding)

Day	Dish name	Dish code	CF [gCO$_{2e}$]	WF [L]				CF	WF
				green	**blue**	**grey**	**total**		
Monday	Turkey burger with burrito rice	M_2M	771	332	32	69	432	🟡	🟡
	Yogurt	D_2M	222	88	5	14	107		
Tuesday	Chicken roast	M_2Tu	355	195	5	39	240	🟢	🟢
	Fruity shortbread	D_2Tu	67	51	13	7	71		
Wednesday	Spinach and cheese cannelloni	M_2W	587	148	18	29	195	🟢	🟢
	Ginger oat cakes	D_2W	50	33	8	4	45		
Thursday	Savoury lamb	M_2Th	2171	443	36	7	486	🔴	🟡
	Blueberry cake	D_2Th	96	47	10	7	64		
Friday	Fish fingers with sliced potato bake	M_2F	292	55	9	10	74	🟢	🟢
	Melon/pineapple	D_2F	221	43	5	12	60		

Table 5-9: CF and WF of the meals served in Week 3 (all values refer to one portion, the WF components may not add up to the total WF due to rounding)

Day	Dish name	Dish code	CF [gCO_{2e}]	WF [L]				CF	WF
				green	blue	grey	total		
Monday	Tomato and herb meatballs	M_3M	2576	628	25	89	741	🔴	🔴
	Yogurt	D_3M	222	88	5	14	107		
Tuesday	Turkey breast with sliced potato bake	M_3Tu	571	201	5	41	247	🟢	🟢
	Carrot cake	D_3Tu	85	44	7	7	57		
Wednesday	Quorn™ and mixed bean chilli	M_3W	598	203	37	39	279	🟢	🟢
	Shortbread	D_3W	67	51	13	7	71		
Thursday	Sausage and mash	M_3Th	610	343	28	63	434	🟡	🟡
	Melon/pineapple	D_3Th	221	43	5	12	60		
Friday	Fish fillet with rice and vegetables	M_3F	403	126	35	19	181	🟢	🟢
	Lemon cake	D_3F	88	47	10	7	63		

Table 5-10: CF and WF of the meals served in Week 4 (all values refer to one portion, the WF components may not add up to the total WF due to rounding)

Day	Dish name	Dish code	CF [gCO_{2e}]	WF [L]				CF	WF
				green	blue	grey	total		
Monday	Beef and veggie bites and spaghetti	M_4M	2116	519	21	74	614	🔴	🟡
	Yogurt	D_4M	222	88	5	14	107		
Tuesday	Chicken fajita with bean and rice	M_4Tu	603	336	33	68	437	🟡	🟡
	Blueberry and apple crumble	D_4Tu	249	62	12	9	83		
Wednesday	Roast beef dinner with sliced potato bake	M_4W	1962	465	17	66	548	🔴	🟡
	Blueberry cake	D_4W	96	47	10	7	64		
Thursday	Lamb kofta with pitta and salad	M_4Th	2107	459	38	12	509	🔴	🟡
	Melon/pineapple	D_4Th	221	43	5	12	60		
Friday	White fish fillet with creamy mash and baked beans	M_4F	447	149	16	30	196	🟢	🟢
	Fruity granola pots	D_4F	125	52	15	11	79		

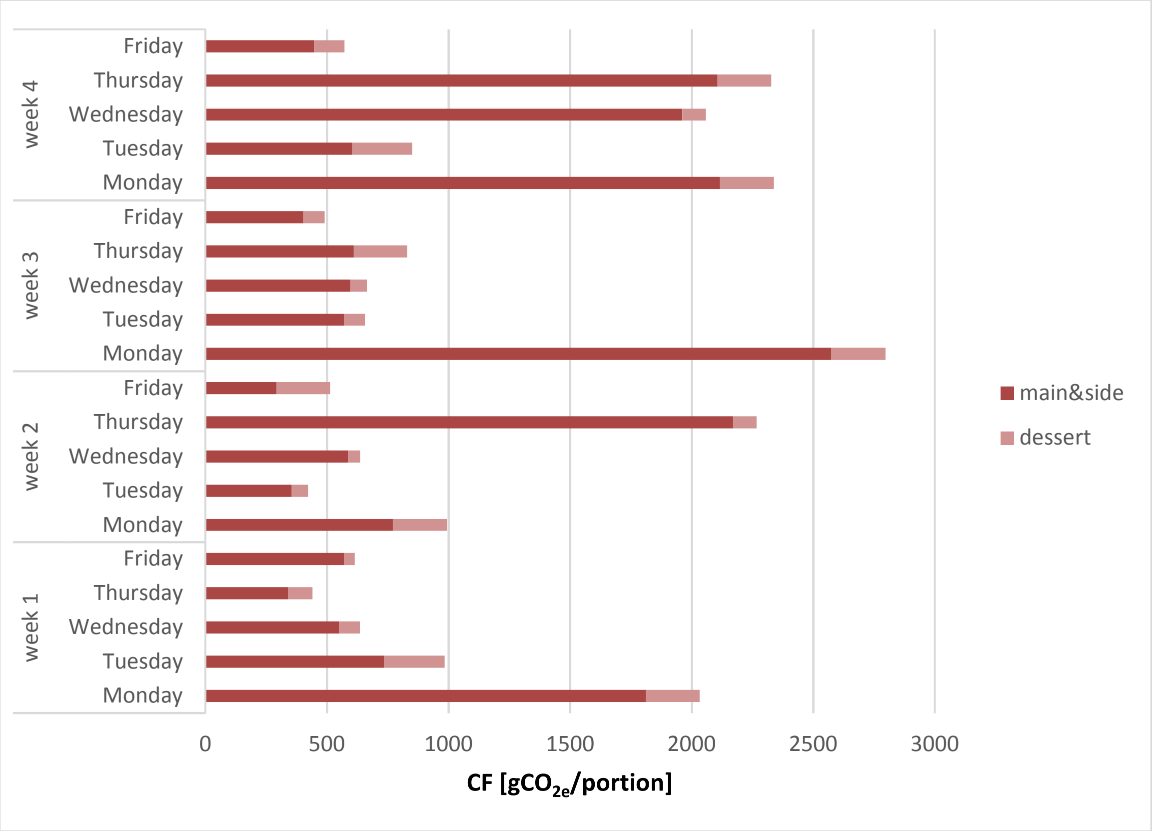


Figure 5-13: CF of the meals served each day

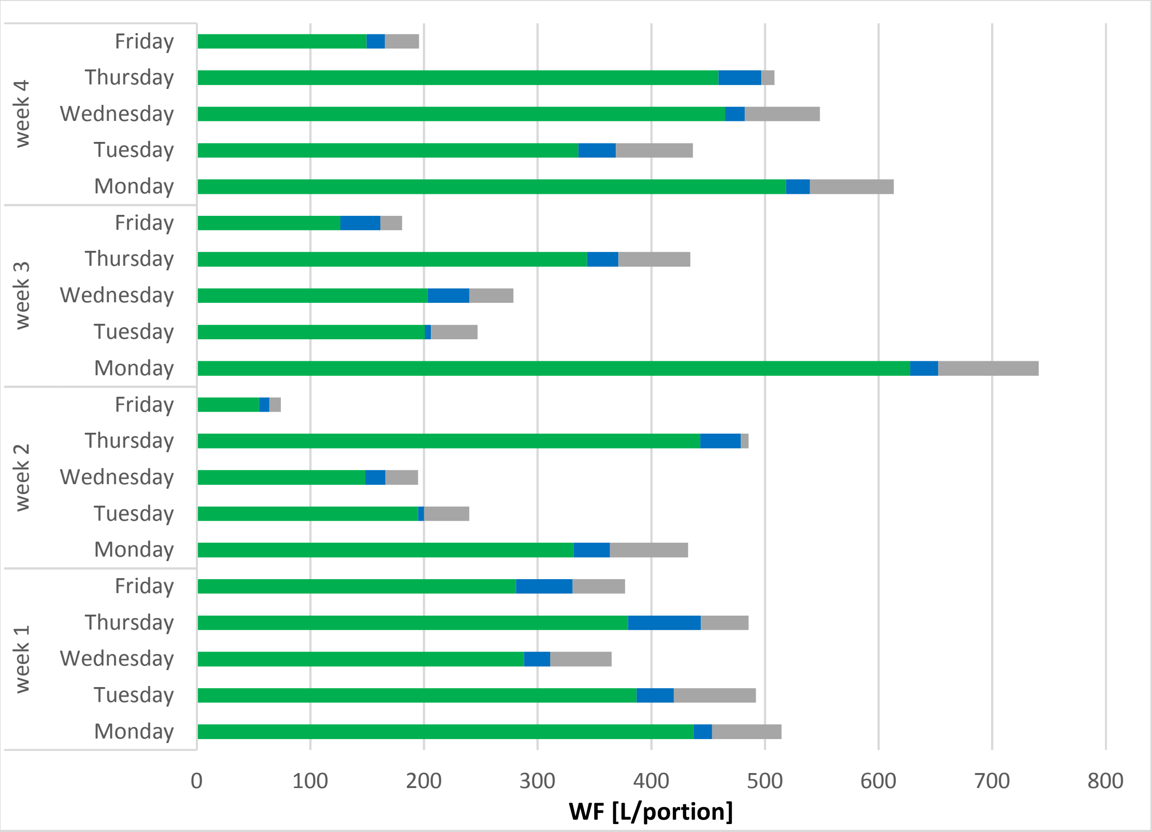


Figure 5-14: Green, blue and grey WF of the main and side dishes served each day

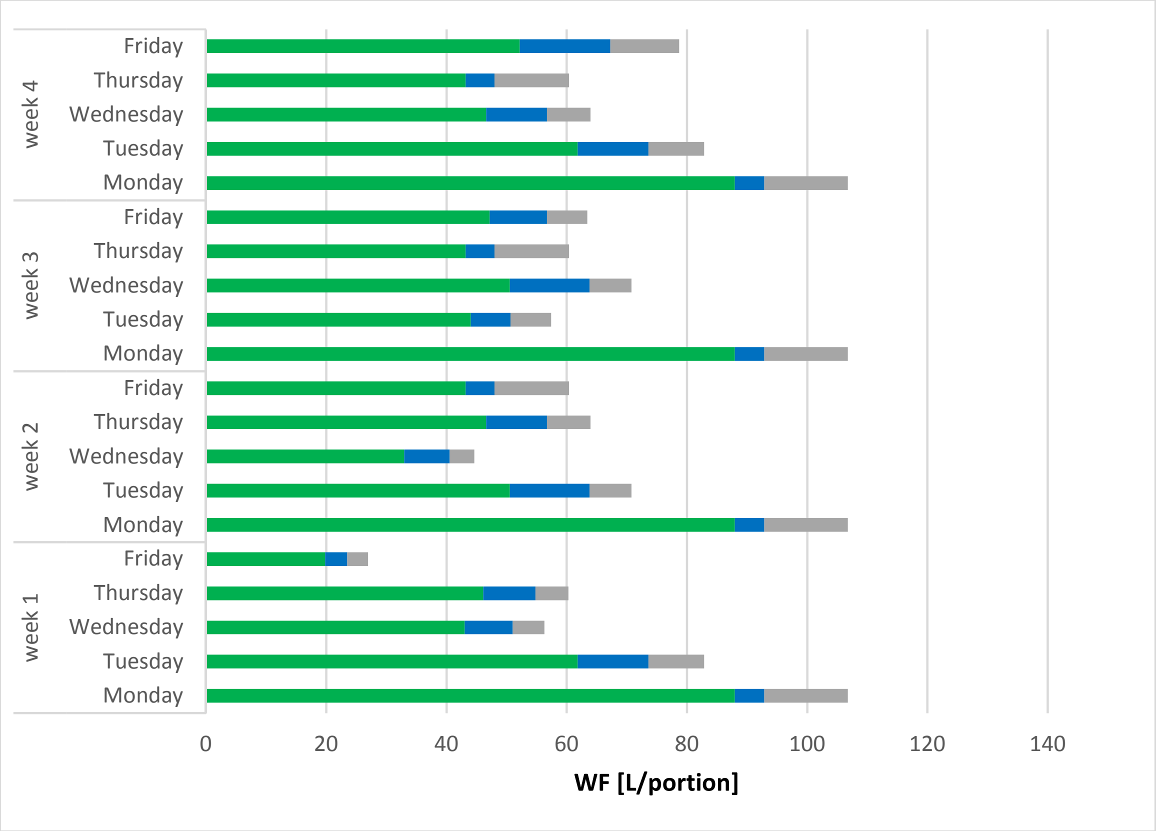


Figure 5-15: Green, blue and grey WF of the desserts served each day

When comparing the results obtained, it is possible to see how beef and lamb based recipes are characterised by high values of CF compared to the other recipes, and fish and chicken based recipes have the lowest values of CF. The two vegetarian recipes in the menu have average values of CF, and dairy ingredients, rice and Quorn^{TM} are the main *hotspots* (i.e. the ingredients responsible for most of the CF). In terms of WF, these variations are less marked, with beef, lamb and pork-based recipes presenting higher values, and vegetarian and fish based recipes presenting lower values. Yogurt is the dessert with the highest WF and the second highest CF, following “blueberry and apple crumble” (due to its high cream content). These findings are in line with the ones presented in Figure 5-9 and Figure 5-11 showing the hierarchy of food products in terms of carbon and water intensity.

When looking at the three components of WF separately, similarly to what was identified in the analysis of the WF database (Figure 5-11), some dishes with a relatively high total WF present low values of blue WF and *vice versa*. For instance, the dish with the highest blue WF is M1_Th (chicken pesto pasta), due to the use of walnuts in the recipe (that present the highest blue WF in the database); however six dishes present higher values of total WF. Those are: M1_M, M3_M, M4_M and M4_W (beef-based), M1_Tu (pork-based) and M4_Th (lamb-based). In contrast, the dish with the highest total WF (741 L) (and also with the highest green/grey WF) was M3_M (tomato and herb meatballs), due to the use of beef, whereas this dish presents only an average value of blue WF (25 L).

5.5 Case Study 2 (CS2): assessment of *best practice* recipes

The purpose of the second case study (CS2) was to use EATS to assess the environmental impact of a set of *best practice* recipes (from a nutritional perspective), and assess how they performed in terms of environmental sustainability. This represents a further application of EATS, which can provide the evidence base to design *best practice* recipes taking into account also the environmental lens.

As in CS1, a number of missing ingredients were identified and either added to the tool, replaced by a proxy, or omitted if no suitable proxy was found. The following ingredients were added to the tool: apricots, coconut milk, honey and dates. Table 5-11 presents a list of the ingredients which were either replaced by a proxy or omitted from the recipes. The full set of recipes used to develop the analysis is presented in Appendix D, Part 5.

Table 5-11: List of proxies used / omitted ingredients in CS2 (numerical values in brackets show the weight conversion applied)

Ingredient	Proxy
Breadcrumbs	Bread
Brown rice	Rice
Couscous	Pasta
Egg noodles	Pasta
Garlic puree	Garlic (x 2)
Parsnips	Carrots
Lemon juice	Lemons (x 3.5)
Tomato pureé	Tomato passata (x 3)
Tortilla wraps	Bread
Wine vinegar	Vinegar
Baking powder	*No proxy found - omitted*
Beansprouts	*No proxy found - omitted*
Beef stock cube	*No proxy found - omitted*
Chicken stock cube	*No proxy found - omitted*
Cornflour	*No proxy found - omitted*
Custard power	*No proxy found - omitted*
Golden syrup	Sugar
Herbs	*No proxy found - omitted*
Plum sauce	*No proxy found - omitted*
Rhubarb	*No proxy found - omitted*

The results of this case study are presented in Table 5-12 and Figure 5-16 to 5-27. Table 5-12 shows the CF and the WF (green, blue, grey and total value) for each dish analysed. The dishes presented are Meat-based mains (code M), Vegetarian mains (code V), Fish-based mains (code F), Side dishes (code S) and Desserts (code D). In this case the *traffic light system* used to show the impacts in case study 1 was not adopted; this is due to the fact that the intervals against which the impacts are classified into green, amber and red are defined for a full meal (main, side and dessert). In this case study, the analysis is conducted for dishes separately and therefore such classification does not apply. Figure 5-16 shows graphically the CF for all the main dishes, a detailed breakdown of the meat-based, vegetarian and fish-based main dishes is provided in Figures 5-17, 5-18 and 5-19 respectively. Figure 5-20 and 5-21 provide the CF of the side dishes and desserts respectively. Figure 5-22 provides the aggregated value of WF for all the main dishes, whereas Figures 5-23 to 5-27 present the three components of WF separately for the meat-based, vegetarian and fish-based main dishes, side dishes and desserts respectively. A discussion follows the figures.

Table 5-12: CF and WF of the recipes analysed in CS2 (all values refer to one portion, the WF components may not add up to the total WF due to rounding)

Dish code	Dish name	CF [gCO_{2e}]	WF [L]			
			green	**blue**	**grey**	**total**
M1	Beef Bourguignon	2215	540	26	68	634
M2	Beef chow mein	1618	438	13	62	513
M3	Beef meatballs	1867	439	17	62	518
M4	Chicken curry	696	370	43	73	486
M5	Chicken couscous	371	236	6	45	286
M6	Chicken balti pie	440	258	12	56	325
M7	Chicken chasseur	455	232	5	46	283
M8	Chicken fajitas	490	198	6	44	248
M9	Chicken with rice	452	261	26	49	337
M10	Roast chicken	628	368	7	72	447
M11	Lamb shepherd's pie	2064	468	40	23	531
M12	Pork meatballs	716	284	27	52	362
M13	Macaroni and cheese with pork	803	430	30	74	534
F1	Pollok fillet	145	12	1	3	16
F2	Salmon and broccoli pasta	376	207	14	33	255
F3	Salmon fishcake	377	162	15	30	207
F4	Salmon and vegetable noodles	385	213	13	37	264
F5	Salmon fish pie	441	196	19	35	250
F6	Salmon pasta	400	214	15	36	265
F7	Salmon pie	432	193	23	31	247
F8	Spaghetti marinara	520	206	22	34	262
F9	Tandoori salmon	309	149	14	24	186
V1	Beetroot patties	266	130	8	10	147
V2	Cheese quiche	421	131	9	22	162

V3	Vegetarian pie	470	206	14	49	269
V4	Vegetable lasagne	554	303	21	76	399
V5	Chilli with rice and beans	455	254	39	51	344
V6	Quorn™ curry	281	119	8	20	147
V7	Pizza with lentil sauce	381	112	9	27	148
V8	Cheese quesadilla	349	141	7	34	183
V9	Quorn™ and vegetables stir fry	323	162	7	30	199
V10	Pizza	396	106	6	22	134
V11	Quorn™ paella	475	209	38	35	281
V12	Lentil and bean patties	136	160	10	39	208
V13	Tortilla	434	117	6	28	152
V14	Vegetarian burrito	357	230	22	53	305
V15	Vegetable curry	550	284	6	21	311
S1	Cauliflower rice	75	63	8	9	80
S2	Rice and peas	250	199	30	42	271
S3	Roasted root vegetables	37	7	1	3	11
S4	Runner bean slaw	36	20	2	6	27
S5	Summer vegetable polonaise	131	44	3	10	56
S6	Winter red coleslaw	19	12	3	2	18
S7	Potato mash	37	12	2	4	18
S8	Couscous with roasted vegetables	79	51	1	8	61
S9	Savoury rice	178	100	29	17	146
S10	Vegetable paella	243	120	33	15	168
D1	Apple and banana cake	50	30	4	5	40
D2	Apple berry fool	187	71	14	13	99
D3	Apple flapjack	25	16	2	2	19
D4	Banana cake	113	87	14	11	112
D5	Banana muffins	63	38	6	5	49
D6	Cocoa beetroot muffins	89	108	10	5	123
D7	Date and cocoa brownie	78	92	25	6	123
D8	Pear sponge	126	70	9	9	88
D9	Rhubarb and custard cake	49	27	5	4	36
D10	Rice pudding and peaches	318	129	33	22	184
D11	Rice pudding apricot compote	253	87	24	15	127
D12	Winter sponge	85	38	4	8	51
D13[10]	Oaty apple crumble	92	55	10	9	74

Table continues on the following page

D14	Oaty fruit crunch	80	56	7	8	71
D15	Peach and raspberry cobbler	95	51	17	11	79
D16	Summer fruit yogurt crunch pots	101	44	13	10	66

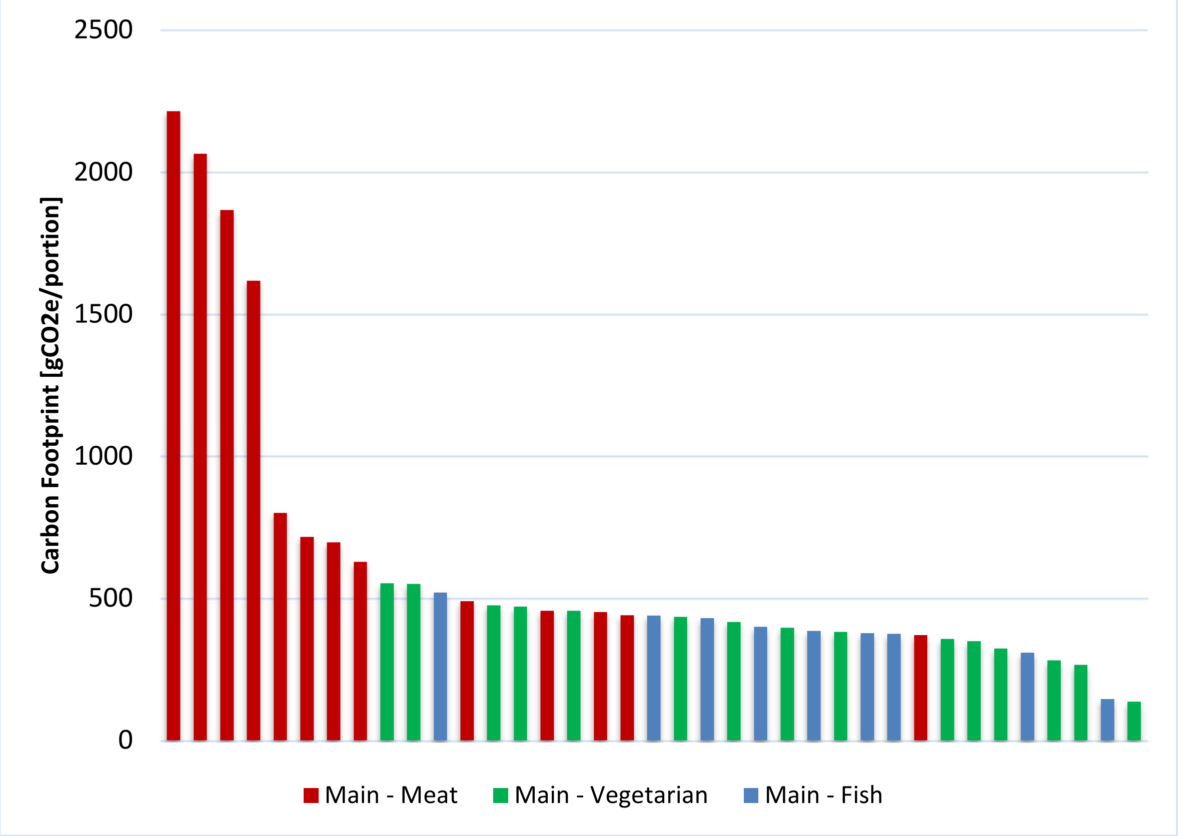


Figure 5-16: Overview of CF of main dishes of CS2

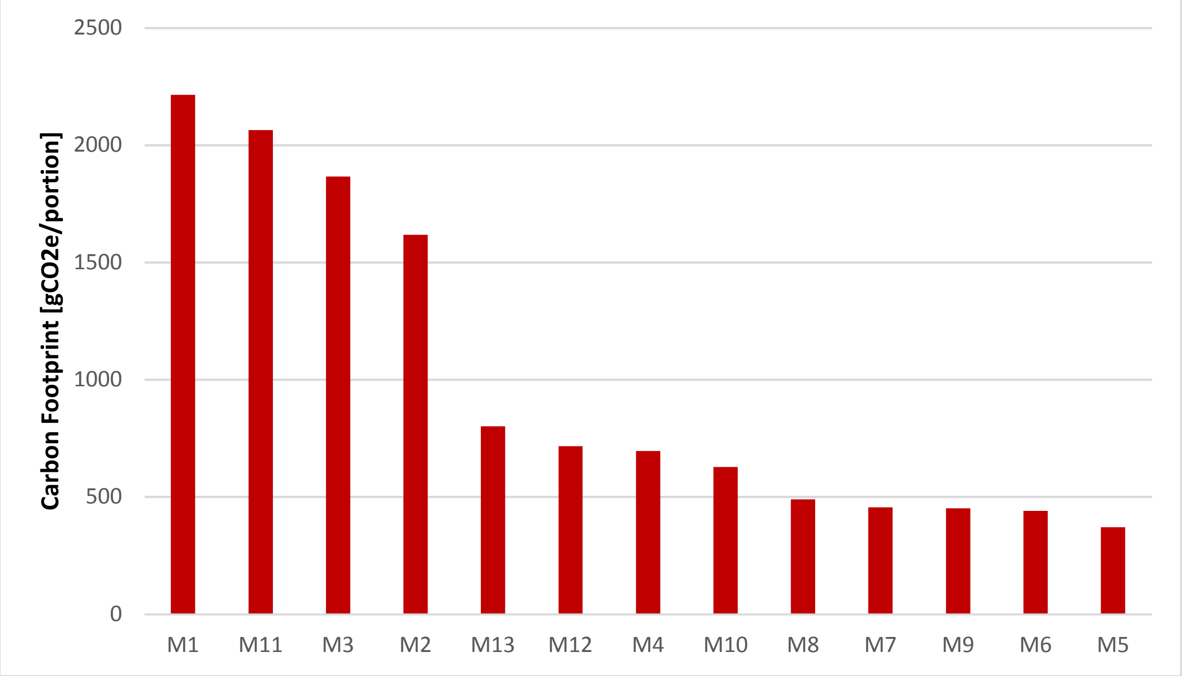


Figure 5-17: CF of meat-based main dishes of CS2

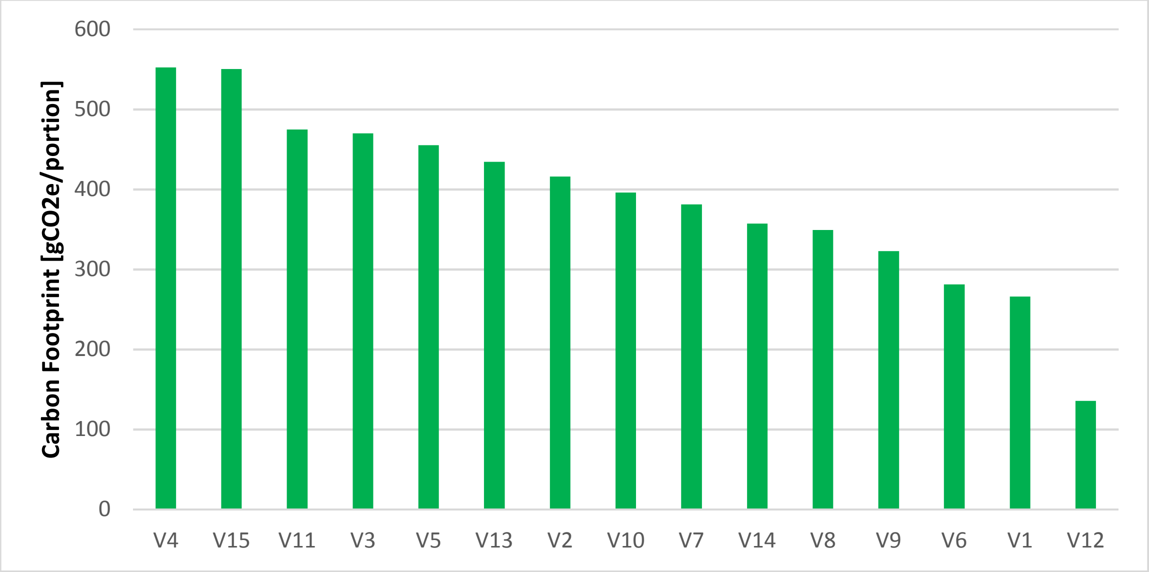


Figure 5-18: CF of vegetarian main dishes of CS2

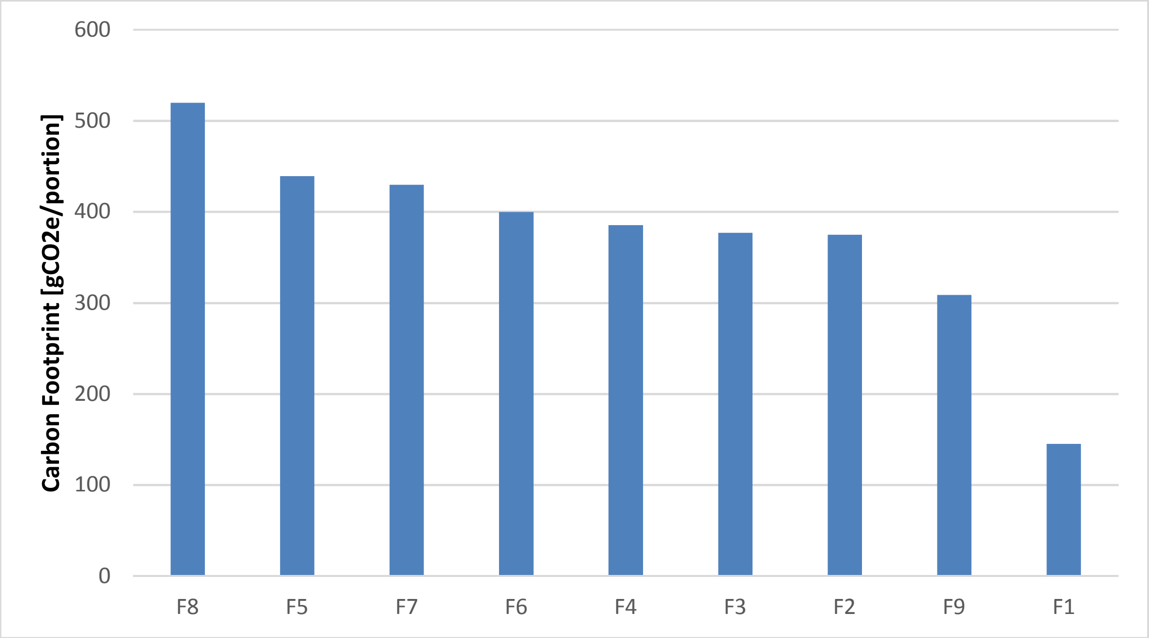


Figure 5-19: CF of fish-based main dishes of CS2

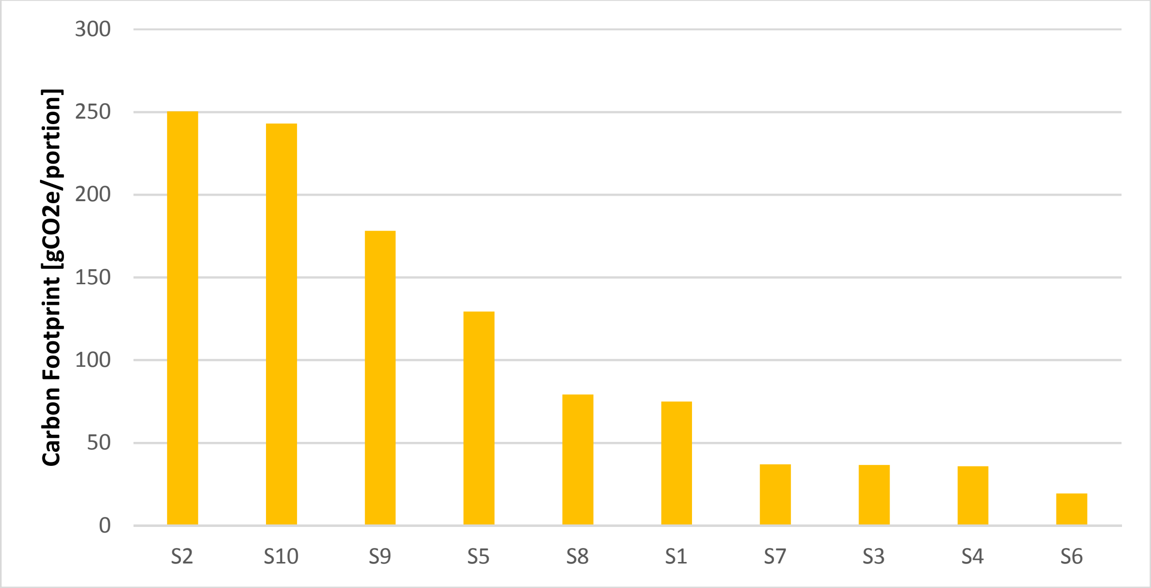


Figure 5-20: CF of side dishes of CS2

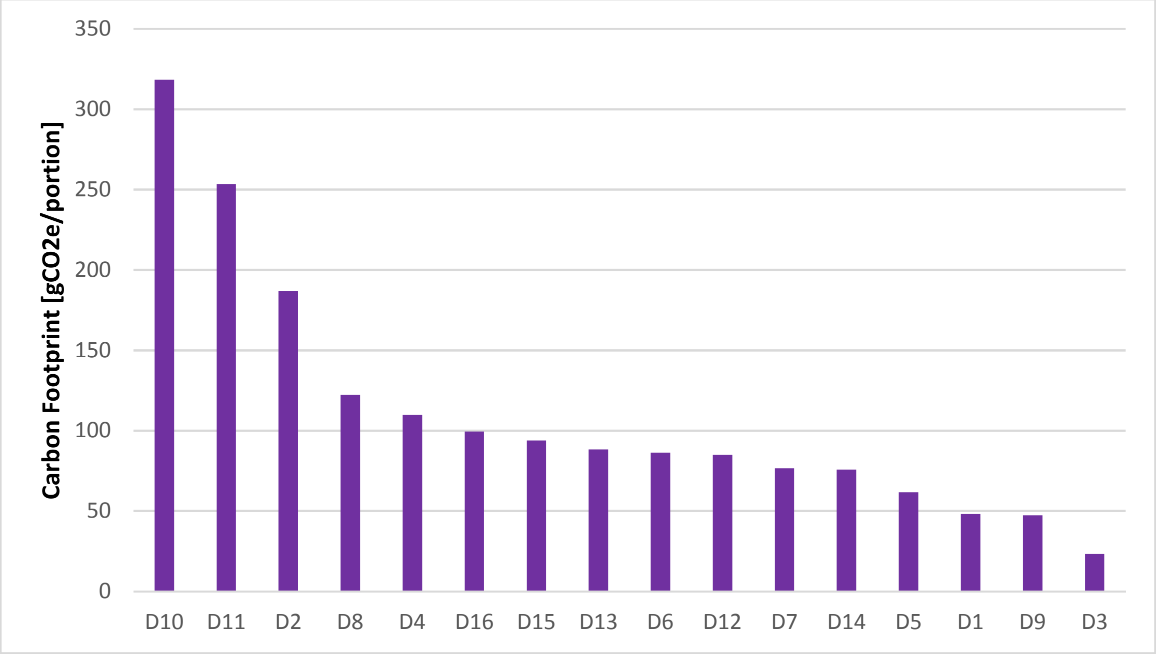


Figure 5-21: CF of desserts of CS2

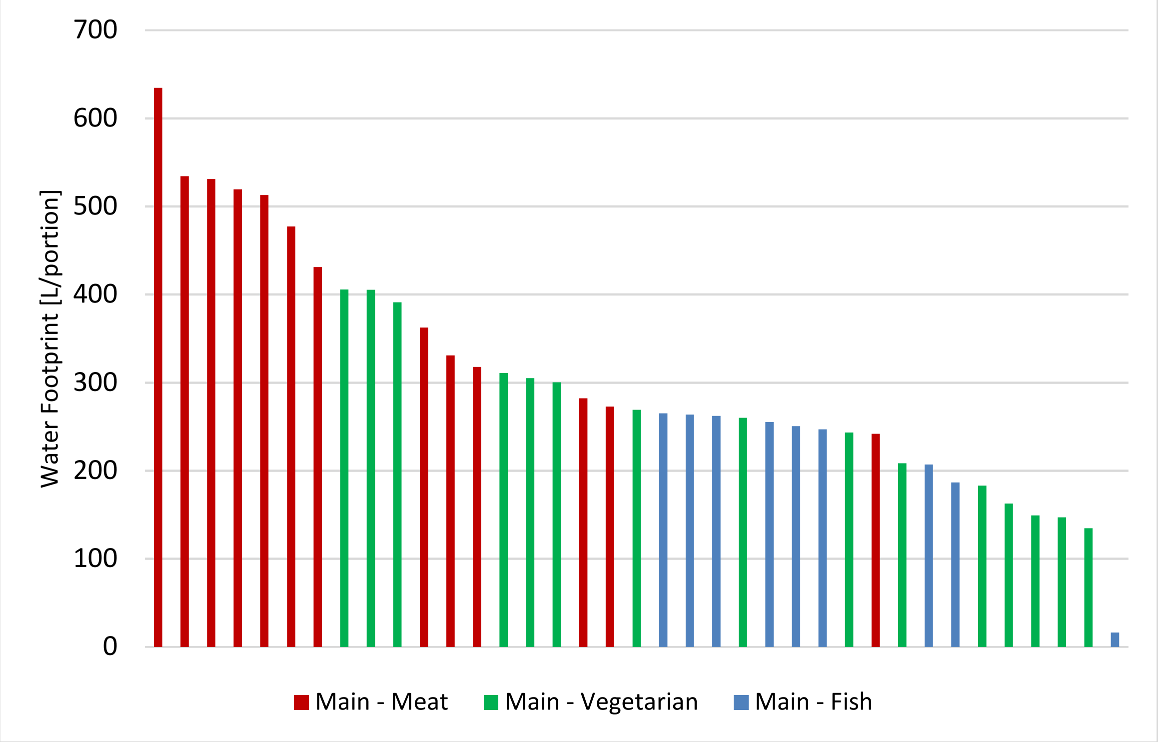


Figure 5-22: Overview of WF of main dishes of CS2

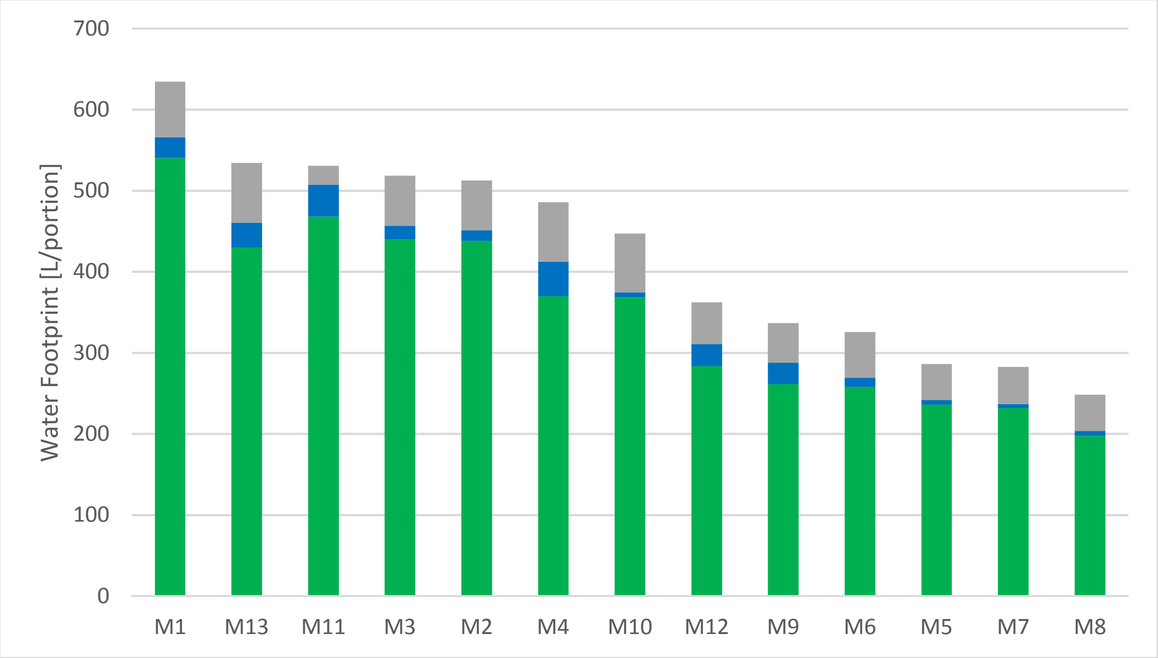


Figure 5-23: Green, blue and grey WF of meat-based main dishes of CS2

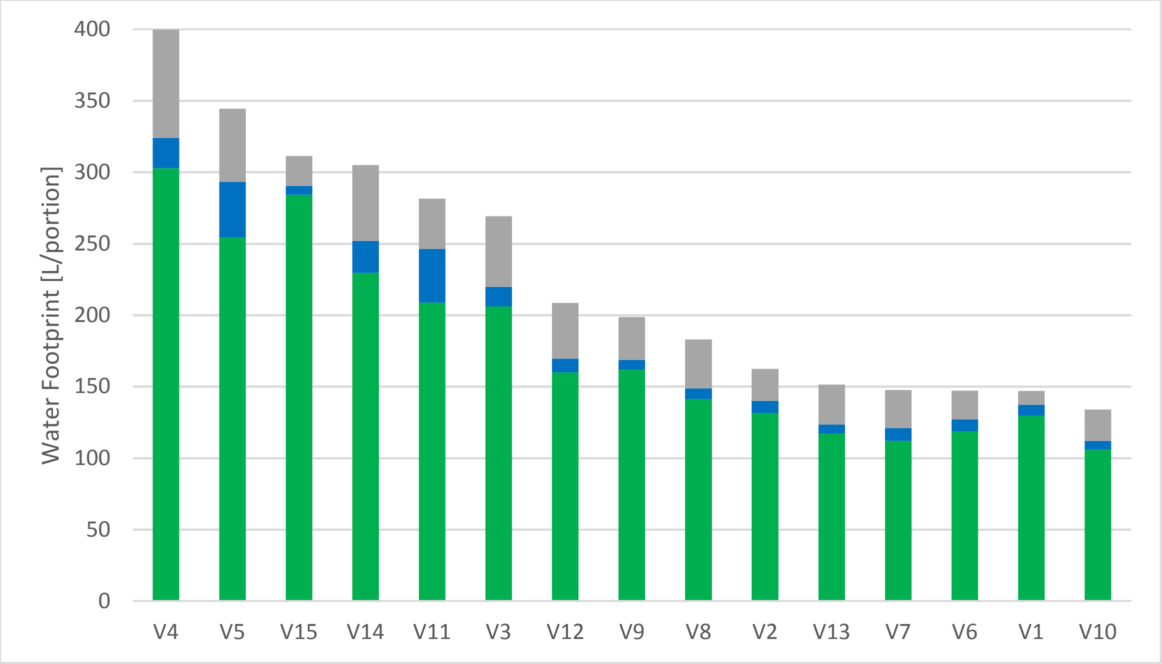


Figure 5-24: Green, blue and grey WF of vegetarian main dishes of CS2

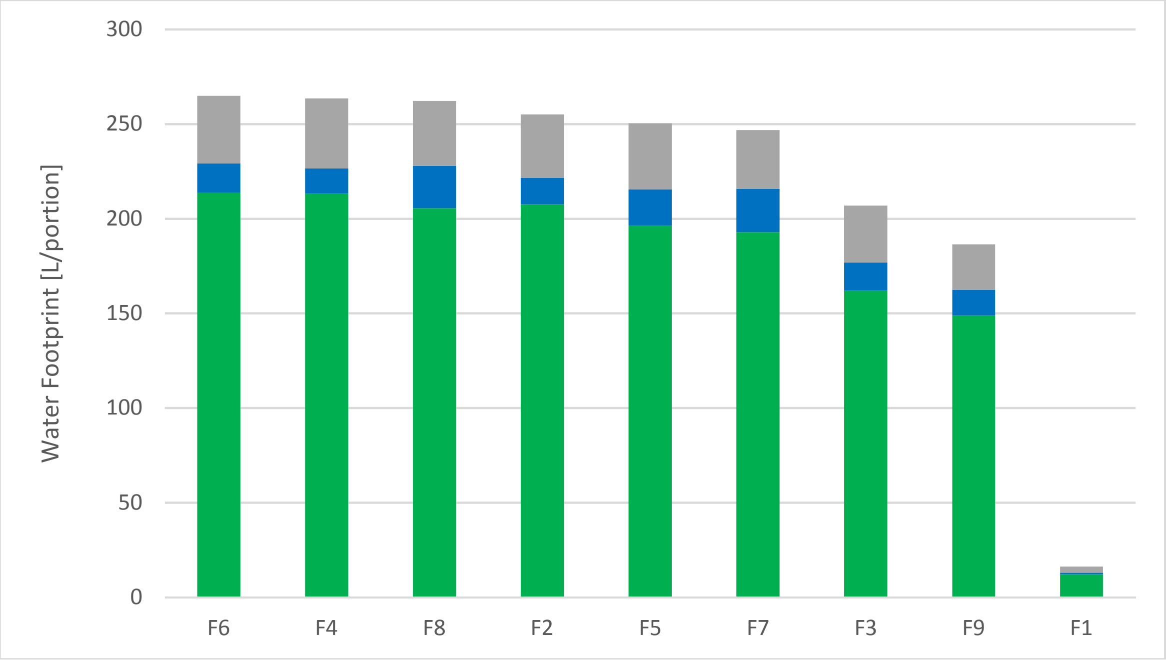


Figure 5-25: Green, blue and grey WF of fish-based main dishes of CS2

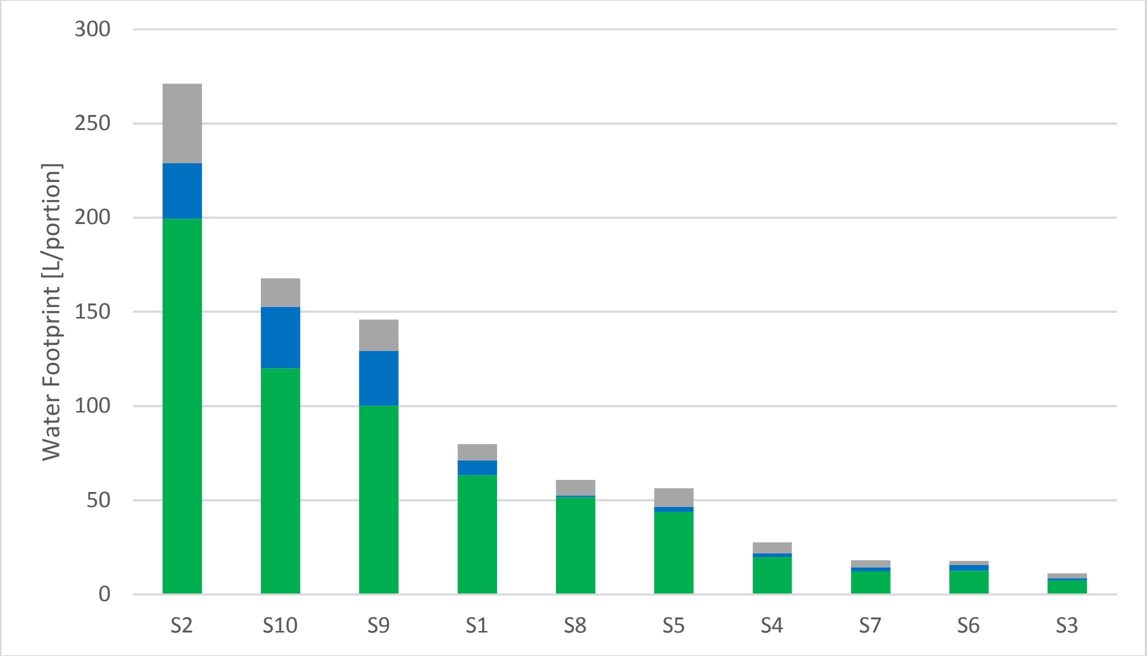


Figure 5-26: Green, blue and grey WF of side dishes of CS2

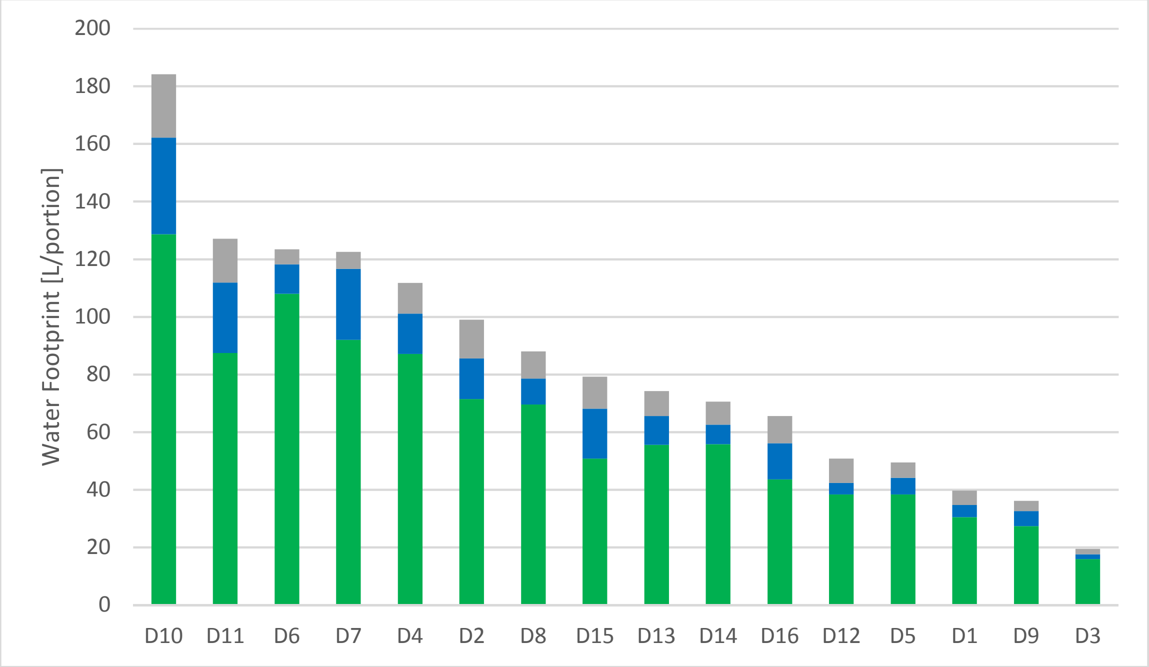


Figure 5-27: Green, blue and grey WF of desserts of CS2

It is possible to identify from Table 5-12, Figure 5-16 and Figure 5-22 a clear trend according to which meat recipes are more carbon and water intensive than fish based and vegetarian ones. Another factor that significantly influences the CF of a recipe is the amount of dairy ingredients, as for instance the CF of cheese (average value = 8298 gCO_{2e}/kg), cream (average value = 6386 gCO_{2e}/kg) and butter (average value = 8085 gCO_{2e}/kg) is higher than that of pork (average value = 6329 gCO_{2e}/kg) and chicken (average value = 4037 gCO_{2e}/kg) as reported in Table 5-2. When looking at the meat based main dishes (Figure 5-17 and Figure 5-23), it is possible to see how those with either beef or lamb have the highest values of CF and WF. In terms of carbon intensity there is a marked difference between recipes in which the main ingredient is ruminant livestock (beef or lamb) and recipes where it is non-ruminant livestock (pork or chicken), whilst for WF this is less marked, as pork based recipes have comparable impacts to beef and lamb based ones. This finding is in line with the results presented in Figure 5-12, where it is possible to see how the values of WF of different food categories decrease more gradually than those of CF (where there is a sharp difference between ruminant livestock products and all the other products – which have a CF which is more than 70% smaller than the CF of both lamb and beef). The side dishes that present the highest values of carbon and water footprints all contain rice (which has a high carbon footprint due to the production of methane during its cultivation (Blengini and Busto, 2009) and presents a higher WF than alternative starchy carbohydrate foods such as pasta and potatoes). Similarly, rice based desserts have the highest CF and are amongst those which have the highest WF together with those made with cocoa (growing cocoa beans requires large quantities of green water (Ridoutt and Pfister, 2010)). Amongst the fish-based dishes, F1 presents a value of WF (equal to 16 L) which is significantly smaller compared to all the others (where values range between 186 and 264 L), this is due to this dish being prepared with wild caught fish, whilst all the others are prepared with farmed fish (see Section 5.3).

When looking at the different colours of WF, the green component of WF is predominant, in line with the trend previously identified (Section 5.3) and therefore dishes with the highest values of total WF are likely to also present the highest values of green WF. The dishes presenting the highest blue WF are M4 (43 L, main *hotspot* rice), M11 (40 L, main *hotspot* lamb), V5 and V11 (respectively 39 and 38 L, main *hotspot* rice). The dishes presenting the highest grey WF are V4 (76 L, *hotspot* beans), M13 (74 L, *hotspot* pork), M4 and M10 (respectively 73 L and 72 L, *hotspot* chicken).

While the values of WF are only calculated for the production phase (see Section 4.1), the values of CF are calculated for all the phases included in the system boundaries: production, transport and preparation. EATS calculates the contribution of each phase to the CF and presents it to the user in the form of a pie chart (an example is provided in Figure 4-9). The proportional contribution of each phase to the CF (calculated across the 63 recipes analysed) are presented in Figure 5-28. It is possible to see how the production phase is predominant, followed by the preparation phase and the transport phase (this is in line with the findings of existing literature, e.g. Saarinen et al. (2012), Davis et al. (2010), Sonesson et al. (2005), Virtanen et al. (2011)). Unsurprisingly, the predominance of the production phase is more accentuated for those dishes that have carbon intensive ingredients (i.e. meat-based main dishes). The small average contribution of the transport phase is partly influenced by the assumption made on the origin of the ingredients (whenever possible this was assumed to be the UK).

In Section 5.7, a sensitivity analysis is performed to discuss, amongst other aspects, the influence of this assumption on the results.

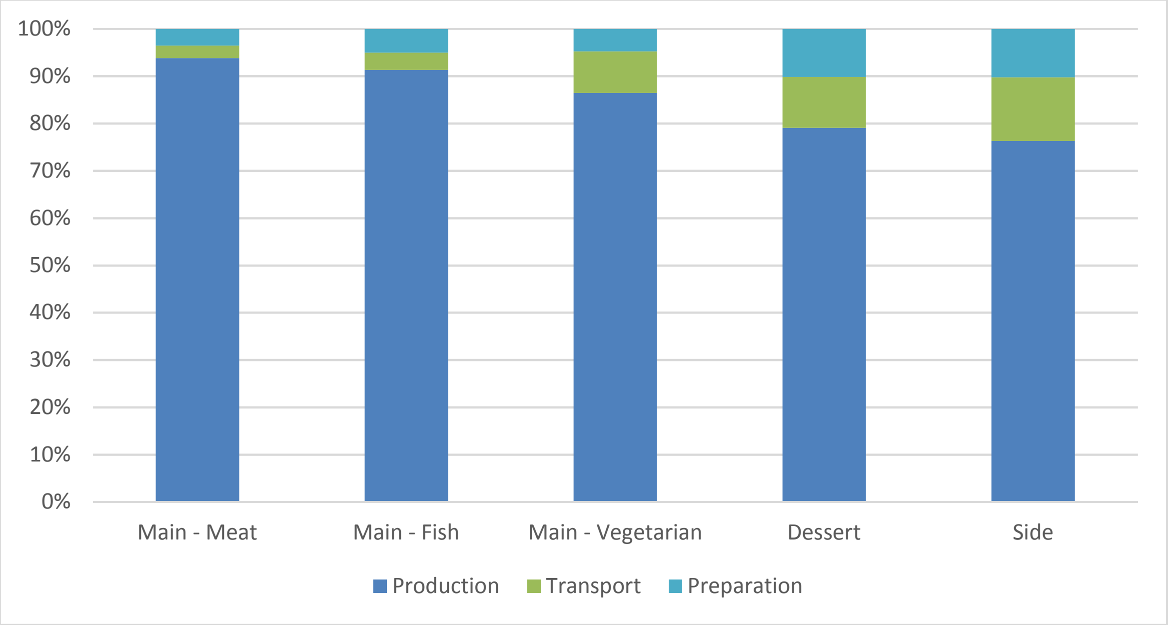


Figure 5-28: Average contribution of each phase to the CF, calculated for the meat-based, fish-based, and vegetarian mains dishes, side dishes and desserts of CS2

To conclude, the main lessons learned from the first two case studies are:

- As the production phase is predominant in both CF and WF, the choice of the composition of the meals is crucial to the designing of low impact menus
- In terms of CF, vegetarian (with low dairy content) and fish based recipes have similar impacts which are lower than for meat recipes;
- In terms of WF, wild fish-based recipes present the lowest impacts, followed by farmed fish-based dishes and vegetarian dishes (with low dairy content);
- Amongst meat based recipes, those with beef and lamb are the most carbon and water intensive;
- The main *hotspots* in vegetarian recipes are dairy ingredients, rice and pulses for both CF and WF;
- Amongst desserts rice is a *hotspot* ingredient for both CF and WF while cocoa is a *hotspot* ingredient for WF.

5.6 Case study 3 (CS3): assessment of the environmental impact of primary school meals in England

The purpose of the third case study was to use EATS to assess the average CF and WF of primary school meals served in England. The starting point was the Primary School Food Survey dataset, collected in 2009 across a nationally representative sample of 139 schools in England (Haroun et al., 2011). Based on the average environmental impacts (of CF and WF) it was possible to estimate the national impacts of Primary school meals in one year. This case study shows a further use of the tool developed in this project, which is to be used in combination with an existing dataset in order to estimate the environmental impact of a catering sector at a large geographical scale (e.g. at national level). Furthermore, having calculated the overall impacts of primary school meals in England, it was possible to use this result to estimate potential savings at national level associated with the implementation of reduction measures. This aspect is developed further in Section 5.10.2.

5.6.1 Average impacts and contribution of each group to total impacts

In brief the outcome of this case study revealed the following for the 6690 school meals analysed:

- The average value of CF per meal in 2009 was 1,059 gCO_{2e};
- The average value of WF per meal in 2009 was 568 L.

These two values were used to calculate the intervals against which to define a score of CF and WF within the EATS tool as described in Section 4.3.1. Therefore, the resulting intervals were:

- Green CF, when $CF \leq 741$ gCO_{2e}
- Amber CF, when 741 $gCO_{2e} < CF < 1377$ gCO_{2e}
- Red CF, when $CF \geq 1377$ gCO_{2e}
- Green WF, when $WF \leq 398$ L
- Amber WF, when 398 L $< WF <$ 738 L
- Red WF, when $WF \geq 738$ L

Assuming that the average number of school children having school meals every day in 2009 is 1,636,833 - based on an average take-up of school meals of 39.3% (Haroun et al., 2011), and that there are 190 school days in one year, the total yearly values can be found. In other words:

- The total CF for all meals served in 2009 was 1,636,833 * 190 * 1059 = 329 million $kgCO_{2e}$;
- The total WF for all meals served in 2009 was 1,636,833 * 190 * 568 = 177 million m^3.

Using these values further investigation of the results was undertaken. As explained in Section 4.4.2.3, each item code used in the assessment of the CF and WF of the school meals (recorded in the PSFS) was assigned to an item group (i.e. meat items, fish items, vegetarian items and vegan items). Figure 5-29, Figure 5-30 and Figure 5-31 present a comparison between the distribution by weight of the four groups of items and their relative contribution to the total CF and WF. Therein it can be seen that meat items, which represent 10% of the total weight, are responsible for 52% of the total CF, and 38% of the total WF. In comparison, vegetarian items, which contribute 28% of the total weight, are responsible for 28% of the total CF, and 40% of the total WF. Finally, vegan items, contributing 59% of the total weight, are responsible for only 15% of the total CF and 20% of the total WF.

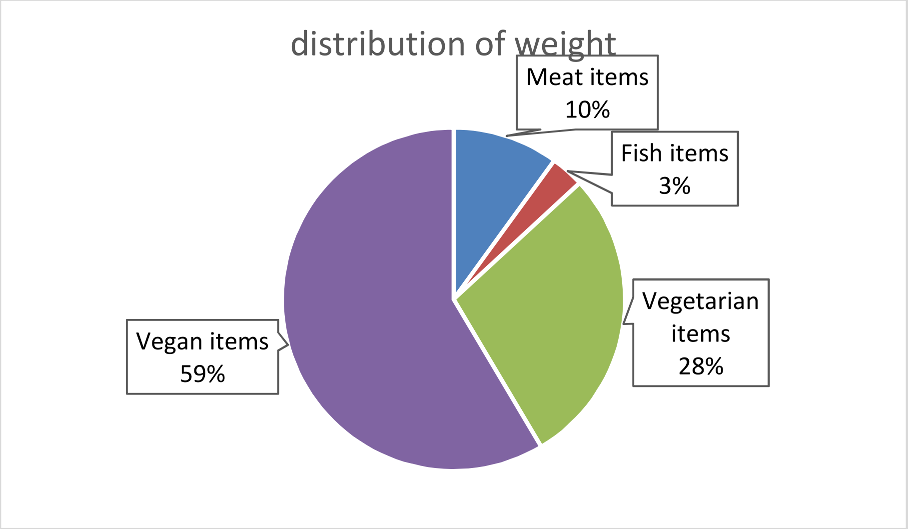


Figure 5-29: Distribution of weight of each group of items

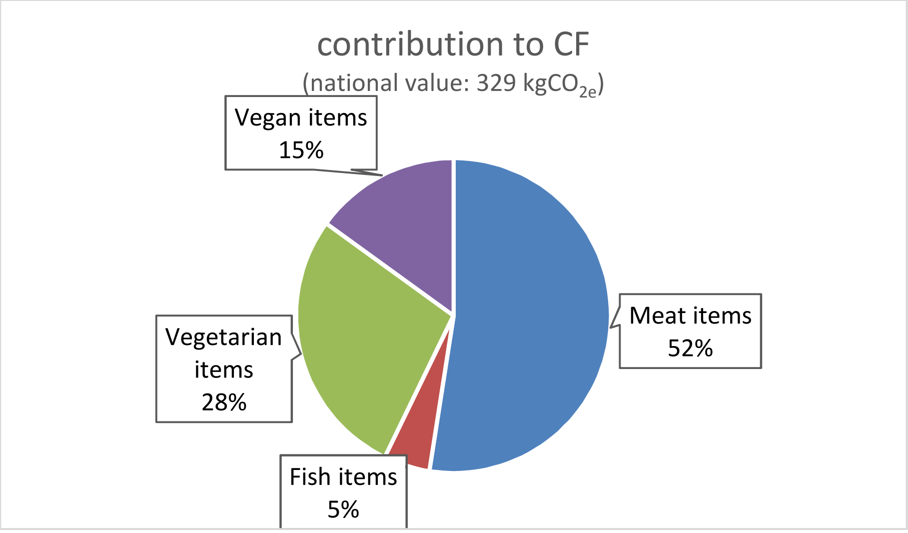


Figure 5-30: Contribution to the total CF of each group of items

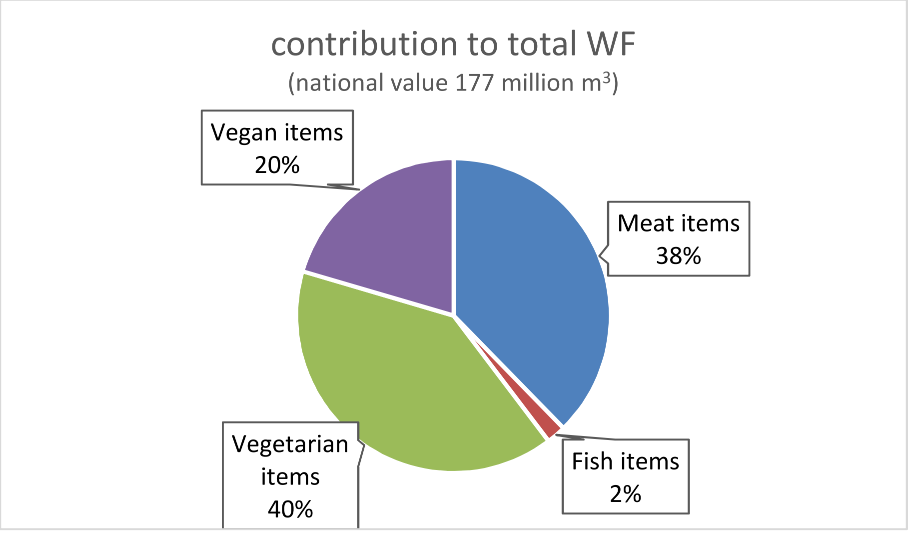


Figure 5-31: Contribution to the total WF of each group of items

Figures 5-32, 5-33 and 5-34 present the contribution to the blue, green and grey WF of each group of items. The first plot shows that for the blue component of the WF, the contribution of meat items is substantially smaller than for the total WF, and at the same time a substantial increase is observed for the vegan items; this finding is in line with similar research (Vanham et al., 2013). Instead, the distribution of the grey and green WF are closer to the distribution of the total WF, with the exception of the grey WF of vegetarian items which is 28% compared to 40% of the reference case (and at the same time the grey WF of vegan items which is 29% compared to 20%), the reason for this will be discussed in Section 5.6.3.

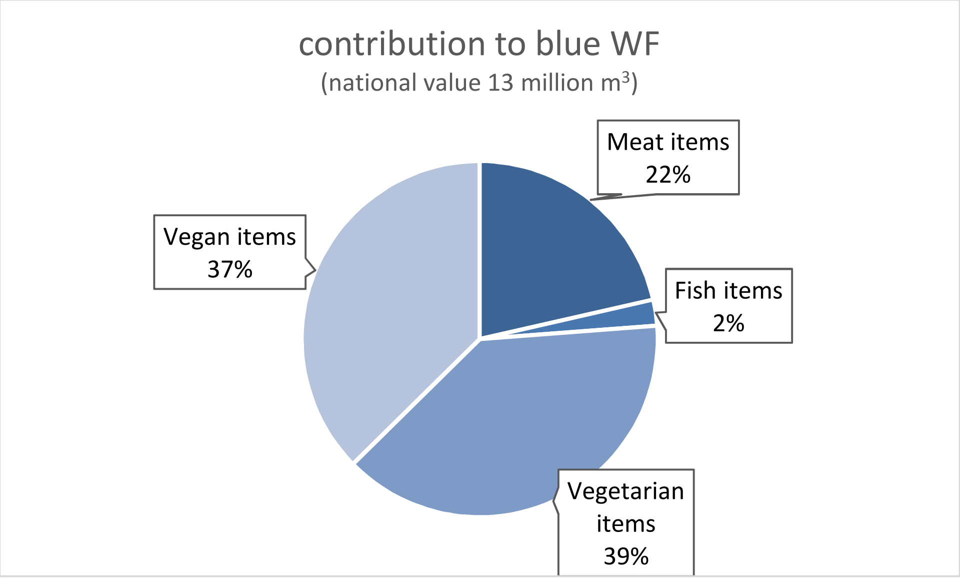


Figure 5-32: Contribution to the blue WF of each group of items

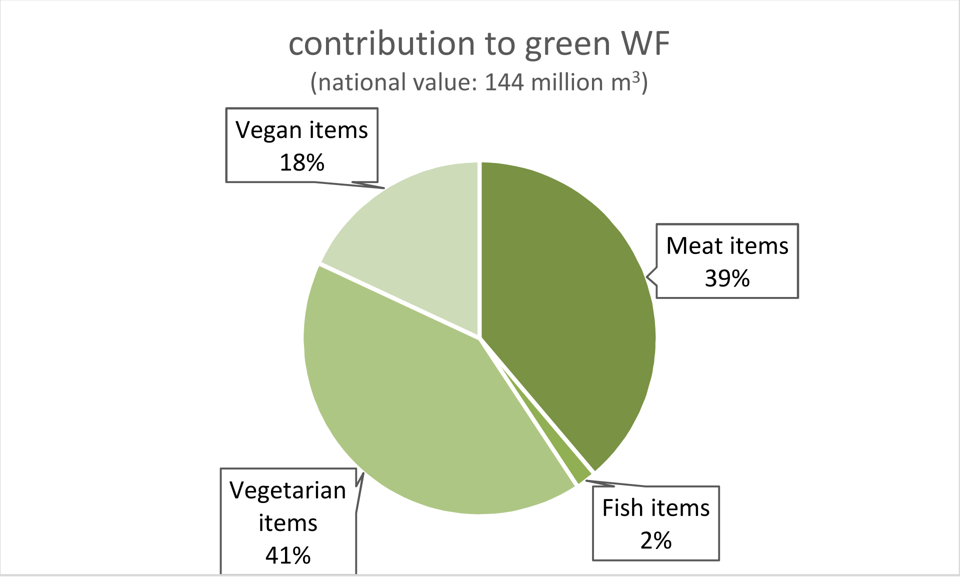


Figure 5-33: Contribution to the green WF of each group of items

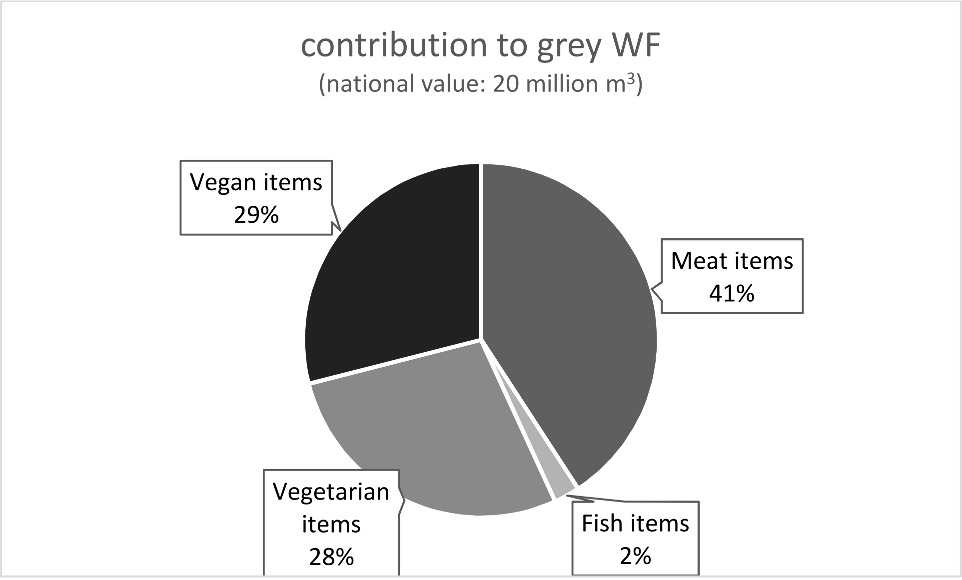


Figure 5-34: Contribution to the grey WF of each group of items

5.6.2 Identification of *hotspots*: carbon footprint

The meat items group is the largest contributor to the total CF (in line with the findings of CS1 and CS2). As significant differences exist between the CF of different types of meat (as shown in Figure 5-9) in order to investigate the effects of these variations, this group was further divided into four sub-groups.

- A1: Beef-based dishes;
- A2: Lamb-based dishes;
- A3: Pork-based dishes;
- A4: Poultry-based dishes.

By comparing Figures 5-35 and 5-36 it is possible to identify the differences between the distribution of each sub-group by weight and by CF. Therein it is possible to see how beef and lamb dishes together contribute almost three quarters of the overall CF of this group, even though they represent (by weight) less than half of the total. On the other hand, poultry-based dishes represent 30% of the total weight, but are responsible for only 13% of the total CF. This finding is in line with what identified in both CS1 and CS2.

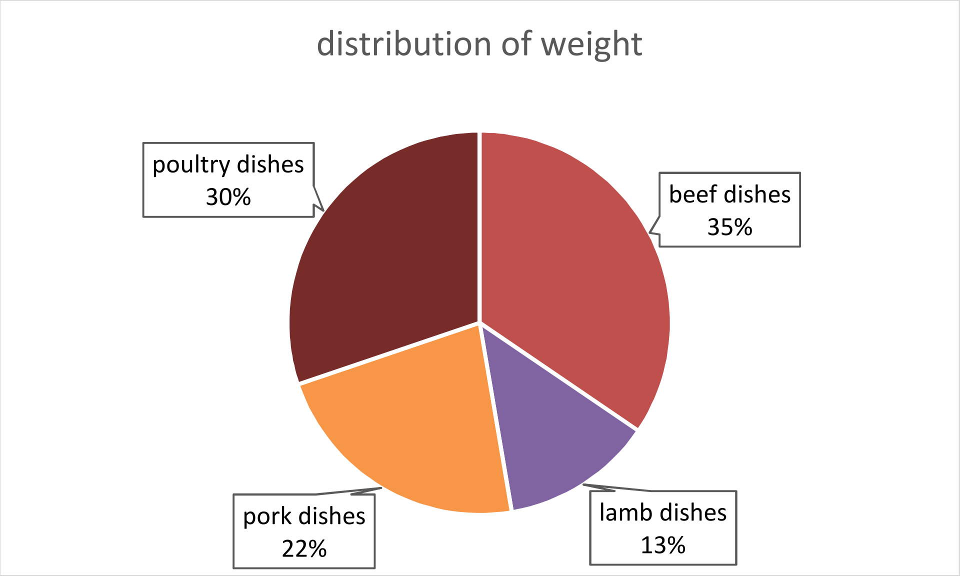


Figure 5-35: Distribution on weight of each subgroup of meat items.

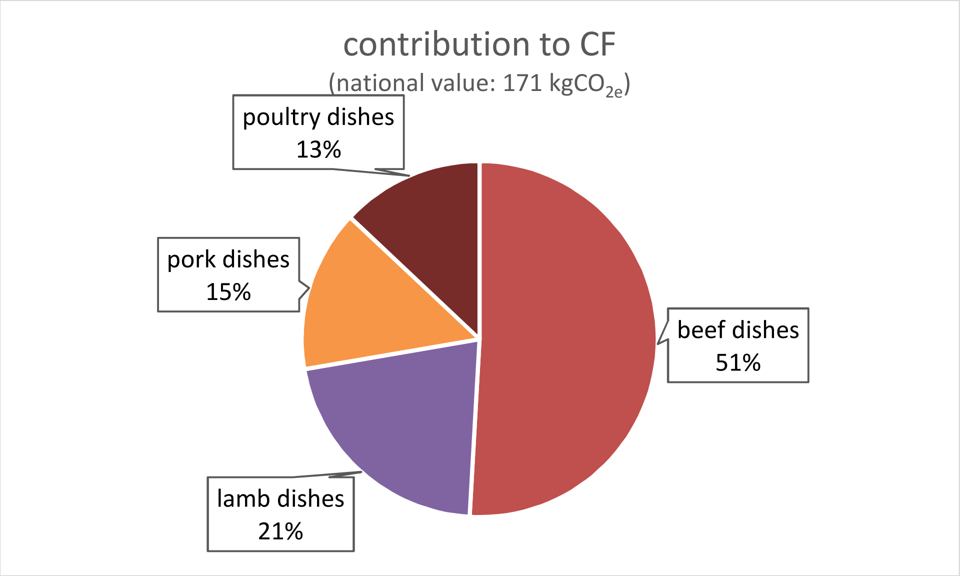


Figure 5-36: Contribution to CF of each subgroup of meat items.

5.6.3 Identification of *hotspots*: water footprint

When looking at the distribution of the WF across the same sub-groups (presented in Figure 5-37), this is more balanced across different types of meat dishes. This is because the variations in WF for different species of livestock are less noticeable than those in CF. [This is only true for the WF of livestock raised in the UK; when global average values of WF are taken, the difference between monogastric livestock and ruminant livestock is more pronounced, as can be seen previously in Figure 5-10.]

This suggests that, if meat is sourced from within the UK, a partial replacement of red meat (e.g. 25%) with white meat in school meals would have a significant effect on reducing the total CF, but less so on reducing the total WF, whilst the reduction in meat dishes *per se* would have an effect on both impact categories.

Furthermore, the relative proportions of the four subgroups for the blue and grey WF are different to those of the green WF and of the total WF (Figures 5-37, 5-38, 5-39 and 5-40). Beef items for instance, as cattle are mainly grass fed in the UK, have a relatively low contribution to the blue WF compared to pork items. When looking at the grey WF, pork and poultry-based dishes present a larger contribution than beef and lamb (this is a consequence of the higher use of concentrated feed for pork and poultry which implies the use fertilizer that causes a larger grey WF contribution (Mekonnen and Hoekstra, 2012)).

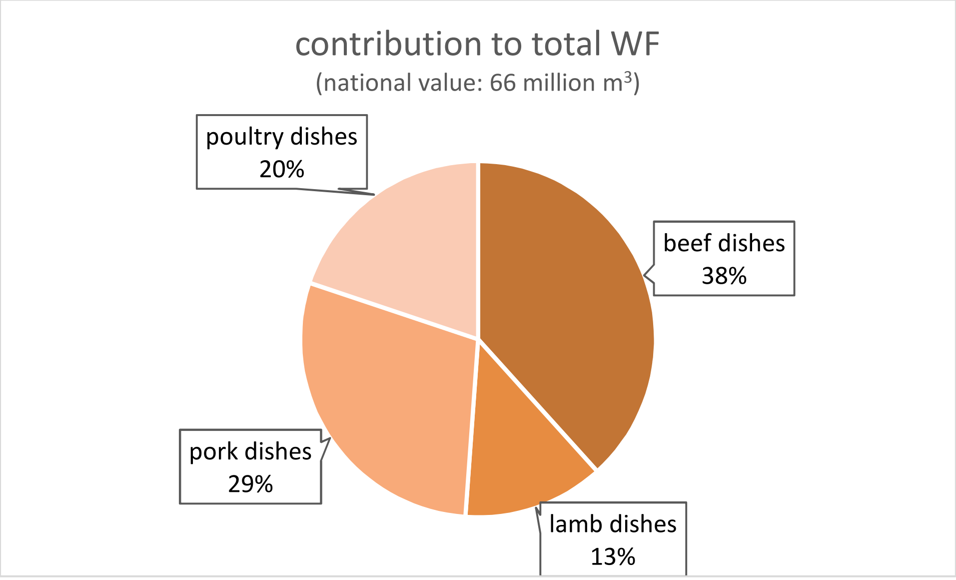


Figure 5-37: Contribution to the total WF of each subgroup of meat items

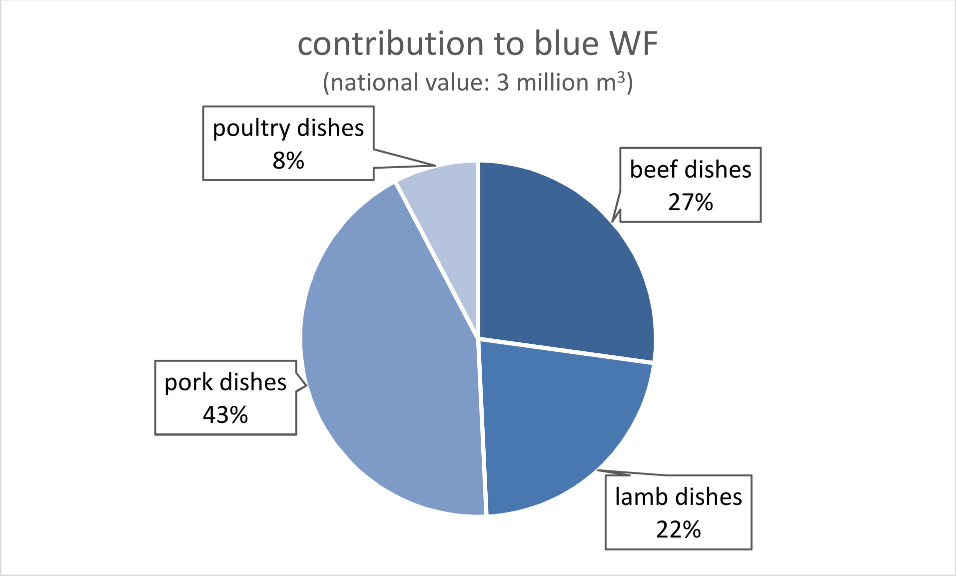


Figure 5-38: Contribution to the blue WF of each subgroup of meat items

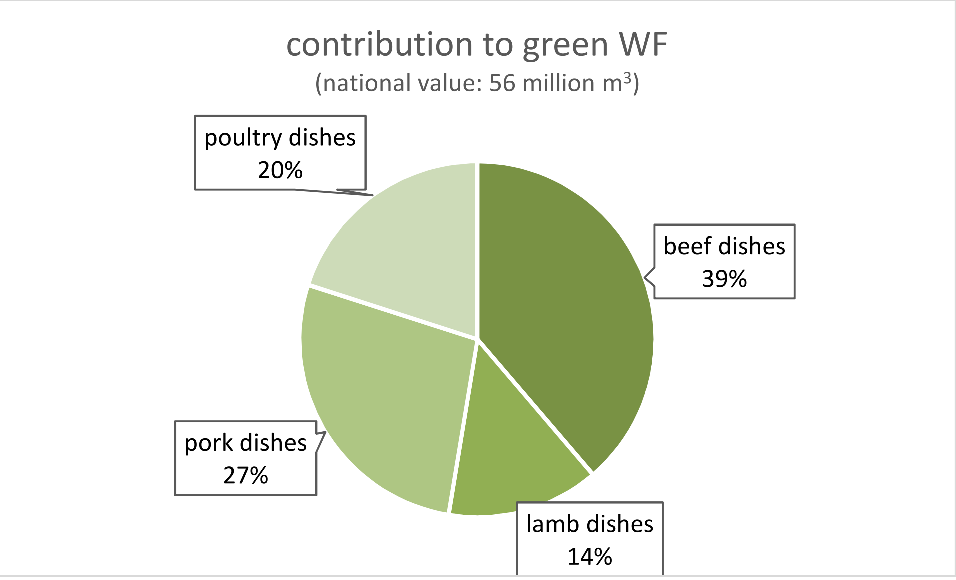


Figure 5-39: Contribution to the green WF of each subgroup of meat items

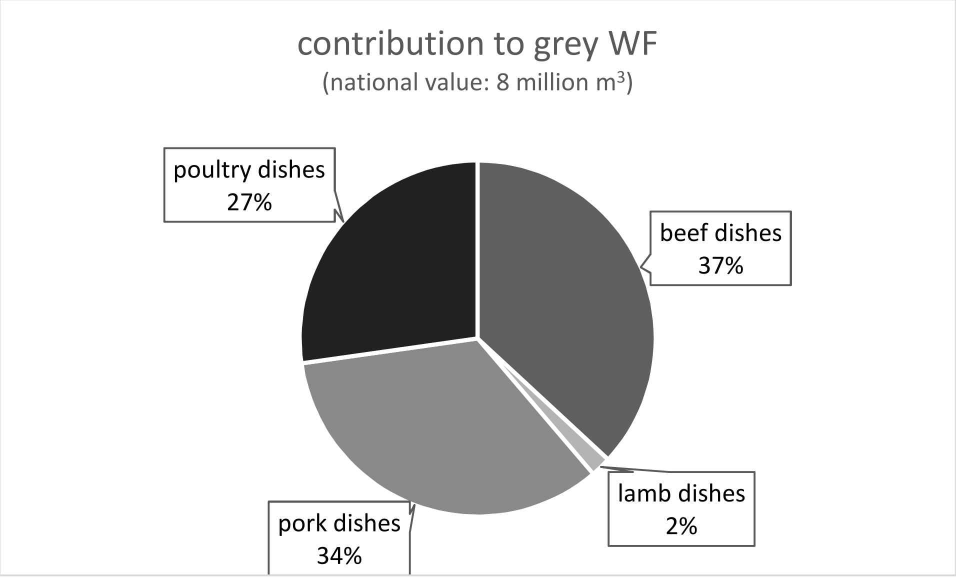


Figure 5-40: Contribution to the grey WF of each subgroup of meat items.

The list of items identified as vegetarian mainly included: vegetarian main dishes (e.g. lentils and vegetable curry), side dishes which included dairy ingredients (e.g. creamy potato mash), vegetarian sandwiches (e.g. egg and mayonnaise sandwich) and all desserts that had dairy ingredients. This group was the largest contributor to the WF (even though the difference between contribution by weight and contribution to the WF is higher for group A). Desserts represented 72% of the total weight of this group and 83% of the total WF. In order to further investigate the contribution of group C to the total WF this was divided into three subgroups:

- C1: chocolate desserts;
- C2: non-chocolate desserts;

- C3: savoury vegetarian items.

As shown in Figures 5-41 and 5-42, chocolate desserts represented 12% of the total weight of this group but contributed to almost half of the total WF (and 55% of the green WF). This is due to the fact that cocoa has a very large green WF compared to most food items (as can be seen in Figure 5-11) (Mekonnen and Hoekstra, 2011). Chocolate is therefore a *hotspot* ingredient when looking at the WF of school meals, and therefore a partial replacement of chocolate desserts with fruit-based desserts would significantly reduce the overall WF. [The average WF of a serving of the chocolate desserts recorded in the survey was 415 L, while the average WF of a serving of fruit salad was 58 L]. As chocolate desserts usually contain dairy ingredients (e.g. milk, butter, cream and yogurt), this would lead to a parallel reduction in CF. [The average CF of a serving of the chocolate desserts recorded in the survey was 192 gCO_{2e}, while the average CF of a serving of fruit salad was 38 gCO_{2e}.]

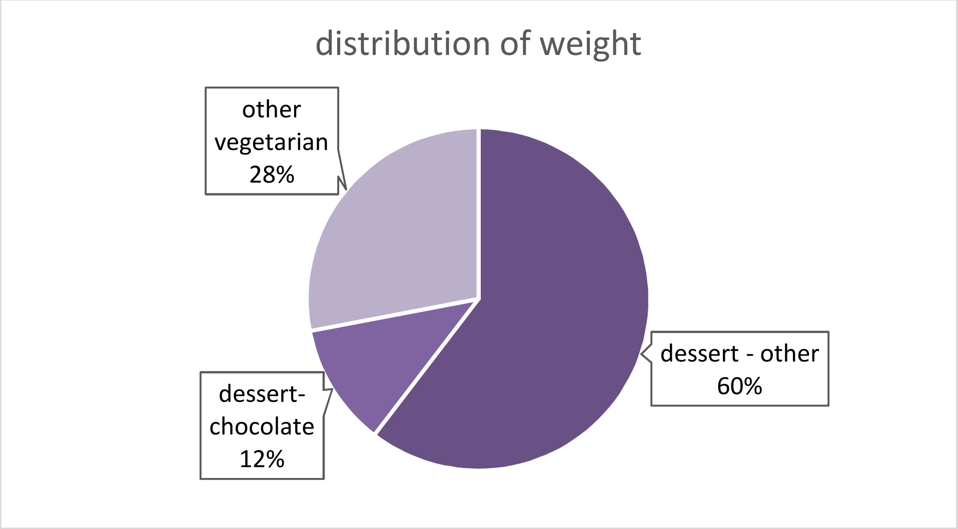


Figure 5-41: Distribution of weight of each subgroup of vegetarian items

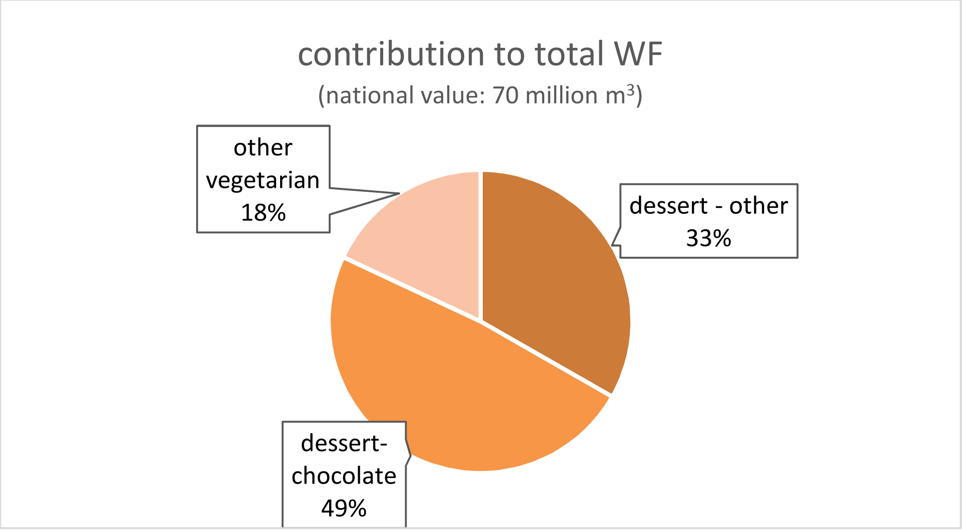


Figure 5-42: Contribution to the total WF of each subgroup of vegetarian items

Figures 5-43, 5-44 and 5-45 present breakdowns of the contribution of the subgroups of vegetarian items to the blue, green and grey WF respectively. It is possible to see how for both the blue and grey WF the distribution of each subgroup is more aligned with the distribution by weight (Figure 5-41), and therefore no *hotspot* ingredient(s) can be identified within this group for blue and grey WF.

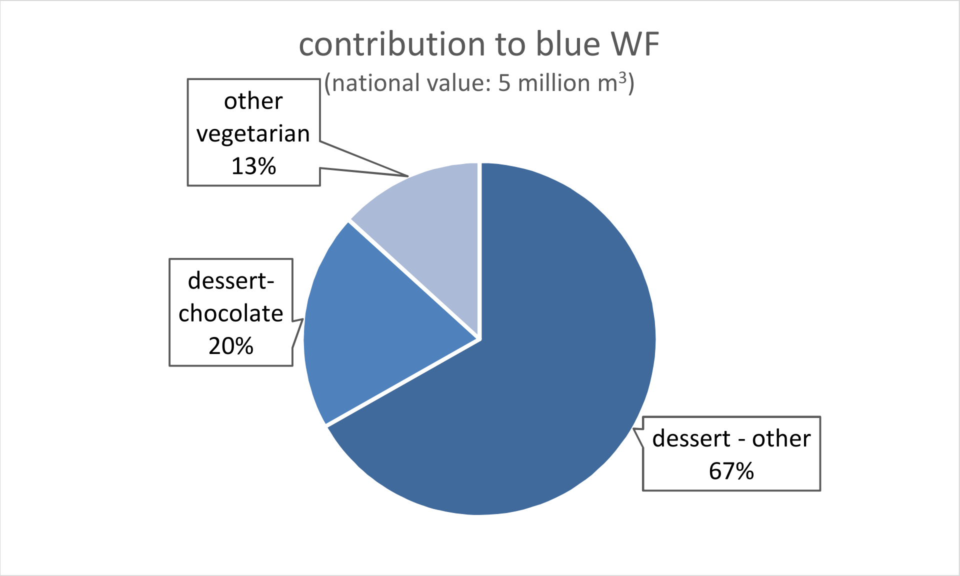


Figure 5-43: Contribution to the blue WF of each subgroup of vegetarian items

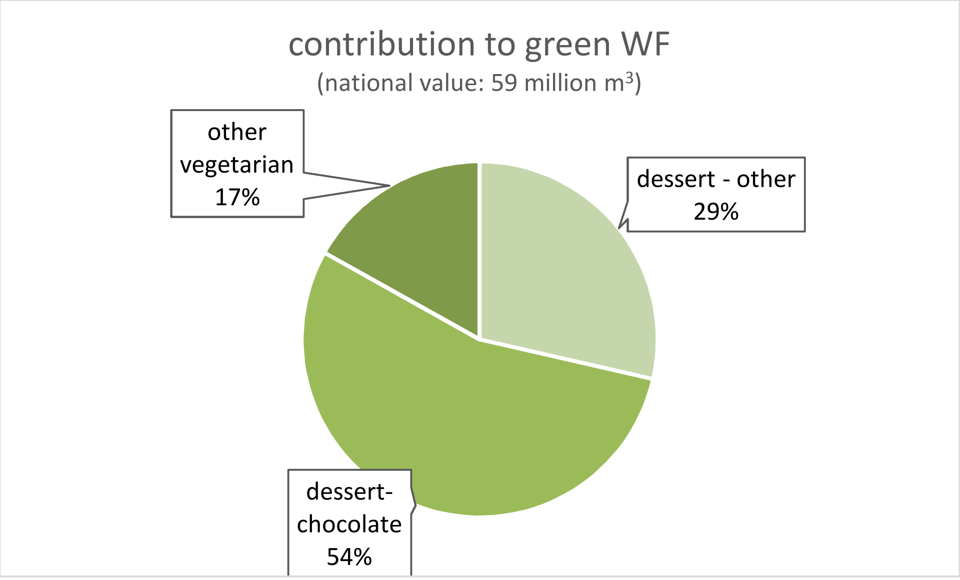


Figure 5-44: Contribution to the green WF of each subgroup of vegetarian items

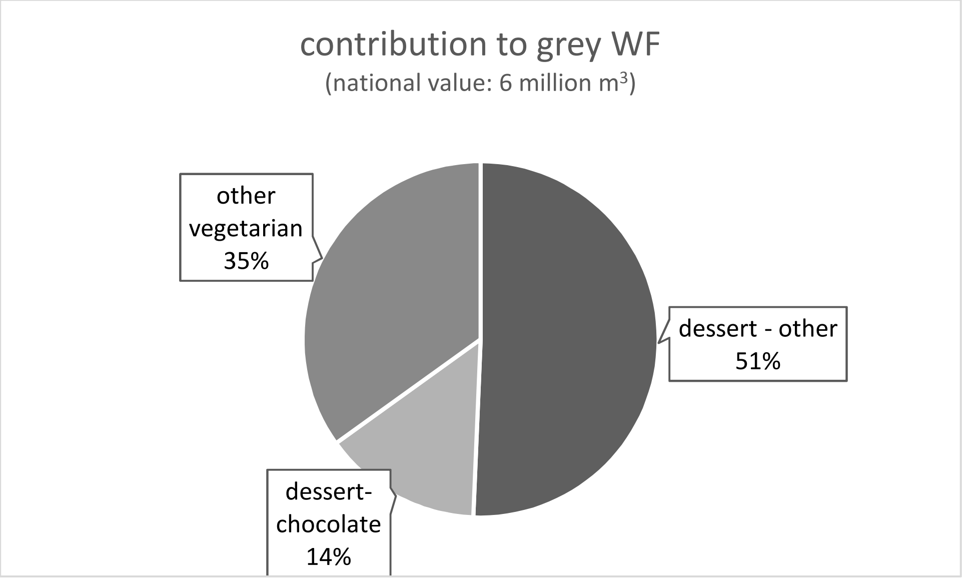


Figure 5-45: Contribution to the grey WF of each subgroup of vegetarian items

5.6.4 Lessons learned from CS 3

In this case study, the average CF and WF of a primary school meal served in England were calculated according to the Primary School Food Survey dataset collected in 2009 in the UK. This enabled the assessment of the environmental impact of primary school meals served in England and the identification of a number of *hotspots*.

The analysis here presented shows that meat dishes represent a significant *hotspot* both in terms of CF and of WF of primary school meals (being responsible for more than half of the total CF and more than one third of the total WF). In particular, beef and lamb-based dishes contributed significantly to the total CF (being responsible for 37% of the total emissions). Therefore, a reduction in meat dishes would reduce the environmental impact of the service. This could be achieved by introducing more vegetarian alternatives to traditional meat-based main dishes, by partially replacing the meat content of dishes with plant-based sources of protein (such as pulses), and by partially replacing red meat dishes with white meat and fish dishes. Allied to this would be a requirement to make such meals a more attractive option, not least for primary school children.

When looking at the contribution of each group to the total WF, vegetarian dishes were responsible for 40% of the total impact. This was mainly due to chocolate desserts, which alone were responsible for 19% of the total WF. Therefore, a strategy to reduce the WF could be that of replacing chocolate desserts with other types of desserts, including healthier fruit options.

5.7 Sensitivity analysis of the results

A sensitivity analysis was performed to assess the level of influence of various assumptions on the results provided by EATS. In order to do so the main dish M8 (Chicken Fajitas) was selected from the ones analysed in CS2, and six alternative scenarios were created by varying each time one of the parameters assumed in the baseline case. The reasons for choosing this dish were that:

- It had mid-range values of both CF and WF;
- It did not include ingredients that were responsible alone for more than 75% of either the CF or the WF (as this would reduce the variability of the results related to parameter changes regarding the other ingredients);
- Part of the ingredients were horticultural products that out of season in the UK are grown in heated greenhouses (which would enable to consider the aspect of seasonality in the sensitivity analysis).

Table 5-13 shows the parameters within the *baseline* scenario (M8) and the respective parameter changes for the six the alternative scenarios (M8.1 to M8.6). In the baseline case, the following assumptions are made (as explained in Section 4.4.2):

- The origin(s) of the ingredients are those presented in Table 4-14 and Table 4-15;
- All ingredients produced in the UK are seasonal (therefore the use of heated greenhouses is not required for horticultural products);
- The transport mode is by truck for ingredients produced in the UK and by cargo ship for all the other ingredients;
- The cooking appliances used are run on natural gas.

Table 5-13: Baseline and alternative scenarios for sensitivity analysis

Scenario	Origin of ingredients	Horticultural production	Transport mode	Cooking appliances
M8 (Baseline)	See Table 4-14 and Table 4-15	Open field / non heated greenhouse	Truck (UK products) and cargo ship otherwise	Gas hob
M8.1	*Unknown (World)*	Baseline	Baseline	Baseline
M8.2	Baseline	Baseline	*Truck (EU products) and cargo ship otherwise*	Baseline
M8.3	*50 km away for UK products, baseline for remaining products*	Baseline	Baseline	Baseline
M8.4	Baseline	*Heated greenhouse*	Baseline	Baseline
M8.5	*Horticultural products from Spain, baseline for remaining products*	Baseline	Baseline	Baseline
M8.6	Baseline	Baseline	Baseline	*Electric hob*

In scenario M8.1 it is assumed that the origin of all ingredients is unknown, and therefore the option “World” is selected for each ingredient. In scenario M8.2 the origin of the ingredients is the one assumed in the baseline scenario but the transport mode is assumed to be by truck for all the ingredients sourced from within the EU. In scenario M8.3 the ingredients sourced from the UK are assumed to have travelled 50 km to reach the school kitchen (as opposed to 250 km of the baseline case). In scenarios M8.4 and M8.5 it is assumed that the horticultural products used in the recipe are not seasonal; in the first case they are still produced in the UK, and therefore they have been produced in heated greenhouses, whilst in the second, it is assumed that these ingredients are sourced from Spain. In scenario M8.6 the energy source in the school kitchen is changed from natural gas to electricity.

The results of the sensitivity analysis are shown in Table 5-14 and Figures 5-46 and 5-47. When the origin of all the ingredients is unknown (scenario M8.1) and therefore a conservatively long forfeit transport distance is assumed in the calculations, the CF is 18% higher compared to the baseline case. Conversely, applying the hypothesis of locality to all the ingredients produced in the UK (scenario M8.3), leads to a minor reduction in the CF (-1%) compared to the baseline. Changes in the transport mode of the products sourced from outside the UK and within the EU (replacing transport via cargo ship with refrigerated trucks) lead to an increase in the CF by 3% (scenario M8.2). When the horticultural products in a recipe are out of season in the UK, there are two alternative options: they can be produced in the UK in heated greenhouses (scenario M8.4) or imported from overseas (scenario M8.5). The first scenario presents the highest value of CF (46% increase compared to the baseline), while the second present a negligible increase (smaller than 1%). This result clearly shows that when choosing local products that are not seasonal, the reduction in the CF due to shorter transport distances is most likely outweighed by the significant increase in the CF of production, deriving from the use of heated greenhouses. The last scenario (M8.6) investigates the influence of preparing a meal with cooking appliances running on electricity rather than on natural gas; in this case the increase in the total CF (+5%) is related to the current UK average electricity production mix (therefore if the electricity was instead produced through renewable energy sources this scenario would most likely present a lower CF compared to the baseline).

The sensitivity analysis shows that variations in the assumptions made on cooking appliances, transport distances for the ingredients produced in the UK and transport mode, are not likely to significantly affect the results (all variations of the results are smaller than 5%). The parameters that can affect the results are the production method of horticultural products and the choice of the country of origin of the ingredients. This analysis shows how the concepts of locality and seasonality cannot be separated and that “local food” does not always mean “sustainable food”. Ultimately it highlights the importance of purchasing seasonal horticultural products.

In the third case study, all the horticultural ingredients that resulted to be non-seasonal, were assumed to be imported from overseas rather than produced in the UK in heated greenhouses (see Table 4-17). The sensitivity analysis presented here, shows that this assumption could lead to an underestimation of the results.

When the same analysis was applied to the WF, out of the six alternative scenarios presented above, only scenarios M8.1 and M8.5 presented different results. This is because the calculation of the WF performed by EATS is not influenced by the production method - nor by any assumptions relating to the transport or preparation phase (the WF is only calculated for the production phase). However, unlike the calculation of the CF of the production phase, the calculation of the WF of production is affected by the origin of the ingredients. Hence, in scenario M8.1, which assumes an unknown origin for all the ingredients, the WF is calculated using the average global value of WF of each ingredient. This causes an increase in the WF of the meal analysed from 248 L per portion (baseline case) to 545 L per portion (scenario M8.1). This is in line with what is presented in Section 5.3 and in particular in Figure 5-10, where it is possible to see that the global values of WF of food products tend to be higher than the average EU values and UK values. In scenario M8.5, where the horticultural ingredients are assumed to be produced in Spain rather than in the UK, the WF is slightly higher (250 L per portion). It is therefore possible to state that the only assumption that can significantly influence the final result in the calculation of the WF of a recipe is the origin of the ingredients, and that when this information is not available the results will most likely be overestimated.

Table 5-14: Results of sensitivity analysis on CF [gCO_{2e}/portion]

Scenario	CF (Total)	CF (Production)	CF (Transport)	CF (Preparation)	Variation from baseline
M8	490	455	20	15	-
M8.1	579	455	109	15	+18.2%
M8.2	507	455	37	15	+3.5%
M8.3	483	455	13	15	-1.4%
M8.4	714	680	20	15	+45.7%
M8.5	492	455	23	15	+0.4%
M8.6	514	455	20	39	+4.9%

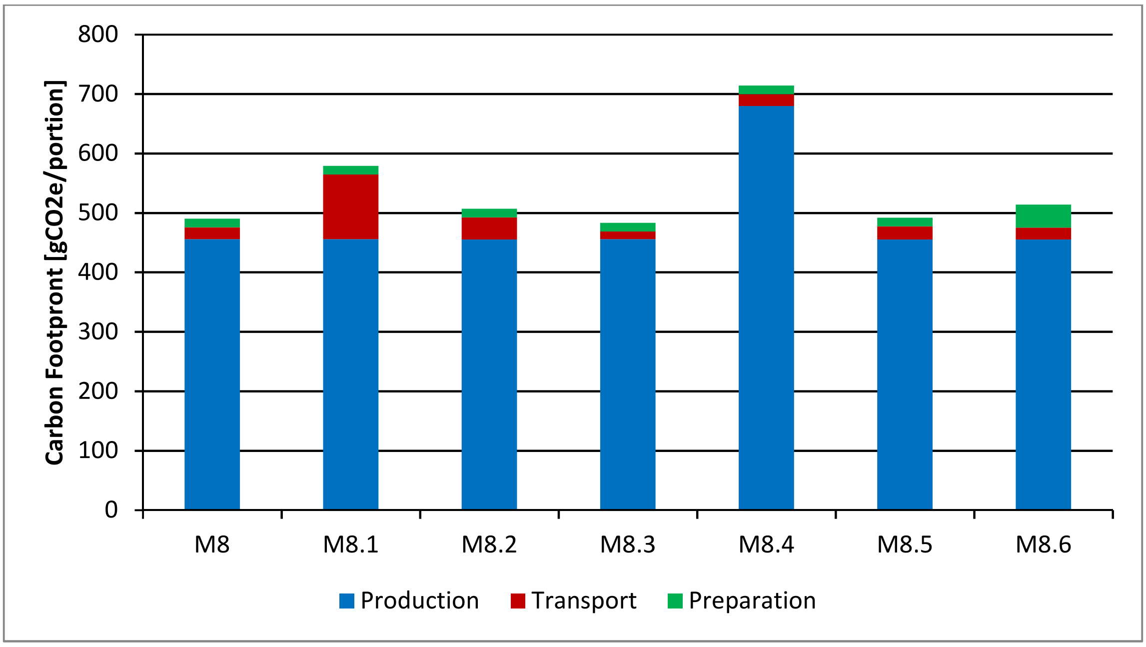


Figure 5-46: Results of sensitivity analysis on CF

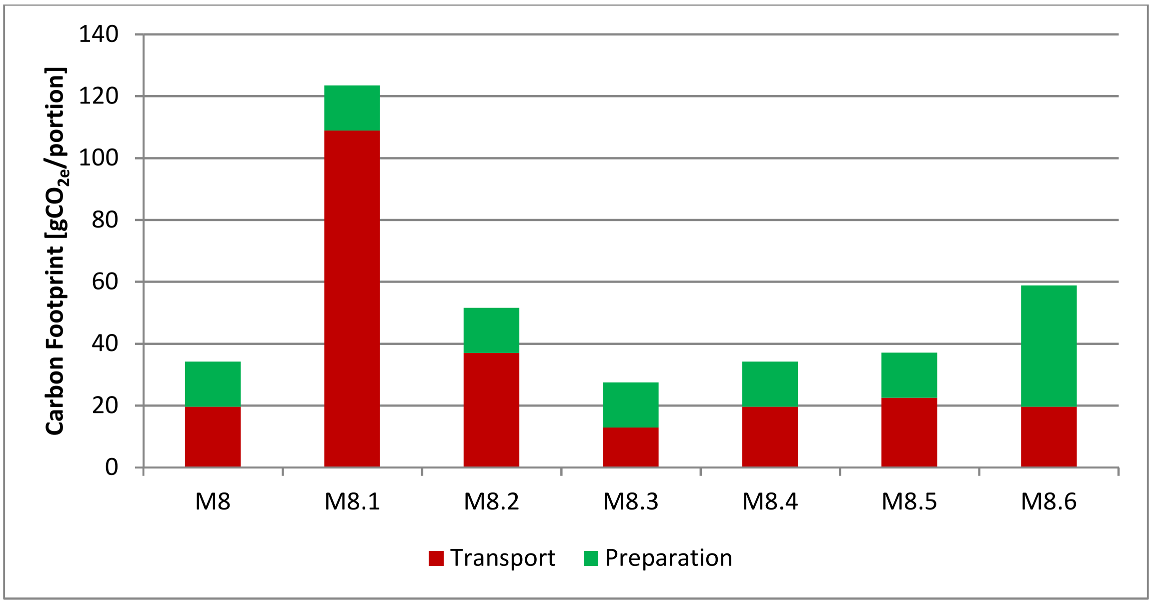


Figure 5-47: Results of sensitivity analysis on CF (transport and preparation phase only)

5.8 Validation through users' feedback

In this final step of the tool validation stage, a survey was sent to a number of catering companies in the UK, in order to gather some feedback on the perceived usefulness and user friendliness of the tool, and to improve it in its final version. Out of the 42 school catering companies contacted by the researcher, only 5 catering professionals agreed to test the tool and complete the survey. This is a very small number and therefore the results of the survey cannot be used to accurately predict how a potential user of the tool might feel when using it. However, the feedback provided by the catering professionals who responded to the survey was very useful in identifying aspects of the tool that could be improved and in giving an indication of what some professionals in this sector consider are the main potentials offered by applying such a tool and the main barriers to its application.

In the following, the results of this process are presented by reporting each question of the survey along with the answers obtained and briefly discussing the related implications.

Testing the general satisfaction with the tool and the perceived user friendliness.

Question 1: Please rate your agreement with these statements.

- It was easy to learn how to use EATS;
- I feel comfortable using EATS;
- The user manual provided is clear;
- The interface and the presentation of results are pleasant and clear.

The purpose of this question was to test whether the tool meets the requirements of *meaningfulness* and *usability* (requirements 2 and 3, Section 3.1.). Based on the answers of the participants, it was possible to assess whether the interface needed to be improved to become more user friendly and whether the results provided were easy to understand. These are both necessary conditions in order for the tool to be utilised on a large scale, and therefore strongly influence the potential impact of this research work. The 5 participants agreed with all the statements, and two of them provided additional comments. One suggested some changes in the name of the ingredients (e.g. “courgettes” instead of “zucchini”), the other added: “*I would be happy to use the tool. As a purchaser I would want to ensure the origin was as precise as possible to get the right outcome*.”

Due to this comment, two additional options were added to the country of origin dropdown list in order to enable users to highlight the case where products were sourced locally, those were: “closer than 30 miles” and “closer than 100 miles”.

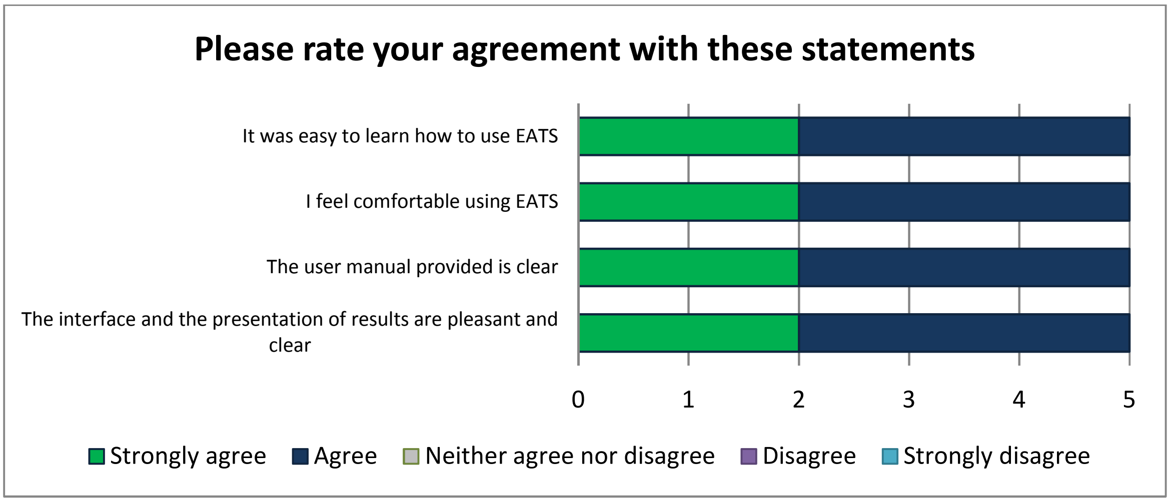


Figure 5-48: Users’ general satisfaction with the tool

Assessing the contextual applicability of EATS

Question 2: When filling in the ingredients table, was there any product that was missing from the list provided? If yes, which one/ones?

The purpose of this question was to assess the comprehensiveness of the list of food products provided (requirement 1, Section 3.1), and to identify any missing ingredients. Two participants stated that they found all the ingredients they needed in the list while three stated that they could not find all of them. When asked to list the missing ingredients they answered: cornflour, fruit juice, tinned tomatoes and herbs. The second item was already on the list (under apple juice, pineapple juice and orange juice), no additional search was therefore performed. As for the remaining items, a systematic search of the literature was performed to include them in the databases of carbon and water footprints. No literature was found for cornflour or herbs; however, it was possible to add tinned tomatoes to the databases.

Assessing the perceived benefits associated with the use of the tool.

Question 3: The use of EATS can bring the following benefits:

- Demonstrate the commitment of your organization to delivering a sustainable catering service
- Aid in the preparation of sustainability reports;
- Obtain certifications (e.g. Food for Life Partnership);
- Identification of *hotspots* in the menus (i.e. ingredients or meals that have a high impact on the environment);
- Help create sustainable menus;
- Other – please specify.

The purpose of this question was to investigate the reasons why catering companies would choose to use EATS. All the participants agreed with three of the options offered: the identification of *hotspots,* aid in the preparation of sustainability reports and the demonstration of the commitment of their organization to sustainability issues. One of them did not make a statement when choosing the option “help create sustainable menus”, and two did not express an opinion regarding the option “obtain certifications”. This might be due to the fact that there is no explicit link between the results offered by the tool and the requirements that catering companies need to fulfil in order to receive the main sustainability certification in this sector (offered by the Food for Life Partnership programme). This aspect will be further developed in the discussion section.

When asked to provide additional comments, one of the participants stated that if the “local” option was added to the origin dropdown list, it would help make the case for obtaining the Food for Life certification. This comment is in line with the one mentioned above that asked for the addition of a “local” option, and was addressed as explained previously. One of the participants suggested as an additional benefit the option "Aid to winning contracts", which is a potential benefit of the application of the tool which could have a significant impact on its spread.

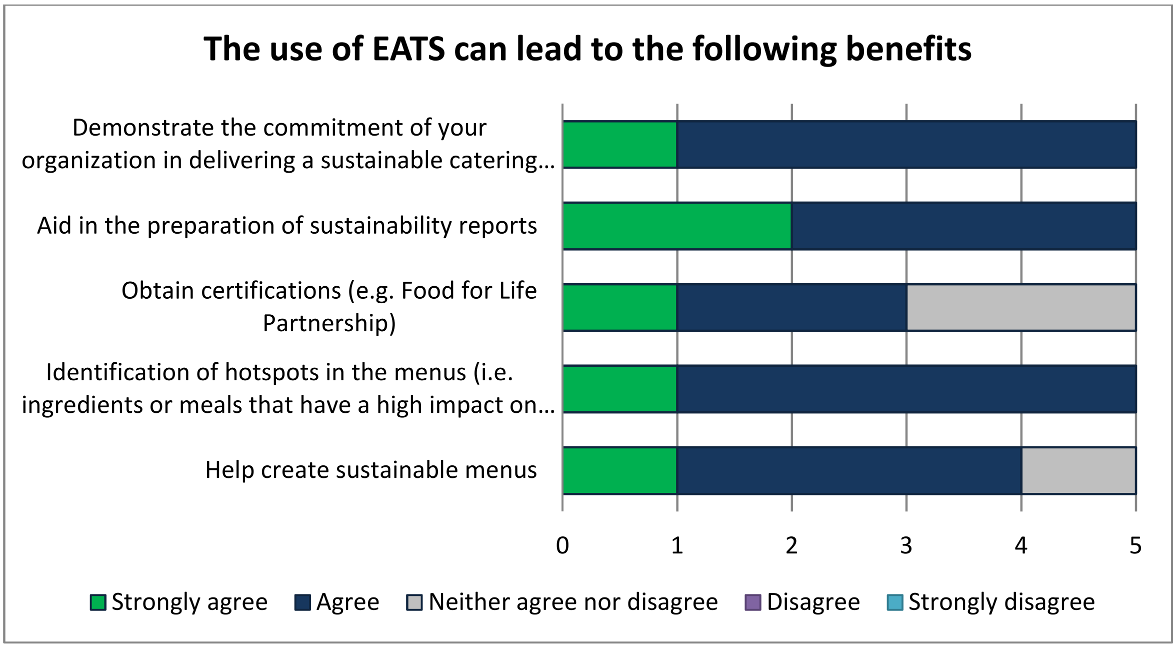


Figure 5-49: Perceived benefits of using the tool

Assessing the perceived barriers to the implementation of the tool

Question 4: Barriers to the implementation of EATS in your organization

- Lack of time;
- Lack of staff;
- Confidentiality of the results obtained;
- Other.

Not surprisingly the option "lack of time" was chosen by all the participants. "Lack of staff" was seen a constraint for three participants, while one did not express an opinion and one strongly disagreed. These two barriers represent a potential constraint to the spread of EATS; however the author's view is that if some of the benefits outlined above became a priority for catering companies, the workload would be organised differently and those barriers would become less evident.

Three out of the five participants did not believe the confidentiality of the data would be a problem, which is probably due to the fact that catering companies are already used to sharing their data in order to obtain certifications.

Under "Other barriers" one of the participants added: *"Suppliers change source countries regularly, meaning the charts are always changing"* and another participant wrote *"May conflict with existing system. Additional work to repeat current system but different outcome. Could the two systems be merged?"* These two comments provide a very interesting perspective on the prospect of further developing EATS. Catering companies use procurement tools to keep track of changes in orders (deriving from changes in the menus) and at the same time to assess the nutritional value of each recipe and the related allergens. Therefore if the analysis developed by EATS could be merged with existing procurement tools, this would eliminate the additional workload created by the introduction of a new tool. Currently suppliers have to communicate any change in nutritional values or allergens to the catering company, and this is updated in the procurement tool. In the same way, there is no reason why changes in the country of origin of products could not be updated in the procurement tool as well, eliminating the barrier suggested by one of the participants.

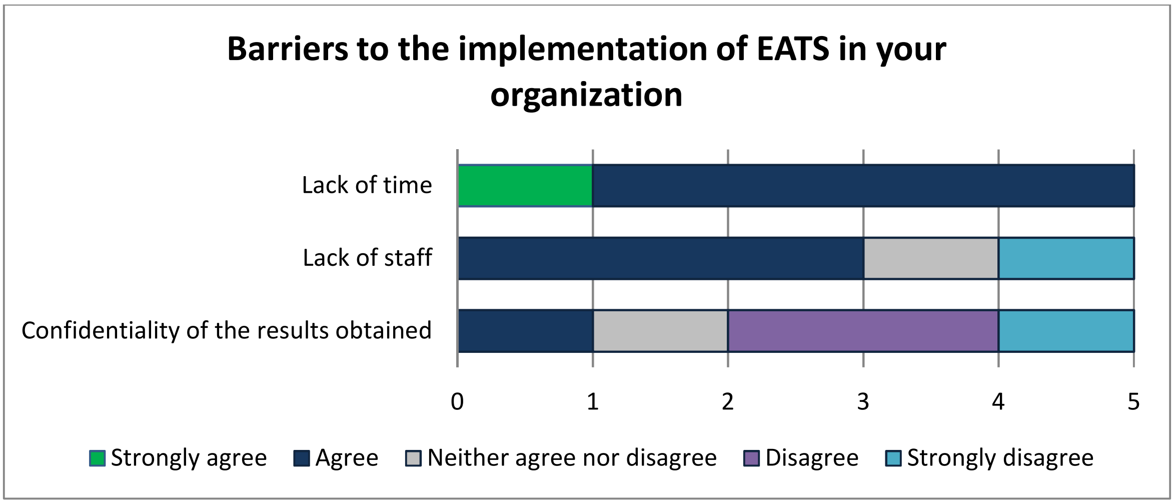


Figure 5-50: Perceived barriers to using the tool

To conclude, this last stage of the tool's validation enabled the researcher to:

- Verify that there is an interest in (at least some) catering companies towards the potential application of EATS or similar tools to enable a reduction of the environmental impact of the menus served;
- Identify the main perceived benefits and barriers associated with the implementation of EATS;
- Test the comprehensiveness of the list of food products provided by tool and add the missing ingredients identified.

The additional comments provided by the participants clearly show how, when thinking about the sustainability of the service, they believe transport distances play a bigger role than the composition of meals. One of the potential impacts of the application of EATS is the dismantling of the "common sense myth" on *food miles*, which has been identified as recurrent in the public opinion (Garnett, 2008, DEFRA, 2005, Morgan, 2010).

5.9 Application of the developed procedural assessment: modifying a menu

An example of the application of the procedural assessment described in Section 4.5 is provided here. The aim of this procedure is to modify an existing menu, in this case the menu presented in the first case study, with the purpose of reaching a targeted reduction in terms of both CF and WF. In this example, the target is a 20% reduction for both the total values of CF and WF. For the full calculations developed in this section see Appendix C.

The four-week cycle menu of CS1 is analysed with EATS and the total CF and WF (calculated for one person for four school weeks, hence 20 meals) are: CF = 23124 gCO_{2e} & WF = 9278 litres. Then, two scenarios are defined. A scenario comprises an alternative menu in which some of the meals have been replaced by low impact alternatives:

- In the first scenario, the purpose is to prioritise the reduction of CF, and therefore the four meals which have the highest CF are replaced with alternative meals;
- In the second scenario, the purpose is to prioritise the reduction of the WF, hence the four meals which have the highest WF are replaced with alternative meals;

In this example all the replacement meals were selected from the second case study (CS2), choosing respectively the four main and side dishes which had the lowest CF and the four main and side dishes which had the lowest WF (See Table 5-12). It is important to highlight that no additional considerations were made on the nutritional quality of the new menu suggested, as the procedural assessment does not consider this aspect, but only focuses on the environmental impact of the menus. For obvious reasons the suggestion of alternative menus should be made after making sure that they perform equally or even better in terms of nutrition; however in order to provide an example of application of the procedural assessment this aspect was omitted herein.

The meals presented in CS1 include a main dish and a side dish while in CS2 main dishes and side dishes were analysed separately; each meal from CS1 was therefore replaced by a combination of a main dish and a side dish from CS2. Table 5-15 provides, for each scenario, the codes and impacts (both the numerical value and the colour code) of the meals removed from the initial menu and of those chosen to replace them.

Table 5-15: Meals removed and replacement meals and relative impacts

Scenario	Meals removed (from CS1, Tables 5-7to 5-10)			Replacement meals added (from CS2, Table 5-12)		
	Code	CF [gCO2e]	WF [litres]	Codes	CF [gCO2e]	WF [litres]
Minimum CF	M_2Th	2171 🔴	486 🟡	V12+S6	155 🟢	226 🟢
	M_3M	2576 🔴	741 🔴	F1+S4	181 🟢	43 🟢
	M_4M	2116 🔴	614 🟡	V1+S3	303 🟢	158 🟢
	M_4Th	2107 🔴	509 🟡	V6+S7	318 🟢	165 🟢
Minimum WF	M_1M	1812 🔴	515 🟡	F1+S6	164 🟢	34 🟢
	M_3M	2576 🔴	741 🔴	V10+S4	432 🟢	161 🟢
	M_4M	2116 🔴	614 🟡	V1+S3	303 🟢	158 🟢
	M_4W	1962 🔴	548 🟡	V7+S7	418 🟢	166 🟢

Based on these substitutions, it was possible to calculate the CF and WF savings obtained in the two scenarios and the total savings per pupil per academic year (considering that the academic year consists of 190 days). These values are presented in Table 5-16.

Table 5-16: Savings obtained through the application of the procedural assessment

Scenario	% of CF saved	% of WF saved	CF saved per pupil per year [kgCO$_{2e}$]	WF saved per pupil per year [m^3]
Minimum CF	35%	19%	76	17
Minimum WF	31%	20%	68	18

In this case, only one of the two scenarios meets the reduction target for both CF and WF, and therefore the "Minimum WF" scenario is the selected option. Alternatively, the "Minimum CF" scenario could be modified to meet the 20% WF saving, and at the same time achieve greater savings in terms of CF compared to the other scenario.

Figure 5-51 shows the average CF and WF of a meal in the current menu and in the two alternative menus. It is important to highlight that such substantial savings were obtained by replacing only one meal per week with a low impact alternative (and therefore with minor disruption). The potential impact of applying similar changes at national level are discussed in Section 5.10.2.

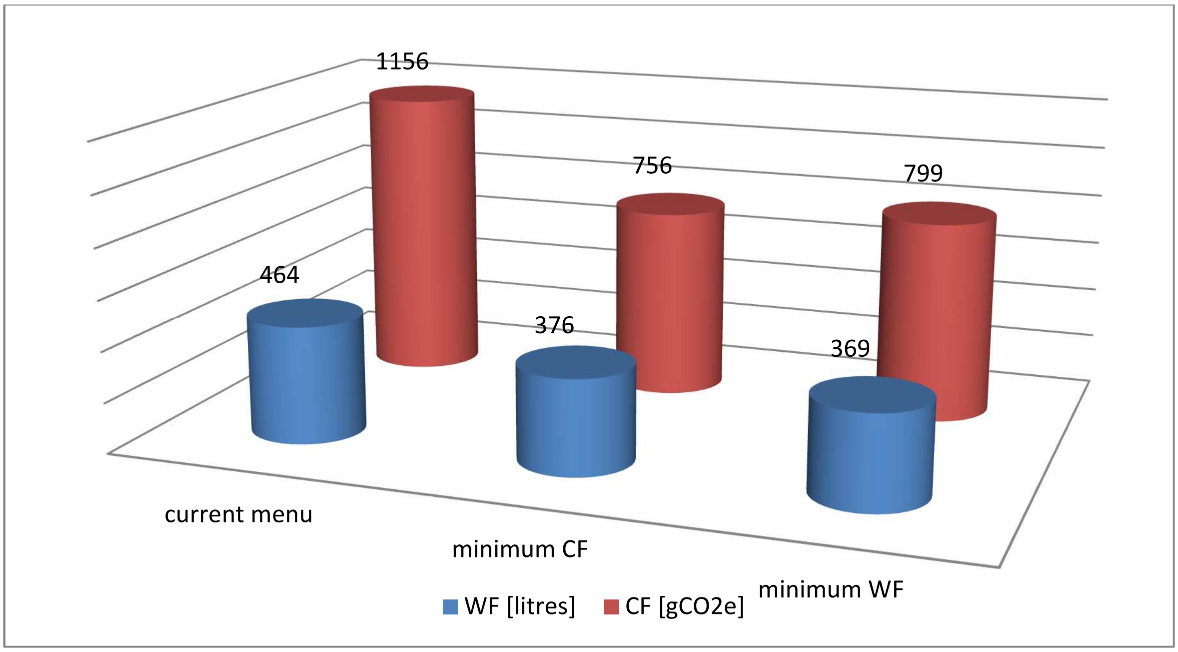


Figure 5-51: Average impact of a meal in the current menu and the two alternative menus

5.10 Discussion

In this section, the findings of this research are discussed critically in the context of existing research. The potential implications are investigated together with the necessary conditions for their verification and the limitations of this study are outlined and discussed.

5.10.1 Comparison with literature

A literature review was performed to identify relevant studies that used an LCA approach to assess the environmental impact of school meals. Four studies were found that responded to the research criteria.

Study 1: Saarinen et al. (2012) performed an LCA of nine lunches served by a primary school in Finland. In this work the impacts were calculated from *cradle to plate*. This paper does not provide the full recipes used to calculate the impacts of the meals analysed, therefore a direct comparison with the results that would have been obtained by using the EATS tool cannot be performed. Nevertheless, the values of CF obtained in this work ranged from 570 to 2060 gCO_{2e} per meal, and are therefore comparable with those obtained in the first case study of this doctoral thesis that ranged between 422 and 2797 gCO_{2e} per meal (see Figure 5-52).

Study 2: Benvenuti et al. (2016) assessed the CF and WF of 106 different dishes served in an Italian primary school and developed an optimised menu. In this case, Benvenuti et al. (2016) only considered the agricultural production of the ingredients (adopting a *cradle to farm gate* approach) and therefore underestimated the real impacts by excluding transport and preparation. Similarly to the previous study, the full recipes used in this work are not provided. However, the range of values of CF obtained in this work varies between 125 and 1691 gCO_{2e} per meal, partly overlapping with the range of values found in this current work, but towards the lower end, which is most likely a consequence of the smaller system boundaries adopted by Bevenuti and colleagues.

As for the quantification of the WF, this ranged between 471 and 2804 L per portion. These values are significantly higher than those found in the first case study of this work (where the WF ranged between 244 and 848 L per portion); this is probably due to the fact that Benvenuti et al. (2016) used the global average values of WF in their analysis, while in this study the national values were used according to the country of origin of each ingredient (as explained in section 4.3.1). For the UK, the national values are generally lower than the global values (as can be seen in Figure 5-10).

To verify the validity of the values of WF obtained in this work, the average WF of a primary school meal, obtained in the third case study as equal to 568 L per portion, was compared with a study by Vanham et al. (2013). In their work, they estimated that the WF of a recommended diet (based on German dietary recommendations) is 3291 litres per capita per day. If alcoholic beverages and non-edible agricultural products are subtracted, it results in 2980 litres per capita per day. The WF of a school lunch, as estimated in this work, represent about 20% of that, which is to be expected as in their calculations they assumed an average daily energy intake of 2200 kcal, whilst the average energy intake of the school meals of CS3 is 495 kcal (this value was extracted from the PSFS data set).

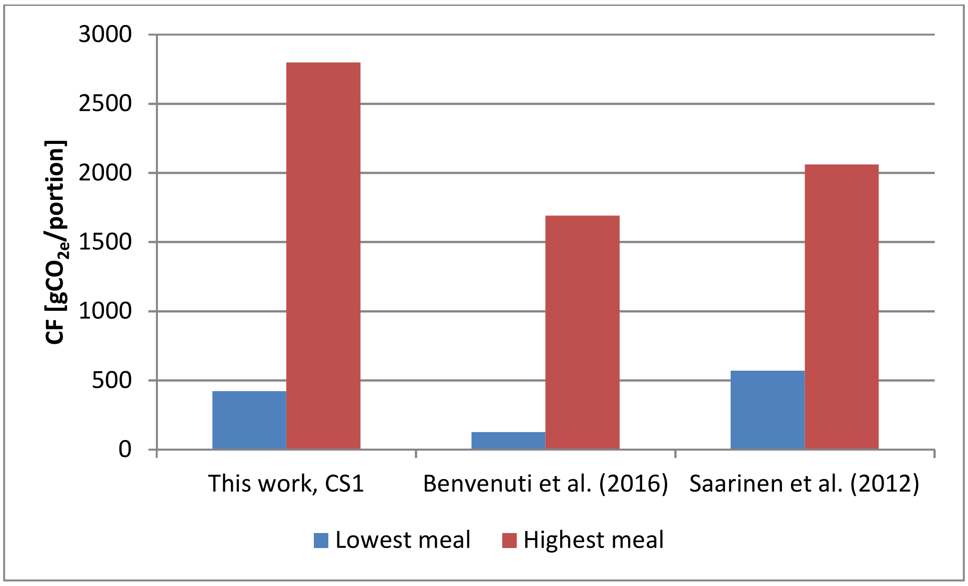


Figure 5-52: Comparison between the lowest and highest value of CF obtained in CS1 of this work, in the work conducted by Benvenuti et al. (2016) and by Saarinen et al. (2012)

Study 3: Ribal et al. (2016) calculated the CF of a set of dishes (20 starters, 20 mains and 7 desserts) served by a school caterer in Spain, basing their results on secondary data from LCA studies, and including the whole supply chain (from *cradle to plate*). Based on this, they developed an optimization algorithm to generate menus that responded to a set of nutritional, environmental and economic requirements. It is important to highlight that Ribal and colleagues did not conduct a systematic literature review to extract the values of CF of different food products from the literature, but instead they chose for each food product one source from which to take the value of CF. This entails that the results they obtained are highly dependent on the sources chosen. For instance, in the case of beef there is a large variability of values of CF in the literature (the systematic review conducted in this work showed a variation between 8031 and 50151 gCO_{2e}/kg, with a 95% confidence interval raging between 24492 and 28654 gCO_{2e}/kg, as shown in Table 5-2). Ribal et al. (2016) used a value of CF of beef equal to 20385 gCO_{2e} /kg, therefore significantly lower than the average value of 26573 gCO_{2e} /kg used in this current study.

As this study provided the detailed recipe of each dish, it was possible to re-calculate the CF of a selection of dishes using EATS in order to test the tool against an existing set of results. Amongst the main dishes, those for which all the necessary ingredients could be found in the EATS database were selected, and the results of this comparison are shown in Figure 5-53. It is possible to see that for the dishes containing beef the CF calculated with EATS is higher than that obtained by Ribal et al. (2016), whilst the opposite can be noticed for the chicken-based dishes (the CF of chicken used in the EATS database is 4037 gCO_{2e} /kg, while the one used by Ribal and colleagues is 5970 gCO_{2e} /kg). Nevertheless, if the methodological differences explained above are taken into account, the results obtained with the EATS tool are reasonably close to those obtained in the original work.

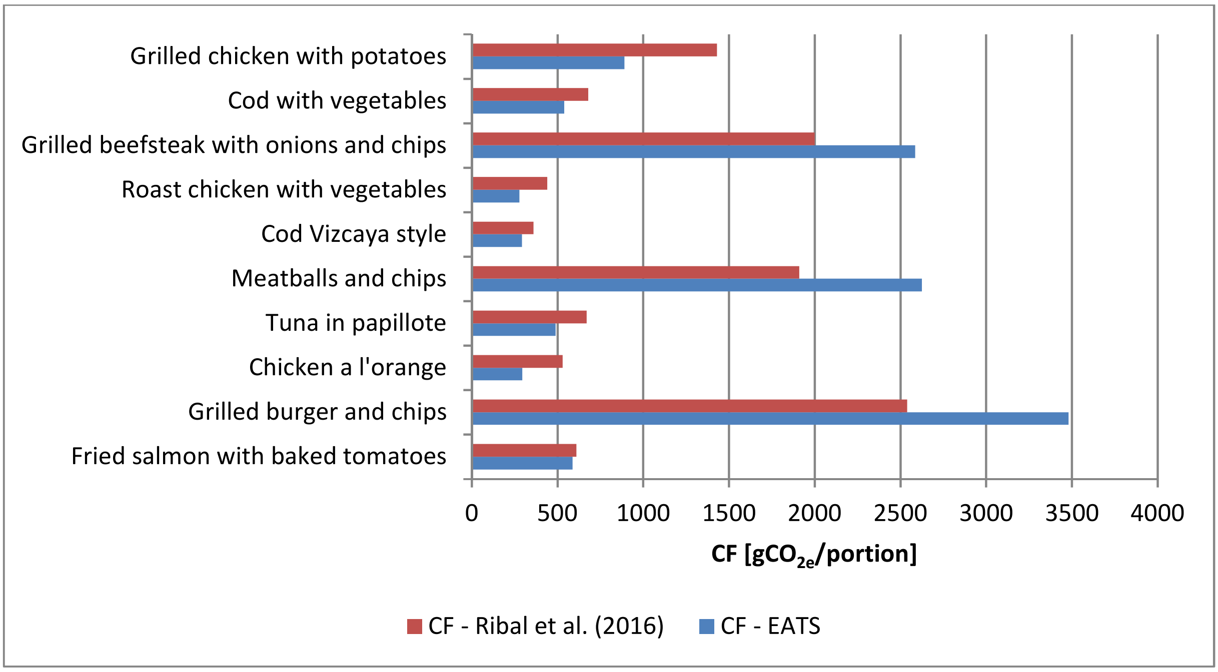


Figure 5-53: Comparison between the results obtained by Ribal et al. (2016) and those obtained applying the EATS tool to the same set of dishes, for ten selected dishes

Study 4: Wickramasinghe et al. (2016) assessed the contribution to climate change and the nutritional quality of primary school meals served in England, using the PSFS as a starting point. This approach presents several similarities with the work conducted in the third case study (CS3) of this doctoral project, as in both cases the PSFS dataset was used to conduct the analysis. However, there are a number of different methodological choices, and consequent variations in the results which are contrasted and compared to the results presented in this doctoral thesis. In their analysis, the value of CF obtained for an average primary school meal was 720 gCO_{2e}. This is approximately 30% lower than the value found in this current study (equal to 1059 gCO_{2e}). The main methodological differences between the two studies are that in this work a number of additional considerations were included. These are:

- Transport emissions (even though their contribution is relatively low anyway);
- Waste along the supply chain (as explained in Section 4.2.7);
- Weight loss caused by cooking (as explained in Section 4.4.2.3).

These are very important considerations, not least for the last factor which can significantly affect the results: for instance, meat can lose around 30% of its weight due to cooking (Chappell, 1954). Not considering this weight loss when calculating the CF of a meal (based on the weight of a serving at consumption stage, which is the quantity recorded in the survey) can cause an underestimation of the CF of food items that contribute significantly to the overall impacts. If food waste and weight losses were not considered, the average value of CF of a primary school meal from CS3 of this study would be 780 $kgCO_{2e}$. In other words, by using the same list of meals as the one analysed by Wickramasinghe et al. (2016), and removing the main differences in the calculation of the CF (i.e.

accounting for food waste and weight losses), the average value of a primary school meal calculated with EATS is only 8% higher than the one calculated by Wickramasinghe and colleagues. This remaining difference can be explained by the different underlying data on the CF of food products collected by the authors of this paper.

In conclusion the EATS tool yields results that are comparable with those obtained by previous research. Furthermore, the main difference between the research work presented in this doctoral thesis and that presented in the four articles analysed above is - the creation of a tool that can be directly used by catering companies to assess the performance of their meals. The work by Wickramasinghe et al. (2016) is similar to the work here presented as they both aim at assessing the environmental impact of meals commonly served in primary schools in the UK. However, it differs from it for three main reasons:

- Firstly, due to the methodological differences discussed above;
- Secondly, because it does not include the WF in the assessment;
- Lastly, because it does not provide a platform to compare alternative recipes.

5.10.2 Application, potential impact(s) and necessary conditions

EATS has been shown to have enormous potential to be used as a tool to assess the environmental impacts (i.e. CF and WF) of primary school meals and by using the accompanying procedural assessment in parallel it could help users develop menus with significantly reduced environmental impacts. This has potential positive impacts but for them to be achieved necessary conditions are required. Both of these aspects are now discussed.

5.10.2.1 Multi-sectoral, regional, national and international application

EATS was created for direct application to the UK primary school catering sector, although with minimal adaptation EATS (and therefore the procedural assessment it informs) could easily be applied and impact upon any public food sector, and indeed the tool is equally applicable to all those engaged in designing menus, whatever the scale. In order to apply EATS to other types of food services, such as secondary education, hospitals, prisons, workplace and university canteens, the list of food products recorded in the CF and WF databases would need to be expanded to include any missing products served therein (for instance tea and coffee).

In order to apply EATS to catering services (and other food sectors) in other countries outside the UK (but in Europe) a number of measures would be required.

- Firstly, the list of food products recorded in the databases would need to be expanded to include all those food products commonly served in the country of interest;
- Secondly, the emission coefficients used in the current version of EATS to calculate the contribution to climate change of the transport and preparation phase are taken from UK

datasets (see Sections 4.2.4 and 4.2.6), and therefore would need to be updated to the equivalent values calculated for the country of interest;

- Thirdly, the transport routes and distances from each country of origin were calculated assuming the UK as final destination, and therefore would need to be updated.

As shown by Figure 5-3, the literature of LCA of food is significantly Eurocentric; for this reason if EATS were to be adapted to a country outside of Europe the accuracy of the results would certainly be reduced. Hence for the reliability to be improved the tool would need a number of regional refinements over and above those listed above.

5.10.2.2 Potential impact(s)

The potential impact arising from the application of the procedural assessment suggested by this research to all primary schools in England is discussed here by using, as a starting point, the results of Section 5.9 (in which potential savings in the CF and WF of the menu analysed in the first case study are quantified) and of the third case study (in which the overall CF and WF of primary school meals served in England are estimated). In order to provide an example of application of the procedural assessment, two alternative menus were suggested by replacing the meals that had the highest CF/WF with low CF/WF alternatives. In the "Minimum CF" scenario the CF of the menu was reduced by 35%. In the "Minimum WF" scenario the WF was reduced by 20%. In Section 5.6.1 the total CF and WF of primary school meals in England in one year were estimated as 329 million kgCO$_{2e}$ and 177 million m^3.

If all the primary schools in England were to take a similar initiative to the one presented, and with the help of the procedural assessment informed by EATS achieved a 35% CF reduction in their menus, this would mean a total reduction of 114 million kgCO$_{2e}$ in one year. This is roughly equal to the emission reductions obtainable from stopping all road traffic one day each week in the city of Glasgow [calculation based on the value of emissions from road traffic reported by the Department for Business Energy & Industrial Strategy (2015)]. Similarly, the overall saving at national level, associated with a 20% reduction in the WF of all the school menus in the country (as obtained in the "Minimum WF" scenario) would be equal to 36 million m^3. An overview of the savings obtainable at national level in the two scenarios analysed is presented in Table 5-17. These figures show that significant savings could be obtained if the procedural assessment suggested was adopted at national level.

Table 5-17: Potential reduction of CF and WF at national level through the application of the procedural assessment

Scenario	CF saved	WF saved	CF saved in England per year [million kg CO$_{2e}$]	WF saved in England per year [million m^3]
Minimum CF	35%	19%	114	34
Minimum WF	31%	20%	102	36

5.10.2.3 Necessary conditions

First necessary condition:

Catering companies would need to be willing to allocate human and economic resources to use the procedural assessment *and EATS when planning new menus.*

In order for this to happen, catering companies would need to receive incentives to reduce the environmental impact of their services. This could be promoted through regulation, for instance in the form of tax reductions, or by giving priority to companies that can prove they have a lower environmental impact in the bidding process. Alternatively, the provision of an environmentally sustainable food service could be promoted by adapting the existing certification schemes to become more quantitative, for instance by including carbon reduction targets, as is already the case in other sectors (e.g. the energy efficiency certification of buildings). For instance, the target savings set within the procedural assessment could be suggested through regulation. Finally, if the tool was to become more user friendly, or if it was incorporated in existing procurement software already in use by catering companies (as suggested by one of the interviewees), the time needed to train staff to use it would be reduced and therefore catering companies would be more willing to adopt it.

Second necessary condition:

EATS would need to be regularly updated.

In order for this condition to be verified the tool needs to be built in a transparent way that enables easy updates (requirements 6 and 7, Section 3.1). However, the update of the tool would need to be responsibility of a single person or institution, to ensure that the validity of the results is maintained and to avoid that the tool is updated on an *ad hoc* basis by different institutions into several versions (providing different results).

Some parts EATS would be relatively straightforward to update (e.g. emissions coefficients related to the electricity mix and emissions coefficients related to transport, which are both updated on a yearly basis). Other parts would require significant more time and resources: in particular keeping up-to-date the CF database, due to the large amount of LCA literature published every year on food products.

Third necessary condition:

Parents and pupils need to be willing to accept changes in the menus (initiatives like meat-free days or simply variations in traditional recipes to replace *hotspots* with lower impact ingredients).

In order for this to happen, changes in the menus that aim at decreasing the environmental impact of the service, would need to be carefully thought through in order to include a range of considerations on the nutritional quality and appeal (visual and taste) of the meals, the economic feasibility and the cultural acceptability (considering the ethnical background of the students enrolled to each school). The cultural acceptability of dietary changes (such as meat reduction and consumption of seasonal and local products) was investigated by O'Keefe et al. (2016). This study identified a number of barriers to changing eating practices (including the resistance to any perceived choice restriction, and the perception that meat plays an important role in providing a nutritionally complete diet, especially for children). It also highlighted that consumers would be more willing to change their habits for health or cost reasons rather than environmental reasons. For these reasons, when applying changes to school menus in line with the ones recommended by this research, the messages used to communicate them to families would have to be focused on the synergies between environmental benefits and associated health benefits. Furthermore, less radical changes to the menus (e.g. if meat was partially replaced by an alternative source of protein three days a week rather than if no meat option was available for one day a week) would be more easily accepted by parents and pupils and would not be seen as a constraint to their freedom of choice.

5.10.3 Limitations of this study and how they could be addressed

A discussion of the limitations of this study is provided herein, together with the suggestion of potential strategies to address them in future research (this aspect is further developed in Section 6.3).

- When defining the system boundaries of the EATS tool (see Figure 4-4), a number of inputs and outputs relevant from a Nexus perspective were left outside the system boundaries. These included:
    1. The inputs and outputs linked to the production, management and disposal of the infrastructure and equipment necessary for food production, distribution, school meals preparation and consumption
    2. The inputs and outputs linked to the disposal of plate and kitchen waste, packaging waste and human excretion, including the potential for energy generation from waste
    3. The water required and the water polluted when producing fuel and energy used for the distribution of food, when shipping goods and during the preparation of meals

  In the first two cases, the mentioned flows were excluded as they were considered outside the scope of this work, which was focused on the assessment of the environmental sustainability of different menu choices; although, from a nexus perspective, aspects such as the impacts/benefits of waste management decisions are particularly relevant. Finally, the water inputs for the production of energy and fuel used for transport and meals' preparation and the water used during meals' preparation were excluded as they were considered to be negligible when compared to the water footprint of production of the ingredients (Jefferies et al. 2012), while the water footprint linked to shipping goods was not included as no method currently has been formulated to assess this water use (Vanham, 2016).
- In the literature review (performed to create the CF database), a significant number of food products were found to be underrepresented. Therefore, the statistical analysis performed to

verify the meaningfulness of using the average values of CF, was constrained by the small sample size. Due to data availability, when calculating the CF of the production phase, it was not possible to take into account the country of production of each food product. Furthermore, even though the LCA methodology is ISO standardized (ISO, 2006c, ISO, 2006b), a number of methodological choices are left to the practitioner (e.g. system boundaries definition, choice of functional unit, etc.). Whilst measures were taken, when collecting the data, to limit the consequent variation in the results, (as explained in Section 4.2.2), sometimes there is a lack of information disclosed within literature sources making vetting somewhat impossible.

- The statistical analysis performed on the data collected in the CF database, enabled to calculate the accuracy of the average values of CF of the food products listed within the tool. However, it was decided not to perform a similar assessment for each meal analysed by the tool (i.e. provide error bars for the meals of CS1, CS2 and CS3). This is because the level of uncertainly of the results provided by EATS is not only connected to the quality of the data of the CF database, but also to several other assumptions (e.g. travel distances, routes, cooking times, energy consumption of cooking appliances), and therefore it was deemed not feasible to systematically assess the uncertainty of the results of the tool.
- The decision to represent the WF in its aggregated form in the outputs of EATS, as the sum of the blue, green and grey component could be considered misleading due to the significantly different opportunity costs of blue and green water, and the different physical meaning of grey water when compared to blue and green water. Nevertheless, this decision was taken with the purpose of providing simple and understandable results to the users of the tool. A breakdown of the blue, green and grey components of WF was presented in the three case study analyses, in order to discuss how the results are affected by this choice. In a future version of the tool this level of detail could be included (e.g. by enabling the users to choose between considering the total WF, or the three components separately).
- The survey used to gather the opinion on the tool of its potential users was completed by only a small number of participants. This means that the results are only indicative but not fully representative of how the average person would feel when trying to use EATS. One way to overcome this limitation could be by organizing workshops in catering companies in which members of staff are taught how to use EATS and their feedback on the tool is directly collected.
- Contribution to climate change and water use were the only two impact categories considered in this study, this decision was taken as a consequence of data availability and the requirement of providing results that are easy to communicate to an audience of non-LCA experts. However, many scholars have highlighted the importance of considering all the impact

categories used in a traditional LCA, in order to avoid the risk of burden shifting (Ridoutt et al., 2014, Schmidt, 2009). If in the following years more data was to become available (e.g. more researchers started to include land use amongst the impact categories) the analysis could be repeated for the additional impact categories. Furthermore, the threat to biodiversity conservation posed by the excessive consumption of wild fish is not represented in this work, as the meals containing wild fish were amongst those with the lowest impacts (especially in terms of WF). For this reason, this tool (and the procedural assessment it informs) should be used in combination with existing recommendations [such as the FAO code of conduct for responsible fisheries (FAO, 1995)].

- In the third case study, the average CF and WF of a primary school meal in England are calculated based on the data set recorded in the Primary School Food Survey. It should be noted that this survey was conducted in 2009 and no similar survey has been conducted since. A number of political decisions taken between 2009 and now have affected food provision in schools (Nelson, 2014). For this reason, this data source might not precisely represent the current situation. Furthermore, the data recorded in the survey did not include information on the amounts of food that were prepared in the school kitchens but not served. Additionally, in this case study the meal preparation phase was not considered, due to lack of data. For these reasons the values of CF and WF of an average primary school meal obtained in this case study are likely to underestimate the real impacts. Furthermore, as the PSFS was conducted over three months, the results might be affected by seasonality and not fully represent the average impact of a primary school meal in England.
- The example of application of the procedural assessment provided in Section 5.9, does not include considerations on nutrition when suggesting alternative, low impact, menus. Therefore the reductions in CF and WF obtained, might be an overestimation of the reductions that would have been obtained if, in the suggestion of the improved menus, the nutritional element had also been taken into account.
- This study focused solely on environmental sustainability, neglecting social and economic sustainability; however, these aspects are of crucial importance when addressing the school catering sector. In order to support decision makers in the design of a catering service that is socially sustainable two main aspects would need to be considered: nutritional properties and cultural acceptability of the suggested new menus. In terms of economic sustainability, it is important to remember that schools (as all public sectors) are constantly constrained in terms of budget. In order to include this aspect in the analysis, the suggested procedural assessment should be expanded to suggest new menus that achieve at the same time improved nutritional content and lower environmental impact without increasing the costs.

6 Conclusions and Future Work

Current food production and consumption practices are depleting natural resources and polluting ecosystems at a rate that is unsustainable, and they are also one of the main causes of anthropogenic climate change. If this trend does not change, externalities of food production will be exacerbated in future decades due to population growth, economic growth and consequently changing lifestyles. This will compromise the capacity of nations to produce food for future generations.

Strategies that aim at rebalancing the demand for food with the planet's limited capacity to support its production, need to focus both on the production and the consumption sides of the equation. The research presented in this doctoral thesis is aligned with one of those strategies, and specifically the one supporting the promotion of a dietary change towards diets that are less water intensive and that produce less greenhouse gas emissions.

The public food sector offers tremendous potential for influencing such a shift, but in order to do so the correct information on sustainable food choices needs to be delivered. Currently in the UK national guidelines for public food procurement and sustainability schemes for the catering sector fail to adopt a rigorous approach to environmental sustainability and avoid promoting a shift towards low impact diets. This research aims at addressing this shortfall by creating a procedural assessment that can be used to assess the environmental impact of menus served in the primary education sector, identify *hotspot* meals and design improved menus. The procedural assessment is informed by an LCA-based tool that catering companies and local authorities can use to self-assess the environmental impact of a primary school meal in terms of its carbon and water footprint.

The tool was tested with three case studies to demonstrate its potential in assessing the environmental impacts of an existing menu, of a set of *best practice* recipes and of the primary school catering sector at national level in England. Furthermore, the tool was validated through a statistical analysis of the underlying data, by testing the results it provides against an alternative tool and by collecting feedback from potential users. An example of application of the procedural assessment was provided and the potential impact arising from the application of such a strategy was discussed.

6.1 Summary of research

The research has achieved the objectives outlined in Section 1 by:

- Critically reviewing the existing literature to identify the best method to assess the environmental impact of food production in order to inform food production and consumption choices;
- Collecting from the literature and forming a database of values of carbon footprint (CF) and water footprint (WF) for a range of food products that comprehensively cover most ingredients used in the preparation of primary school meals in the UK;

- Using these values to develop a tool that can be used for the self-assessment of a primary school meal from *cradle to plate*;
- Verifying that the tool met a set of requirements through performing a statistical analysis of the underlying data, developing three case studies and collecting feedback from users, and validating the tool by comparing its results with existing studies;
- Developing a procedural assessment informed by the tool for the design of environmentally sustainable menus.

It is possible to draw the following conclusions from the research:

- Section 2 demonstrates a clear need to foster a cultural shift towards low impact dietary choices; however, it also reports that more clarity is required in order to communicate what is meant by "sustainable food". After reviewing existing methods for the evaluation of the resources used and the environmental impact of food production, LCA was chosen as the most powerful tool in serving this purpose and providing the correct information on the environmental sustainability of dietary choices.
- In the development of the Environmental Assessment Tool of School meals (EATS) two databases were created to calculate the carbon footprint (CF) and water footprint (WF) of school meals. From an analysis of the data collected in the CF database (presented in Section 5) a number of conclusions can be drawn:
    - The literature on food LCA is affected by a number of biases: it is mainly focused on the assessment of the global warming potential (GWP), with other impact categories significantly less represented; it mostly focuses on food products produced in Europe (followed by the US and Australia); and it is skewed towards a small group of food types (mainly meat and dairy), while other food products are largely underrepresented.
    - There is a clear hierarchy of food products in terms of their CF: meat from ruminant livestock presents the highest values, followed by dairy products, meat from monogastric livestock, fish, rice, legumes, fruit and finally vegetables.
- From an analysis of the data collected in the WF database (presented in Section 5) it appears that:
    - The geographical origin of production of food products is an important variable in assessing their WF. It is therefore crucial to have access to this information (at national level or possibly even at regional level) in order to provide accurate results in terms of WF.
    - As for the case of CF, there is a hierarchy of food products in terms of their WF. Certain food products have similar performances for both impact categories (meat

from ruminant livestock has amongst the highest values of both CF and WF), while in other cases there are discrepancies (for instance nuts have low CF but high WF).

- The trends identified in the analysis of the CF and WF databases were reflected by the case study analyses: dishes containing ruminant livestock products had the highest impacts, and vegetarian (with low dairy content) and fish based dishes had the lowest.
- From the analysis of the results of the second case study it emerged that across the life cycle of a meal the phase presenting the largest contribution to the CF is the production of the ingredients (between 76% and 94% of the overall CF). This highlights the importance of focusing on the composition of meals in order to reduce the life cycle impact of a meal.
- The third case study enabled the identification of a number of *hotspots* in the primary school meals consumed in England: beef and lamb-based main dishes (responsible alone for 37% of the total CF) and chocolate-based desserts (responsible alone for 19% of the total WF).
- In the example of application of the procedural assessment (Section 5.9) the following savings were obtained by replacing from each weekly menu (of the first case study) the meal characterized by the highest impact with a low carbon/low water alternative:
  - In the “minimum CF” scenario, a reduction of the total CF of 35% (equal to 76 $kgCO_{2e}$ per pupil per academic year) and of the total WF of 18% (equal to 16 m^3 per pupil per academic year);
  - In the “minimum WF” scenario, a reduction of the total CF of 31% (equal to 68 $kgCO_{2e}$ per pupil per academic year) and of the total WF of 20% (equal to 18 m^3 per pupil per academic year).
- The savings obtained in this example indicate that if a similar measure was applied to all primary schools in England the following savings could be achieved in one school year: in the “minimum CF” scenario 114 million $kgCO_{2e}$ and a WF of 34 million m^3, in the “minimum WF” scenario 102 million $kgCO_{2e}$ and a WF of 36 million m^3.

6.2 Value of the research

The value of the research was achieved by:

- Conducting a systematic review and a meta-analysis of the existing literature on the carbon footprint of 110 food products commonly used in the preparation of primary school meals in the UK;
- Developing a new dataset of values of CF of food products;
- Creating EATS, a tool that enables catering companies and local authorities to self-assess the CF and WF of a recipe, with the purpose of identifying *hotspot* meals and comparing alternatives in the design of new menus;

- Developing a procedure, informed by EATS, for the assessment of the environmental impact of menus served by the primary school catering sector and the design of improved menus (Figure 4-11).

EATS represents a new and unique method to assess the environmental impact of a school meal. It was built in order to meet seven main requirements, the fulfilment of which guarantee that the tool:

- Can be used to assess the environmental impact of the meals commonly served in the primary education sector in the UK;
- Is easy to use and presents accessible results for non-scientific audiences;
- Calculates the environmental impacts using a consistent method, including all the relevant phases of the life cycle;
- Can be straightforwardly reviewed and updated in time.

A similar procedural assessment was not available in the literature, and this shortcoming is reflected in the national guidelines and sustainability schemes for the UK catering sector, which fail to adopt a life cycle approach when promoting the provision of an environmentally sustainable service.

Thanks to its simple user interface and to an accurate choice of the results provided and of the information required for the quantification of the impacts, EATS and the procedural assessment it informs offer enormous potential for future impact. Firstly, in influencing policy makers by suggesting strategies to reduce the environmental impact of the catering sector in primary education, such as introducing changes to menus and give preference to seasonal products. Secondly, in informing decision making by providing a method for the development of low impact menus. Thirdly, in engaging and educating non-scientific audiences (and in particular students) on the topic of sustainable food choices.

6.3 Recommendations for further work

A number of possibilities for further research were recognized during the course of this project:

- The procedural assessment developed in this research should be expanded in order to include nutritional considerations and economic considerations in the design of new school menus. This could be done by developing EATS into a new optimization tool that generates new recipes that meet a set of environmental, nutritional and cost requirements.
- A more comprehensive range of impact categories should be used in the assessment of the environmental impact of a meal, including for instance land use and biodiversity loss. However, this should not compromise the main purpose of the tool, which is to enable non-scientific audiences to understand the environmental impact of food choices.
- EATS could be expanded to include more food products in order to enable the assessment of meals served by other sectors (e.g. hospitals, universities, prisons, workplace canteens, restaurants, etc.). Furthermore, by combining the results offered by the tool with existing data

on food consumption in the afore-mentioned catering sectors, it would be possible to calculate the contribution of each sector to national GHG emissions and national water consumption and to quantify the potential impact of strategies to reduce the carbon and water intensity of the menus served.

- The statistical analysis performed to assess the uncertainty of the value of CF of each food product should be expanded (including considerations on the uncertainty of the calculation of the impacts linked to the remaining life cycle stages) to provide a range of uncertainty for the CF of each meal calculated by the tool
- EATS should be developed on a different platform in order to increase its user-friendliness. Additionally, this would enable to increase the level of detail of the information provided by the user. For instance, the tool could provide a customised dropdown list of potential countries of origin (including extra-EU28 countries) for each ingredient, based on the largest exporters of each food product to the UK. In this way, the current limitation to the EU28 countries would be removed, without compromising the user-friendliness of the tool (as this limit was set in order to provide the user with a manageable list of countries). Furthermore, by developing EATS on a different platform, this could be modified to enable the user to choose a mode of transport for each ingredient (in the current version of EATS the same mode of transport applies to all the ingredients coming from outside the UK). Potentially, two different versions of EATS could be developed: a web-based version with the purpose of engaging with the general public and a version integrated within procurement software specifically for catering companies.
- The educational opportunity offered by EATS could be further explored by developing it into a tool that could be directly used for teaching schoolchildren the importance of sustainable food choices.

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Appendix A

Appendix A. List of publications

De Laurentiis, V., Hunt, D.V.L., Lee, S.E. & Rogers, C.D.F. 2018. EATS: a life-cycle based decision support tool for local authorities and school caterers. *The International Journal of Life Cycle Assessment*, 1-17.

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Appendix B

Appendix B. User Manual

The user manual was developed to support potential users when testing the EATS tool. It is both reported below and included in the CD attached to this manuscript in the form of a Power Point presentation (Appendix D-Part 6).

Environmental **A**ssessment **T**ool of **S**chool meals

User Manual

Step 1 – Adding a new recipe

Click on the button *New Recipe*[1] - this will clear the results from the previous analysis. Type the name of the new recipe next to the cell *Meal Name*.

Meal name	Cheese quiche
Number of portions	
Appliance 1 - Cooking time [min]	
Cooking appliance 1	Cooking appliance
Appliance 2 - Cooking time [min]	
Cooking appliance 2	Cooking appliance
Appliance 3 - Cooking time [min]	
Cooking appliance 3	Cooking appliance

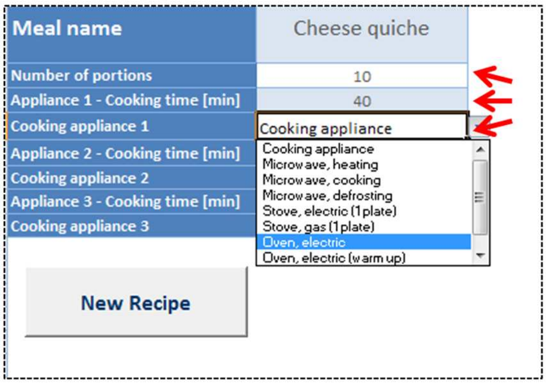
Ingredient	Food Name	Country	Weight [g]
1	CHEESE	Netherlands	

1. If Macros are not enabled in your version of Excel an error message will appear when pressing any button. In that case do the following: Click the Office Button / Click on Excel Options / Click on Trust Center / Click on Trust Center Settings / Select macro settings from the menu on the left / Select the option “Enable all macros” / Click OK

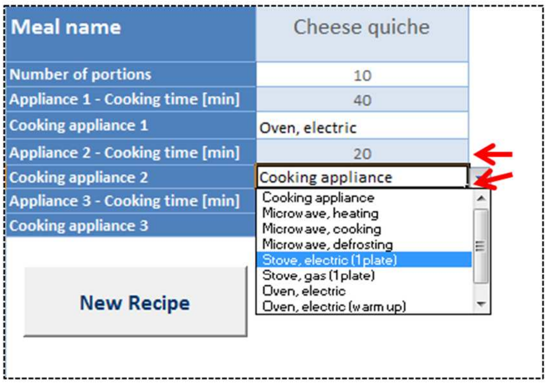
<u>Step 2</u> – Cooking phase details

Insert the number of portions that are being prepared, the cooking time in minutes, and select from the drop down list the cooking appliance used.

If more than one cooking appliance is utilized during the preparation (e.g. Electric stove and then Electric oven),repeat this operation for *Cooking appliance 2*. This can be repeated for up to three appliances.



Meal name	Cheese quiche
Number of portions	10
Appliance 1 - Cooking time [min]	40
Cooking appliance 1	Cooking appliance
Appliance 2 - Cooking time [min]	
Cooking appliance 2	
Appliance 3 - Cooking time [min]	
Cooking appliance 3	

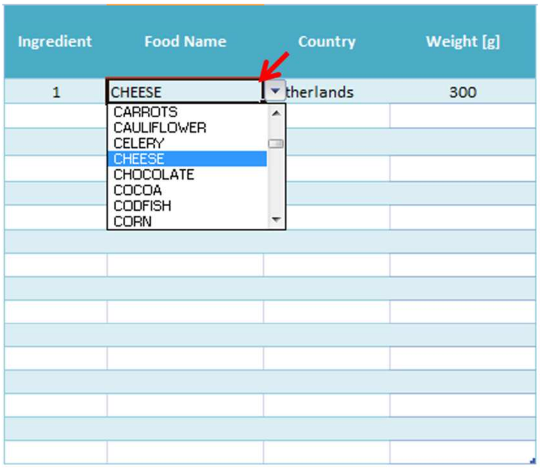


Meal name	Cheese quiche
Number of portions	10
Appliance 1 - Cooking time [min]	40
Cooking appliance 1	Oven, electric
Appliance 2 - Cooking time [min]	20
Cooking appliance 2	Cooking appliance
Appliance 3 - Cooking time [min]	
Cooking appliance 3	

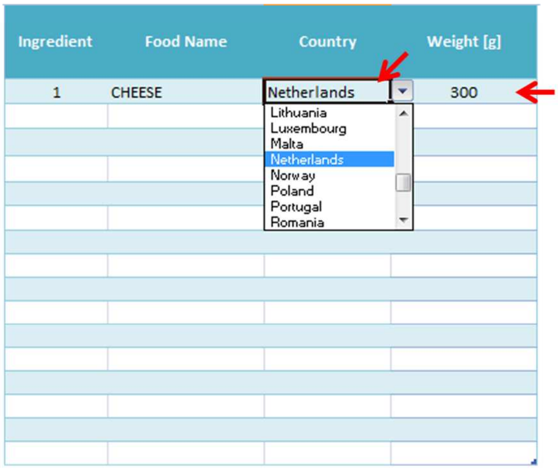
<u>Step 3</u> – Adding ingredient 1

Click on the *Food Name* and *Country*[1,2,3] cells for Ingredient 1 and choose from the drop down menus the correct options.

Type the weight of that ingredient in grams (necessary to make the number of portions specified earlier) under the *Weight* header.



Ingredient	Food Name	Country	Weight [g]
1	CHEESE	therlands	300

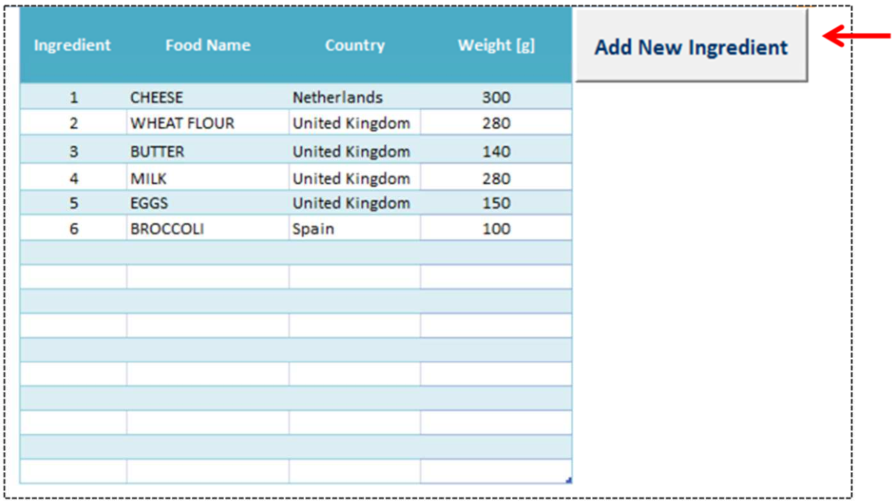


Ingredient	Food Name	Country	Weight [g]
1	CHEESE	Netherlands	300

1. By country it is meant where the food item was produced, if this information is not available select the last element of the list, i.e. “World”.
2. If the country of production does not appear on the list select “World”.
3. If the food item was produced in the UK the user has three options: select “United Kingdom” (if no more information is available or it comes from more than 100 miles), select <30 miles if it has travelled less than 30 miles, select <100 miles, if it has travelled less than 100 miles.

<u>Step 4</u> – Adding the other ingredients

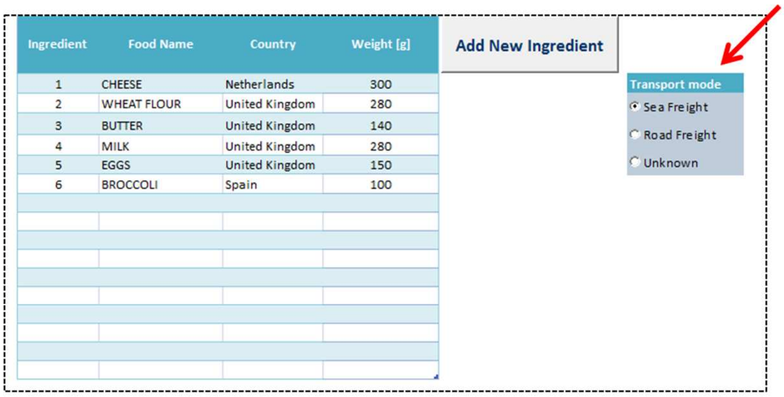
Click on the button *Add New Ingredient*, this will add a row to the ingredients table
Repeat step 3
Continue until all ingredients are entered



Ingredient	Food Name	Country	Weight [g]
1	CHEESE	Netherlands	300
2	WHEAT FLOUR	United Kingdom	280
3	BUTTER	United Kingdom	140
4	MILK	United Kingdom	280
5	EGGS	United Kingdom	150
6	BROCCOLI	Spain	100

Step 5 – Choosing transport mode

When the country selected (Step 3) is the United Kingdom the tool automatically considers as transport mode road freight. But if some of the ingredients come from outside the UK the user can choose between two alternative transport modes: road freight and sea freight. If this information is not available click on “Unknown”.



Ingredient	Food Name	Country	Weight [g]
1	CHEESE	Netherlands	300
2	WHEAT FLOUR	United Kingdom	280
3	BUTTER	United Kingdom	140
4	MILK	United Kingdom	280
5	EGGS	United Kingdom	150
6	BROCCOLI	Spain	100

Transport mode

● Sea Freight

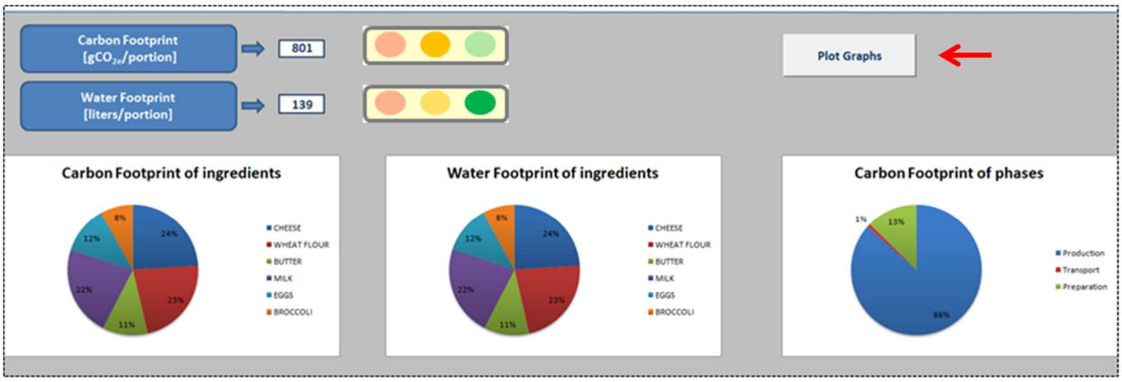
○ Road Freight

○ Unknown

Step 6 **– Plotting the results**

The tool will now provide the user with the values of Carbon Footprint and Water Footprint of one portion of the meal entered and a traffic light for each impact telling the user if the impacts are lower than the average meal (green), similar to the average (amber) or higher than the average (red)[1].

To add graphical representations of the CF and WF across the various ingredients and phases, press the button *Plot Graphs*.



Carbon Footprint [gCO_{2e}/portion] → 801

Water Footprint [liters/portion] → 139

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1. As the reference average meal comprises of a main dish, a side dish and a dessert, a full meal should be entered in the tool in order to perform a meaningful comparison.

Final remarks

Both the graphs and the tables can be copied and pasted in a separate document, for the creation of a report, the values of total carbon footprint and water footprint should also be included.

If after plotting the graphs one or more ingredients are added to the table the user will have to cancel and re-plot the graphs.

It is not possible to remove ingredients after they have been added by deleting a row of the table, for doing this there are two alternatives:

- Clicking on the “New Recipe” button and starting again from step 1
- Changing the weight of the undesired ingredient to zero (in this way it will not be included in the calculations of CF and WF but it will still be mentioned in the legend of the plots).

Appendix C

Appendix C. Application of the developed procedural assessment, detailed calculations

For each weekly menu the total CF and WF are calculated from the daily values reported in Tables 28 to 31.

These are:

CF (week 1) = 4707 gCO_{2e}

WF (week 1) = 2568 L

CF (week 2) = 4831 gCO_{2e}

WF (week 2) = 1774 L

CF (week 3) = 5439 gCO_{2e}

WF (week 3) = 2241 L

CF (week 4) = 8147 gCO_{2e}

WF (week 4) = 2695 L

The total CF and WF of the four-week cycle for the menu of CS1 are:

CF (tot_menu1) = 23124 gCO_{2e}

WF (tot_menu1) = 9278 L

Two scenarios are defined: the "minimum CF" and the "minimum WF" scenario. The codes and the CF and WF of the meals removed from the initial menu (menu1) and of those chosen to replace them (in menu2) are reported in **Error! Reference source not found.**.

The total CF of the new menu in the "minimum CF" scenario can be calculated as follows:

CF(tot_menu2) = CF(tot_menu1) – [CF(M_2th) + CF(M_3M) + CF(M_4M) + CF(M_4Th)] + [CF(V12) + CF(S6) + CF(F1) + CF(S4) + CF(V1) + CF(S3) + CF(V6) + CF (S7)] = 23124 - (2171 + 2576 + 2116 + 2107) + (155 + 181 + 303 + 318) = 15110 gCO_{2e}

Similarly the total WF of the new menu in the "minimum CF" scenario can be calculated as follows:

WF(tot_menu2) = WF(tot_menu1) – [WF(M_2th) + WF(M_3M) + WF(M_4M) + WF(M_4Th)] + [WF(V12) + WF(S6) + WF(F1) + WF(S4) + WF(V1) + WF(S3) + WF(V6) + WF (S7) = 9278 – (486 + 741 + 614 + 509) + (226 + 43 + 158 + 165) = 7521 L

Therefore the savings reported in Table 37 are calculated as follows:

% CF saved = [CF(tot_menu1) – CF(tot_menu2)] /CF(tot_menu1) = (23124 – 15110) /23124 = 35%

% WF saved = [WF(tot_menu1) – WF(tot_menu2)] /WF(tot_menu1) = (9278 – 7521) /9278 = 19%
CF saved (per pupil per academic year) = [CF(tot_menu1) – CF(tot_menu2)]* γ = (23124 – 15110) * 9.5 = 76131 gCO_{2e} = 76 $kgCO_{2e}$
WF saved (per pupil per academic year) = [WF(tot_menu1) – WF(tot_menu2)]* γ = (9278 – 7521) * 9.5 = 16691 L = 17 m^3

Where the coefficient γ is obtained as:
γ = number of days in a school year / number of days in the menu analysed = 190 / 20 = 9.5

The same calculations apply to the “minimum WF” scenario.

Appendix D

Appendix D. Electronic material (CD)

Part 1: EATS

This Excel worksheet presents the tool developed as part of this doctoral project. The calculations performed by the tool are explained in detail in Section 4. For clarity, the databases used by the tool are reported separately in Parts 2 and 3 of this appendix.

Part 2: CF database

This Excel worksheet presents the CF database created as explained in Section 4.2.2. For each record the following information is reported:

- Record number;
- Food category;
- Food product;
- Reference, which is the reference of the source from which the value was taken;
- System boundaries used in the original study;
- Geographical location of production considered in the study;
- Year of publication;
- Additional information (e.g. production method, species, region of production);
- Carbon footprint (calculated for the system boundaries of the original study);
- Carbon footprint (adapted in order to be calculated from cradle to farm/factory gate).

The last value of carbon footprint, was calculated from the one extracted from the sources consulted as explained in Sections 4.2.2.4 and 4.2.2.5. This is the value used by EATS.

The additional information was recorded in order to better understand variations in the values of CF collected for the same food products. For instance, it was possible to identify a large difference between the CF of horticultural products grown in heated greenhouses compared to those grown in open fields and unheated greenhouses, which resulted in the decision of presenting them separately in the tool. No clear trend was identified for the remaining production methods (e.g. organic versus conventional), and therefore this information was not used further in the development of the tool.

The list of references of the sources recorded in the CF database is reported in Appendix E.

Part 3: WF database

The water footprint database was mainly collected from two databases published by the Water Footprint Network (as explained in Section 4.2.3). Additionally, some values were extracted from other sources. This worksheet reports the values of WF extracted from the literature for each country of the EU28 (when available) and the global average value.

In the studies consulted other than the ones published by the Water Footprint Network, only one value of WF was reported. In this case this was assumed to be the global average value.

This worksheet is made of 4 parts reporting:

- The total WF (as the sum of the green, blue and grey component);
- The green WF;
- The blue WF;

- The grey WF.

EATS uses by default the total value of WF to perform the calculation of the WF of a meal. However, in Section 5, the results of the case study analyses show separately the values of green, blue and grey WF of the meals analysed. This was obtained by using a modified version of the tool in which the WF database had been replaced by the other three databases reported in this appendix.

Part 4: Case Study 1 – ingredients table

This worksheet reports the data used to perform the first case study analysis. This information was provided by a catering company.

For each dish analysed (identified by a code) the following information is reported:

- Dish name
- Number of portions prepared at the same time
- Time of use of cooking appliances (in minutes)
- Quantities of each ingredient (measured in grams)

By entering this information in EATS (together with the data on the origin of the ingredients and the transport mode assumed as explained in Section 4.4.2), the environmental impacts of the dishes of the first case study were calculated.

Part 5: Case Study 2 – ingredients table

This worksheet reports the data used to perform the second case study analysis. The structure is the same as explained for case study 1. This information was collected from the website http://whatworkswell.schoolfoodplan.com/articles/category/52/recipes-menus. Some of the recipes were amended when part of the ingredients could not be found in the tool as explained in Section 5.5.

Part 6: User manual

This power point presentation reports the User Manual for the EATS tool, presented also in Appendix B.

Appendix E

Appendix E. Reference list of the CF database

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