



**Quantifying the impact of policies addressing sustainable and
healthy diets**

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Abstract

There is increasing concern regarding the sustainability of global food production. It is unclear whether sustainable diets are healthy diets, and vice versa. The UK Government has declared its intention to achieve sustainable food procurement, but it is unclear whether this would lead to healthier foods provided in the public sector. In this thesis, I developed a method to quantify simultaneously the nutritional impact and carbon footprint of policies addressing sustainable and healthy diets using the primary school meals sector in England as an example.

I systematically reviewed the literature to produce a list of the amounts of greenhouse gas emissions (GHGEs) in KgCO_2e associated with the production of a kilogram of different foods. . These data were incorporated into a nutritional database (constructed from a dietary survey) - the Primary School Food Survey (PSFS) 2009 database. This dataset contains information on meals provided by schools and packed lunches from a representative sample of primary school children in England. GHGE values of individual food items from the systematic review were used to allocate a GHGE value for each food item included in the PSFS using a novel method.

I analysed this dataset to present the current status of primary school meals with both nutritional and GHGE values. This analysis showed that a higher proportion of primary school lunches are healthier than packed lunches, when healthiness is defined as meeting nutrient-based standards for school foods – 64.5% of school lunches met at least 7 of the 14 standards compared to 43.2% of the packed lunches. But the mean GHGE value associated with a school lunch was slightly higher than packed lunches.

Mean value (95% uncertainty interval) of a school lunch was 0.72 (0.71 – 0.74) compared to 0.70 (0.69 -0.71) KgCO₂e. Incorporating uncertainty in GHGE parameters inflated the confidence intervals considerably. Scenario analyses showed that if primary school food sector in England achieves new food-based standards (published by the School Food Plan in July 2014) the proportion of meals achieving 7 or more nutrient-based standards would increase but the standards for saturated fat, salt and free sugars would be less likely to be achieved. The carbon foot print would also go up.

If we adopt a 'Meat Free Mondays' policy, the proportion of meals achieving 7 or more nutrient-based standards will increase and the carbon foot print will be reduced. In both of those scenarios the nutrient-based standards for saturated fat, salt and non-milk extrinsic sugar are less likely to be achieved. Linear programming analyses showed that to construct a primary school meal which meets specific nutrient based standards with minimum GHGE values, it is possible to achieve a 40% reduction in GHGEs.

The results of this thesis can be used to guide Government efforts to achieve healthy, sustainable food provision in primary schools and other sectors. The methods developed here can improve modelling studies that consider nutritional outcomes and sustainability outcomes simultaneously, particularly with regard to incorporating uncertainty into modelling results.

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List of abbreviations

CCC - Committee for Climate Change

CO₂e- Carbon dioxide equivalent

EU – European Union

FCRN – Food Climate Research Network

FFQ – Food frequency questionnaire

GBS – Government Buying Standards

GHGE – Greenhouse gas emission

LCA – Life cycle assessment

MFM – Meat Free Monday

NCDs – Non-communicable diseases

PSFS – Primary School Food Survey

WWF- World Wildlife Fund

SFP – School Food Plan

1 Introduction

This first chapter provides a brief summary of the thesis and what is covered in the proceeding chapters to guide readers.

The aim of the thesis is to quantify simultaneously the nutritional impact and carbon footprint of policies addressing sustainable and healthy diets using the primary school meals sector in England as an example.

Chapter 2 is a narrative review of the literature on sustainable, healthy diets, and shows the contribution of agriculture and global food production to greenhouse gas emissions (GHGEs). It demonstrates the importance of changing the type and quantity of food we eat in order to meet the UK Government's GHGE reduction target. It shows that changing diet is not only an environmental concern, but it has a major impact on health. This means that any policy that aims to improve the healthiness of diets will have an impact on the GHGE of foods and any policies to improve the sustainability of food will have an impact on health. The second chapter concludes by highlighting the importance of having a method to quantify health and sustainability outcomes of policies simultaneously and by introducing the aims and objectives of this thesis.

Chapter 3 presents the methods used to answer each research question in this thesis. It presents the research questions covered in each chapter and discusses the methods used. It also provides details about the main dataset used in this thesis, the Primary

School Food Survey (PSFS) and how these data files were manipulated to create the dataset used.

Chapter 4 is a systematic review of life cycle analyses that have been used to estimate GHGE of different food categories. This is the first systematic review which has been undertaken to estimate GHGE for all food groups. It is difficult to compare these values directly in a wholly robust way, due to several issues and these issues are described in chapter 4. This chapter presents mean GHGE values for common food groups and these values are used to estimate the GHGE of primary school meals and answer research questions in chapter 5, 6 and 7.

Chapter 5 presents the status of current primary school meals from both nutritional and environmental perspectives. This chapter (and the following two) use the main dataset of primary school foods and it provides details of the database and how it was used to estimate the mean GHGE of primary school meals and packed lunches. This chapter introduces a novel method to incorporate uncertainty around estimates of GHGE for foods (alongside uncertainty from sampling error) when estimating mean carbon footprints. Achievement of nutrient based standards in primary school meals is discussed in this chapter and finally it compares the GHGE values of meals that achieve those standards with meals that do not achieve those standards.

Chapter 6 reports on scenario analyses which considers nutritional and environmental outcomes of two selected policies which aim to change primary school meals. One policy option aims to make primary school meals healthier and the second policy aims

to make them more sustainable. This chapter compares the nutritional quality and GHGE values of primary school meals in each of these policy scenarios with the baseline values reported in chapter 5.

Chapter 7 demonstrates how to construct a primary school meal with minimum GHGE values using linear programming methods. The model optimises for GHGE values and constructs the meal which meets all the nutrition based primary school meal standards for the minimum GHGE. Next, it ignores different nutrient based standards and finds the primary school meal that is closest to the current average meal whilst reducing GHGE by 5%, 10%, 20%, 30% and 40%. The results demonstrate the impact on different food groups and on the nutritional quality of meals. This analysis helps to understand whether it is possible to maintain GHGE intensive food categories in primary school meals if we want to make them more sustainable and at what stages a drastic reduction would occur for each food group.

Chapter 8 provides an overall discussion of the thesis. It summarises its main findings, discusses the implications of those findings and compares with other literature. It also describes the strengths and limitations of the study.

2 Background Review

This chapter discusses the environmental sustainability of food, current policy discussions to improve the sustainability of food production and consumption and the need for quantifiable methods to assess their effectiveness. This chapter also describes the link between nutrition and environmental sustainability and the importance of integrating these two.

2.1 Background

The UK Government has recognised greenhouse gas emission (GHGE) reduction as a priority concern and pledges to take appropriate measures to tackle it (UK Government 2008). Similar responses were observed from many international agencies and governments after the International Panel on Climate Change (IPCC) reported that many physical and biological systems on the planet are changing due to anthropogenic global warming. They also highlighted that many impacts of climate change can be avoided, reduced or delayed by mitigation (IPCC 2007). The UK Climate Change Act 2008 sets a target to cut the total annual GHGE by 80% by 2050 with an interim target of a reduction of 34% by 2020 compared to the 1990 levels (UK Government 2008).

Agriculture is one of the main anthropogenic sources of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) all of which significantly contribute to global warming (Hazell and Wood 2008). CO₂ is generated by burning fossil fuels (coal, natural gas and oil), and products such as trees and wood products, and also as a

result of certain chemical reactions (e.g., manufacture of cement). CO₂ is removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle. Greatest source of CH₄ emission in Europe is the agricultural sector. CH₄ is also generated during the production and transport of coal, natural gas, and oil. Agriculture sector mainly contribute to CH₄ emission through enteric fermentation and livestock manure. Cows and sheep are the highest contributors (Moss, Jouany et al. 2000). Rice paddies also contribute to CH₄ emission (Zhang, Wang et al. 2011). A major source of agriculture related N₂O emissions is from untreated manure on pasture land (EPA 2014). Also, when artificial nitrogen-based fertiliser is applied to crops, some of the nitrogen is fixed into the soil (which is the aim) but some of it is released into the atmosphere as N₂O. These gases have a higher global warming potential than CO₂. Depending on the time scaled used, CH₄ can be about 25 times more potent than CO₂ and N₂O can be 300 times more potent than CO₂ (IPCC 2007).

The Committee for Climate Change (CCC) reported that agriculture emissions account for 8% of total emissions in the UK (CCC 2010). When all of food production is considered this increases to around one fifth of UK greenhouse gas emissions (Garnett 2008, CCC 2010). The World Wildlife Fund (WWF) estimated that if we include the effects of certain aspects of land use associated with agriculture (e.g. deforestation), then UK food production and consumption is responsible for 30% of the total GHGs (Audsley, Brander et al. 2009). Globally, food production is responsible for around one third (19% -29%) of emissions, this is less than energy production but more than the transport sector (Vermeulen, Campbell et al. 2012).

Reduction in the GHGE related to food production and consumption in the UK is vital in order to achieve the targets set by the Climate Change Act 2008. Reductions in emissions from primary agriculture production are more difficult to achieve than for other sectors. This is because of reasons described above; intrinsic biological processes causing emissions such as methane, and because nitrous oxide emissions are associated with applying nitrogen-based fertilisers to crops.

Technological advances can contribute to the reduction of emissions from some sectors such as transport and energy. But GHGEs from agriculture are difficult to control with such measures (Kasterine and Vanzetti 2010). It is generally argued that to achieve meaningful reductions in emissions, a combination of improved farming methods and reduced livestock production is required (Audsley, Brander et al. 2009). The CCC estimated that a 50% reduction in livestock will reduce agriculture related GHGE by 40% from current levels and total UK GHGE by 2% (CCC 2010).

Current UK Government recommendations for 'healthy diets' do not refer to sustainability at all (PHE 2014). A recent scientific report of the 2015 Dietary Guidelines Advisory Committee (DGAC) in USA introduced measures to improve the sustainability of diets. This report highlights the importance of linking health, dietary guidance, and the environment to promote human health and sustainability. It also draws the attention to the rapidly evolving research on diets and environmental sustainability and need for better evidence (USDA 2015). Changes in agricultural productions will inevitably lead to changes in food availability and consumption, and could potentially be in conflict with current UK Government recommendations for

consumption. Therefore, achieving these GHGE targets require changes to the supply side (production) and demand side (consumption) of the food system in such a way as to meet an as yet undefined 'sustainable healthy diet' (Macdiarmid, Kyle et al. 2011).

2.2 What is a sustainable diet?

Definitions of sustainability vary. Some definitions have several dimensions such as social, economic and environmental. Some definitions take it narrowly to refer to only environmental sustainability. The World Commission on Environment and Development report emphasised that humanity can achieve "sustainability" by ensuring that it meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland 1987). The Food and Agriculture Organization (FAO) defines sustainable diet as "diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources"(FAO 2010). The Food Climate Research Network (FCRN) identified several issues to consider when defining a sustainable diet. They are: nutrition, environment, economy and food supply, society and ethics and other food related health issues (Garnett 2014). The same report has shown while it is hard to disagree with the importance of these different dimensions, wider definitions lack meaningful specificity.

When it comes to environmental sustainability there are different components such as GHGE, water, land use and biodiversity (Williams, Audsley et al. 2010). The UK Climate Change Act and most of the other legally binding policies use GHGE as the key measure of environmental sustainability. For the purpose of this study, I will also use GHGE as the measure for environmental sustainability of food. Whilst this presents some limitations to the holistic approach of addressing sustainability of food systems, a wider definition of sustainability is beyond the scope of this thesis. Although comparability of data sources is problematic, the data on GHGE from different food categories is relatively more abundant than for other sustainability measures. Also, many sustainability metrics for food categories are correlated (e.g. GHGE and land use) implying that focussing on GHGE only will provide some insight into broader sustainability issues (Garnett and Godfray 2012).

Previous reports and studies have provided much information on sustainable diets. Most published research papers present the environmental impact of one or few food items (Dalgaard and Halberg 2004, Biswas, Graham et al. 2010, Maraseni, Cockfield et al. 2010, Nilsson, Sund et al. 2011). To make a decision on the sustainability of a diet we need comparable information on the environmental impact of different food items included in a diet. One commonly cited source for GHGE data on all food groups is the *How low can we go?* report, published by the WWF (Audsley, Brander et al. 2009).

While this report helps us compare different food items, it did not use a systematic approach to estimate the environmental burden of different food groups – indeed, no single review has systematically compared GHGE by food groups across the whole of the UK diet. Therefore one of the most important steps towards defining a sustainable

diet in the UK is to conduct a systematic review and provide comparable estimates for different food items in a diet.

2.3 Why consider nutrition?

Achieving the changes needed to reduce GHGEs from food production and consumption has implications for public health. Dietary patterns and nutritional intake is strongly associated with health outcomes in a population (Murray and Lopez 2013, Murray 2015). Unhealthy diet is a risk factor for many non-communicable diseases (NCDs) including cardiovascular disease and some cancers. NCDs are responsible for the majority of the global burden of diseases. In 2013 NCDs accounted for more than 69% of deaths worldwide (Murray 2015). More than 28% of all deaths (161, 000 in 2012) in the UK are from cardiovascular disease with a further 166, 000 deaths due to cancer (Townsend, Williams et al. 2014). The Global Burden of Disease project estimates that over 10% of DALYs in the UK are due to dietary risk factors – greater than the impact of any other risk factor (IHME 2010).

The literature shows that NCDs could be prevented or delayed by adopting a diet low in saturated fat, free sugars, salt and energy dense foods and high in fibre, wholegrain cereals, legumes, fruits and vegetables (Everitt, Hilmer et al. 2006, IHME 2010).

Therefore implications of dietary changes due to GHGE reduction (for example, by moving away from an animal-based diet), which would have a substantial impact on the quantity and quality of foods consumed in the UK, should be examined very closely.

As described above changes in diets would have impacts on population health outcomes and on the environment. Therefore it is important to assess simultaneously both the environmental and health outcomes of any policies aiming for population level dietary changes in order to provide policy makers with evidence across different domains so they can make evidence-based decisions.

2.4 How to measure the nutritional quality of a diet

There are several methods to measure the nutritional quality of a diet. Some studies use biomarkers such as 24 hour urine collection to estimate the sodium consumption and doubly labelled water studies to measure energy. But these are expensive measures and cannot provide information on the broad content of the diet. Therefore most of the large surveys collect data on food consumption from participants. There are different methods to collect dietary information in a survey. They include diet history, food frequency questionnaires, dietary recalls and diaries. Interviews can be administered by face to face, telephone, postal or web-based methods. But face to face provide the opportunity directly to observe actual meals consumed and identify additional information (EFSA 2009). The nutrient content of this diet can then be obtained by linking the food consumption data with estimates of the nutritional content of foods from a food-composition table which provides macro and micro nutrient quantities per unit of different food items (FSA 2002). Reference values per nutrient or per food group are available based on the age and sex for each population group to assess the healthiness of diets. The dietary reference values for energy published by the Scientific Advisory Committee on Nutrition is an example (SACN 2011).

Common macronutrients included in assessments of 'healthiness' of diets are total fat, saturated fatty acids, trans fatty acids, non-milk extrinsic sugars (free sugars) and fibre. Common micronutrients include vitamins (such as vitamin A), minerals (such as, iron and zinc). Salt levels are also normally considered when assessing the healthiness of diets (FSA 2002 , Bates, Lennox et al. 2011).

2.5 How to measure the nutritional quality of a meal

Based on the dietary information collected, researchers can also assess the healthiness of a meal. The overall quality of a meal can be assessed by using the recommended daily (sometimes weekly) intakes of foods (e.g. fruit and vegetables, oily fish, etc.) and/or of nutrients. When measuring the nutritional quality of a meal account needs to be taken of the fact that one meal cannot be expected to supply the recommended daily or weekly amount of a food or nutrient. In this thesis, I used two different definitions to define "healthy school meals" and these methods are described in Chapter 3 and Chapter 5.

There are different approaches to assess the "healthiness" of meals. For example there are macronutrient only approaches, micronutrient only approaches, combination of both macro and micro nutrients and food based approaches (Ballard 2014). Although there are various tables/lists describing the nutrients and foods that should be included in a healthy meal, sometimes it is impossible to achieve every single standard in each meal.

2.6 Strategies to promote sustainable healthy diets

There are several policy options that have been suggested to reduce the GHGE related to food production and consumption. The fourth carbon budget report has suggested the following policies to reduce emissions associated with agriculture (CCC 2011).

Voluntary agreements between the Government and the food industry to reduce emissions associated with the food sector. These agreements should be backed by a mechanism for legally binding monitoring and enforcement systems.

Information provision: Providing better information to farmers on improved farming methods to reduce emissions. Developing a better understanding about opportunities for emission reduction.

Grants, subsidies, levies and taxes: A wide mix of incentives and penalties to encourage low carbon production and promote sustainable farming. These measures could be taken at EU level or in the UK.

Cap and trade scheme: Placing a price on greenhouse gas emissions from agriculture and providing incentives to farmers to adopt alternative low emission farming methods.

Direct regulation: Introducing standards on greenhouse gas emissions and restricting certain unsustainable farming methods.

According to the CCC report the Government has acknowledged that industry led initiatives should be supported by other policies such as the Common Agriculture Policy and other EU level initiatives.

According to the CCC, choice editing is another option to change behaviour by government and or industry, limiting the choices available for consumers (E.g. offering low carbon intensity food or reducing the portion sizes available). Introducing a carbon tax on foods to reflect the relative carbon content is another policy option to promote sustainable food. The CCC recommends the government should consider these full range of options as a single measure is not adequate to achieve the UK emission reduction targets (CCC 2011).

The former UK government published plans to foster a cultural and behavioural change by leading the initiative to promote sustainable healthy diets in the public sector. The Government said, it will set the agenda by leading with examples to procure food and food services that reflect the changes that it is aiming for across the whole of the food chain (Defra 2011). The preferred policy option is to achieve this by raising baseline levels of compliance with sustainability and nutritional standards of government food procurement by adopting minimum government buying standards (GBS) for the wider public sector (schools, hospitals, prisons etc.). An impact assessment of the previous GBS (2007- 2009 period) highlights the need to consider both sustainability standards and nutritional standards of diets when implementing such policies (Defra 2010).

But changing diets to make them more sustainable is not integrated in food guides that have been developed for specific settings such as school food (SFP 2014) or hospital food. The UK Government official guide to a healthy diet, the “eatwell plate”

also does not provide any guidance on how to improve the diets from a sustainable point of view. (PHE 2014).

But the promotion of healthy and sustainable diets is accepted as an overarching Government objective. The Government report 'Food 2030' highlighted five actions by the government to create a sustainable and secure food system (UK Government 2010). These are encouraging change through voluntary, regulatory, or economic approaches; lead by example; enable change (by providing tools, evidence and advice and information); build evidence; provide policy leadership.

The media and non-governmental organisations (NGOs) have provided information and started campaigns to educate the public on how to improve sustainability of diets. Commonly promoted messages include reduce meat, waste less food, eat more fruits and vegetables, eat more seasonal and local food and buy food with certified labels for sustainability (TG 2014, WWF-UK 2014). The introduction of "Meat Free Mondays" and the promotion of "less but better meat" are some of the campaigns run by NGOs in the UK (Eating Better 2014). These actions logically support the sustainability agenda, but as yet the health and environmental benefits have not been assessed.

2.7 Evidence for policy actions

The Food Climate Research Network (FCRN) have reported that we have seen a proliferation of research related to the relationship between nutrition and the environment in the past few years (Garnett 2014). It reports that our understanding of

the issue has increased significantly and a few forward-thinking official policy bodies have incorporated these findings in to recommendations in countries such as Netherlands and Sweden (NFA , HCN 2011). However, most countries including the UK have not integrated sustainability with dietary guidelines. The FCRN reported that there is sufficient evidence to justify change in current dietary patterns and to indicate the desired direction of travel. However, we need further research to understand the main influences on our diet, which of them have the critical implications to health and sustainability and how to shift the consumption in more healthy and sustainable direction? (Garnett 2014).

The lack of progress in incorporating sustainability and nutrition messages in the UK and other countries indicates that despite the generation of much new evidence we have not been able to communicate this evidence to policy-makers or after reviewing evidence policy-makers have not yet been willing to connect two types of disciplines (environmental sustainability and nutrition) to make a clear message. Current global challenges are slowly forcing researchers and policy makers to take a more inter-disciplinary approach to nutrition and sustainability. But when it comes to specific actions, such as revising dietary recommendations to incorporate sustainability goals, progress has been very slow indicating a lack of capacity or clarity on how to integrate. Research methods and evaluation methods which would help policy makers to understand how to integrate them and how to measure expected outcomes of these policy decisions would facilitate this process.

For initiatives to produce environmentally sustainable healthy diets they need to be informed by a good evidence base. A tool to measure the health and sustainability of different diets is essential to build this evidence base. Currently there is no tool that simultaneously estimates the impact of such initiatives on GHGE and public health. Therefore we cannot prioritise available policy options based on evidence and we cannot design policies in order to achieve optimal health and environmental benefits. This is a major challenge as policy options can be assessed only with one aspect (eg: either nutritional or environmental) and fail to receive support from all sectors to implement them. If we could design food policy options by simultaneously assessing both environmental and health outcomes, they are likely be more successful (Johnston, Fanzo et al. 2014).

As mentioned above several government reports have highlighted that the government should provide stewardship by adopting these principles for food provided in the government sector. The public sector spends about £ 2.4 billion per year for food and catering services in schools, hospitals, armed forces, prisons and government agencies. The highest percentage of public sector spending for food is on school dinners (29%) and further and higher education sector spending another 29% (Bonfield 2014). This project aims to demonstrate how to quantify the environmental impact of government sector food and nutrition and GHGE changes of policies to promote sustainable healthy diets. This project uses the primary school food sector as an example to demonstrate how to integrate nutritional and GHGE data for research and estimate the expected outcomes of relevant policies.

2.8 Estimating the GHGE of the school food sector

There are two common approaches to estimate the total GHGE of meals provided in a sector (e.g. for primary school meals). One approach is to use national level data which shows the proportion of GHGE for each food group (chicken, potatoes etc.), to allocate a value for each food group and to estimate the total GHGE (CCC 2010) on the basis of the commodities used to create all primary school foods. Another approach is to estimate the GHGE associated with production (and consumption) of a unit of food item using a life cycle assessment and to apply this to a representative sample of school foods. This would provide a value for the amount of each food item in a single meal and that could be used to estimate the total GHGE for that sector by scaling up the results of the representative sample to the whole population (Macdiarmid, Kyle et al. 2011). The former (top-down) approach could be used if you have statistics for the total amount of different food items used in that sector. Procurement details or tenders might provide these quantities. For the latter approach (bottom up approach) you need GHGE values for raw material food items provided in that sector, recipes for meals and quantities of meals provided in that sector. This thesis uses novel methods based on a systematic review of the LCA literature to conduct a bottom-up assessment of the carbon footprint of primary school food in the UK.

2.9 Conclusion:

Improving the sustainability of the food sector is an essential part of mitigating climate change. Changes to food production and consumption due to climate change mitigation reasons would inevitably have an impact on nutrition and public health. Therefore it is important to quantify simultaneously both environmental sustainability and nutritional impact of any policy actions.

2.10 Aim of the thesis

The aim of the thesis is to develop a model to quantify simultaneously the environmental and health impacts of policies to improve diets, using school meals as an example.

3 Methods

This chapter explains the general methods and the underlying datasets used throughout the thesis to answer the research questions in the proceeding chapters. More detailed methods are provided in each analysis chapter where necessary. The research questions that are addressed in the proceeding chapters are also provided here for reference.

3.1 Introduction

There is a large body of emerging literature showing the relationship between food and greenhouse gas emission (GHGE) (Carlsson-Kanyama and González 2009, Vermeulen, Campbell et al. 2012). Several studies have shown that adoption of a healthy diet would contribute to improve the environmental sustainability (Macdiarmid, Kyle et al. 2012, Westhoek, Lesschen et al. 2014). Vieux et al argues that high nutritional diet is not associated with low GHGE (Vieux, Soler et al. 2013). Therefore the literature shows that that nutritional quality of food and greenhouse gas emissions (GHGE) of foods are related but may not be aligned, and hence it is important to estimate the impact of food-based policy on both GHGE and nutritional quality of the diet simultaneously.

This thesis aims to demonstrate how to quantify the outcome of policies addressing sustainable healthy diets. Previous reports which estimated GHGE related with the production of different food groups have used inconsistent methods and have not yet been reviewed systematically. I need a set of GHGE values for different food groups

that have been produced systematically to provide parameters which can be used to answer research questions on sustainable healthy diets. This thesis concentrates on primary school meals: these are important as it is one of the very few sectors where good data are available on the current provision of meals and the UK government has the influence to change provision standards in order to meet either health or sustainability agendas.

3.2 Research questions

This section states the research questions answered in each chapter and how these questions contribute to the overall aim of the thesis.

Chapter 4 provides details of the systematic review and the three questions answered in this review are:

1. How do GHG emissions associated with production and consumption of 1kg of different food groups vary between food group?
2. How do GHG emissions associated with production and consumption of 1kg of food vary within food groups, due to differences in farming methods and locations?
3. How do reported GHG emissions estimates associated with production and consumption of 1kg of food vary due to differences in the choice of system boundary?

GHGE values estimated from the systematic review are used to answer the five research questions in this thesis. They are:

Research question 01: What is the contribution of primary school meals to the total greenhouse gas emissions (GHGEs) in England?

Research question 02: Are current primary school meals that achieve nutrient based standards less GHG intensive than meals that do not achieve those standards?

Research question 03: What environmental and nutrition changes can we expect if we change the current primary school meal plate to achieve new School Food Plan recommendations?

Research question 04: What environmental and nutrition changes can we expect if we change the current primary school meal menus to include a 'Meat free Monday'?

Research question 05: How can we change school meals to achieve the UK government target of GHGE reduction?

3.3 Chapter 4 methods

Greenhouse gas emissions (GHGEs) associated with the production and consumption of single food categories or small groups of foods are readily available, but a single comparable dataset of GHGEs for a large set of foods that cover most foods consumed at a population level are rare. Previous studies have used multiple methods to obtain this data. The Livewell report by the WWF (Macdiarmid, Kyle et al. 2011) used values used by the How Low Can We Go? report (Audsley, Brander et al. 2009). The How Low Can We Go? report used GHGE values from Life Cycle Assessment (LCA) of commonly used food items and these values were picked from several publications (mostly from a single research group). LCA is a process for evaluating the environmental burden associated with the entire life cycle of products including the extraction of raw materials, manufacturing, transportation and distribution, use, re-use and maintenance, recycling and final disposal (Guinée, Gorrée et al. 2002). The literature shows that the LCA value for a food can significantly vary in different studies based on

the methods used to calculate the LCA. Therefore it is difficult to pick a single study as the best estimate for any particular food group. There are no systematic reviews published to identify the best available values of GHGEs using LCA of food groups. I designed a systematic review to combine the disparate literature to produce rigorous estimates of GHGEs associated with different food groups, incorporating different methods of production and different regions of production. Eight medical and geographical databases were searched from 1995 to 2012 to identify lifecycle assessment (LCA) studies of food. Global warming potential (GWP) per kg of food, in kg of carbon dioxide equivalent over 100 years (KgCO_2e), was recorded from 68 papers with details about farming methods, location, and the boundaries of lifecycle. Further details of this review and the protocol are provided in chapter 4. Final results were presented as mean GHGE value (KgCO_2e per Kg of food) and a range with minimum and maximum values for food groups in a commonly used food frequency questionnaire.

3.4 Chapter 5 methods

To answer the research questions for chapter 5, I needed data on primary school meals, and data on the GHGEs of foods.

Data on primary school meals

The School Food Trust conducted a survey called “Primary School Food Survey 2009” (PSFS) in a nationally representative sample of 139 primary schools in England (SFT 2010). It involved selecting a random sample of 290 primary schools (from the Department for Children, Schools and Families database) stratified according to

region, school type and postcode. Of the 290 schools, 50% agreed to take part and six schools withdrew later.

These schools were spread across all nine government office regions, with participation lowest in the North West, and highest in the North East and London. Information on both school lunches and packed lunches were obtained for the analysis.

There is substantial variability in participation rates in well-established surveys. The 50% response rate in this PSFS could introduce non-response bias effects on estimates.

Nonresponse bias refers to the systematic errors introduced in the study when reasons for study participation are associated with the epidemiologic area of interest (Choung, Locke et al. 2013). In this survey, the school who are actively promoting health meals might have a higher tendency to take part in the survey and vice versa.

This could bias my results about the total amount of GHGEs from primary school meals, since GHGEs and healthiness are associated. But it will not bias my results comparing GHGEs of healthy and unhealthy meals, as this does not depend on representativeness of the dataset.

The PSFS report provides a list of reasons why schools did not wish to take part in this survey. The most common reasons were not interested in taking part in surveys (31%) followed by too busy (23%). The report does not address specifically how 50% response rate could have influenced its findings. Nevertheless this is the largest primary school food survey available in England and only nationally representative dataset.

The PSFS recorded descriptions and weight of all foods and drinks offered by participating schools at lunch time over five consecutive days. The number of portions of each food item served from the menu, their starting weights and the total number of students catered on that day was recorded by school caterers using a booklet provided to them.

Individual level meals data were collected by trained researchers. They visited each school for 5 days in a week and collected details of 10 pupils having a school lunch from different service points or rooms. The report doesn't describe this as a random selection. They recorded these student's food selections and left over weights.

In addition to these 10 children, data collectors approached 5 children per day having packed lunches in the same schools. The "box check sheet" described items brought by children in their packed lunches with starting and leftover weights.

For school lunches a sample of 6,690 students from 136 schools were included in the final analysis (3,247 boys; 3,339 girls; 104 sex not recorded). A total of 3,488 students (1,610 boys; 1,818 girls; 53 sex not recorded) were included in the final analysis of packed lunches from 138 schools.

Nutritional analysis of the foods provided for school lunches and brought to school as packed lunches was estimated with reference to the Food Standards Agency nutrient databank (FSA 2002). The FSA nutrient databank is the freely available food composition table for the UK and is regularly used for national nutritional analyses

including the National Diet and Nutrition Survey (Food Standards Agency 2011). The databank holds data on the nutritional content of over 8000 foods commonly consumed in the UK. The nutritional data held in the databank primarily comes from chemical analysis of collected samples of foods. For composite foods, the nutritional data of ingredients are combined according to identified recipes. For the PSFS, similar foods in the nutrient databank were linked to foods identified in schools.

The School Food Trust was contacted to obtain the raw datasets for the PSFS. They provided a link to download this datasets and they are now available in the UK Data Archive. (<http://discover.ukdataservice.ac.uk/catalogue?sn=7144>)

The Head of Research and Evaluation at the School Food Trust was contacted to clarify issues with the data set.

Data on greenhouse gas emission of food

The results of chapter 4 provide an estimate of mean GHGE value per Kg of each food group with minimum and maximum values (as identified from individual studies in the systematic review). These values were used to assign GHGE values for food items in the school lunch databases to estimate GHGE associated with current school meals and also model expected GHGE changes by changing the school lunches.

Preparation of the database by adding GHGE data to the PSFS dataset

The PSFS dataset was manipulated in Excel. It contained food items served in primary school by school, number of portions with nutritional information.

Three different data files provided by the PSFS survey were used in this analysis. The PSFS inventory data file contains information about food items available in each school and their nutritional quality. It provides 15,523 data points with 26 variables. Variables include school identification number, day of the week data collected, food name, food code, number of portions served, measured weight of portions, 14 nutrients (macro and micro nutrients per 100g) of each food item. The PSFS tray check data file provides details of individual students who ate school lunches. It provides 38, 148 data points with 10 variables including, school id, student id, day, sex, age, food, food code, left over weight and details of second serving.

The PSFS box checks sheet database provides details of students who ate packed lunches with 17,272 data points and 31 variables. Variable includes school id, pupil id, age, sex, day of the week, food, food code, starting weight, left over weight, macro and micro nutrients.

For each food item consumed by students in the tray check data file, I searched relevant information such as starting weight and nutritional information from the PSFS inventory data file and created one database for school lunches. The packed lunch database contained individual level food items and their nutritional values in the same database.

To answer relevant research questions it is important to define “individual meal” from the database. The database lists individual food items consumed by a student separately. The dataset list details of individual selection of food items by students in their plates for lunch with leftover weight. It also contains the school id and student id

with each food item. I sorted data by the student ID variable, to understand what comprised an individual school lunch consumed by study participants and to define an individual school meal to understand their overall nutritional value. (E.g. when I sorted by student id 1 of the school 100260, the individual student's lunch on that day comprised items shown in the table 3.1.

Table 3-1 List of food items selected by an individual student

Student ID	School ID	age	Day of the week	food	Food code	Left over weight (g)	Seconds?
1	100260	5	Monday	Flapjack	84	0	No
1	100260	5	Monday	Custard	109	0	No
1	100260	5	Monday	Cucumber	266	10	No
1	100260	5	Monday	Sweetcorn	309	40	No
1	100260	5	Monday	Cup of tap water	539	0	No
1	100260	5	Monday	Potato	799	33	No
1	100260	5	Monday	bolognaise sauce	1073	25	No

The first step was to assign GHGE values to all the food items listed in the database.

This was completed in two stages; first for the food inventory data sheet (school lunches) and then for the packed lunches.

Each food item had a unique food code given by the School Food Trust. In the dataset a food item could be composite (that is, composed of several food groups e.g. pizza) or non-composite (e.g. apple). The dataset was arranged in the order of food codes and manually checked for whether or not the individual items could be given a GHGE values based on the systematic review. If food codes represented an item closely matched to the food groups in my systematic review, the relevant GHGE mean value and minimum and maximum values were assigned to that food code (NB: the range of

results identified in the systematic review was input to allow for uncertainty analyses, described later). If the specific food item was not available from the systematic review, the relevant group value was assigned. E.g.: the systematic review provided a specific value for apples but not for apricots, so for apples the specific GHGE estimates for 'apples' were used, but for apricots the mean value for the food category 'fruit' was used. This method was applied to other common food groups such as vegetables, fish and fruit juices. The use of averaged proxy data has been recognised as an acceptable compromise for initial research work using LCA results, when resources (time, budget, and expertise) are limited (Mila i Canals, Azapagic et al. 2011). For some food items a GHGE value could not be directly given from the systematic review (e.g. composite foods which consisted of more than one individual food items such as pizza, lasagne or sandwiches). To estimate the GHGE of composite food items, a recipe was identified using a standard method and the following procedure was followed.

Estimating GHG emissions for recipes:

This approach was adopted from a previous study conducted by Scarborough et al (Scarborough, Appleby et al. 2014). McCance and Widdowson's the Composition of Foods (FSA 2002) was used as the first source to search for a recipe. It is the primary source document that makes up the majority of the UK Nutrient Databank which was described earlier. This source was searched first as if a match was found this would ensure that the same recipe was used to assign both GHG emissions and nutrient composition data to a food. If the relevant food item was not available in that dataset, the food code name was searched using the "Google" search engine and the first recipe that matched the food code was selected. Based on the identified recipe,

ingredients were listed in weight order. Most of the ingredients could be matched with GHGE data from the systematic review. Where an ingredient could not be matched with a GHGE value from the systematic review (e.g. shortcrust pastry), then a further recipe was identified for that ingredient using the same method. When a recipe showed the quantity of an ingredient without its weight (e.g. a medium egg, medium onion etc.) estimates for the weight were taken from a UK Government guide to standard portion (HMSO 1993). For each food code the weights of the ingredients were added in the order of heaviest to lightest, and a 90% threshold was used such that once a value greater than 90% was achieved the remaining ingredients were disregarded. This threshold was applied to remove small ingredients with unknown GHG emissions from the calculations (e.g. 'a pinch of curry powder'). Estimates of GHGE per 100g for each of the ingredients in the composite food were then sourced from the systematic review in the same way as described for non-composite foods earlier. Finally, the GHGE per 100g for the ingredients were combined weighted by the contribution of the ingredients to the final food item in order to estimate GHGE per 100g for each of the composite food items.

In the PSFS dataset there were 1,556 unique food codes consumed by students and 1,012 of these were composite food items.

Contribution of primary school meals to total GHGEs in England

The starting weight of portions and the number of portions served was given in the PSFS database for all food items reported in the data collection period. Combining these data with the GHG emissions data described above, allowed for an estimation of

the total GHGE for 6,690 school lunches and 3,488 packed lunches in England.

According to the Department of Education statistics in January 2013, there were 4.3 million pupils in state-funded primary schools (Department for Education 2013). The PSFS reports shows that on average 39.3% of these school children were having school meals every day. Total number of portions prepared was used as the key variable of interest for each food in each school. Since this is based on a nationally representative sample of schools, I could use the data to calculate an average GHGE per student per day. Based on the number of school children consuming school lunches per day and the number of school days I calculated the total emissions from primary school lunches per year in England. Similar methods were used to calculate the total emissions from packed lunches per year and the total emissions from the primary school food sector.

Distribution of weights and GHGE of school meals by eatwell plate Categories.

The NHS Choices website highlights the different types of food that make up our diet, and shows the proportions by which we should eat them to have a well-balanced and healthy diet using the eatwell plate (NHS 2013).

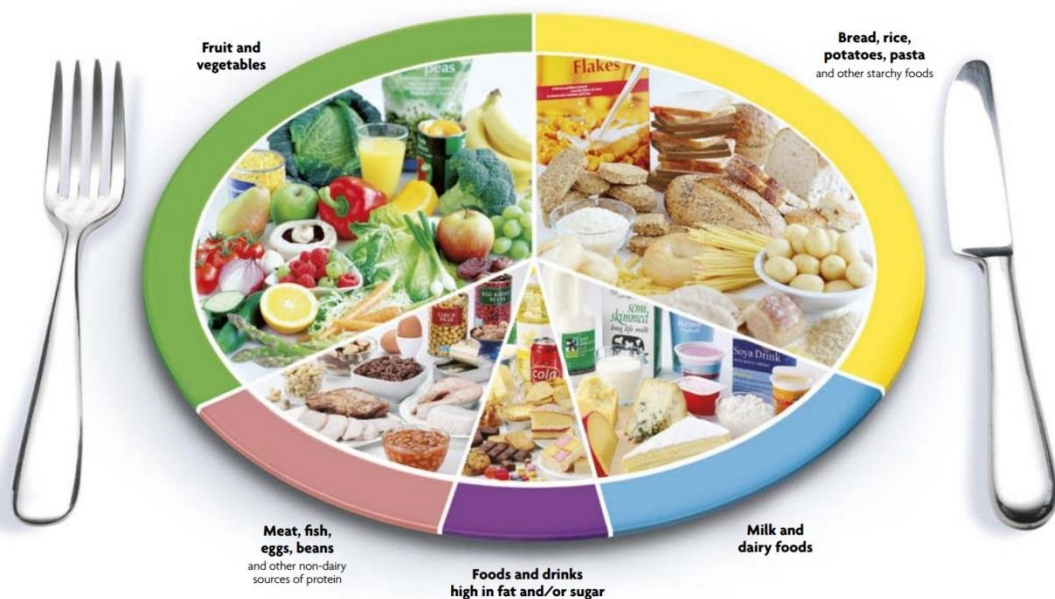
The eatwell plate (Figure 3.1) is a visual representation of how different foods contribute towards a healthy balanced diet. It shows the size of the segments for each food groups for anyone over the age of 2 years.

The guide comprises of five-groups:

- Bread, rice, potatoes, pasta and other starchy foods
- Fruits and vegetables
- Meat, fish, eggs, beans and other non-dairy sources of protein
- Milk and dairy foods
- Foods and drinks high in fat and /or sugar

The National Food Guide and its food group classification (Gatenby, Hunt et al. 1995) provides a list to classify food in to the five good groups.

Figure 3.1 The eatwell plate



Department of Health in association with the Welsh Government, the Scottish Government and the Food Standards Agency in Northern Ireland

Each food code in the PSFS was allocated in to the relevant category of the eatwell plate based on the National Food Guide Classification (Gatenby, Hunt et al. 1995).

Composite foods (i.e. foods that fall into more than one category from the eatwell plate such as pizza, where the base is from the 'bread, rice, potatoes, pasta and other starchy foods' category and the toppings can be from the 'fruit and vegetables', 'milk and dairy' and 'meat, fish, eggs, beans and other non-dairy sources of protein' categories) were categorised with reference to the recipe identified to assign GHGE to the food. The composite foods were split between the different eatwell plate categories by estimating the proportion of weight for each raw ingredient (all of which could be assigned to a single eatwell category).

The data were analysed to show the distribution of packed lunches and school meals' weight and GHGE distribution by eatwell plate categories. There were compulsory nutrient based standards for primary school meals until September 2014 (Table 3.2). These were a set of standards which aims to provide the right balance of nutrients for development and growth of children – by ensuring a minimum level of certain vitamins and minerals, protein, etc. and maximum level of certain nutrients such as fat, saturated fat, free sugars, salt, etc. (SFT 2007).

The second objective for chapter 5 was to compare GHGE values of school lunches that achieve previous nutrient based standards and lunches which do not achieve these standards in order to estimate whether the goal of achieving healthy school meals and sustainable school meals are currently synergistic or in tension with each other.

Table 3.1 shows how food items consumed by a participant in the study are displayed in the dataset. We summarised nutritional and GHGE of seven food items consumed by this study participant to estimate values per individual meal of this student.

Nutrient based standards

The School Food Trust report which was published in 2010 provides the list of nutrient based standards (Table 3.2) for primary school lunches (Haroun, Harper et al. 2012). These standards were compulsory at the time of publishing this report. A set of new variables were created in STATA to estimate the absolute values of energy and nutrients from each food item based on the portion weight. Collapsing the data by student ID allowed me to estimate the energy and nutrient values from the complete individual school meal. These values were compared against the values provided by nutrient-based standards (14 different standards) to assess whether each meal is achieving them. The analysis identified meals which achieved each of those standards.

Table 3-2 Nutrient-based standards for primary school lunches

Nutrient	Min/Max	Proportion of recommended daily intake nutrients	Infants Aged 4-6 School year R,1,2	Juniors Aged 7-10 School years 3-6	Average Aged 4-10 School years R-6
Energy (kcal)	EAR	30% ± 5%	465-514	529-585	504-557
Protein (g)	Min	30% RNI	5.9	8.5	7.5
Carbohydrate (g)	Min	50% food energy	65.2	74.2	70.6
*NMES (g)	Max	11% food energy	14.3	16.3	15.5
Fat (g)	Max	35% food energy	19	21.6	20.6
Saturated fat (g)	Max	11% food energy	6	6.8	6.5
Fibre (g)	Min	30% calculated reference value	3.9	4.5	4.2
Sodium (mg)	Max	30% SACN recommendation	357	595	499
Vitamin A (µg)	Min	35% RNI	140	175	175
Vitamin C (mg)	Min	35% RNI	10.5	10.5	10.5
Folate (µg)	Min	35% RNI	35	53	53
Calcium (mg)	Min	35% RNI	158	193	193
Iron (mg)	Min	35% RNI	2.1	3	3
Zinc (mg)	Min	35% RNI	2.3	2.5	2.5
* Non-milk extrinsic sugars			Reference Nutrient Intake (RNI)		

3.5 Uncertainty analysis:

The analysis provides point estimates, e.g. it provides the mean GHGE value per school lunch. But different studies from the literature report a different set of values for GHGE per food item (see Chapter 4 for details). The estimation of GHGE per food is a relatively new discipline in nutrition related research and due to these wide range of GHGE values reported in the literature, researchers can query the accuracy of these point estimates. There are no published studies which have conducted an uncertainty analysis to estimate the uncertainty in measures of total GHGE related to food using actual values reported in literature. In this study I developed a novel method to

estimate the uncertainty in results due to imprecise estimates of reported GHGE values. For each food item which had more than one estimate of GHGEs in the systematic review in Chapter 4, I estimated the mean value giving an equal weight for all the studies included. In the uncertainty analysis I created 1000 different datasets, where the GHGE for each food item and each ingredient for composite foods was randomly picked by an Excel model from the individual list of relevant GHGE values reported in the systematic review. These random selections were then used to generate GHGE of each school meal and packed lunch. In each of the 1000 datasets, the GHGE for each of the school meals and packed lunches were generated randomly, with equal chance of selecting any of the estimates found in the systematic review, which allowed for a Monte Carlo analysis to estimate uncertainty around GHGE estimates (assuming that the sets of GHG estimates identified in the systematic review are independent of each other). Using these 1000 different estimates, a range was provided for the GHGE value reported in each analysis. More details of this uncertainty analysis are provided in Chapter 5.

3.6 Chapter 6 methods

The Department of Education introduced a new set of standards in 2014 for all school food served in schools, with the School Food Plan (SFP 2014). Instead of nutrient based standards, The School Food Plan introduced these new standards claiming they give more freedom to school cooks to create imaginative, flexible and nutritious menus.

Research question 03: What environmental and nutrition changes can we expect if we change the current primary school meal to achieve new School Food Plan standards?

To answer this question (first scenario for analysis in this chapter), nutritional quality and average GHGE value of meals which achieve the new School Food Standards was estimated. This new plan was first implemented in September 2014 and we do not have data collected from schools after that. From the PSFS dataset I identified the meals which met these new standards and estimated their nutritional quality and GHGE to compare with the current values. Details of these standards and portion size calculations are given in Chapter 6. The new standards do not refer to nutrients and they are based on food based standards. There are seven standards we can use for this modelling and they were given equal weight to quantify the “healthiness of individual meals”. The percentage of meals that achieved each nutritional standard (from previous set of standards) was compared with the current values to see whether introduction of these new standards could improve the nutritional quality of school meals. The average GHGE of meals that achieved new School Food Plan Standards was compared with current values to understand whether introduction of new standards have increased the sustainability of primary school meals.

Previous studies have suggested different dietary scenarios that would improve the sustainability of meals. E.g. some studies have looked at scenarios such as moving to a vegetarian diet or vegan diet as counterfactual scenarios (Berners-Lee, Hoolohan et al. 2012). Saxe et al estimated the global warming potential of different dietary scenarios including a New Nordic Diet (NND) which contains locally produced Nordic foods

where more than 75% is organically produced. This study also introduced food substitution to compare the new diets with the average Danish diet (Saxe, Larsen et al. 2013).

Research question 04: What environmental and nutrition changes can we expect if we change the current primary school meal menus to include ‘Meat Free Mondays’?

In Chapter 6, as the second scenario (research question 04) I have selected “Meat Free Mondays”, which is proposed as a potential step towards a sustainable diet in the UK. For this scenario meat containing food items served on Mondays were identified and substituted with a meat free meal. We do not have good information on food substitution to inform the model about what food items would be eaten by primary school children if we remove meat containing food items from the menus on Monday. Their choice would be limited to what is offered by caterers and I therefore assumed that caterers would replace meat containing meals with meat-free food items currently on the menus. Therefore I estimated the average nutritional value and GHGE value of meat free meals in the dataset and used those values to replace the meat containing meals on Monday. The average nutritional quality and GHGE of school meals were estimated with these new values and compared with current estimates to see whether introduction of a Meat Free Monday policy would change the “healthiness” and sustainability of school meals.

3.7 Chapter 7 methods

The UK government target for GHGE reduction and the contributions of the food sector for GHGEs was discussed in Chapter 2.

Research question 05: How can we change school meals to achieve the UK government target of GHGE reduction?

This question was answered using linear programming, a mathematical tool for analysing and optimising school meals.

Linear programming technique as a mathematical tool

Linear programming (also called linear optimization) is a mathematical technique which allows for identification of the best outcome (such as minimum cost or best nutritional value) in a mathematical model (Vershik 2007). Linear programming has been used for nutrition research to construct a healthy low-cost diet during the World War II by George Stigler. He explained the basis and advantages of using this mathematical technique as opposed to results of manual estimates by expert nutritionists (Stigler 1945). With the rapid development of personal computers, the use of linear programming has become one of the standard set of tools in many industries. Breind et al mentioned that linear programming has been used in many fields of applied research. But due to the complexity of mathematically modelling the underlying structure of food selection practices, it has been rarely used to answer questions related to human nutrition (Briend, Darmon et al. 2003). But now we see different types of nutrition related studies using this technique. Most of the nutritional work that has used linear programming has aimed to formulate diets which achieve

nutritional standards at a minimum cost. The technique is further explained and described in a programme called “The diet problem”, which shows how to select a set of foods that will satisfy specified nutritional requirements (constraints of the model) using a linear programme model (NEOS 2012).

I used the same approach to formulate school lunches which meet nutrition based standards keeping a minimum GHGE value (instead of cost of food).

Rationale for using linear programming

Generally to formulate an optimal diet you need background information such as a list of food items, their energy and nutrient composition, estimated maximum daily portion size that can be recommended and their price (in this project GHGE instead of the price). According to Breind et al, the most commonly used alternative method is called “trial and error” approach. In this approach, different food combinations are repeatedly tried to formulate diets based on background information. The final solution may or may not be optimal and several backward steps are required to find a solution. In contrast, with the same background information provided, linear programming quickly and efficiently provides an optional diet where possible (Briend, Darmon et al. 2003). When formulating a diet is not possible, the model will clearly indicate that new food items must be introduced to the list, or that the constraints set in the model are unreasonable. For example if we want to achieve a certain GHGE reduction target, and if it is impossible to formulate an optimal diet that meets nutrient standards whilst reducing GHG emissions below a specified level , the model will clearly indicate that in the analysis. This will provide clear evidence supporting the

need of looking at low GHGE intensive food production and introduction of new food items to the list. I used this technique to answer the research question 05.

Food categories for linear programming

The eatwell plate classifies individual food items into five groups based on nutritional and other information from a health perspective. They do not always represent the same categories or similar food items as if they were grouped according to the GHGE values. Therefore to allow a meaningful analysis we subdivided these main categories in to 20 food groups as shown in the Table 3.3. In this we have considered food items which vary either nutritionally or by carbon footprint, and combined them into subgroups (e.g. shrimp and prawns were listed separately from fish as they had a significantly higher GHGE value compared to other fish items. Red meat was listed separately as it has a significantly higher GHGE value compared to white meat products.).

Table 3-3 Food categories in the database

Main category	Sub-categories*	No
Bread, rice, potatoes, pasta and other starchy foods	Potatoes	1
	Bread, rice ,pasta and other starchy foods	2
Fruit and vegetables	Fruits	3
	Tomatoes	4
	Other vegetables	5
	Fruit juices	6
Meat, fish, eggs, beans and other non-dairy sources of protein	Shrimp and Prawns	7
	Fish	8
	Egg	9
	Beans, pulses and products	10
	Red meat	11
	White meat	12
	Other meat products	13
Milk and dairy	Milk	14
	Cheese	15
	Yogurt and other dairy items	16
Foods and drinks high in fat and /or sugar	Butter, margarine, spreads, creams, dips	17
	Crisps, fried snacks, cakes, biscuits, chocolate and other sweets	18
	Non- diet drinks	19
Water, stock,		20
*These categories are used for linear programming modelling		

Background information for the model

I estimated the mean nutritional value for each nutrient listed in school lunch nutritional standards including energy and mean GHGE value and mean weight for each of the above 20 categories using STATA 11 SE. Water was excluded from the model as we consider the GHGE value of water as zero. The mean nutrient and GHGE values per 100g of each food group were estimated as inputs for the model.

The model was built using Microsoft Excel – “Solver” function. The Solver uses linear programming as a solving method (Microsoft 2015). In this model GHGE could be set as the variable to be optimised (to create a meal with the minimum GHGE value) while achieving a set of nutritional standards (constraints). As the second step of the analysis, instead of minimising for the GHGE, the model was asked to construct a meal to achieve specified GHGE value, while minimising for the difference between the current and new meals. This approach allows for an understanding of the types of food items in a meal which achieves the current GHGE targets with minimal deviation from current meal patterns. Details of the model and step by step analysis are provided in Chapter 7.

4 Comparing greenhouse gas emissions from different food groups; a systematic review.

This chapter reports on a systematic review of greenhouse gas emissions (GHGEs) associated with 1kg of food (as consumed) for each food group included in the European Prospective Investigation into Cancer and Nutrition (EPIC) food frequency questionnaire. It is important to produce robust estimates of these quantities, as they will be used as parameters in the diet / nutrition / emissions model that is described in following chapters, and that is used for the analyses reported in chapters 5, 6 and 7.

4.1 Introduction

GHGE reduction is one of the most pressing political challenges faced globally today, and measures are taken at various levels to address this issue. The UK Climate Change Act 2008 sets a target to cut the total annual GHGEs by 80% by 2050 with an interim target of a reduction of 34% by 2020 compared to the 1990 levels (UK Government 2008). The gases considered in these targets are the six direct greenhouse gases defined by the Kyoto Protocol (UNFCCC 2007):

1. Carbon dioxide (CO₂)
2. Methane (CH₄)
3. Nitrous oxide (N₂O)
4. Hydrofluorocarbons (HFCs)
5. Perfluorocarbons (PFCs)
6. Sulphur hexafluoride (SF₆)

There are several sectors which contribute to the total emissions in the UK.

Combustion of fossil fuels in the energy sector is the largest contributor to GHGEs in the UK followed by the agriculture sector which accounts for about 10% of total emissions (NAEI 2013). When all of the food system (i.e. farm to fork) is considered the contribution from the agriculture sector increases to around one fifth of UK greenhouse emissions (Garnett 2008, CCC 2010). Even this larger figure does not take into account emissions arising from deforestation or other land use change overseas that are caused by agriculture to produce food for the UK (Garnett 2008). The World Wildlife Fund (WWF) estimated that if we include the effects of certain aspects of land use change associated with agriculture (e.g. deforestation), then UK food production and consumption is responsible for 30% of total GHGEs (Audsley, Brander et al. 2009).

Therefore agriculture and the food chain are important sectors to tackle to achieve overall GHGE reduction targets. This would require appropriate policy interventions at local level and globally. In 2008, the European Commission presented the Sustainable Consumption and Production Action Plan. It includes a series of proposals on sustainable consumption and production by complementing a range of existing policies and provides measures to address gaps. It highlights the importance of quantifying the environmental impact of food and drink products along the supply chain to identify hotspots and opportunities for improvement (EC 2008, Peacock and De Camillis 2011).

Most of the estimates of GHGE associated with a product are derived from modelling using different data sources for emissions and resources used during the entire life

cycle of that product. Life Cycle Assessment (LCA) is considered as the best available method to estimate the environmental burden of a product and has been used widely to estimate the environmental burden of different food products. This is a process which considers all the steps in a production including the extraction of raw materials, manufacturing, transportation and distribution, use, re-use and maintenance, recycling and final disposal (Guinée, Gorrée et al. 2002). Ideally every LCA considers the entire life cycle, which is from 'cradle to grave' of a food product. Detailed LCA is favoured as it attempts to provide a more holistic approach to estimate the environmental burden. Simplified and conceptual LCA is also common due to practical reasons, such as lack of data on all stages of the process of development of a product (Pelletier 2006).

The Food and Agriculture Organisation (FAO) estimated that the livestock system accounts for 18% of global GHGEs. This is higher than the emissions from the transport sector (FAO 2006). A European Union (EU) commissioned report estimated that the contribution of livestock is around 13% of total GHGEs in the EU (JRC 2010) and it has been estimated as 8% for the UK (Garnett 2008). These differences could be partly due to different methods of estimation and different methods of food production.

Assumptions made regarding the system boundary for the calculation such as inclusion of emissions from fertilizer production, impact of land degradation and deforestation could also contribute to these differences in estimates.

Different food groups contribute different amounts to the total GHGE, due to differences in production process (Valin, Havlik et al. 2013). Different studies

produce significantly different estimates of GHGEs associated with food groups and it is therefore difficult directly to compare final estimates. Because of this variability in results, to compile evidence based definitions of sustainable diets it is necessary to synthesise the available literature in a transparent and comprehensive manner.

Studies which use life cycle assessment (LCA) are normally restricted to a limited number of food groups in each study as they need to conduct a detailed estimation of GHGEs throughout the food production system with multiple data inventories.

Similarly, most of the studies include only one or a few production method for each food group in each study.

The International Organization for Standardisation (ISO) has standardized the methods for conducting LCAs. The ISO 14040:2006 report describes the principles and framework for LCA and the main components are: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements (ISO 2006). Out of those six, the report says that the four essential components are: goal definition and scoping, life cycle inventory, impact assessment, and improvement assessment.

Previous attempts to produce a comprehensive set of comparable estimates by food groups have not been conducted systematically (Sonesson, Davis et al. 2010, Vries and Boer 2010, Milani, Nutter et al. 2011). My synthesised estimates could be used to

compare the environmental impacts of different food groups and identify which food groups should be targeted to reduce the GHGEs by addressing production and consumption. However, non-systematic methods may bias the findings of these reviews. Therefore the estimation of the environmental impact of different food groups through a systematic process has become an urgent task in order to make informed decisions about achieving sustainable healthy diets. This review will examine different LCA studies used to estimate the GHGEs of food types and provide information to compare different food groups. This systematic review aims to:

- 1) combine the disparate literature to produce rigorous estimates of GHGEs associated with different food groups, incorporating different methods of production and different regions of production;
- 3) inform future models of healthy and sustainable food consumption.

4.2 Research questions:

1. How do the GHGEs associated with 1kg of different food groups vary by food group?
2. How do the GHGEs associated with 1kg of food vary within food groups, due to differences in farming methods and location of production?
3. How do reported GHGEs estimates associated with 1kg of food as consumed vary due to differences in the choice of system boundary?

4.3 Methods

4.3.1 Inclusion / exclusion criteria for considering studies for this review

The following criteria were used to select studies to be included.

Inclusion:

- 1) Study must be a LCA estimating GHGEs associated with production *or* consumption of at least one food type that is included in the EPIC Oxford FFQ (see appendix).
- 2) The GHGE value should be reported in carbon dioxide equivalent (CO₂e) or individually for three main gases- CO₂, N₂O and CH₄.
- 3) The study must report on for essential components of an LCA as set out by the International Organization for Standardization (ISO) which has standardized the methodology to conduct LCAs.

Exclusion:

Studies will be excluded from the review if:

- Greenhouse gas emission data are not presented in CO₂es or it was not possible to estimate GHGEs as values for all three main individual gases (CO₂, N₂O and CH₄) are not presented.
- Details are not provided about the method of calculation.
- Study not available in the English language.
- Study presents results for farms or areas as opposed to an amount of a food type

- Study presents results for farms or areas as opposed to a functional unit of a food type (e.g. kg of food as consumed).

Authors of the studies which have not explained the method of calculation clearly were contacted to obtain these details. When I could not obtain required details due to lack of contact details or lack of response, those studies were excluded.

4.3.2 Type of outcome measures

There are different environmental measures we could use to compare the environmental impact of a product. For the purpose of this review we are only interested in GHGEs. It is the most commonly reported impact category and policy targets are set around the reduction of GHGEs. You could measure GHGEs in many different ways, and there is no agreed standard method. These different ways include: gases included in the calculation and time frame for converting to CO₂ equivalent. Some studies report the emission of individual greenhouse gases. Most of the studies summed up the impact based on their equivalent factor compared to the impact of CO₂ over a 100 year time period to estimate the global warming potential (GWP). The most commonly used conversion factors are: 21 for CH₄ and 310 for N₂O (Vries and Boer 2010). These are called the global warming potential (GWP) factors and the final estimate of GWP is given in KgCO₂e. For this review, I report the final estimates of GWP as CO₂e with a 100 year timeframe. If this was not the outcome measured in the study then the results were converted to this common metric.

4.3.3 Search methods for identification of studies:

Search methods used for the systematic review are explained in several steps below.

Eight databases were identified for the search. They were CAB Abstracts – Ovid SP, ASSIA (Applied Social Sciences Index and Abstracts), CENTRAL (The Cochrane library), Global Health – Ovid SP, MEDLINE- Ovid, Web of Science, Geography and Ecology.

Food related search terms were identified from the food frequency questionnaire used by the EPIC Oxford study 2010(EPIC-Oxford 1992). The aim of the EPIC Oxford FFQ is to produce a comprehensive assessment of food consumed by the study participants.

This questionnaire was used as it is currently used by a prospective study and the research team is based in the same department which provides further collaborative opportunities. In each data base title, keywords and abstracts fields were searched with these search terms. These search terms were: ‘Food’ and all the bold headings in the food frequency questionnaire used by the EPIC Oxford study in 2010: meat, dairy, milk, cheese, yogurt*, egg*, fish*, bread, cracker*, spread*, cereal*, drink*, beverage*, potato*, rice, pasta, pizza, sweet*, snack*, dip*,dressing*, soup*, sauce*, vegetable*, fruit* .

Search terms for the environmental outcomes were searched in the title, abstracts and keywords fields. They were greenhouse gas*, Carbon food print, Carbon dioxide, CO₂, Methane, CH₄, Nitrous oxide, N₂O, Global warming, GHG emission and Emission.

Records identified in the above two searches were combined using the term “AND” and selected hits were exported in to Endnote software. These hits were screened by reading the abstracts to select full papers for the review. The Food Climate Research

Network (FCRN) and United Nations Environment Programme websites were searched for additional resources. Additionally, the Google search engine was used with same search terms and the first five pages were screened to identify new studies.

4.3.4 Data extraction

The GHGEs of food products depend on the production system and the setting. Some studies compared different production systems or settings for the same food group. These details were recorded if appropriate outcome measures were presented to compare these categories.

Although LCAs are designed to measure the impact of a product ‘from cradle to grave’, in practice the system boundaries used are not consistent across studies. Results depend on what was considered as the production systems (system boundary definition) and it varies significantly between studies. I categorised the stages commonly included in a LCA in to six main stages. They are:

- 1- Forest loss and / or land use change (emissions due to impacts of occupying, reshaping and managing land for agricultural purposes;
- 2- Land use (direct impacts, which are related to land use, like nitrate leaching or diffuse emissions from soil to air etc.);
- 3- Pre-farm activities such as fertilisers, fuel etc./primary resources;
- 4- On farm activities;
- 5- Any post farm gate/ post production activities up to retail;
- 6- Household/consumption related activities.

Stages included in a study were recorded with the final estimates of global warming potential.

4.3.5 Analysis methods

Some studies presented more than one production system for each food group. We gave an equal weight for each of these production systems and calculated a mean estimate of GHGs for each food group in each study. These mean values were used to estimate the mean value per food group across all of the identified studies. Minimum and maximum values were also reported to demonstrate the range of these estimates.

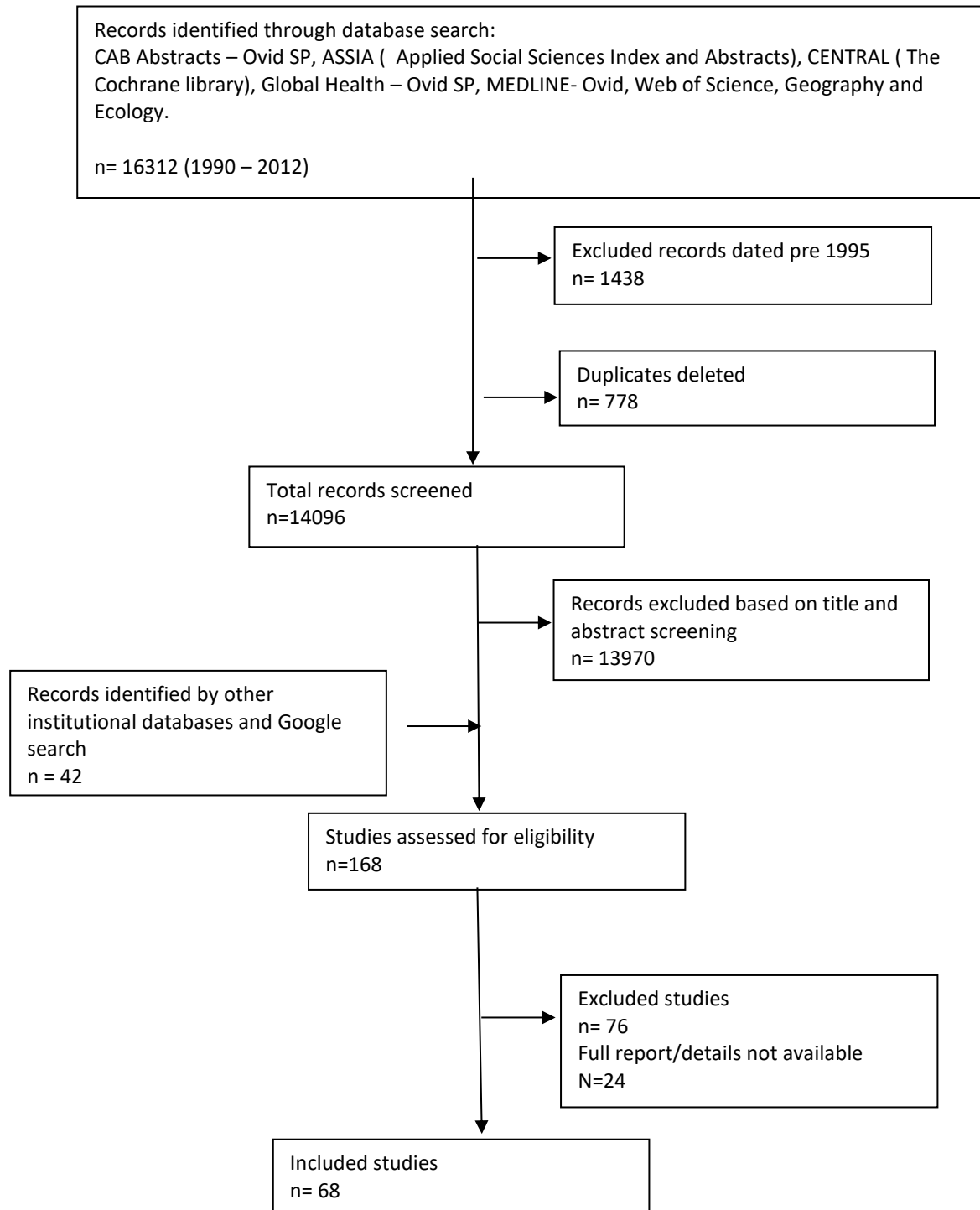
4.4 Results

The database search identified 14,096 papers from 1995- 2012 and they were screened with titles and abstracts to select papers for this review, which identified 126 papers. A further 42 papers were added through searching other relevant websites (e.g. Food Climate Research Network, United Nations Environment Programme).

A total of 68 studies were included in the final analyses. Table 4.1 describes these studies providing information on setting/s, subgroups or different farming methods considered in the study and stages of the life cycle included in the analysis. Some studies (Cederberg, Persson et al. 2011) included stage one with rainforest loss in the LCA up to the farm gate, whereas some studies (Ziegler and Valentinsson 2008) excluded forest loss and included LCA up to consumption. The setting of the production contributes to the variations in GWP estimates. For example Williams,

Audsley et al. 2006 estimated the GWP for food groups in England and Wales, while (Dalgaard 2007) estimated GWP for food imported to the UK from Denmark.

Figure 4.1 Study flow diagram



Most of the studies (out of 76) were excluded due to lack of details about the methodology and system boundary. More than a fifth of excluded studies measured the GHGE per area of land (per Km² of paddy field etc.) and it was impossible to estimate the GHGE per Kg of food product. Around 15% of these excluded studies measured the GHGE per kg of animal feed and could not estimate the GHGE per any food groups included in my search terms. Proportion of studies excluded due to each reason is given in Appendix 4.

Table 4-1 Summary of studies included in the analysis

Study id	Author and date	Setting	GWP of special Farming method/ system mentioned or compared?	Final stage	included stages
1	(Williams, Audsley et al. 2006)	England and Wales	Organic , non-organic,	Farm gate	2,3,4,5
2	(Williams, Pell et al. 2008)	UK and imported to UK		RDC in the UK	2,3,4,5
3	(Winther, Ziegler et al. 2009)	Norway	Farmed ,captured fish		3,4,5
4	(Cederberg, Flysjo et al. 2009)	Sweden	Not specified	Retailer at Stockholm	2,3,4,5
5	(Dalgaard 2007)	Denmark to UK		Delivered to Harwich Harbour	2,3,4,5
6	(Nielsen, Nielsen et al. 2003)	Denmark to UK	Mixed	Delivered to retail store	2,3,4,5
7	(Nguyen, Hermansen et al. 2010)	EU	Dairy bull calf and suckler cow calf	Farm gate	1,2,3,4
8	(Silvenius and Gronroos 2003)	Finland	Cultivated fish	Processing centre	3,4,5
9	(Ziegler and Valentinsson 2008)	Sweden	Conventional trawling and creeling	Consumer	3,4,5,6
10	(Andersson and Ohlsson 1999)	Sweden	Tomato paste imported from cultivated countries	Consumer	2,3,4,5,6
11	(Basset-Mens and van der Werf 2005)	France	Good agricultural practice, Red label, French organic	Slaughter	2,3,4
12	(Williams, Audsley et al. 2010)	England and Wales	Organic, non-organic	Farm gate,	2,3,4,5
13	(Ziegler, Emanuelsson et al. 2011)	from Southern Senegal to Spain	Trawled and artisanal	Port in Spain	3,4,5
14	(Aubin, Papatryphon et al. 2009)	France	Flow throw traditional system	Farm gate	3,4
		France	Land based Re circulating system	Farm gate	

		Greece	Marine based farm	Farm gate	
15	(Nilsson, Sund et al. 2011)	Sweden	Not mentioned	Retailer	3,4,5
16	(Casey and Holden 2005)	Ireland	Not mentioned	Farm gate	3,4
17	(Ogino, Orito et al. 2007)	Japan	Cow- calf system, barn fed	Market	3,4
18	(Johnson, Phetteplace et al. 2003)	USA	Cow- calf system- conventional / intensive grazing/direct/mixed	Farm gate	2,3,4
19	(Schau 2012)	Atlantic fish to Norway	Not mentioned	Consumer	3,4,5,6
20	(Beccali, Cellura et al. 2009)	Italy to other countries	Not mentioned	Distribution firm	2,3,4,5
21	(Biswas, Graham et al. 2010)	Australia	Sub-clover, wheat and mixed pasture	Farm gate	2,3,4
22	(Boer 2003)	Sweden	Conventional and organic	Farm gate	2,3,4
		Netherland	Conventional, environmental friendly and organic	Farm gate	2,3,4
		Germany	Conventional intensive, conventional extensified and organic	Farm gate	2,3,4
23	(Brommer, Stratmann et al. 2011)	Germany	Coffee machines- energy efficient, average and inefficient	Consumer	3,4,5,6
24	(Mila i Canals, Burnip et al. 2006)	NZ	Grade 1 and 2 apples produced in different areas: Central Otago and Hawke's Bay	Farm gate	2,3,4
25	(Carlsson-Kanyama 1998)	Sweden	Not mentioned	Retailers	2,3,4,5
26	(Cederberg, Persson et al. 2011)	Brazil	Pastured	Farmgate	1,2,3,4
27	(Dalgaard and Halberg 2004)	Denmark	Different types of farms-	Farmgate	2,3,4
28	(Hospido and Tyedmers 2005)	Spain	Tuna from Atlantic, Indian and Pacific Ocean	Delivery to port	3,4,5
29	(Kramer, Moll et al. 1999)	Netherland	Not mentioned	Farm gate	2,3,4
30	(Maraseni, Cockfield et al. 2010)	Australia	Not mentioned	Farm gate	2,3,4,5

31	(Meisterling, Samaras et al. 2009)	USA	Conventional and organic	Shipping station	2,3,4,5
32	(Milai Canals, Sim et al. 2011)	Europe	Not mentioned	Consumer	1,2,3,4,5,6
33	(Basset-Mens, Ledgard et al. 2009)	New Zealand	Average Vs 3 intensification scenarios	Farm gate	2,3,4
34	(Capper, Cady et al. 2009)	USA	Milk production in 1944 Vs 2007	Production in farm	2,3,4
35	(Eide 2002)	Norway	Small, middle size and large dairy farm	Consumer	3,4,5,6
36	(FAO 2010)	Global	Meat from slaughtered dairy animals Vs fattened surplus calves and regional estimates calves	Retail	1,2,3,4,5
37	(Haas, Wetterich et al. 2001)	Germany	Milk intensive, extensified and organic	Farm gate	2,3,4
38	(Thoma, Popp et al. 2010)	USA	Not mentioned	Farm gate	2,3,4
39	(Thomassen, Calker et al. 2008)	Netherland	Conventional and organic	Farm gate	2,3,4
40	(O'Brien, Shalloo et al. 2012)	Ireland	Grass vs Confinement	Farm gate	1,2,3,4
41	(Mila i Canals, Munoz et al. 2008)	UK	Fresh Vs frozen	Consumer - sewage treatment after digestion	2,3,4,5,6
		Spain to UK	Spain Vs UK produced to consume in the UK	Consumer - sewage treatment after digestion	2,3,4,5,6
		Africa to UK	UK Vs Uganda/Kenya produced to consume in the UK	Consumer - sewage treatment after digestion	2,3,4,5,6
42	(Muller-Lindenlauf, Deittert et al. 2010)	Germany	Different types of organic farms	Production in farm	2,3,4
43	(Pathak, Jain et al. 2010)	India	Not mentioned	Consumption	2,3,4,5,6
44	(Peters, Rowley et al. 2010)	Australia	Grain finished and grass finished	Gate of the meat	2,3,4,5

				processing plant	
45	(Nemry, Theunis et al. 2001)	Belgium	Not mentioned	Consumption	2,3,4,5,6
46	(Casey and Holden 2006)	Ireland	Conventional and organic	Farmgate	2,3,4
47	(Phong, Boer et al. 2011)	Vietnam	Rice-based and high input fish system , rice-based and medium input and orchard-based and low input fish system	Farmgate	2,3,4
48	(Ripoll-Bosch, Boer et al. 2011)	Spain	Grazing, mixed and no grazing	Farmgate	2,3,4
49	(Pelletier and Tyedmers 2010)	From Indonesia to Europe		Harbour in Europe	3,4,5
50	(Roy, Ijiri et al. 2009)	Japan	Different types of rice EG: brown rice and Parboiled rice	Consumer	2,3,4,5,6
51	(Saunders and Barber 2008)	UK	UK Vs NZ production to consume in the UK	Up to UK harbour	2,3,4,5
		New Zealand	UK Vs NZ production to consume in the UK	Up to UK harbour	2,3,4,5
52	(Eriksson, Elmquist et al. 2005)	Sweden	Different feed systems- soy, pea and Synthetic amino acids	Farm gate	2,3,4
53	(Tynelius 2008)	Sweden		Retail	2,3,4,5
54	(Pelletier 2008)	USA	Not mentioned	Farm gate	2,3,4
55	(Pelletier and Tyedmers 2007)	Canada	Farmed salmon different feeds	Farm gate	3,4
56	(Davis, Sonesson et al. 2010)	Spain and Sweden	Not mentioned	Consumer	2,3,4,5,6
57	(Subak 1999)	USA	US Feedlot and African pastoral	Farm gate	2,3,4
58	(Usva, Saarinen et al. 2009)	Finland	Not mentioned	Broiler, cucumber and cheese- retail other food groups consumer and waste included	2,3,4,5,6
59	(Hospido, Moreira et al. 2003)	Spain	Galician milk production	Processing stage	2,3,4,5

				gate	
60	(Mollenhorst, Berentsen et al. 2006)	Netherland	Battery-cage system, the deep-litter system with and without outdoor run, and the aviary system with outdoor run	Farm gate	2,3,4
61	(Zehetmeier, Baudracco et al. 2012)	Germany	Constant milk but decreased beef output Vs constant milk and beef out put	Farm gate	2,3,4
62	(Ziegler, Nilsson et al. 2003)	Baltic sea to Sweden	Trawl , Gilnet and mixed	Reaching the household	3,4,5,6
63	(Tuomisto and de Mattos 2011)	Thailand	Cultured meat	Factory gate	2,3,4
		California	Cultured meat	Factory gate	2,3,4
		Spain	Cultured meat	Factory gate	2,3,4
64	(Vergé, Dyer et al. 2008)	Canada	Farm gate	Farm gate	2,3,4
65	(Vazquez-Rowe, Moreira et al. 2010)	Atlantic sea to Spain	Purse seining fleet and bottom trawling fleet	Arriving at the port	3,4
66	(Vintila 2010)	Romania	Conventional and organic	Retail	2,3,4,5
67	(Wang, Xia et al. 2010)	China	No	Post production	2,3,4
68	(Sheane, Lewis et al. 2011)	Scotland	Mixed	Consumption	1,2,3,4,5,6

Stages:

1. Forest loss and / or land use change (emissions due to impacts of occupying, reshaping and managing land for agricultural purposes
2. 2- Land use (direct impacts, which are related to land use, like nitrate leaching or diffuse emissions from soil to air etc.);
3. 3- Pre-farm activities such as fertilisers, fuel etc./primary resources;
4. 4- On farm activities;
5. 5- Any post farm gate/ post production activities up to retail;
6. 6- Household/consumption related activities

How do GHGEs associated with 1kg of different food groups vary by food group?

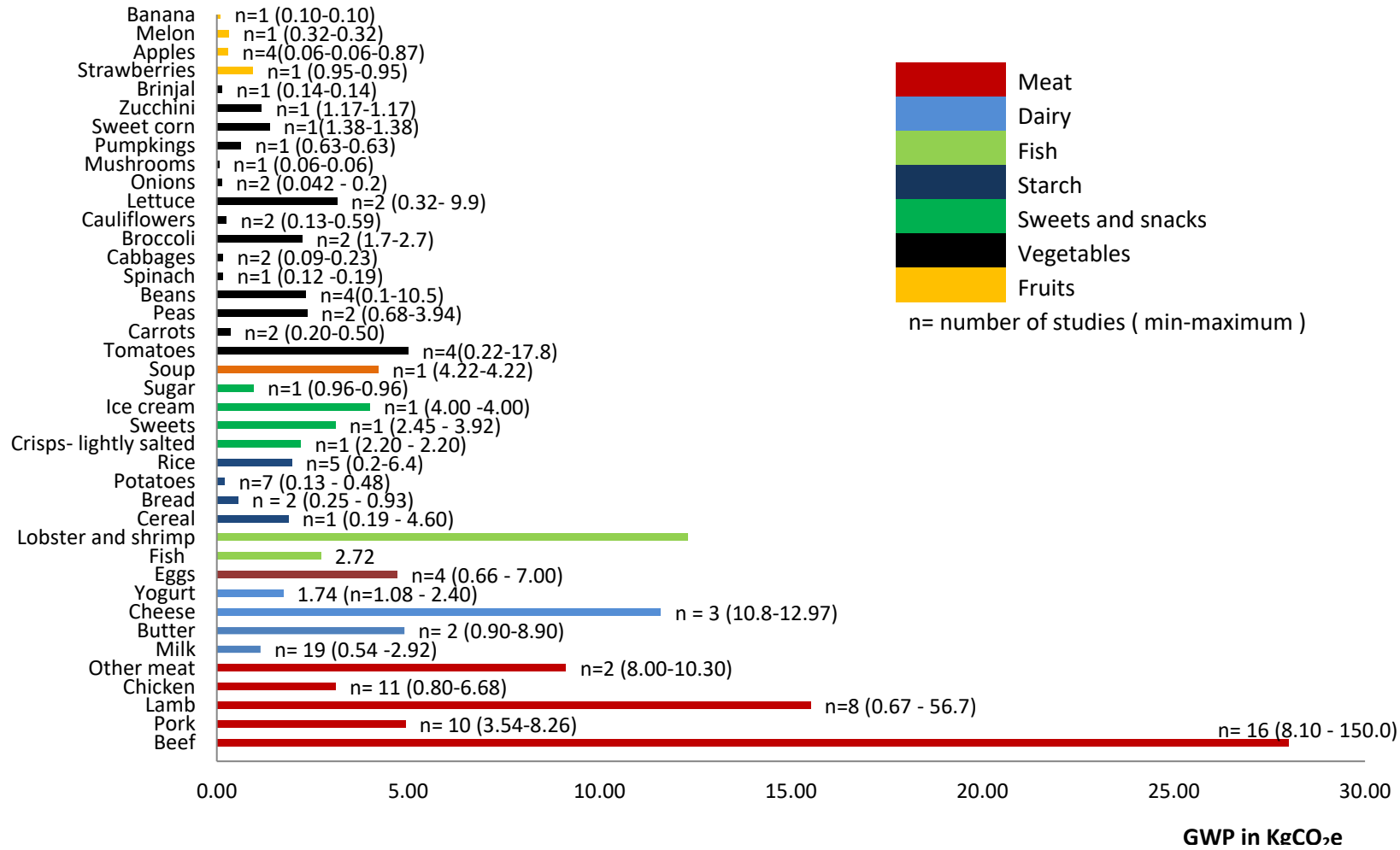
GWP in KgCO₂e per Kg of food by food group are presented in the Table 4.2 and Figure 4.2. For each food group, the table shows the number of studies selected for this final analysis, the range of values and mean value per study with references. Beef (28.00) and lamb (15.52) had the highest values per Kg of group and, bread (0.56), fruits (0.53) and potatoes (0.21) were among the lowest values. One cup of 125ml coffee contained 0.06 KgCO₂e, and GWP for 1Kg of fruit juice was 2.92 KgCO₂e. . The GWP of 1Kg of milk is 1.14 (0.54 – 2.92) based on 19 studies included. In this review I selected s 16 studies for beef, 10 for pork and 19 for milk compared to 7 studies for potatoes and 4 studies for tomatoes. There is a lot of variety in the number of studies that have been identified for each food group, with more studies for animal-based foods. Animal based foods tend to have the highest GHGE values. Within some food groups there is a lot of inter-category variability.

Table 4-2 Summary results, global warming potential (Kg CO₂e) per Kg of main food groups in the Food Frequency Questionnaire

	Food group	No of studies included	Range	mean per study	References (study id from Table 4.1)
1	Beef	16	8.10- 156.00	28.00	1,2,4,6,7,17,18,26,36,44,45,46,57,61,64,66
2	Pork	10	3.54 - 8.26	4.93	1,4,5,11,25,45,47,52,56,66
3	lamb	8	0.668 - 56.7	15.52	1,2,21,45,44,48,51,66
4	Chicken	11	0.80 - 6.68	3.10	1,2,4,6,43,45,47,53,54,58,66
5	Other meat	2	8 -10.3	9.12	43,66
6	milk	19	0.54 - 2.92	1.14	1,4,16,22,27,33,34,35,36,37,38,39,40,42,43,51,59,61,68
7	Cheese	3	10.8 - 12.97	11.60	4,58,68
8	Yogurt	2	1.08 - 2.4	1.74	4,68
9	Eggs	4	0.66 - 7.00	4.72	1,4,43,60
10	Fish (not including lobster and shrimp)	12	0.09 - 6.40	2.72	3,8,55,6,62,14,65,19,28,43,47,49
11	Lobster and shrimp	3	3.00 - 67.5	18.60	6,9,13
12	Bread	2	0.25 -0.93	0.56	6,43
13	Butter	2	0.90 - 8.90	4.90	43,68
14	Cereal	1	0.19 - 4.60	1.87	66
15	Potatoes	7	0.13 - 0.48	0.21	2,6,12,25,29,30,43
16	rice	5	0.2 - 6.4	1.96	25,43,47,50,67
17	Crisps- lightly salted	1		2.20	15
18	Sweets	1	2.45 - 3.92	3.10	15
19	Ice cream	1		4.00	68
20	Sugar	1		0.96	6
21	Tomato ketchup	1	0.68-0.98		10
22	Soup	1		4.22	32
23	Fruits	7	0.065 - 1.37	0.53	2,24,43,51,30,30,47
24	Tomatoes	4	0.22 - 17.80	5.00	1,2,25,30
25	Vegetables	8	0.042 – 11.00	1.49	25,30,41,29,43,58,51,47

	DRINKS				
	Coffee	1		0.48	23
	Orange / lemon juice	1		2.93	20
	Cola	1		0.33	15
	Lasi	1		0.35	43

Figure 4.2 Greenhouse gas emissions (GWP in KgCO₂e) of food groups



Fish generally has a lower GHGEs value compared to meat. But some shell-fish such as lobster and shrimp have a very high GHGE value. This average estimate of 18.60 (3.00-67.5) is based on three studies which analysed the lifecycle of lobsters and shrimp.

Foods grouped under starchy foods (rice, potatoes and bread) contain generally lower GHGE values compared to other groups. Rice is generally considered as a product with higher environmental burden. This is mainly due to the methane emissions from rice fields (Zhang, Wang et al. 2011). But LCA shows when you consider the overall emissions of the production system its GWP is only 1.96 (0.2 -6.4) per 1 kg of rice.

Overall the GWP of vegetables is 1.49 (0.042 – 11.00) and the highest value within the group is reported for green beans. It is an outlier in the vegetable category as more than 80% of its GWP is due to transport stage by airfreight to the UK. This is the only food group in this systematic review which significantly increased its GWP due to transport as most of the other studies included sea freight as the mode of transport, which has a relatively modest carbon footprint.

The results show a value of 4.22 KgCO₂e for soup and this is based on several soup cube products manufactured by the industry. They include processing and packing of soup cubes and could be significantly different to the GWP value of home-made soup products.

The availability of a higher number of studies for a food group does not always guarantee a precise estimate of GWP. Beef and milk are the two groups with the highest number of studies included in this review. This could be due to the availability of reports and popular

discussions mentioning that livestock contribute to the major proportion of GHGE in agriculture and researchers focus on these products to try and identify opportunities for GHGE reductions. Milk showed a narrow range (0.54 – 2.92) with 19 studies compared to the wide range reported for beef (8.1 - 156) with 16 studies. This variation is mainly due to the system boundaries considered in assessments, which will be covered later in this chapter.

How do GHGEs associated with 1kg of food vary within food groups, due to differences in farming methods and locations?

The tables in the Annex show estimates for each food group. Studies which estimated GHGEs of a particular food group are presented in each of these tables.

Organic and conventional systems are commonly compared in LCA reports. Organic production systems aim to produce food with an environmentally friendly approach with relatively less inputs. Therefore it is commonly anticipated that organic products will have a lower greenhouse gas emissions, but less yield per unit of land. Table 3 summarises GHGEs values associated with organic and conventional production methods. Only studies which included both organic and conventional methods in their LCA were included for this analysis. Mean GWP associated with one Kg of organic beef is 18.2 KgCO₂e compared to 21.3 in the conventional method. The organic production does not always give lower GHGE values and for products such as pork, chicken, eggs, potatoes and tomatoes it was higher than the conventional method.

Table 4-3 GWP associated with organic vs conventional production of 1kg of food

Food group	Organic Mean (range) <i>KgCO_{2e}</i>	Conventional / non-organic Mean (range) <i>KgCO_{2e}</i>
Beef	18.2 (16.6 – 20.0)	21.3 (13.07 - 28.5)
Pork	5.0 (3.5 - 6.0)	4.7 (3.4 - 6.3)
Lamb	9.0 (8 .0-10.1)	17.7 (17.5 – 18.0)
Chicken	5.3 (3.8 - 6.7)	4.3 (4.0 - 4.6)
Milk	1.3 (0.9 -1.5)	1.2 (0.8 -1.4)
Egg	7.0	5.5
Potatoes	0.2	0.19
Tomatoes	17.8	9.14

Organic and conventional were not the only production systems compared in LCA reports.

The GHGEs of one Kg of beef produced by the suckler cow calf system was significantly higher than the emissions from the dairy bull calf system. Free range chickens and eggs receive wider approval due to higher level of animal welfare compared to battery cage production systems. Eggs from battery cage hens contained 3.9 KgCO_{2e} per 1 Kg of eggs compared to 4.2 for free range eggs. This could be explained by the less energy expenditure of animals in battery cage production and the requirement of less energy inputs. Similarly other food groups also showed differences due to different farming methods within each food group.

The GHGEs associated with a product changes based on the location due to several factors. One Kg of tomatoes produced in Spain reported a lower level of GHGEs (0.74) compared to tomatoes produced in the UK (2.24). One Kg of tomatoes produced in Sweden and Australia reported GHGE values of 3.3 and 0.22 respectively. Other food groups also showed

differences due to production locations. Table 4 compares GHGEs of 1 Kg of selected food products produced in the UK vs Australia/New Zealand region.

Table 4-4 GWP of 1kg of selected food groups, UK vs Australia/New Zealand

Food group	UK	Australia or New Zealand
Beef	23.97 (Williams, Pell et al. 2008)	9.9 (Peters, Rowley et al. 2010)
Lamb	14.14 (Williams, Pell et al. 2008)	10.2 (Peters, Rowley et al. 2010)
Milk	1.19 (Williams, Audsley et al. 2006)	0.933 (Basset-Mens, Ledgard et al. 2009)
Lettuce	1.4 (Mila i Canals, Munoz et al. 2008)	0.32 (Maraseni, Cockfield et al. 2010)

Some of this difference is due to the different LCA system boundaries considered by authors. Difference in the GHGE of products such as lettuce could be explained by the difference in production systems. Higher value for lettuce in the UK could be attributable to all year around production in greenhouses. Similar explanations could be given for the higher value of UK tomatoes compared to the lower value in Spain. These results show GHGEs of food vary by the location and production systems.

How do reported GHGE estimates associated with 1kg of food as consumed vary due to differences in the choice of system boundary?

Some studies attempted to include more stages of the life cycle in the LCA compared to others. Only two out of 68 studies, considered all six stages described in the methods

section. Twenty seven studies did not include the deforestation stage and considered the system boundary up to the farm gate (stages 2-4). A study which considered stages 2-4 in USA estimated the GHGs of one Kg of beef as 14.8 (Subak 1999) compared to 156 which included deforestation in Brazilian beef (Cederberg, Persson et al. 2011). Two studies considered stages 1 to 4 for beef category and their average was 101.7 compared to average estimate of 12.66 from the four studies which included stages 2-4. This shows that inclusion of emissions from land use change can significantly change the final estimate for foods. A study which included emissions up to the retailer (stages 2-5) estimated the GWP of one Kg of pork in Sweden as higher (6.1) than an estimate which included emissions up to the consumer (stages 2-6) in Belgium (3.6). This shows that inclusion of a wider system boundary does not always give higher estimates, as it also depends on the place and production system.

Therefore the variations between food groups could be explained by different factors such as the differences in locations, differences in production systems and differences in the system boundary considered in the LCA. Current data are inadequate to quantify the relative contributions of these factors to explain these differences in final estimates of a food group.

4.5 Discussion:

4.5.1 Summary of findings

The results of this study present mean values of GWP of different food groups in a commonly used food frequency questionnaire. Where possible it presents data for different farming methods within each food group.

The red meat products- beef and lamb had the highest values per Kg of group and, bread, fruits and potatoes were among the lowest values. Fish generally contains a lower GHGE value compared to meat products, but lobster and shrimp showed higher values in this study.

The GHGE values within a food group are different according to the place of production. However, there were not enough studies identified in this review to evaluate how much of the differences in place of production were due to genuine differences, and how much were due to different methods applied in the LCA analysis, especially with regard to the choice of system boundary.

My results also show that choice of the system boundary can significantly change the final estimate of GHGEs and especially the emissions due to land use change or deforestation become highly influential towards the GWP of a food product.

4.5.2 Implication of research

Studies are included in this review from different countries with different system boundaries. Some studies estimated the GWP of overseas products up to the UK harbour or retail stores. Some studies considered farm gate as the end point in their analysis. It is possible to add estimated GWP associated with transport of product in to the UK. The most common type of transport is sea freight and it has been estimated that this method of transport generates between 0.007 and 0.0153 kgCO₂ emissions to transport a tonne per Km (Saunders and Barber 2008). Based on these estimates a Kg of product transported to

the UK from different parts of the world will add following values to the total estimate (Table 4.5).

Table 4-5 Average greenhouse gas emissions of 1kg of products due to sea freight to the UK

Country	GWP Kg CO₂e
From EU	0.01
From South America	0.035
From USA	0.034
From Africa	0.035
From New Zealand	0.1

Therefore transport values were not added to the total emissions in the Table 2 and they are unlikely to change the GHGE ratings of food groups. However air transport would add around 0.7 CO₂ kg /t per Km (Vintila 2010) and one study included vegetables transported by air. Some studies showed that imported food products have a lower GHGEs value compared to UK production (Saunders and Barber 2008, Williams, Pell et al. 2008).

Therefore guidelines and messages which indicate local food is always environmental friendly should be interpreted with caution.

The Food And Agriculture Organization of the United Nations (FAO) says that the long-term objective of their Organic Agriculture Programme is to enhance food security, rural development, sustainable livelihoods and environmental integrity by building capacities of member countries in organic production, processing, certification and marketing (FAO 2006, IFOAM 2013). According to the International Federation of Organic Agriculture Movements the principles of organic agriculture are health, ecology, fairness and care (IFOAM 2013). Regarding some environmental impacts however, conventional and organic agriculture offer competing advantages. Depending on the chosen indicator of environmental performance

(i.e. land use, energy use, GWP, etc.), and the particular system under study, LCAs and other energy-based analyses have reached varying conclusions with regard to the environmentally preferable method of growing and raising food. Therefore interpretation of environmental sustainability of organic products through LCA has become controversial (Friel, Barosh et al. 2014). Our results show that the range of GHGE estimates overlap between conventional and organic products. For pork and chicken the mean value of organic products was slightly higher than the conventional value, whereas for lamb the mean value for organic product was half of the conventional value. These findings are consistent with other individual studies (Williams, Audsley et al. 2006, Vintila 2010), but other environmental indicators such as land use, acidification potential, eutrophication potential should also be considered before making conclusions about the environmental suitability of a production system. Generally organic production is associated with more land use per kg of food produces (Williams, Audsley et al. 2006, Point 2008) and there is no widely accepted method to develop a composite score to rate the overall environmental burden of a product. Policies and statements which promote organic food to reduce GHGEs should be treated with some caution.

Storage of carbon is lowest in crop lands after deserts. Therefore land conversion accounts for a significant amount of emissions equal to a third of the value of emissions due to fossil fuels globally. Agriculture is the most important contributor to land conversion (Bellarby and Foereid 2008) and the impact of land use change due to food chains has been widely discussed in literature (Friel, Dangour et al. 2009, Cederberg, Persson et al. 2011). It is important to capture the land use change in LCA of food products to provide accurate

estimates of GHGEs . As shown in this review a majority of studies excluded this stage and underestimate the total environmental impact.

Red meat products such as beef and lamb account for a higher GWP due to its biological production mechanisms. Methane accounts for a larger share of this GWP and red meat production is one of the main sources of methane emissions. The greatest source of methane emission in Europe is the agricultural sector. The agricultural sector mainly contributes in two key stages; enteric fermentation in ruminants and livestock manure is the key stages of methane emissions in agriculture. The transfer of hydrogen is beneficial to degradation of cell wall carbohydrates in the diet of ruminants. Formation of methane is the major mechanism of hydrogen transfer and elimination, in these animals which leads to methane production (Moss, Jouany et al. 2000). Due to these reasons livestock products are associated with higher GWP and it has been in the centre of focus in the discussion of reducing GHGEs of food systems. This context encouraged more scientists to study livestock production systems and as a result, we have the highest number of LCA reports on these livestock products. These studies consistently show that cows and sheep produce high amounts of GHGEs irrespective of the method of raising them. This shows that it would be difficult to reduce the GHGEs associated with livestock (to meet the UK Government GHGE reduction target) merely by improving production systems or by improving technology, while keeping the same amount of red meat in the plate.

With current population growth globally the demand for land, food and energy will continue to grow. By 2050, global farm animal production is expected to double from present levels. Policy makers and organizations should work collaboratively to mitigate and prevent the environmental impact from agriculture by changing regulations, production systems and food consumption patterns (Koneswaran and Nierenberg 2008). Garnett warns that LCA results alone can give a distorted impression of the environmental sustainability and could prompt mitigation strategies that are counterproductive. Therefore policy makers need to be aware of the limitations of LCA as it may not capture the full benefits and disbenefits of products, (Garnett 2009).

The systematic review presented here gives a mean value of GHGE for each food group and this will be sufficient for further studies described in this thesis. Nutritional data bases will provide details on the quantity of each food types consumed by each participant and they do not provide the information on the origin of those food and production types. Therefore only a mean value for each food type consumed could be allocated and that is estimated in this analysis. These results could be used to quantify the impact of policies which aim to change the diets such as the UK government buying standard policy (Defra 2011) or new school food standards (SFP 2014).

Future research in to LCA of food should make efforts to follow a uniform approach to allow more meaningful comparisons between different studies. This should include common definition of stages in the life cycle and inclusion of similar activities always under the same category, for example inclusion of processing and packaging as post farm gate rather than on farm activities etc. LCA studies should try to compare existing production systems always

where possible (organic vs conventional etc.) to understand which products are more sustainable.

4.5.3 Comparison with other literature

Our findings are consistent with most of the previously published reports and studies which claimed livestock products such as beef and lamb have a higher GHGE per unit of production compared to fruits and vegetables (Basset-Mens and van der Werf 2005, Casey and Holden 2006, Williams, Audsley et al. 2006, Garnett 2008, Audsley, Brander et al. 2009, Garnett 2009).

Other studies have also showed significant differences of productions systems and how they contribute to the overall GHGE difference per Kg of the same food product. A comprehensive assessment of the livestock industry around the world was carried out by researchers from the International Livestock Research Institute in Kenya, the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia and the International Institute for Applied Systems Analysis (IIASA) in Austria. Their report shows that due to the poor feed quality and because of the high mortality rates in herds in sub-Saharan Africa a cow consumes more than 10 times of what a cow consumes in North America or Europe to produce the same amount of meat. Similar differences were reported for poultry and pigs as well (Herrero, Havlik et al. 2013).

4.5.4 Strengths and weaknesses

This systematic review used food related search terms from a commonly used food frequency questionnaire and results of the study could be used to link GHGE values of each food group in to common nutritional data bases. This would allow us to answer important research questions around sustainable healthy diets. According to my understanding this is the first time a systematic approach was used to synthesise current literature on GHGEs of food groups.

The LCA approaches reviewed here are designed to give comparable estimates of GHGE for different agricultural process. However, it has been suggested that the LCA method underestimates the environmental impact of fishing , as it does not consider the impact of over fishing, fuel emission from combustion at sea and seafloor ecosystem disturbances (Ellingsen and Aanondsen 2006). Therefore, GHGEs for fish and seafood reported here may be underestimated in comparison to other land-based agricultural products.

This systematic review included studies from any country if they met the criteria. It would be ideal to have UK specific GHGE data for all food groups. To get representative values for UK food, we cannot just consider LCAs conducted in the UK. More than 50% of some food groups are imported to the UK from different countries. Therefore to get representative data we need to have data on exact amounts imported to the UK from each country and GHGE data based on LCA studies conducted in those countries. Looking at the limited number of LCA reports available for food items, we cannot match these with imported locations for all the food groups.

Although we considered the functional unit of the study as one kg of food products, it could be different due to the differences in the last stage of the system considered in the analysis. One Kg of carcass meat is different to a Kg of edible meat prepared at home. Likewise one Kg of fish caught from the sea is different to a Kg of cleaned, gutted and frozen fish at the supermarket. These differences should be considered when interpreting the results of this review. The GHGE values presented in this chapter are for 1 Kg of the raw product. The system boundary is different and most studies considered regional distribution centre of supermarkets as the end point. For most food items such as meat, fish, fruits and vegetables edible weight is less than the weight at supermarket due to food preparation losses. We did not do any corrections to address this as it could vary between different food products, even within the same food group. Therefore the overall GHGE value could be an underestimate.

Quality assessment

I used a quality criteria developed by the Joint Research Centre of the European Commission for LCAs and published in the ILCD handbook. It has six aspects and Table 4.6 describes those data quality indicators.

Table 4-6 Data quality indicators and description

Number	Indicator	Description
1	Technological representativeness (TeR)	Degree to which the data set reflects the true population of interest regarding technology including for included background data sets, if any
2	Geographical representativeness (GR)	Degree to which the data set reflects the true population of interest regarding geography, including for included background data sets, if any
3	Time-related representativeness (TiR)	Degree to which the dataset reflects the true population of interest regarding time/ age of the data, including for included background data sets, if any.
4	Completeness (C)	Share of flows that are quantitatively included in the inventory. i.e. degree of coverage of overall impact
5	Precision/ uncertainty (P)	Measure of the variability of the data values for each data expressed (e.g. low variance = high precision).
6	Methodological appropriateness (M)	The applied LCI methods and methodological choices are in line with the goal and scope of the dataset.

For all included studies a score of 1 – 5 (quality rating) was allocated for each indicator. Low numerical value, 1 was given for “very good” and higher numerical value, 5 was given for “very poor or unknown”. Overall data quality rating (DQR) was calculated based on the following formula given in the ILCD handbook.

$$DQR = \frac{TeR + GR + TiR + C + P + M + X_w * 4}{i + 4}$$

X_w : weakest quality level obtained (highest numeric value) among the data quality indicators

i = number of applicable data quality indicators

Based on the DQR, studies are allocated in to three groups. The Table 4.7 shows the values for each data quality indicator. My inclusion criteria included international standards for LCA studies and technological and methodological aspects were checked against the said goal of the study. Therefore in included studies, these indicators received a relatively higher score. According to the ILCD handbook for any study which has a uncertainty value with a relative

standard deviation of more than 25%, a score of 5 (very poor) should be assigned. This guide is developed for all LCA studies, not just for agriculture studies. But almost all the studies which estimated uncertainty in my systematic review showed a deviation of more than 25% and was allocated the 5 (very poor) score. Studies which did not estimate the uncertainty also gets the same score. According to the formula to estimate the DQR, the rating of the weakest quality level is counted 5 – fold. As a result all the studies were allocated in to the lowest group. The original DQR is shown in the DQR1 column of the Table 4.7. After reviewing these findings, I excluded the fifth indicator (precision/uncertainty) and re-calculated the DQR (shown as DQR-2). Final value of DQR 2 were used to estimate tertiles and studies in the first tertile have the higher quality scores relative to the second tertile. Third tertile has studies which has relatively lower quality scores.

Table 4-7 Data quality score

Study id	First author	Year	Technological Representativeness (Ter)	Geographical representativeness (GR)	time-related representativeness (TiR)	Completeness	Precision/uncertainty (P)	Methodological appropriateness (M)	Data Quality Score (DQS 1)	Data Quality Score(DQS 2)	Tertile based on DQS2
1	Williams	2006	1	1	3	2	5	2	3.4	2.25	1
2	Williams	2008	1	1	3	2	5	2	3.4	2.25	1
3	Winther	2009	1	2	3	3	5	2	3.6	2.5	2
4	Cederberg	2009	3	2	3	2	5	2	3.7	2.625	3
5	Dalgaard	2007	1	1	4	2	5	2	3.5	2.75	3
6	Nielsen	2003	1	3	2	2	5	2	3.5	2.375	1
7	Nguyen	2010	1	2	2	2	5	2	3.4	1.875	1
8	Silvenius	2003	1	2	3	3	5	2	3.6	2.5	2
9	Ziegler	2008	1	1	3	2	5	2	3.4	2.25	1
10	Andersson	1999	1	2	4	2	5	2	3.6	2.875	3
11	Basset-Mens	2004	1	1	3	3	5	2	3.5	2.375	1
12	Williams A.G	2010	1	1	4	2	5	2	3.5	2.75	3
13	Ziegler	2011	1	2	3	3	5	2	3.6	2.5	2
14	Aubin	2008	1	2	2	4	5	3	3.7	3	3
15	Nilsson	2011	1	2	3	3	5	2	3.6	2.5	2
16	Casey, J.W.	2004	1	2	2	4	5	3	3.7	3	3
17	Ogino. A	2007	1	3	2	4	5	3	3.8	3.125	3
18	Johnson DE	2003	1	3	3	3	4	2	3.2	2.625	3
19	Schau,E	2012	1	2	4	2	5	2	3.6	2.875	3
20	Beccali, M	2009	1	2	4	2	5	2	3.6	2.875	3
21	Biswas WK	2010	1	3	3	3	5	2	3.7	2.625	3
22	Boer IJM d.	2003	1	2	2	3	5	2	3.5	2.375	1
23	Brommer E	2011	1	2	3	3	5	2	3.6	2.5	2
24	Milai Canals, L	2006	1	3	2	3	5	2	3.6	2.5	2
25	Carlsson-Kanyama	1998	1	2	3	2	5	2	3.5	2.375	1
26	Cederberg	2011	1	3	2	2	5	2	3.5	2.375	1
27	Dalgaard, R.	2004	1	2	3	3	5	2	3.6	2.5	2

28	Hospido, A.	2005	1	2	3	3	5	2	3.6	2.5	2
29	Kramer K.J.	1998	1	2	4	1	5	2	3.5	2.75	3
30	Maraseni	2010	1	3	3	2	5	2	3.6	2.5	2
31	Meisterling	2009	1	3	3	2	5	2	3.6	2.5	2
32	Milà i Canals	2011	1	2	3	1	5	2	3.4	2.25	1
33	Basset-Mens	2008	1	3	3	3	5	2	3.7	2.625	3
34	Capper	2009	1	3	3	3	5	3	3.8	2.75	3
35	Eide	2002	1	2	4	2	5	2	3.6	2.875	3
36	FAO	2010	1	3	4	2	5	2	3.7	3	3
37	Haas	2001	1	2	3	3	3	2	2.6	2.5	2
38	Thoma	2010	1	3	3	3	5	3	3.8	2.75	3
39	Thomassen	2008	1	2	3	3	4	2	3.1	2.5	2
40	O'Brien	2012	1	2	4	2	5	2	3.6	2.875	3
41	Milà i Canals	2008	1	1	4	2	5	2	3.5	2.75	3
42	Muller-Lindenlauf, M	2010	1	2	3	3	4	2	3.1	2.5	2
43	Pathak	2010	1	3	3	2	5	3	3.7	2.625	3
44	Peters G.M.	2010	1	3	3	2	5	2	3.6	2.5	2
45	Nemry F.	2001	1	2	3	2	5	2	3.5	2.375	1
46	Casey J	2006	1	2	3	3	5	2	3.6	2.5	2
47	Phong L.T	2011	1	3	3	3	3	3	2.8	2.75	3
48	Ripoll-Bosch	2011	1	2	3	3	5	2	3.6	2.5	2
49	Pelletier and Tyedmers	2010	1	3	2	3	5	2	3.6	2.5	2
50	Roy et al	2009	1	3	3	2	5	2	3.6	2.5	2
51	Saunders	2008	1	3	3	2	5	2	3.6	2.5	2
52	Eriksson	2005	1	2	2	3	5	2	3.5	2.375	1
53	Tynelius, G	2008	1	3	2	3	5	2	3.6	2.5	2
54	Pelletier	2008	1	2	3	2	5	2	3.5	2.375	1
55	Pelletier	2007	2	2	2	2	5	3	3.6	2.5	2
56	Davis	2010	1	1	1	2	5	2	3.2	1.625	1
57	Subak	1999	1	2	3	3	5	3	3.7	2.625	3

58	Usva	2009	1	3	3	2	5	3	3.7	2.625	3
59	Hospido	2003	1	1	1	2	5	2	3.2	1.625	1
60	Mollenhorst	2006	1	1	1	3	5	2	3.3	2.125	1
61	Zehetmeier M	2011	1	1	1	3	5	2	3.3	2.125	1
62	Ziegler	2003	1	1	1	2	5	2	3.2	1.625	1
63	Tuomisto	2010	1	2	3	3	5	3	3.7	2.625	3
64	Verge	2008	1	1	3	3	5	2	3.5	2.375	1
65	Vazquez-Rowe	2010	1	2	1	2	5	2	3.3	1.75	1
66	Vintila	2010	1	2	2	2	5	2	3.4	1.875	1
67	Wang	2010	1	1	1	3	5	2	3.3	2.125	1
68	Sheane	2011	1	2	2	1	5	2	3.3	1.75	1
DQS 1 score is based on all six aspects. DQS2 excludes precision/uncertainty.											
Tertile one - higher quality studies, Tertile two – middle group , Tertile 3 – Lower quality											

I estimated the mean GHGE values of studies in the first tertile for several food groups and compared with the mean value of studies which were not included in the first tertile. This allows understanding the impact on final GHGE estimates based on the study quality.

Table 4.8 shows these estimates for pork and lamb.

Table 4-8 Average GHGE values for pork and lamb, by data quality group

Pork				Lamb			
Study ID	Data quality Tertile	GHGE KgCO _{2e}	Average	Study ID	Data quality Tertile	GHGE KgCO _{2e}	Average
1	1	5.95		1	1	13.8	
11	1	4.86		2	1	12.85	
25	1	6.1		66	1	13	
45	1	3.6		45	1	18.8	
52	1	4.3					14.61
66	1	4					
			4.80				
4	3	3.54		21	3	5.325	
5	3	3.77		44	2	10.7	
47	3	8.26		48	2	48.03	
				51	2	1.734	
			5.19				16.45

Table 4.8 shows that average values for GHGE for pork and lamb do not change significantly based on the data quality of included studies.

4.6 Conclusion

A large number of LCA studies of food products have been published. This study provides synthesised values of GHGE per unit production of food groups in a commonly used food frequency questionnaire.

5 Primary school meals, England – current status

This chapter mainly provides descriptive statistics about the dataset that I used and then results of the first two research questions, aimed at quantifying the greenhouse gas emissions (GHGE) from school meals and identifying the association between ‘healthy’ and ‘sustainable’ primary school meals. This chapter compares the GHGE of primary school meals to understand whether healthy meals are more environmentally sustainable than unhealthy meals.

5.1 Introduction

The nutritional quality of primary school meals in England has been assessed previously (Rogers, Ness et al. 2007, Haroun, Harper et al. 2012). These studies have used food composition tables to estimate nutrients in school foods observed in a representative sample to analyse the healthiness of meals. GHGE of food has also been analysed in various publications and sustainable diets have been suggested previously (CCC 2010). Both these components are important to assess the impact of a policy, as health and environmental sustainability are two major topics in current policy and research work. Previous reports have quantified them separately and this project aims to demonstrate how to quantify them simultaneously to produce more useful evidence for future policy discussions. By considering nutritional quality and GHGE simultaneously, we can identify whether policies aimed at reducing the environmental burden of primary school food provision are likely to have a positive or negative impact on the nutritional quality of the school meals and vice versa.

5.2 Research questions

This chapter aims to answer following research questions:

Research question 01: What is the contribution of primary school meals to the total greenhouse gas emissions (GHGE) in England?

Research question 02: Are current primary school meals that achieve nutrient based guidelines less GHG intensive than meals that do not achieve those guidelines?

5.3 Methods

The methods used to develop the dataset and for the analyses in this chapter are described in chapter 3. Here, a brief recap is provided.

I used the “Primary School Food Survey (PSFS)” data set, a nationally representative survey in 139 primary schools in England (SFT 2010). There were 6,690 students who ate school lunches and 3,488 students who brought packed lunches included in this dataset. For school lunches, nutritional information of all the dishes available in the menu was recorded in a separate dataset and another dataset was created with data collected by measuring trays of a sample of students who ate school lunches. This dataset included the food item, unique food code, starting weight, left over weight and nutritional information for key macro and micro nutrients. Using the systematic review I conducted (reported in chapter 4) on GHGE values per unit production of different food groups, a unique GHGE value was estimated for each food code. GHGE values of composite foods were estimated by allocating GHGE values of ingredients according to the proportion of weight. These values were combined with the nutritional information for each food code to develop the final dataset for analysis.

Using this amended dataset, I estimated the mean GHGE per school lunch and per packed lunch. These values were used to estimate the total GHGE of primary school meals in England. Each meal consumed by a child may consist of several composite and non-composite foods. Average GHGE value per school lunch and packed lunch was estimated by aggregating all the items consumed by a child on that day and these values were used to estimate the total GHGE from primary school meals in England, per year.

To answer the second research question, the first step was to define a “healthy meal” and identify which meals meet this definition. The nutrient-based standards described in the PSFS were used to define healthy meals. The number and proportion of meals which met these criteria are presented for both packed lunches and school lunches. Mean GHGE value for healthy meals and unhealthy meals were estimated for both packed lunches and school lunches and compared using t-tests.

5.3.1 Uncertainty analysis

There are two main types of uncertainties associated with this analysis. They are: uncertainty due to sampling error (introduced by the representative sample from the PSFS) and the uncertainty due to parameters we used to estimate nutritional values and GHGE values. Standard statistical analyses estimate the uncertainty that is due to sampling error. The nutritional information for food items has been taken from food composition tables – a technique that is commonly used in nutrition research projects and that is largely accepted by the scientific community. Estimating the uncertainty in results due to imprecise estimates of nutrient values is beyond the scope of this project. In this study, the GHGE parameters were introduced from a systematic review, which identified a large range in GHGE

associated with different food groups due to differences in production technique, location of production, and boundary of the life cycle assessment (see chapter 4). The method described below incorporates this additional uncertainty into the 95% confidence intervals around the results reported in this chapter.

Uncertainty due to GHGE values

For this study, I estimated the mean GHGE values for food items using the systematic review results (reported in chapter 4). As described in chapter 3, the mean GHGE value identified in the systematic review for each food group was then applied to the database of food items from the PSFS in order to estimate GHGE for primary school meals. This method gives an equal weight to individual studies which were included in the systematic review. In the uncertainty analysis, I created 1000 separate datasets, where the GHGE values for each food group varied randomly between the datasets. For each dataset, one study result for each of the food categories included in the systematic review was selected at random, and these values were used to generate the GHGE for school lunches and packed lunches.

Table 5-1 Selected GHGE values for food groups

Food	Mean Value	Random value	1	2	3	4	5	6	7	8	9	10
Potatoes	0.21	1.9.....	0.4	0.2	1.9	0.2	0.1	0.3	0.1			
Lamb	15.52	48.3.....	13.8	12.85	5.32	18.8	10.7	48.3	1.74	13		
Pork	4.93	1.48.....	5.95	3.54	3.77	4.86	6.1	3.6	8.26	4.3	1.48	4

Table 5.1 shows an example with three food groups; potatoes, lamb and pork. For mean GHGE values and point estimates of results, the mean value of selected studies was used. But for the uncertainty analysis the computer randomly selects a value from the range of

values reported in the literature. For potatoes the mean value is 0.21 KgCO₂e. When we ask the computer to use a random value, it picks any value from the given list. Each time when the computer select a random value for each of the food group, based on that selection the GHGE of each food code gets automatically updated in a separate Excel sheet, including re-estimation from the recipes used for composite foods. Based on the unique GHGE value per food code, the total GHGE of food items consumed by individual students in the PSFS are automatically updated. This process was automated and run 1000 times, producing 1000 PSFS datasets augmented with different estimates of GHGE.

These 1000 datasets were imported into STATA and for each research question, the STATA analysis produced 1000 different results and exported them into a single separate dataset. Here, each single set of results incorporates the uncertainty due to sampling error, and the difference between the 1000 set of results is an estimate of the uncertainty due to GHGE parameters. This final dataset was analysed in order to estimate the total uncertainty in the results due to both sampling error and GHGE parameters.

For example, to estimate the mean GHGE for packed lunches in England, the final dataset produced 1000 different estimates of mean and SD of GHGE of packed lunches, where each SD provides information about uncertainty due to sampling error. The 1000 different estimates of the mean provide information about uncertainty due to GHGE parameters. In order to estimate the uncertainty due to GHGE parameters, the 2.5th and 97.5th percentiles of the mean values were calculated.

To estimate the total error both due to sampling and GHGE parameters, confidence intervals (CIs) were calculated from the SD for each of the 1000 set of results. To quantify the total error the 2.5th centile of the low CI and 97.5th centile of the high CI was selected. The mean value was presented with the uncertainty with pure GHGE error, total uncertainty and the percentage due to the uncertainty around GHGE parameters as a percentage of total uncertainty.

5.4 Results

In the PSFS dataset, there were 1,556 unique food codes (different food items) consumed by 6,690 students. There were 38,148 food items surveyed for the study and more than 26,000 of them were non-composite food items (i.e. they belong in one single category of the eatwell plate) (Table 5.2).

In packed lunches there were 943 unique food codes. More than 17,000 food items were surveyed. Of the packed lunch items, the highest number of items was in the fruits and vegetables category followed by the milk and dairy category. Weight distribution of composite packed lunch items showed that highest proportion was attributed to bread, other cereal and potatoes group followed by the meat, fish and alternatives group.

Table 5-2 Descriptive statistics

		School lunches	Packed lunches
No of meals		6,690	3,481
No of unique food codes		1,556	943
No of food items		38,148	17,272
Non- composite items		26,240	7,759
No of non-composite food items in each eatwell plate category	Bread, Other Cereals and Potatoes	7,415	361
	Milk and Dairy	1,686	1,284
	Meat, Fish and Alternatives	2,253	213
	Fruit and Vegetables	9,601	5,311
	Fatty and Sugary Foods	1,829	77
	Water	3,456	513
Composite food items		11,906	9,485
Weight (%) distribution of composite food by eatwell plate category	Bread, Other Cereals and Potatoes	24.8 %	37.2%
	Milk and Dairy	24.2 %	6.3%
	Meat, Fish and Alternatives	19.2 %	23.0%
	Fruit and Vegetables	20.6 %	17.2%
	Fatty and Sugary Foods	11.2 %	16.3%
Per meal GHGE value range (KgCO ₂ e)		0.04 - 5.59	0.34 - 10.99
Per meal IQR of GHGE ((KgCO ₂ e)		0.40 - 0.80	0.46 – 0.86

The GHGE values of individual school meals had a wide range, 0.04 to 5.59 KgCO₂e for school lunches and from 0.34 to 10.99 KgCO₂e for packed lunches (Table 5.2).

The tray check data showed the student with the lowest GHGE value school meal (0.04 KgCO_{2e}) was consuming the following meal on that particular day (total energy 301 Kcal):

- White bread – 3 chunks (24g * 3)
- Raw carrots (13g)
- Half a Jacket potato (107g)

The school lunch which reported the highest GHGE value (5.59 KgCO_{2e}) contained following items (total energy 835 Kcal).

- Beef burger (150g)
- Potato wedges(73g)
- Fruit salad (105g)
- Cup of water (130g)

The packed lunch with the lowest GHGE value (0.34 KgCO_{2e}) contained following items (total energy 221Kcal).

- Brown wholemeal nan bread with margarine and sugar (61g)
- Bottle of tap water (282g)

The packed lunch with the highest GHGE value (10.99 KgCO_{2e}) contained following items (total energy 1069 Kcal).

- Pasta (285g)
- Beef stew (335g)
- Meat pie (112g)

Table 5.3 shows the percentage distribution of weight and GHGE of school food by eatwell plate categories. (see chapter 3 for details on food groups and classifications).

Table 5-3 Distribution of weight and GHGE by eatwell plate food categories, school lunch

Food category	Weight (%)	eatwell plate recommendation (% of mass)	GHGE (%)
Bread, Other Cereals and Potatoes	26.8	33	7.4
Milk and Dairy	17.8	15	19.6
Meat, Fish and Alternatives	12.1	12	41.5
Fruit and Vegetables	35.1	33	22.7
Fatty and Sugary Foods	8.2	8	8.7

More than a third of the weight is contributed by fruits and vegetables in school lunches and around a quarter from bread, other cereals and potatoes. Meat, fish and alternatives contributed by only 12% of the weight in contrast to 41% of total GHGE. Fatty and sugary food remained low (around 8%) in its contribution to both weight and GHGE (Figures 5.1 and 5.2).

Figure 5.1 Distribution of weight by food group, school meals

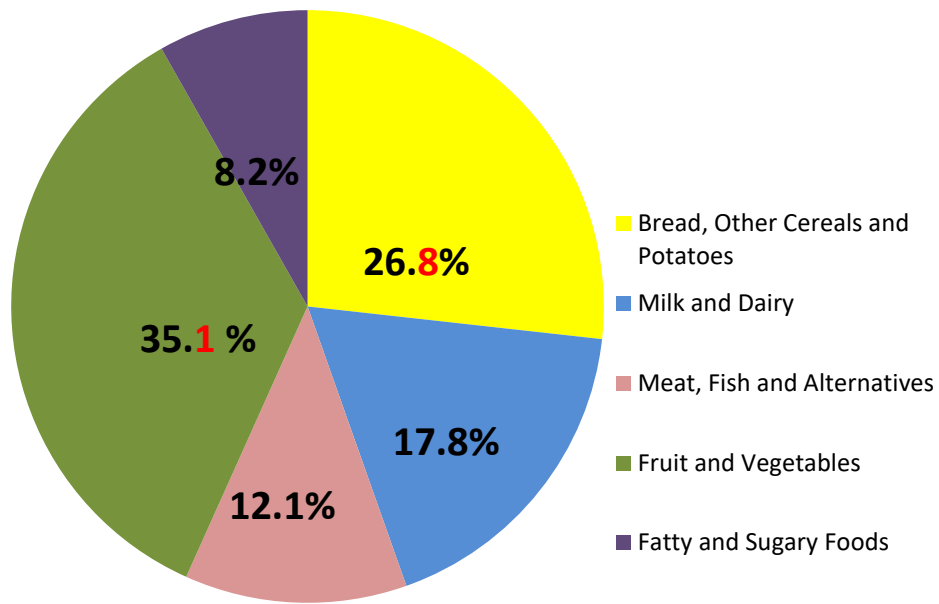


Figure 5.2 Distribution of GHGE by food group, school meals

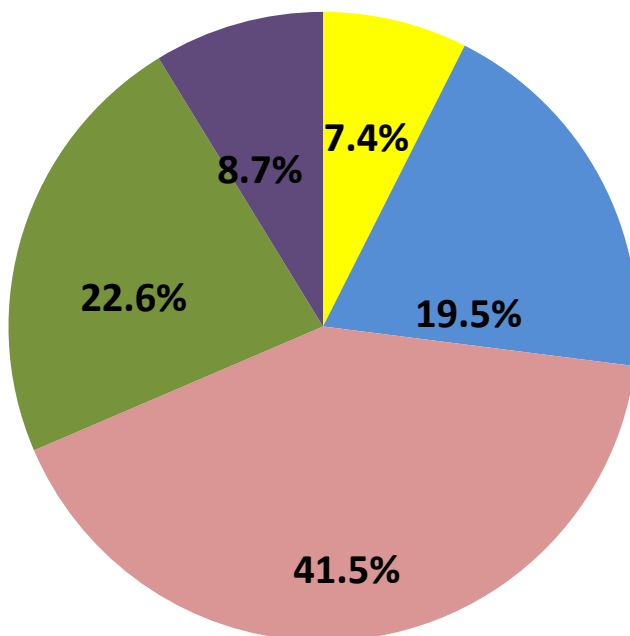


Table 5-4 Distribution of weight and GHGE by eatwell plate food categories with fruit juice as a separate category, packed lunches

Food category	Weight (%)	GHGE (%)
Bread, Other Cereals and Potatoes	14.8	5.9
Milk and Dairy	7.6	19.2
Meat, Fish and Alternatives	8.7	27.9
Fruit and Vegetables	18.4	8.6
Fruit juice	44.1	30.1
Fatty and Sugary Foods	6.30	8.3

Around 62% of the weight of packed lunches was due to fruits and vegetables (primarily due to large serving sizes of fruit juices, which make up 44% of weight of packed lunches). Bread, other cereals and potatoes contributed 15% of the weight and all the other groups contributed less than 10% of the weight. Similar to the school lunches, the meat, fish and alternatives group contributed to only 9% of the weight, but 28% of the GHGE. The milk and dairy category contributed around 8% for the weight and 19% of the GHGE. Fatty and sugary food remained low in both categories (Table 5.4, Figures 5.3 - 5.4).

In both school lunches and packed lunches the highest contribution to the food weight was from fruits and vegetables group and the highest contribution to the GHGE was from meat fish and alternatives for school lunches and, from fruit juices for packed lunches.

Figure 5.3 Distribution of weight by food group, packed lunches

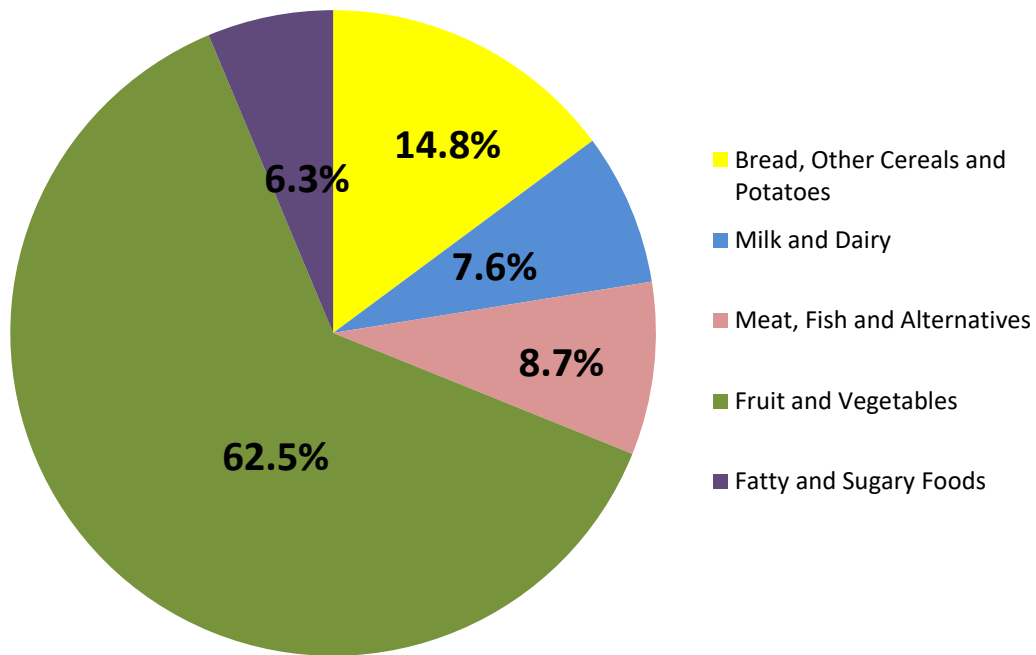
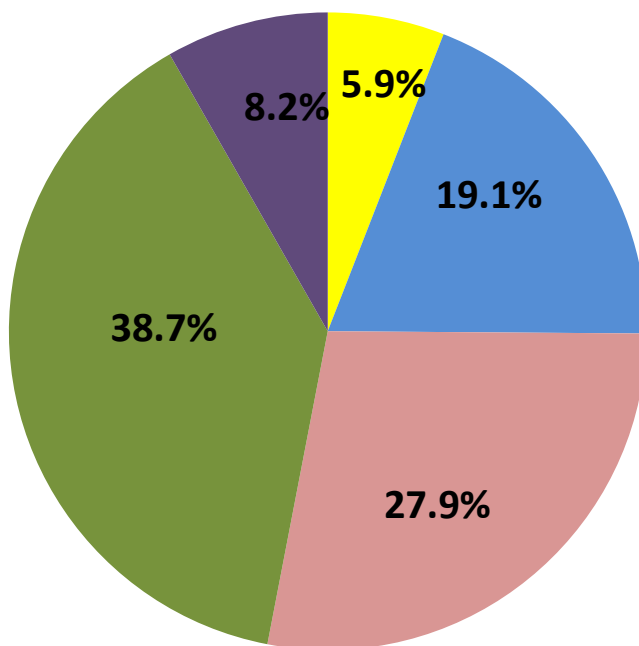


Figure 5.4 Distribution of GHGE by food group, packed lunches



5.4.1 Total GHGE from school food

Research question 01: What is the contribution of primary school meals to the total greenhouse gas emissions (GHGE) in England?

Different food items consumed by an individual student were grouped together to generate a single meal per student. The GHGE values and nutritional values of those individual meals were analysed separately for school lunches and packed lunches.

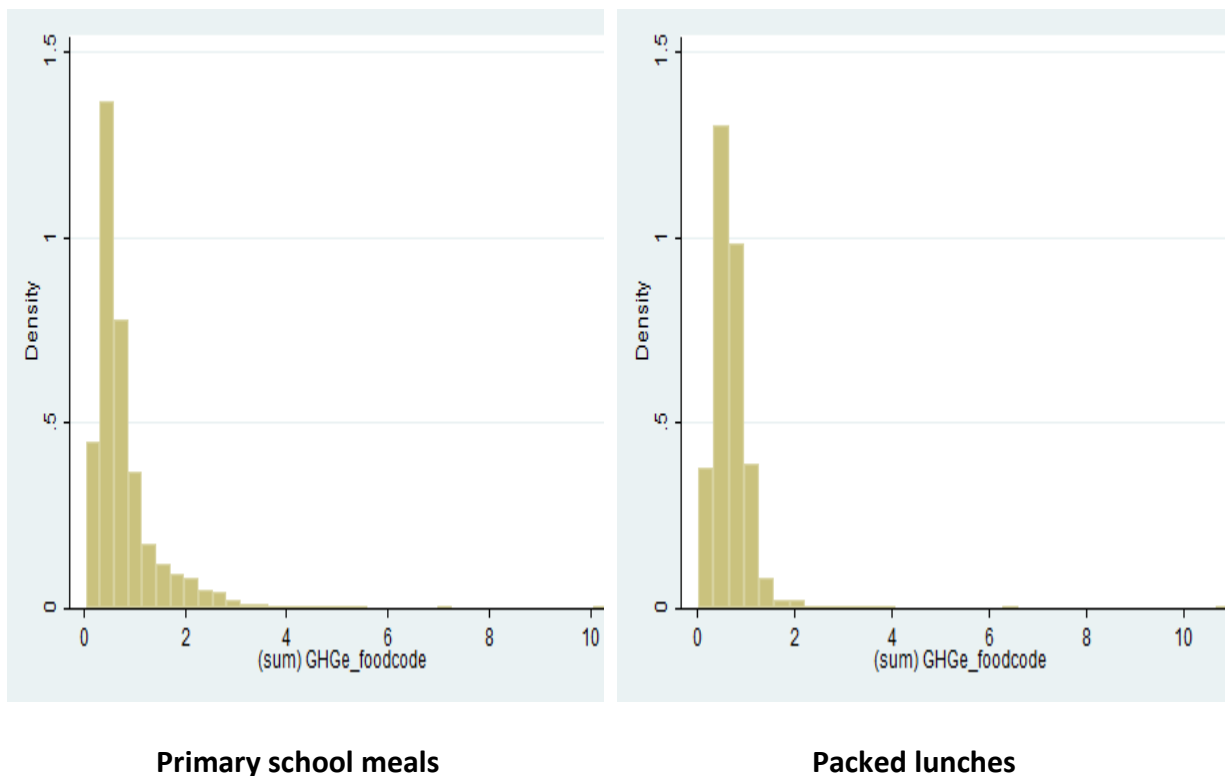
GHGE of school lunches and packed lunches

The mean GHGE value per school lunch was estimated as 0.72 KgCO₂e based on 6,691 meals. Of the 4.2 million primary school children in England around 39% take school lunches (Haroun et al 2009). There are 190 school days per year in England. Therefore, the annual GHGE from primary school meals is 224 million KgCO₂e per year. Similarly the mean GHGE value per packed lunch is 0.70 KgCO₂e and the total GHGE of packed lunches was estimated as 354 million KgCO₂e per year (Table 5.5).

Distribution of GHGE of school lunches and packed lunches

Figures 5.5 shows the distribution of GHGEs of primary school meals and packed lunches. Observation of these distribution graphs shows that they are skewed due to few meals with a very high GHGE values. I wanted to test the impact of these outliers on my results and whether those observations should be dropped from the analysis.

Figure 5.5 Histograms for GHGEs of primary school meals and packed lunches



Based on the Figure 5.5, I selected a cut-off value and dropped meals which had the GHGEs value of 4.00 KgCO_{2e} or more. From the school meal dataset 28 out of 6,690 meals were dropped and the new value is 0.70 compared to the original value of 0.72 KgCO_{2e}. For packed lunches 2 observations out of 3,481 were deleted and the GHGE per packed lunch did not change up to two decimal points.

The central limit theorem states that given that data are collected from sufficiently large independent random samples, it could be treated as “normally distributed” regardless of the actual distribution (Barany and Vu 2007, Tsallis and Queiros 2007). The PSFS is a large survey conducted in England with a representative sample. Coupled with that and dropping outliers gave almost similar estimates in the analysis, I decided to use the original dataset to conduct parametric statistical analyses to address the research questions in this thesis.

5.4.2 Uncertainty around the total GHGE of school lunches

Using only the mean GHGE parameters (and hence restricting the uncertainty analysis to incorporate only sampling error), the confidence intervals around the mean GHGE value for a school lunch are 0.72 KgCO₂e (0.71 – 0.74). Uncertainty based on only the difference in GHGE parameters produces confidence intervals of 0.53 – 1.26. Incorporating both sources of uncertainty gives a final confidence interval of 0.52 – 1.34 (Table 5.5).

This shows that 89% of the uncertainty around the mean GHGE value of a school lunch is due to the uncertainty around GHGE parameters. Confidence intervals around the estimate of total GHGE from school lunches is 161.7 million – 416.7 million KgCO₂e per year.

Table 5-5 GHGE values (KgCO₂e), mean per meal and total per year by school lunches and packed lunches

	Mean GHGE (KgCO₂e)	Minimum-Maximum	95% uncertainty due to sampling error only	95% uncertainty due to GHG parameter variance only	95% uncertainty interval based on sampling and GHG parameter variance	No of primary school children, in England	Total emissions per year (190 school days)	Uncertainty estimates around total emissions
School lunch	0.72	0.04 - 5.59	0.71– .74	0.53 – 1.26	0.52 – 1.34	1,636,833	223,918,754	161,719,100-416,737,681
Packed lunch	0.70	0.34 - 10.99	0.69 – 0.71	0.59 – 0.90	0.58 – 0.94	2,663,167	354,201,211	293,481,003 - 475,641,626
Total						4,300,000	578,119,965	455,200,103-892,379,307

Similarly 86% of the uncertainty around the mean GHGE value of a packed lunch is due to the uncertainty around GHGE parameters. Confidence intervals around the estimate of total GHGE from school lunches is 455 million – 892 million KgCO₂e per year

5.4.3 Are healthy meals always sustainable?

Research question 02: Are current primary school meals that achieve nutrient based guidelines less GHG intensive than meals that do not achieve those guidelines?

As explained in chapter 3, a meal was defined by combining information of different food items each student consumed on a day. Table 5.6 shows the PSFS (SFT 2010) nutrient-based standards for a primary school meal (Table 5.6). In both school lunches and packed lunches only one in ten meals achieved the recommended energy level. Almost all the meals achieved protein levels and only about a quarter of meals achieved Zinc levels. Compared to school lunches, a higher proportion of packed lunches had more than the recommended level of sugar, saturated fats and sodium.

Table 5-6 Nutrient based standards for a primary school meal and achievement in school meals and packed lunches

	Nutrient	Min/Max	Nutrient based standard	SCHOOL MEALS			PACKED LUNCHES		
				Mean	SE	% of meals achieved	Mean	SE	% of meals achieved
1	Energy (kcal)		504-557	485.95	2.19	11.1	619.71	3.67	10.9
2	Protein (g)	Min	7.5	18.47	0.09	96.0	18.43	0.14	95.1
3	Carbohydrate (g)	Min	70.6	70.45	0.33	45.8	89.89	0.55	70.9
4	Non milk extrinsic sugars (g)	Max	15.5	14.06	0.14	60.1	24.03	0.29	36.0
5	Fat(g)	Max	20.6	16.26	0.11	72.8	23.30	0.20	45.7
6	Saturated Fatty Acids(g)	Max	6.5	6.15	0.05	60.6	8.68	0.09	37.5
7	Fibre(g)	Min	4.2	4.76	0.03	54.7	4.07	0.04	38.8
8	Sodium (mg)	Max	499	528.71	3.74	54.0	855.96	6.46	15.3
9	Vitamin A (µg)	Min	175	332.79	4.95	50.8	174.60	4.46	28.5
10	Vitamin C (mg)	Min	10.5	23.05	0.24	72.1	41.46	0.66	79.2
11	Folate (µg)	Min	53	63.19	0.35	59.0	54.08	0.60	38.7
12	Calcium (mg)	Min	193	202.38	1.63	44.4	286.59	2.49	71.1
13	Iron (mg)	Min	3	2.34	0.01	21.1	2.72	0.02	31.8
14	Zinc (mg)	Min	2.5	2.14	0.01	28.9	2.04	0.02	26.4

Table 5.7 shows the number and percentage of school meals that achieved each number of nutrient based standards. Only 2 meals from more than 6,600 school lunches achieved all 14 nutrient-based standards. The School Food Trust report demonstrated the achievements of nutrient based standards using several cut-off values. For this research study I used the cut-off value of achieving at least half of the nutrient based standards to define a “healthy meal”. All the meals which achieved 7 or more standards were classified as healthy. There were 4,312 meals (64.5%) which achieved at least 7 standards.

Table 5-7 Meeting nutrient based standards, school lunches

Number of standards met	Number of meals	Percentage (%)	Cumulative %
1	2	0.03	0.03
2	25	0.37	0.4
3	87	1.3	1.7
4	353	5.28	6.98
5	783	11.7	18.68
6	1,129	16.87	35.56
7	1,165	17.41	52.97
8	1,227	18.34	71.3
9	1,038	15.51	86.82
10	546	8.16	94.98
11	244	3.65	98.63
12	78	1.17	99.79
13	12	0.18	99.97
14	2	0.03	100

Table 5.8 shows the number and percentage of packed lunches achieving each number of nutrient based standards. None of the packed lunches achieved all 14 standards and two meals achieved 13 of them. Similar to school lunches, I used the same cut-off values (achieving 7 or more standards) to define a healthy meal. There were 1,507 (43.2%) healthy packed lunches according to this definition.

Table 5-8 Meeting nutrient based standards, packed lunches

Number of standards met	Number of meals	Percentage (%)	Cumulative %
1	8	0.23	0.23
2	40	1.15	1.38
3	169	4.85	6.23
4	437	12.55	18.79
5	650	18.67	37.46
6	670	19.25	56.71
7	560	16.09	72.8
8	441	12.67	85.46
9	353	10.14	95.6
10	119	3.42	99.02
11	29	0.83	99.86
12	3	0.09	99.94
13	2	0.06	100
14	0	0	100

Table 5.9 shows the t-test results comparing the mean GHGE of healthy meals vs non-healthy meals for both school lunches and packed lunches. Note that the p values reported in the table are based on sampling error only, uncertainty in GHG parameters only, and both sampling error and GHG parameter uncertainty. The mean GHGE of healthy school lunch was 0.79 KgCO₂e (0.56 – 1.44) compared to 0.59 KgCO₂e (0.42 – 1.04) of unhealthy meals. Among packed lunches also the mean GHGE of healthy meals (0.83 KgCO₂e) was higher than the mean GHGE of unhealthy meals (0.60 KgCO₂e).

Table 5-9 GHGE of healthy meals vs non-healthy meals

		Number of meals	Mean GHGE (kgCO ₂ e)	95% uncertainty due to sampling error only	95% uncertainty due to GHG parameter variance only	95% uncertainty interval based on sampling and GHG parameter variance
School lunches	Unhealthy	2379	0.59	0.58 - 0.61	0.44 – 0.98	0.42 – 1.04
	Healthy	4312	0.79	0.78 – 0.81	0.59 – 1.40	0.56 – 1.44
			P<0.001			
Packed lunches	Unhealthy	1507	0.60	0.59 – 0.61	0.51 - 0.76	0.50 - 0.78
	Healthy	1974	0.83	0.80 - 0.86	0.69 - 1.08	0.67 - 1.15
			P<0.001			

The above definition involves 14 standards including several micronutrients. Healthy meals have a higher GHGE mean value than unhealthy meals. As meat significantly increases the GHGE of a meal and also contains several micronutrients, a possible explanation would be that meat containing meals are more likely to be categorised as “healthy” under this definition, hence it gives a higher GHGE value for healthy meals. A Pearson's Chi-square Test for Independence was performed to test the association between “healthy meals” and “meat containing meals”

Table 5-10 Association between healthy meals and meat containing meals, school lunches

	Meals without meat	Meals with meat	Total
Unhealthy meals (expected frequency)	1,154 (1,230.6)	1,225 (1,148.4)	2,379 (2,379)
Healthy meals (expected frequency)	2,307 (2,230.4)	2,005 (2,081.6)	4,312 (4,312)
Total (expected frequency)	3,461 (3,461)	3,230 (3,230)	6,691 (6,691)
Pearson chi2(1) =15.3134			P value = 0.000

The table 5.10 shows that healthier meals (those that achieve at least seven of the PSFS nutrient standards) are *less* likely to contain meat than less healthy meals. Therefore this does not explain the reasons for healthy meals to have a higher GHGE value compared to unhealthy meals.

The same test was performed for packed lunches. Table 5.11 shows that there is no association (P value is 0.108) between healthiness of a meal and containing meat in pack lunches.

Table 5-11 Association between healthy meals and meat containing meals, packed lunches

	Meals without meat	Meals with meat	Total
Unhealthy meals (expected frequency)	1,004 (980.5)	970 (993.5)	1,974 (1,974)
Healthy meals (expected frequency)	725 (748.5)	782 (758.5)	1507 (1,507)
Total (expected frequency)	1,729 (1,729)	1,752 (1,752)	3481 (3,481)
Pearson chi2(1) =2.589		P value = 0.108	

Alternative definition to classify “healthy meals”

Salt, saturated fat and sugar are the three nutrients that are of greatest public health concern in the list of 14 nutrients provided in table 5.7 (WHO 2003). I applied these three standards to both school lunches and packed lunches to define “healthy meals”. Table 5.12 and Table 5.13 show the number and proportion of meals achieving these standards for school lunches and packed lunches.

Table 5-12 Achieving Sugar, Salt and Saturated Fat standards, school lunches

Number of standards met	Number of meals	Percentage (%)	Cumulative %
0	1,066	15.93	15.93
1	1,692	25.29	41.22
2	1,794	26.81	68.03
3	2,139	31.97	100

Table 5-13 Achieving Sugar, Salt and Saturated Fat standards, packed lunches

Number of standards met	Number of meals	Percentage (%)	Cumulative %
0	1,455	41.8	41.8
1	1,147	32.95	74.75
2	688	19.76	94.51
3	191	5.49	100

When salt, sugar and saturated fat standards were used to define a “healthy meal”, 32% of school lunches were classified as “healthy” compared to 5.5% of packed lunches. Sugar and saturated fat standards are more likely to be achieved than salt levels. More than 40% of packed lunches didn’t achieve any of these standards and 15% of school meals also didn’t achieve any.

Table 5-14 GHGE of healthy meals vs non-healthy meals

		Number of meals	Mean GHGE (kgCO ₂ e)	95% uncertainty due to sampling error only	95% uncertainty due to GHG parameter variance only	95% uncertainty interval based on sampling and GHG parameter variance
School lunches	Unhealthy	4,552	0.81	0.79 - 0.83	0.59 - 1.39	0.57 – 1.44
	Healthy	2139	0.54	0.52 – 0.56	0.44 – 1.02	0.47 – 1.46
P<0.001						
Packed lunches	Unhealthy	3290	0.72	0.70 - 0.73	0.60 – 0.92	0.59 – 0.96
	Healthy	191	0.39	0.35 - 0.42	0.32 – 0.50	0.31 – 0.52
P<0.001						

Table 5.14 shows that when the alternative definition was used to define “healthy meals” the mean GHGE of healthy school lunch was 0.54 (0.47 – 1.46) KgCO₂e , and the mean GHGE of unhealthy school lunch was 0.81 (0.57 – 1.44) KgCO₂e. Similarly the mean GHGE of healthy packed lunch (0.39 KgCO₂e) was lower than the mean GHGE of unhealthy packed lunch (0.72 KgCO₂e).

5.5 Discussion

5.5.1 Main findings

This chapter estimated that the total GHGE due to primary school meals in England per year is 578.1 million KgCO₂e (Table 5.6). This is equivalent to more than 578,000 economy class return journeys between London and New York (CF 2014).

Although we have nutrient based standards for children, identification of “healthy” school meal or packed lunch is not straightforward. Two nutrients-based definitions used to define a “healthy school meal” in this chapter, produced different results with regard to whether healthy meals have lower GHGE. The results suggest that achieving sustainable school lunches and packed lunches may reduce salt, saturated fat and sugar but could jeopardise micronutrient levels. However, due to large uncertainty around the GHGE parameters for food groups in the current literature, the difference between healthy and unhealthy school meals are within the uncertainty intervals, so the results must be treated with caution.

This chapter also shows that 30% of the GHGE of packed lunches are due to fruit juices. These could be removed by replacing fruit juice with bottled tap water, which has also been recommended as a priority in the Government Buying Standards for Food and Catering Services published by the Public Health England (PHE).

5.5.2 Implications of findings

Both classifications used to define healthy meals showed that majority of packed lunches are unhealthy. There is lot of scope for improvement in terms of healthiness of primary school meals. The School Food Plan aims to improve the school food and increase the uptake of school meals to improve happiness, healthiness and educational attainment (Dimbleby and Vincent 2013). New food based dietary guidelines have been developed by the School Food Plan for schools in England. The next chapter (chapter six) models the impact of these new food based dietary guidelines on nutritional quality and GHGE of school meals.

The percentage of healthy school lunches is higher (65%) than the percentage of healthy packed lunches (43%). This finding supports the call for providing free school meals to all children and strategies to increase the uptake of school lunches.

If all students adopted a healthy school lunch defined by low salt, sugar and saturated fat (with a mean GHGE value of 0.54 KgCO₂e), the total GHGE from primary school meals would be 441.2 million KgCO₂e, saving 136.9million KgCO₂e compared to the current total emissions from primary school meals. This is equivalent to avoiding more than 139,000 economy class return journeys between London and New York (CF 2014). This shows that

there is scope to reduce the GHGE from school lunches in England. It is unclear whether attempts to reduce the GHGE of school lunches would result in healthier school meals. The next chapter (chapter six) models a common policy scenario which aims to reduce the GHGE of school meals (“Meat Free Monday”) and whether it makes school meals healthier.

5.5.3 Comparison with current literature

This analysis estimated the total GHGE from primary school meals using a bottom up approach. Scarborough et al estimated that total GHGE due to food consumption in the UK is 95MtCO₂e/year (Scarborough, Appleby et al. 2014) . The total emissions from primary school lunches in England, as estimated in this chapter represent about 0.6% of that.

A previous cross-sectional study conducted amongst primary school children in the UK found similar results to this study, that only 1.1% of packed lunches met all the food-based standards and only 12% met energy level standards (Evans, Greenwood et al. 2010).

The SFT report also showed similar results reported in this chapter, that pupils taking packed lunches had more fruits and fruit juices. But packed lunches contained more fat, saturated fat , non-milk extrinsic sugars and salt (SFT 2010). This SFT report also suggests that when a school met a given standard (by looking at the menus and available food to cater for children), it was more likely that pupils in that school would meet that standard in individual meals. According to the SFT report the majority of schools served meals which met between 7 -10 standards. This chapter shows majority of individual meals (59%) met 7-10 standards.

The literature suggests that policy options should aim to reduce the greenhouse gas intensive meat meals to achieve both environmental goals and health benefits (Garnett

2011). Healthy meals are often considered to be low GHGE intensive (Wilson, Nghiem et al. 2013). But when 14 nutrient standards were used to define healthy meals, they had higher mean GHGE value compared to unhealthy meals. The previous literature has also reported that sometimes, despite containing large amounts of plant-based foods, high nutritional quality diets don't have the lowest GHGE values (Vieux, Soler et al. 2013). These findings challenge the statement of "healthy meals are always environmentally friendly". Therefore this analysis suggests that future policy discussions around this topic should carefully define a "healthy meal" before making any conclusions about the association between the GHGE value and overall healthiness of a meal.

5.5.4 Strengths and limitations

This analysis for the first time demonstrated a method to address the uncertainty due to GHGE parameters of food. Use of GHGE values of food to create databases combining GHGE values and nutrition information is a relatively new discipline. Therefore researchers need to develop methods to increase the acceptability for results and having robust methods to address uncertainty is one of the important aspects. This development would significantly contribute to the advancement of science and acceptability for research findings in this area.

The overall uncertainty of estimates of GHGE for all school lunches reported here is an overestimate as this range is estimated by simply adding the lower and upper limit values of packed lunches and school lunches. I have two different databases for these two groups and they are organised in different ways. Therefore it is not possible to combine them as a single database to get a more precise estimate.

Defining “healthy diets” or “healthy meals” is not straight forward. A systematic review by Marshall et al shows that there are more than 80 different diet quality indices for children and they have used food only standards, nutrient only standards or combination of both of them to assess the “healthiness” of diets (Marshall, Burrows et al. 2014). They require data obtained from a 24 hour dietary recalls or food frequency questionnaires. In this dataset, I have data only for a single meal of the day, per child and it is difficult to draw conclusions about “healthiness of diets” using these diet quality indices. The School Food Trust has looked at the number of nutrient based standards achieved by school meals. This chapter used a similar method by looking at the meals that achieved more than 7 standards and selected key standards (saturated fat, salt and sugar) to define healthy meals.

The conclusion of whether healthy meals have lower GHGEs is sensitive to the definition of “healthy school meal”. The first definition considers both good and bad nutrients and for a meal to be classified as healthy required amounts of those nutrients should be available in the meal. The second definition which considers only three main nutrients classifies a meal as healthy if it didn’t have them more than the amount specified. Therefore meals which have more food items and quantities are likely to achieve more standards in the first definition. (e.g. a diet cola does not have specified nutrients and will not be classified as healthy according to the first definition. But according to the second definition, it doesn’t have saturated fat, salt or sugar more than the specified level and would be classified as healthy). This might partly explain the reason in first definition healthy meals had a higher GHGE value. Meals which had more food items or quantities will have a higher GHGE as we estimate it per weight unit. I analysed school meals per set amount of Kcal to test this scenario. The mid-point of the energy reference range is 530Kcal. Table 5.15 shows that,

when GHGE per 530Kcal is estimated in healthy and unhealthy school meals classified according to the 14 standards, still “healthy meals had a higher GHGE value (0.85) compared to unhealthy meals (0.77 KgCO₂e). Now the difference is 0.08 compared to the previous difference of 0.2 KgCO₂e. But there is no change in the final conclusion of comparison between healthy and unhealthy school lunches using 14 standards.

Table 5-15 15 Mean GHGE per 530Kcal healthy meals vs unhealthy meals (using 14 standards)

	Mean	SE	95% CI
Unhealthy meals	0.77	0.16	0.74 – 0.80
Healthy meals	0.85	0.10	0.83 – 0.87

5.6 Conclusion

This chapter demonstrates how to integrate a nutritional database with GHGE database of food. Although many meals in both school lunches and packed lunches failed to achieve all the nutrient-based standards, a higher proportion of primary school lunches are healthier than packed lunches in England. This analysis shows the definition used to define a “healthy meal” significantly contributes to our conclusion on whether healthy meals are more environmentally sustainable than unhealthy meals. It also shows that there is much uncertainty around the GHGE associated with foods consumed in the UK.

The next chapter will examine how to assess whether strategies to reduce the GHGE of school meals would make them healthier and it will also model the health and environmental outcomes of proposed new school food based guidelines. Next chapter will

also examine the nutritional and GHGE changes of replacing fruit juice with water in packed lunches.

6 Changing the current primary school meals to improve nutritional and sustainability standards

The previous two chapters provided descriptive statistics about the dataset and the nutritional information and greenhouse gas emissions (GHGEs) information of current school meals. This chapter aims to explore the impact of changing current school meals to improve nutritional standards and sustainability standards, using the same dataset described in Chapter 5.

6.1 Introduction

Several policies have been implemented to improve the nutritional standards of school meals (DfES 2006) and some policies such as the Government food procurement policy or Government buying standards have addressed sustainability standards of food (Defra 2011). One of the most recent changes to school lunches was introduced by the School Food Plan (SFP). The first report of the SFP was published in June 2013 by two independent authors appointed by the Government (Dimbleby and Vincent 2013). It provided a series of action points for head teachers to improve the quality of school meals. An expert panel was appointed to revise current standards for school meals. The SFP concluded that nutrient-based standards are too difficult to interpret and school meal guidelines should be based only on food-based standards. This is despite the fact that the previous Children's Food Trust report found that nutrient based standards improved school meals in England (SFT 2010), and there has been a split opinion amongst nutrition experts for a long time regarding whether the food based standards will be more beneficial than nutrient based

standards (Sharp 1992). Still there is no consensus on this issue. Proposed new standards were open for a public consultation in 2014 April and the final version was published in June 2014 (SFP 2014).

The UK Government introduced a policy on universal free school meals for children in reception, year 1 and year 2 in state-funded schools in England from September 2014. This policy will apply to state-funded schools including academies, free schools and maintained schools (DfE 2014). It is expected that the uptake of primary school meals will increase significantly with the new policy. New food based school food guidelines will be applied to these meals, hence the importance of these guidelines and their outcomes will be much more significant. The SFP has tested several menus, which comply with the new standards, for their nutritional standards and concluded that meals would be the same or better than current school meals (Mucavele, Nicholas et al. 2014). But these results are based on a small sample of school menus which are designed according to the SFP standards. In a real world setting there is no guarantee that caterers would try to create the healthiest menus, adhering to these guidelines. They could select food items from their current menus which already comply with the new food-based standards. This report only looked at the nutritional value and there are no quantifiable data on the impact on the environment. Adoption of new food-based school food standards was selected as one of the policy options for analysis in this chapter.

6.2 Research questions

One research question answered in this chapter, based on the school food standard is:

Research question 03: What environmental and nutrition changes can we expect if we change the current primary school meal plate to achieve new School Food Plan recommendations?

In addition to the improvement of “healthiness” of food, there are several policies and actions suggested to improve the sustainability of meals. Examples for such policies are reducing inputs to production systems, minimising waste, better management of stocks and changing consumption patterns (EC 2011). The SFP has mentioned use of sustainable fish and procurement of local food as recommended actions to improve sustainability (Dimbleby and Vincent 2013). Whilst global warming potential is not the only metric of sustainability, the literature shows that we need to change the type of food we eat to achieve UK Government target for GHGE reduction, and by simply changing the sources of food or food production systems we won’t be able to achieve this target (Foley, Ramankutty et al. 2011).

The Children’s Food Campaign is an organisation which coordinates several non-government organisations and academics interested in children’s food. Their response to the public consultation on new food-based guidelines for school meals included a section on improving the sustainability of meals. They criticised the SFP for not taking meaningful measures to improve the sustainability of school meals and suggested “Meat Free Mondays (MFMs)” as a policy option (CFC 2014).

The MFM campaign promotes the concept as a way of bringing the school community together to help the planet and to promote healthy food (MFM 2014). In the latest version of the SFP this policy is given as an option to improve the sustainability of school meals (SFP 2014). Although it is not mandatory in the current school meal guide, it is one of the widely discussed policy options. Therefore this option was selected as the environmental policy for the analysis in this chapter.

Research question 04: What environmental and nutrition changes can we expect if we change the current primary school meal menus to a Meat Free Monday (MFM) scenario?

6.3 Methods

Both research questions in this chapter were answered by using the SFT database, which was described in chapter 5.

Research question 03: What environmental and nutrition changes can we expect if we change the current primary school meal plate to achieve new School Food Plan recommendations ?

The new SFP listed food based standards for each food group. Some of these standards should apply to every meal. E.g. one or more portions of fruit every day. Some standards do not apply to every single school meal. E.g. A portion of meat or poultry should be provided on three or more days each week. Another example is starchy food cooked in fat or in oil no more than two days each week.

The Primary School Food Survey (PSFS) dataset is the best available data source for school meals in England, but it surveyed each child only for one day, so we do not have any data on weekly meals of children. The survey collected information of all the food items available in the school for a week. But the aim of this study is to analyse individual meals consumed by children and not the nutritional quality of food available to children.

The following standards, which are applicable to each meal were selected and they represent at least one standard from each food group. Table 6.1 shows the standards which could be applied to daily meals and these standards were used to define the new school food plan scenario in this chapter.

Portion sizes were given in the SFP document for each food group (SFP 2014).

Table 6-1 Food based standards for a primary school meal

	Food	Portion size (g) 4-10 school years
1	One or more portions of vegetables	40 -60
2	One or more portions of fruit	40 - 60
3	A portion of milk and dairy	Milk: 150 – 200 Cheese: 20 – 30 Yoghurt : 80 - 120
4	One or more portions of starchy food	Potatoes: 120- 70 Bread: 50 - 70
5	A portion of meat, fish, egg or alternatives	Red meat: 50-80 White meat: 60 -85 Fish: 60 – 90 Eggs: 1 egg Soya: 50-70 Beans(cooked): 50-60
6	Drinking water	Always
7	No confectionery or chocolate	None

These standards were applied to all the school meals in the database and meals that met each of these standards were selected for the further analysis.

The PSFS dataset provides the starting weight of each food item and the percentage weight from each food group was estimated during the database preparation stage (See chapter 3 and 5 for more details). Using these variables actual weight of each food group listed in table one was estimated per food item. Based on the portion size provided by the SFP, a variable was created to define whether each food item contained the required amounts

according to the guidelines. Per each meal, a new set of variables were created to identify whether it met each of the standards listed in Table 6.1.

There are seven standards and an equal weighting was given to each of them in order to allocate a score out of seven for each meal. This score was used to classify “healthy meals” defined according to the new food based standards and compare the nutritional and GHGE values of “healthy meals” defined according to the nutritional standards shown in chapter 5.

Research question 04: What environmental and nutrition changes can we expect if we change the current primary school meal menus to a Meat Free Monday?

To answer this question the individual meat containing meals consumed on Mondays were selected. These meals had to be replaced with values of a non-meat containing meal. There is no clear evidence on food substitution and we do not have good data to make an informed decision to predict which food items would be selected by students if meat containing meals were not available. It is possible that caterers would replace meat containing meals on Mondays with a non-meat containing meal similar to what they already have on the menu. Therefore we identified the nutritional values and GHGE values of an average non-meat meal and these values were used to replace meat containing meals on Mondays.

The mean and standard deviation (SD) was calculated for each nutrient and GHGE value of the average non-meat meal and these values were used to create new, normally distributed variables in STATA. These variables were sampled from for replacement meals in the Meat Free Monday scenario.

Nutrient based standards (from the original SFT standards) were used to define healthy meals. The nutritional values and average GHGE values of meals in MFM scenario was compared to the findings in chapter 5, to assess the nutritional and environmental impact of adopting a MFM policy in primary schools in England.

6.4 Results

6.4.1 School Food Plan scenario

Table 6.2 shows the seven food-based standards selected for this analysis and the percentage of current school meals achieving them. In the dataset 42% of meals met the recommendation for having one or more portions of vegetables. Only 9% achieved the recommendation for fruits. In school meal database fruit was offered in more than two third of the daily menus. This analysis shows that only 9% of students selected fruits in adequate portion size specified by the SFP. Drinking water is the recommendation met by most meals (67%) and more than half of the meals met the recommendation for not having any confectionery or chocolate.

Table 6-2 New food-based based standards for a primary school meal

	Food	Min/Max	Portion size (g) 4-10 school years	(%) of current school meals achieved
1	One or more portions of vegetables	Min	40 -60	42.0
2	One or more portions of fruit	Min	40 - 60	8.8
3	A portion of milk and dairy	Min	Milk: 150 – 200 Cheese: 20 – 30 Yoghurt : 80 - 120	12.9
4	One or more portions of starchy food	Max	Potatoes: 120- 70 Bread: 50 - 70	16.7
5	A portion of meat, fish, egg or alternatives	Max	Red meat: 50-80 White meat: 60 -85 Fish: 60 – 90 Eggs: 1 egg	18.2
6	Drinking water	Min	Always	67.0
7	No confectionery or chocolate	Max	None	50.4

The aim of the new SFP food based standards is to help schools and students to improve the nutritional quality of school lunches. Previously the quality of school meals were measured by using the 14 nutrient based standards. Table 6.3 compares the percentage of current school lunches that achieved each nutrient based standard and the percentage of meals which met all the SFP standards (n= 2,420), that achieved each nutrient based standard.

Table 6-3 Nutrient based standards for a primary school meal, current meals vs SFP

				Current school meals			SFP Scenario (n= 2,420)		
	Nutrient	Min/Max	Average aged 4-10 school years	Mean	SE	% of meals achieved	Mean	SE	% of meals achieved
1	Energy (kcal)		504-557	485.95	2.19	11.1	539.74	3.68	13.3
2	Protein (g)	Min	7.5	18.47	0.09	96.0	19.93	0.15	98.1
3	Carbohydrate (g)	Min	70.6	70.45	0.33	45.8	78.06	0.57	57.3
4	Non milk extrinsic sugars (g)	Max	15.5	14.06	0.14	60.1	16.50	0.25	51.12
5	Fat(g)	Max	20.6	16.26	0.11	72.8	18.44	0.19	65.4
6	Saturated Fatty Acids(g)	Max	6.5	6.15	0.05	60.6	6.91	0.08	52.5
7	Fibre(g)	Min	4.2	4.76	0.03	54.7	5.14	0.05	62.6
8	Sodium (mg)	Max	499	528.71	3.74	54.0	574.39	6.32	47.4
9	Vitamin A (µg)	Min	175	332.79	4.95	50.8	401.96	8.98	59.9
10	Vitamin C (mg)	Min	10.5	23.05	0.24	72.1	23.01	0.35	76.3
11	Folate (µg)	Min	53	63.19	0.35	59.0	67.81	0.57	66.3
12	Calcium (mg)	Min	193	202.38	1.63	44.4	219.81	2.68	51.2
13	Iron (mg)	Min	3	2.34	0.01	21.1	2.61	0.02	28.9
14	Zinc (mg)	Min	2.5	2.14	0.01	28.9	2.38	0.02	36.4

The percentage of meals that met the protein standard has slightly increased in the SFP scenario, implying that if the new SFP were adopted across the board protein levels in meals would increase. Similarly the proportion of meals meeting the standards for important micronutrients (e.g. iron, calcium, vitamin A and vitamin C) also increased slightly. However, the SFP scenario showed a decline in the proportion of meals achieving fat, saturated fat, sugar and sodium indicating that foods that meet the new SFP guidelines are less likely to meet these nutrient-based criteria.

Table 6-4 Meeting Nutrient based standards, current school meals vs School Food Plan Scenario

Number of standards	Current meals			School Food Plan Scenario Total = 2,420		
	No of meals	percentage	cumulative percentage	No of meals	percentage	cumulative percentage
1	2	0.03	0.03	1	0.04	0.04
2	25	0.37	0.4	4	0.17	0.21
3	87	1.3	1.7	26	1.07	1.28
4	353	5.28	6.98	92	3.8	5.08
5	783	11.7	18.68	216	8.93	14.01
6	1,129	16.87	35.55	337	13.93	27.94
7	1,165	17.41	52.96	387	15.99	43.93
8	1,227	18.34	71.3	509	21.03	64.96
9	1,038	15.51	86.81	445	18.39	83.35
10	546	8.16	94.97	247	10.21	93.56
11	244	3.65	98.62	117	4.83	98.39
12	78	1.17	99.79	33	1.36	99.75
13	12	0.18	99.97	5	0.21	99.96
14	2	0.03	100	1	0.04	100

Table 6.4 shows the number and percentage of meals that achieved each number of nutrient based standards in current school meals (as explained in chapter 5) and in the SFP scenario.

There are 2,240 meals which met the SFP standards. Similar to the current school meals, even in the SFP scenario there will be only a few meals which can meet all the nutrient based standards. As explained in the chapter 5, the previous reports have used achieving more than 7 -10 standards as a cut-off value to quantify the healthy school lunches. If the same cut-off value of achieving 7 or more standards (as in chapter 5) is used, the Table 6.4 shows that around 72% of SFP scenario meals could be classified as healthy. In current school meals around 65% of lunches meet 7 or more standards. Therefore if we used the 14 nutrient standards to measure the “healthiness” of school meals it shows that in SFP scenario more meals are likely to be classified as healthy, compared to current school meals.

6.4.2 Alternative definition for healthy meals

Achievement of all 14 nutrient based standards in a single meal might not be practical and as was discussed in chapter 5, a commonly used alternative classification was used to define healthy meals. Salt, saturated fat and sugar are the three nutrients that are of greatest public health concern in the list of 14 nutrients provided in table 5.7 (WHO 2003) . Table 6.5 shows the number and percentage of meals achieving these three standards in current school meals and in the SFP scenario.

Table 6-5 Achieving Salt , Saturated Fat and Sugar standards

Current school lunches			
Number of standards met	Number of meals	Percentage (%)	Cumulative %
0	1,066	15.93	15.93
1	1,692	25.29	41.22
2	1,794	26.81	68.03
3	2,139	31.97	100
SFP Scenario			
Number of standards met	Number of meals (total = 2,420)	Percentage (%)	Cumulative %
0	533	22.02	22.02
1	678	28.02	50.04
2	650	26.86	76.9
3	559	23.10	100

When salt, saturated fat and sugar were used to define a “healthy meal” almost 32% of current schools were classified as “healthy”. Out of the meals which met SFP criteria only 23% of meals met these three standards.

6.4.2.1 Greenhouse gas emissions of school meals, SFP Scenario

Table 6.6 shows the mean GHGE values of current school meals and the average value of a meal which met SFP standards.

Table 6-6 Mean GHGE of school meals , current school lunches and SFP scenario

	Mean GHGE	95% CI	No of primary school children	Total emissions per year (190 school days)
Current school lunch	0.72	0.70 – 0.73	1,636,833	223,918,754
SFP meal	0.81	0.78 – 0.83	1,636,833	251,908,598

The mean GHGE value of meal which meets the SFP criteria is 0.81 KgCO₂e compared to 0.72 KgCO₂e. If we assume the total number of primary school children taking the school lunches would remain the same, shifting from current school meals to a SFP scenario would increase the total emissions by 27,989,844 KgCO₂e, which is 12.5% higher than current primary school meal emissions.

6.4.3 Meat Free Monday (MFM) scenario

Research question 04: What environmental and nutrition changes can we expect if we change the current primary school meal menus to a Meat Free Monday?

Table 6.7 shows the percentage of meals achieving each nutrient based standard in current school meals and in the Meat Free Monday (MFM) scenario.

If all the meat containing meals on Monday are replaced by non-meat meals, the proportion of meals meeting energy and carbohydrate standards will increase and the proportion of meals meeting protein and saturated fat standards will decrease. Proportion of meals achieving some micronutrients such as sodium and iron will reduce and micronutrients such as fibre, Vitamin A and Vitamin C will increase in MFM scenario.

Table 6-7 Nutrient based standards for a primary school meal, current meals vs MFM

	Nutrient	Min/Max	Average aged 4-10 school years	Current school meals			MFM Scenario		
				Mean	SE	% of meals achieved	Mean	SE	% of meals achieved
1	Energy (kcal)		504-557	485.95	2.19	11.1	470.78	2.41	28.13
2	Protein (g)	Min	7.5	18.47	0.09	96.0	16.40	0.09	89.6
3	Carbohydrate (g)	Min	70.6	70.45	0.33	45.8	71.32	0.36	51.13
4	Non milk extrinsic sugars (g)	Max	15.5	14.06	0.14	60.1	14.17	0.16	54.58
5	Fat(g)	Max	20.6	16.26	0.11	72.8	15.65	0.12	69.60
6	Saturated Fatty Acids(g)	Max	6.5	6.15	0.05	60.6	6.06	0.05	54.40
7	Fibre(g)	Min	4.2	4.76	0.03	54.7	5.21	0.03	66.33
8	Sodium (mg)	Max	499	528.71	3.74	54.0	490.22	3.65	50.38
9	Vitamin A (µg)	Min	175	332.79	4.95	50.8	278.84	3.95	62.94
10	Vitamin C (mg)	Min	10.5	23.05	0.24	72.1	24.19	0.24	75.50
11	Folate (µg)	Min	53	63.19	0.35	59.0	66.34	0.39	66.28
12	Calcium (mg)	Min	193	202.38	1.63	44.4	215.17	1.81	56.25
13	Iron (mg)	Min	3	2.34	0.01	21.1	2.15	0.01	16.92
14	Zinc (mg)	Min	2.5	2.14	0.01	28.9	2.00	0.01	33.96

Table 6.8 shows the percentage of meals achieving each number of nutrients in current school meals and in the MFM scenario.

Table 6-8 Meeting nutrient based standards, school lunches – current meals and Meat Free Monday scenario

Number of standards	Current meals			Meat Free Monday scenario		
	No of meals	percentage	Cumulative percentage	No of meals	percentage	Cumulative percentage
1	2	0.03	0.03	1	0.01	0.01
2	25	0.37	0.4	2	0.03	0.04
3	87	1.3	1.7	38	0.57	0.61
4	353	5.28	6.98	168	2.51	3.12
5	783	11.7	18.68	431	6.44	9.56
6	1,129	16.87	35.55	929	13.88	23.44
7	1,165	17.41	52.96	1384	20.68	44.12
8	1,227	18.34	71.3	1471	21.98	66.1
9	1,038	15.51	86.81	1177	17.59	83.69
10	546	8.16	94.97	724	10.82	94.51
11	244	3.65	98.62	289	4.32	98.83
12	78	1.17	99.79	67	1.00	99.83
13	12	0.18	99.97	10	0.15	99.98
14	2	0.03	100			

As discussed in chapter 5, the same cut-off value of achieving 7 or more standards was used to define healthy meals. In current school meals around 65% of primary school meals are “healthy” and in the MFM scenario this percentage will increase up to 76%.

Alternative classification of healthy meals

In addition to the above definition, in this scenario also “healthy meals” were classified based on the sugar, salt and saturated fat standards.

Table 6-9 Achieving Sugar, Salt and Saturated Fat standards

Current school lunches			
Number of standards met	Number of meals	Percentage (%)	Cumulative %
0	1,066	15.93	15.93
1	1,692	25.29	41.22
2	1,794	26.81	68.03
3	2,139	31.97	100
Meat Free Monday			
Number of standards met	Number of meals	Percentage (%)	Cumulative %
0	707	10.57	10.57
1	2,343	35.02	45.58
2	2,603	38.90	84.49
3	1,038	15.51	100

Table 6.9 shows that proportion of meals achieving sugar, salt and saturated fat standards would reduce from current value of 32% to 15%, in the MFM scenario.

Adopting a MFM policy is primarily promoted as an option to improve the sustainability of school meals. Table 6.10 compares the average GHGE values of current school meals vs average values in MFM scenario.

Table 6-10 Mean GHGE of school meals, (Meet Free Mondays)

	Mean GHGE KgCO₂e	SD	No of primary school children	Total emissions per year (KGCO₂e) – 190 school days
Current school lunch	0.72	0.60	1,636,833	223,918,754
MFM School lunch	0.68	0.58	1,636,833	211,478,823

As shown in Table 6.10, mean GHGE of a school lunch in the MFM scenario is 0.68 compared to the current value of 0.72 KgCO₂e. If we assume the uptake of primary school meals would remain the same, this new policy will save around 12,439,931 KgCO₂e per year (equivalent to approximately 12,600 economy class return journeys between London and New York per year), or 5.6% of GHGE of current primary school meals.

6.5 Discussion

6.5.1 Main Findings

This chapter considers two different scenarios, one policy option aimed at improving the “healthiness” of school meals and another policy option aimed at improving the sustainability of school meals.

For both the School Food Plan and Meat Free Monday scenarios, whether the scenario meals were considered healthier than the current situation depends on the definition of ‘healthy’, but when based on sugar, salt and saturated fat only, both scenarios were less healthy than current school meals. Total GHGE will also increase in a SFP scenario by 27,989,844 KgCO₂e, almost equivalent to 280,000 economy class return journeys between London and New York (CF 2014).

But the GHGE of school meals reduced in a MFM scenario by an amount equivalent to 12,600 economy class return journeys between London and NY per year (CF 2014).

6.5.2 Implications of findings

The school food plan created a series of new activities following the publication of the initial report. In the initial report “sustainability” was mentioned under the check list for head teachers (Dimbleby and Vincent 2013). It suggested sourcing local food where possible and using sustainable fish sources as measures to improve the sustainability of primary school meals. As shown in previous literature changing the sources of food will not be adequate to meet the current GHGE targets and we need a radical shift in our diets towards more sustainable diets (CCC 2010, Macdiarmid, Kyle et al. 2011). The school food plan was a great opportunity to improve both sustainability and healthiness of food, as school food guidelines were undergoing a major revision. But the emphasis on improving the sustainability has been poor and this was addressed in the Children’s Food Campaign (CFC) response to the public consultation on new school food guidelines. CFC is a campaign consisting of several charities, which wants to improve health and well-being through good food and real food education in every school. (CFC 2014). They highlighted that proposed new food school food plan does not provide any compulsory standards to improve the sustainability and it does not meet other quality standards which apply to food served in, for example, prisons, Whitehall and the armed forces (as part of mandatory Government Buying Standards).

Researchers, practitioners and non-governmental organisations concerned about the environment have called for the school food plan to introduce more robust measures to reduce the GHGE of school meals. This analysis suggests that the GHGE would increase with the new food-based standards. The most commonly discussed food group in relation to the GHGE of meals is red meat (Friel, Dangour et al. 2009). The new food based standards say “a

portion of meat or poultry must be provided at least three times each week". Campaigners expected the school food plan to provide guidance to reduce red meat consumption, but current standards do not provide any upper limit to red meat provision in schools. Results in this chapter support the call for more meaningful measures to reduce the GHGE in school meals.

Meat Free Monday is promoted as a policy option to improve the sustainability and healthiness of meals by reducing the meat in school meals (MFM 2014). The literature shows that familiarity with the meat-free meal idea increases the odds of individuals' willingness to change their meals to make a positive impact on the environment (Joop de Boer 2013). Therefore introducing this concept in schools would help to increase the awareness of this idea in future generations. This analysis shows that Meat Free Monday policy helps to reduce GHGE of school meals and improves a series of nutrient based standards. But it does not reduce the saturated fat, salt and sugar level if we just replace Monday meat containing meals with current non-meat food items that are currently served as vegetarian options in primary schools. This policy should be accompanied with more specific guidance and alternative menus to ensure improved environmental outcomes and health outcomes.

6.5.3 Comparison with current literature

The new school food plan was published recently and the final set of standards was published in July 2014. There has not been much literature published with quantifiable numbers to assess the outcome of these new standards. The only available report was

commissioned by the school food plan and conducted by the Children's Food Trust to develop and pilot test the revised food based standards (Mucavele, Nicholas et al. 2014). The pilot study conducted with 35 schools and 24 caterers representing a range of different types of schools. In this pilot study participants were divided into two groups. Group 1 was asked to plan and cook an interesting, creative and nutritionally balanced one week lunch menu based on the new standards. Group 2 was asked to check the compliance of their current lunch menu using new standards and supporting documents and tools. Participants' feedback was collected using questionnaires. Compliance of the 1-week menu was assessed by checking the planned pilot menus against new food based standards. Recipes with details of portion sizes and number of servings were collected and checked for nutritional quality (within a nutrient framework) using computer software, Saffron™. Schools and caterers showed that the new food based standards are easier to follow, but clear guidance and support should be provided to maintain the nutritional balance of those meals.

There are different opinions about maintaining only nutrient based standards for school meals. The School Food Plan argues that it would be convenient to interpret and improve the nutritional quality of meals (Dimbleby and Vincent 2013). The pilot study found that new food-based standards give greater flexibility for cooks to provide dishes children liked rather than having to provide nutritionally-analysed compliant menu. But some participants have raised concerns that without nutrient based standards micronutrient content would be worse, and level of fat, salt and sugar could be higher (Mucavele, Nicholas et al. 2014). Similar concerns have been raised in previous reports, although food-based standards can help to increase the intake of fruits, vegetables, oily fish etc., may not be sufficient to reduce the salt, sugar and fat (BNF 2011).

There are several standards in new food based standards to reduce salt, sugar and saturated fat (SFP 2014). Some examples are “no confectionary at any time” and “no salt shall be available to add to food after the cooking process is complete”. The challenge would be to maintain and monitor the salt content in cooked food, without a specific standard.

Although these new food based standards allow caterers to do simpler and quicker menu planning with a subsequent reduction in menu analysis cost, the overall cost of the meal goes up due to the types of food and quantity they have to provide (Mucavele, Nicholas et al. 2014). Therefore in a real world setting there is a possibility for caterers to deviate from the healthy options to reduce the overall cost, compared to what they produced during the pilot project. In the UK more healthy foods have been consistently more expensive than less healthy items and recent analysis of trends from 2002 shows that the gap is likely to grow in the future (Jones, Conklin et al. 2014).

The key lesson from the pilot report is that simply by adhering to the types and frequency of food categories specified by the new standards will not make school meals healthier. It shows the importance of addressing portion sizes, provision mix, recipe and product composition (nutrient density) in school lunches. Therefore any monitoring and evaluation mechanisms should include these aspects also and should not be simply a check list of food-based standards to check the type of food category provided.

This pilot study sample is a purposive sample and it is a small number compared to total number of schools and caterers. It is likely that the pilot study participants represent the ‘more engaged’ part of the school food sector as evidenced by their willingness to plan or

check menus and provide feedback. It would be difficult to generalise the findings of this pilot study as concrete evidence to say these new standards would make school food “healthier” than current meals without conducting a rigorous nutritional assessment of meals which are actually provided.

de Boer et al suggest that the idea of restricting meat as a relatively cheap and easy way to mitigate climate change can be counterproductive as it triggers unnecessary responses from the population groups who are sceptical about climate change (de Boer, Schosler et al. 2013) . If the policy of Meat Free Monday leads to higher levels of sugar, salt and saturated fat in school meals it can face even greater criticism. It is important to think about the overall impact of the policy and develop specific guidelines to replace those meals with healthy meat free meals.

Parker suggests that healthcare workers including physicians should work closely with local and national policy makers to advocate for less meat consumption and suggest “Meatless Monday” as a useful concept for getting started (Parker 2011). The paper shows the evidence for recommending less red meat consumption to reduce GHGE and improve public health is based on evidence rated as “consensus, disease-oriented evidence, and expert opinion” and not as good – quality consistent evidence. Therefore more research on this area is needed by simultaneously quantifying the environmental and nutritional outcomes to gain more public support and also to get more attention by policy makers.

6.5.4 Strengths and limitations

The only previously available data on the expected nutritional outcomes of new school food plan is based on a pilot study and caterers had to cook that only during the study period.

This study uses food items currently served in school meals and therefore could give more generalizable results compared to the pilot study. The limitation is this analysis uses recipes currently in use (which meets proposed new food based standards) and there is a possibility that school caterers would change the recipes with the introduction of new standards in the future. In addition, this analysis does not take any account of the acceptability of changes in school meals prompted by either the School Food Plan recommendations or the Meat Free Monday campaign. In particular, the Meat Free Monday scenario assumes that meat containing meals would be replaced by meals that are currently freely chosen within the PSFS dataset. It is not clear whether these meals, or other meat substitutes would be selected by the majority of primary school pupils who currently choose meat-containing meals on Mondays.

6.6 Conclusion

This chapter shows how to quantify environmental and nutritional outcomes of two different policies aimed at improving school meals. Similar methods could be used to quantify policies aiming at other public food sectors.

The introduction of new food-based standards will not improve the nutritional quality of the school lunch (when measured in terms of salt, sugar and saturated fat content), unless recipes are changed. A proper monitoring and evaluation framework should be in place to maintain the nutritional balance, although new standards are only food-based standards.

The Meat Free Monday policy can reduce the GHGE of school meals, but if meal substitutions are the same as current meat free school meals, some aspects of the nutritional quality could be compromised. There should be specific guidance on recipes for substitution meals.

The new School Food Plan food-based guidelines, if followed, are likely to lead to a considerable rise in GHGE associated with primary school meals. Implementing Meat Free Mondays in UK primary schools would likely result in a small but significant reduction in GHGE.

7 Which options would allow primary school meals to achieve UK government greenhouse gas emission reduction targets?

Chapter five and six showed the impact of primary school food consumption on the greenhouse gas emissions (GHGEs) and nutrition related outcomes of changing the meals according to 2014 food based standards for school food and the recommendation for a Meat Free Monday. This chapter will aim to answer the following research question using the linear programming modelling technique.

Research question 05: How can we change school meals to achieve the UK Government target for GHGEs reduction?

This chapter also aims to show how to construct a primary school meal plate with minimal GHGEs, while achieving nutritional standards and to show what would be the components of a primary school meal which enable us to achieve GHGE targets in the UK.

7.1 Introduction

Previous reports have showed that if we want to mitigate climate change and preserve ecosystems from the impact of the food chain, we need to tackle both what we produce and consume (Audsley, Brander et al. 2009, Macdiarmid, Kyle et al. 2011). The importance of promoting a sustainable diet to mitigate climate change was highlighted by the Committee for Climate Change (CCC 2010, CCC 2011). It is commonly thought that a sustainable diet would also be healthy (Scarborough, Allender et al. 2012).

Although several reports have shown that changes in diets are required both to promote health and to mitigate climate change this is not reflected in most dietary guidelines. Reynolds et al (2014) shows that most dietary guidelines only address health aspects, while economic, social or environmental impacts of diets are considered as secondary or substandard issues. (Reynolds, Buckley et al. 2014). Sometimes, if environmental considerations are mentioned, they are relegated to the appendices as in the Australian Dietary guidelines (NHMRC 2011). A similar situation was observed when school food standards were revised in England in 2014. Although environmental sustainability was mentioned in the document no strong recommendations were provided to change the type of food consumed to make school meals more sustainable (Dimbleby and Vincent 2013, SFP 2014). The standards suggest that schools should “encourage all children to have a meat-free day each week” as a tip but this was not a compulsory standard.

In most policy documents and guidelines, healthy and sustainable diets have been considered separately. For example, the eatwell Plate shows what the UK Government recommends for a healthy diet and separately the CCC has developed diets that would considerably reduce both dietary greenhouse gases and land use (PHE , CCC 2010).

A better way forward would be to develop recommendations for a diet which is both healthy and sustainable. One way of doing this would be to construct several healthy diets and see which one is most sustainable (Baroni, Cenci et al. 2007). Another option would be to construct the least GHGE intensive diet which meets nutritional standards, using linear programming techniques (Briend, Darmon et al. 2003). The former approach has the advantage of involving recommended or real diets, where cultural, social and economic

considerations have been taken into account to ensure their palatability. For the latter approach, diets are constructed by a mathematical formula, which aims to minimise one variable (e.g. greenhouse gas emissions) under a set of constraints (e.g. nutritional recommendations). And whilst techniques can be applied to protect against infeasible diets, the process is not guaranteed to produce diets that would be acceptable to the public. Nevertheless, the linear programming approach is a useful way to establish the potential scope for reductions in GHGEs of meals, as analyses using this technique can identify the minimum possible emissions associated with meals that meet current dietary guidelines, thereby providing a baseline against which reasonable targets for GHGE reduction can be set.

The Government could develop recommendations for a sustainable healthy diet which would enable achievement of its GHGE targets and set an example by applying these guidelines to its procurement standards. These recommendations could be applied to all sectors including school food, hospital food and meals on wheels. Linking GHGE data with nutritional information to construct healthy and sustainable diets is still a relatively new area of research and faces methodological challenges. This chapter demonstrates one approach, using primary school meals as an example.

7.2 Research Question

Research question 05: How can we change school meals to achieve the UK government target of GHGE reduction?

7.3 Methods

7.3.1 Data set for linear programming

The eatwell plate classifies individual food items into five categories based on nutritional information from a health perspective (Gatenby, Hunt et al. 1995). These five groups do not coincide with groups of foods with similar GHGE values. Therefore we subdivided these main groups into 20 sub-groups as shown in Table 3.3. In this food items which had the highest GHGE value in those categories (e.g. shrimp and prawns) were listed separately. Red meats were listed separately as they had significantly higher GHGE values compared to other meat products. The original dataset contained more than 1800 unique food items and allocating them to 20 food group presented several challenges. If it was a non-composite food it was allocated to the appropriate food group (e.g. carrots were allocated to the vegetable food group). If it was a composite food it was allocated to the group which had the highest weight contribution (e.g. pizza, was allocated to the bread, rice and all other cereals category as the highest weight contribution was flour). Table 7.1 shows the full list of these 20 food groups. In model output tables in this chapter full name of these groups could not be entered due to limited space and the Table 7.1 shows the short labels provided for each food group in results tables.

Table 7-1 Food categories included in the model

Main category	Sub-categories	No	Label in model output tables
Bread, Other Cereals and Potatoes	Potatoes	1	Potatoes
	Bread, rice and all other cereals	2	Bread
Fruit and Vegetables	Fruits	3	Fruit
	Tomatoes	4	Tomatoes
	Other vegetables	5	Other veg
	Fruit juice	6	Fruit juice
Meat, Fish and Alternatives	Shrimp and prawns	7	Shrimp
	Other fish	8	Other fish
	Egg	9	Eggs
	Beans, pulses and alternative products	10	Beans
	Red meat	11	Red meat
	White meat	12	White meat
	Other meat products and meat alternatives	13	Meat alternatives
Milk and Dairy	Milk	14	Milk
	Cheese	15	Cheese
	Yogurt & other	16	Yoghurt
Fatty and Sugary Foods	Butter, margarine, spreads, creams, dips	17	Butter, oil
	Crisps, fried snacks cakes, biscuits, chocolate and other sweets	18	Crisps, sweets
	non- diet drinks	19	Non-diet drinks
Water, stock,		20	Water

The Primary School Food Survey database which was described in chapter 5 and 6 was used to estimate baseline values for the model in this chapter. As previously described the database has nutrition information for all the food items consumed by primary school children in a representative sample from England. GHGEs values for each food code was added based on the values from the systematic review described in chapter 4.

The first step for the preparation of the linear programming model was to get mean nutrient values and GHGE values per 100g of each of the food groups mentioned in Table 7.1. These values are shown in Table 7.2. The values are weighted means, weighted by the amount of consumption of each food in the PSFS dataset. Water was excluded from the analysis as it is generally considered as having no GHGEs associated with its production. Pre-bottled water will have higher GHGE compared to tap water, but it was impossible to distinguish these in some cases where it was described as “a cup of water”. The model doesn’t have a constraint associated with a minimum amount of water in the meal.

7.3.2 Development of the model

The model was developed in Microsoft Excel. The analysis was done using the “Solver” function. Mean nutrient values and GHGE values per each of the 20 food groups were entered into the model. The first version of the model optimised for GHGE values (i.e. to keep the GHGE value as minimum). Then energy constraints were added to the model, to guide the model to develop a meal appropriate for primary school children. The School Food Trust average nutrient standards (used in chapter 5 and 6) were used for reference values (Table 7.3). The first constraint was to maintain energy level between 504 -557 kcal. Then one by one all the other nutrient recommendations were added to the model as constraints to create the final meal which minimises GHGE whilst achieving all of the nutrient recommendations in the School Food Trust standards. The model estimates the weight of each food group to be included in the constructed meal and the values for each macro and micro nutrient.

Table 7-2 Mean values per 100g of food, inputs to the linear programming model

	Protein (g)	Fat (g)	Carbohydrate (g)	Energy (kcal)	Fibre (g)	NMES (g)	SFA (g)	Vitamin A (µg)	Vitamin C (mg)	Folate (µg)	Sodium (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	GHGE (KgCO ₂ e)
Potatoes	4.15	3.38	21.99	131.55	1.26	0.06	0.93	8.47	7.31	23.94	58.46	17.98	0.63	0.45	0.05
Bread	6.99	8.25	42.66	262.15	2.06	6.14	2.97	64.41	0.79	22.14	329.62	100.03	1.33	0.85	0.14
Fruits	4.92	4.53	19.07	132.36	1.35	3.70	1.70	107.99	5.61	17.27	163.25	54.40	0.68	0.56	0.18
Tomatoes	1.11	0.67	5.17	29.96	1.06	0.06	0.18	95.04	14.98	20.02	28.24	12.22	0.50	0.15	0.47
Other vegetables	3.49	2.09	9.57	68.97	2.20	0.30	0.57	386.20	11.67	28.35	78.20	29.42	0.72	0.43	0.15
Fruit juice	0.58	0.20	8.23	34.69	0.06	8.09	0.11	4.18	13.76	6.48	7.09	8.48	0.17	0.01	0.10
Shrimp	14.70	7.60	11.30	170.00	0.60	0.00	4.06	73.00	1.50	16.00	161.00	25.00	0.40	0.50	1.86
Other fish	10.91	6.34	20.92	181.55	1.45	0.30	1.78	29.13	1.43	17.42	299.26	41.84	1.06	0.68	0.19
Eggs	5.53	12.16	43.04	292.93	1.09	22.94	4.14	122.62	2.59	10.08	286.95	63.98	0.99	0.60	0.31
Beans	4.41	0.32	13.89	72.17	4.77	4.27	0.11	0.35	0.00	21.99	249.05	53.34	0.02	0.50	0.15
Red meat	13.42	10.13	12.44	192.30	0.76	0.06	4.36	73.26	2.04	16.56	268.51	32.38	1.43	2.23	1.72
White meat	19.07	8.38	9.34	186.73	0.83	0.46	2.82	23.03	2.13	10.30	520.38	58.97	0.99	1.38	0.36
Meat alternatives	10.00	5.81	14.48	147.39	2.36	0.63	2.03	73.17	3.91	32.59	443.03	86.38	1.61	1.93	0.19
Milk	4.55	2.95	12.77	92.62	0.31	2.89	1.52	43.03	2.33	8.65	83.62	110.72	0.28	0.61	0.17
Cheese	22.30	30.51	2.44	372.89	0.06	0.43	19.04	335.73	0.24	26.90	711.52	661.90	0.28	3.47	1.13
Yoghurt	4.05	1.61	15.84	90.28	0.20	8.02	1.00	17.78	0.35	1.82	68.53	140.28	0.14	0.50	0.17
Butter, oil	4.01	21.51	49.02	393.69	0.92	27.51	6.62	154.15	1.23	23.36	365.86	47.90	1.57	0.54	0.25
Crisps , sweets	2.77	5.69	23.62	150.80	0.61	11.13	2.61	41.16	0.98	9.97	294.98	46.81	0.63	0.26	0.16

Table 7-3 Nutrient based constraints provided to the model

	Nutrient	Min/Max	Average aged 4-10 school years
1	Energy (kcal)	EAR	504-557
2	Protein (g)	Min	7.5
3	Carbohydrate (g)	Min	70.6
4	Non milk extrinsic sugars (g)	Max	15.5
5	Fat(g)	Max	20.6
6	Saturated fatty acids(g)	Max	6.5
7	Fibre(g)	Min	4.2
8	Sodium (mg)	Max	499
9	Vitamin A (µg)	Min	175
10	Vitamin C (mg)	Min	10.5
11	Folate (µg)	Min	53
12	Calcium (mg)	Min	193
13	Iron (mg)	Min	3.0
14	Zinc (mg)	Min	2.5

To answer the research question in this chapter, it was important to clarify what proportion of reduction in GHGE associated with consumption of food is expected by changing diets to achieve the UK GHGE targets.

A previous report published by the World Wildlife Fund (WWF), the Livewell study estimated that to achieve a total reduction of 70% in GHGEs by 2050, about 39% GHGE reduction should be achieved by dietary changes and remaining 31% could be achieved by changes in production and processing of food. (Macdiarmid, Kyle et al. 2011).

Using the Livewell 2050 results as a guide, I used a 40% reduction in GHGEs from dietary changes as a constraint in the linear programming model, with minimal changes (see below for more details) in each food group compared to current consumption.

Linear programming is a widely used mathematical modelling technique which has been used to create healthy meals optimised for different constraints such as cost and nutritional values (Briend, Ferguson et al. 2001, Ferguson, Darmon et al. 2004). A description of this technique is provided in chapter three. In this chapter linear programming was used to create school meals which can meet nutrient based or food based standards optimised for GHGEs.

Three different optimisation methods were used to answer the research question. For the first method the model optimises for the total GHGE value (keep the GHGE value as minimum) and meets the constraints provided to the model.

In the second and third methods, the model was changed to construct the meal closest to the current primary school meals consumption.

Second method:

If the current weight of any specific food group is w_1 and if the proposed new weight is w_2 , the model optimises for the i

$$i = \sum (w_2 - w_1)^2$$

In this method used throughout the chapter, absolute difference between the new value and current value is taken to estimate the difference. The model minimise the sum of those differences, to keep the change in each food group to a minimum.

The third method takes the relative difference (i.e. difference as a proportion of the current value). If the model is optimising for this i_2 ,

$$i_2 = \sum (v_2 - 100)^2$$

$$v_2 = \frac{w_2}{w_1} \times 100$$

When the model was changed to optimise using this third method it gave similar results to the second method. Therefore the second method was used in this chapter and when results are presented as optimised for minimal changes to current consumption, it uses the second method described above, using the absolute difference rather than relative difference.

7.4 Results

7.4.1 School meals achieving nutrient based standards

When the model created a meal with recommended energy levels, optimised for GHGE values the output was a meal with 383g of potatoes. This simply is a result of the fact that potatoes have the lowest GHGE per kcal of all food categories included in the optimisation modelling. In the next three steps, with the sugar, salt, saturated fatty acids constraints the meal remained unchanged. With the induction of protein, carbohydrate, fat and fibre constraints, amount of potatoes increased. This is because the recommendations for each of these nutrients sets have been reached with a meal that consisted entirely of potatoes.

When the vitamin A constraint was introduced, the model added 373g of vegetables to the meal. With fibre and folate constraints the meal remained potatoes and vegetables. With the calcium constraint it changed the meal to include potatoes, bread, vegetables and

yogurt. With the Iron constraint, it added the meat alternative group to the meal. Adding the final constraint of zinc did not change the components of the meal. The final meal which met all nutrient based standards and optimised for GHGE is shown in Table 7.4 below. Total emissions of this meal was 0.39 KgCO₂e.

Table 7-4 Primary school meal optimised for GHGE and nutrient based standards

Food group	Current weight (g)	Weight (g)	Change (%)	Protein (g)	Fat (g)	Carbohydrate (g)	Energy (kcal)	Fibre (g)	NMES (g)	SFA (g)	Vitamin A (µg)	Vitamin C (mg)	Folate (µg)	Sodium (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	GHGE (KgCO ₂ e)
Potatoes	72.4	259	257.7	10.76	8.76	57.05	341.26	3.27	0.14	2.42	21.97	18.96	62.09	151.64	46.65	1.64	1.18	0.14
Bread	50.99	37	-27.4	2.61	3.09	15.96	98.10	0.77	2.30	1.11	24.10	0.30	8.28	123.35	37.43	0.50	0.32	0.05
Fruits	29.91	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tomatoes	7.4	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other vegetables	65.96	24	-63.6	0.83	0.50	2.28	16.40	0.52	0.07	0.13	91.85	2.78	6.74	18.60	7.00	0.17	0.10	0.04
Fruit juice	28.11	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shrimp	0.01	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other fish	5.94	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eggs	5.78	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beans	13.85	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Red meat	12.31	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
White meat	18.57	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat alternatives	1.66	39	2249.4	3.88	2.26	5.62	57.22	0.91	0.25	0.79	28.41	1.52	12.65	172.01	33.54	0.63	0.75	0.07
Milk	54.04	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cheese	7.08	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yoghurt	9.3	49	426.9	1.98	0.78	7.72	44.01	0.10	3.91	0.49	8.67	0.17	0.89	33.41	68.39	0.07	0.24	0.08
Butter , Oil margarine	10.65	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crisps , sweets	25.31	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total				20.07	15.38	88.63	557.00	5.58	6.67	4.94	175.00	23.72	90.66	499.00	193.00	3.00	2.59	0.39
Current nutrients				18.47	16.26	70.45	485.95	4.76	14.06	6.15	332.79	23.05	63.19	528.71	202.38	2.34	2.14	0.72

Figure 7.1 Weight (g) of different food groups in current meals and modelled primary school meals optimised for GHGE and nutrient based standards

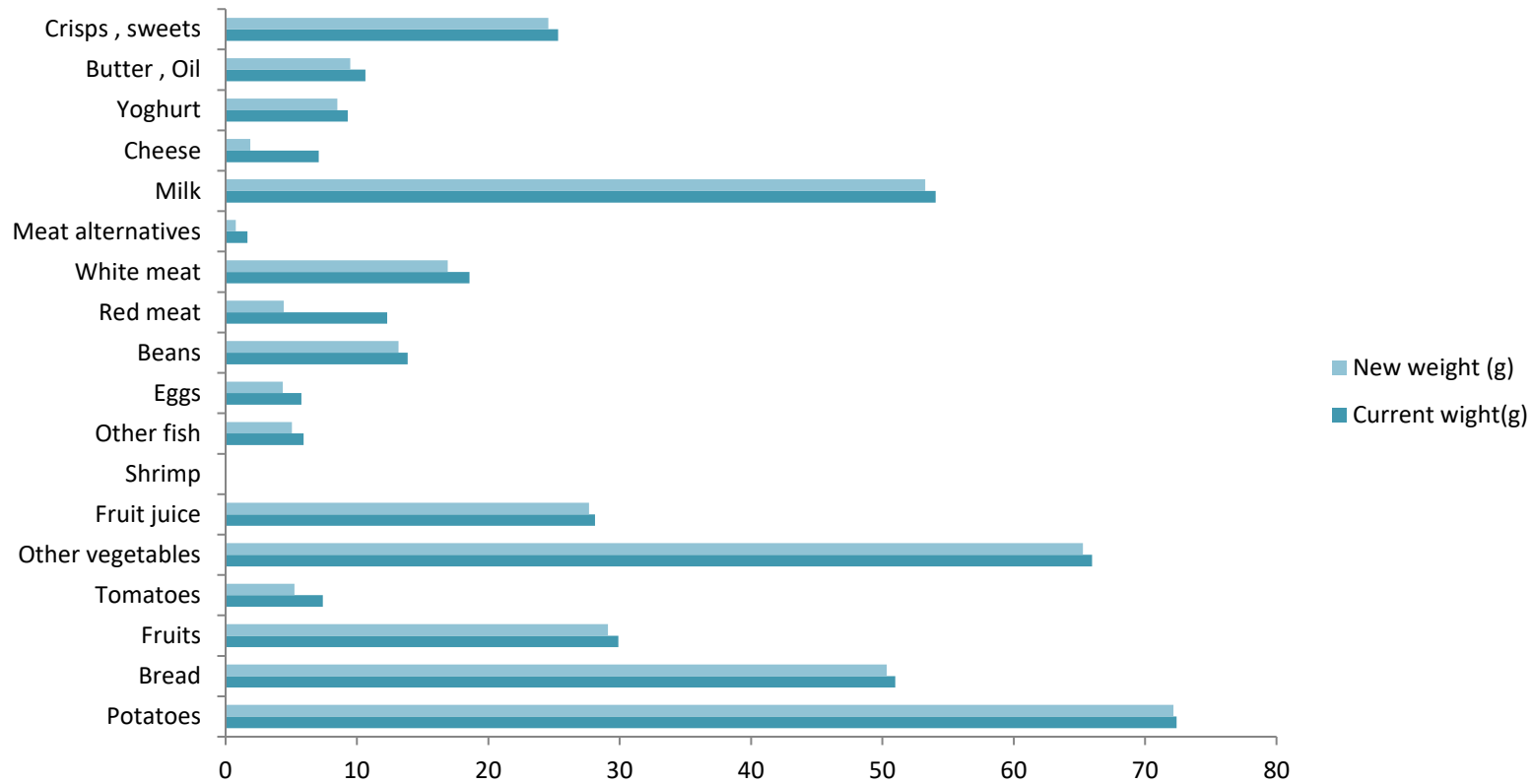
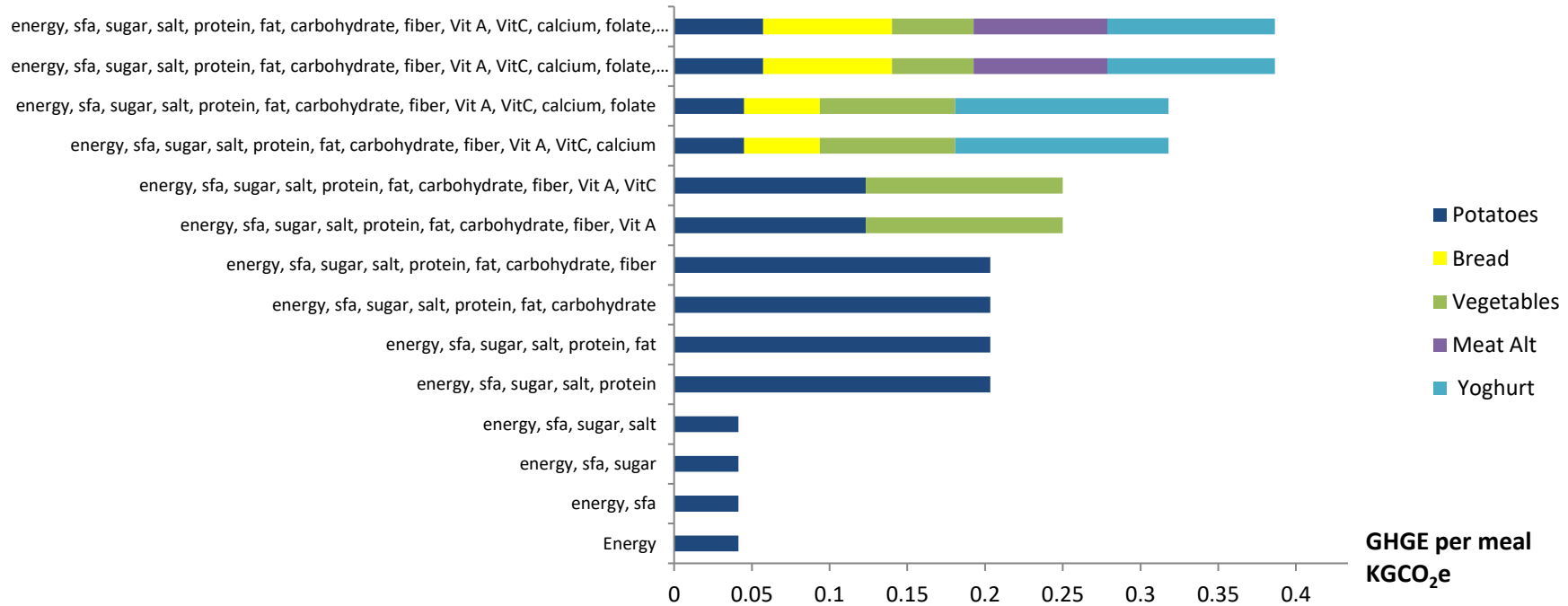


Figure 7.2 Proportion of different food groups in the outputs of the model with each set of nutrient based constraints



Step by step changes in the model output meal is shown in figure. Each bar represents the overall GHGE of the individual meal and the proportion of weight contribution from each food group.

7.4.2 School meals achieving food-based standards

The new School Food Plan introduced food based standards for primary school meals in England (See chapter 6 for details). As the next step of this analysis the model was used to create a school meal which achieved these new food-based standards and optimised for GHGEs. As explained in chapter 6, some of these standards cannot be applied to a single meal. E.g. “A portion of meat or poultry on three of more days each week”. Therefore these nutrient and GHGE values per meal were used to estimate values per week (five school days) and used for the analysis in the model. (See annexure for food-based standards for school meals). A portion of meat is 85g and the minimum of three portions of meat per week would contain 255g. Consumption of meat or poultry on three or more days per week was parameterised as consuming at least 51g per day, daily average of 255g for five days.

The same energy levels (504- 557 kcal) were provided to the model as we need to create a meal which is appropriate for primary school children. When fruits and vegetable standards were introduced it created a meal that consisted of potatoes, fruits and vegetables only. When milk and dairy standard was introduced it included yogurt as a component of the meal. Introduction of starchy food standards did not change the meal, as potatoes were already included in the constructed meal. The introduction of the meat, fish, eggs, beans standards added beans and eggs to the meal. At this stage the meal could be considered as complete for a vegetarian student with a total GHGE of 0.64 KgCO₂e. The final constraint was a portion of meat or poultry on three or more days each week and it introduced white meat to the final meal and final GHGE is 0.73 KgCO₂e. Certain standards such as “oily fish once or more every three weeks” and “no more than two portions of food that has been

deep-fried, batter coated or breadcrumb coated each week” cannot be applied to the model, as our dataset doesn’t have variables to recognise them.

Table 7-5 Primary school meal optimised for GHGE and new food based primary school meal standards

Food group	Current weight (g)	Weight (g)	Change (%)	Protein (g)	Fat (g)	Carbohydrate (g)	Energy (kcal)	Fibre (g)	NMES (g)	SFA (g)	Vitamin A (µg)	Vitamin C (mg)	Folate (µg)	Sodium (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	GHGE (KgCO ₂ e)
Potatoes	72.4	122.49	69.2	5.08	4.13	26.94	161.13	1.54	0.07	1.14	10.37	8.95	29.32	71.60	22.03	0.77	0.56	0.07
Bread	50.99	19.56	-61.6	1.37	1.61	8.35	51.29	0.40	1.20	0.58	12.60	0.15	4.33	64.49	19.57	0.26	0.17	0.03
Fruits	29.91	60.00	100.6	2.95	2.72	11.44	79.42	0.81	2.22	1.02	64.79	3.37	10.36	97.95	32.64	0.41	0.34	0.11
Tomatoes	7.4	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other vegetables	65.96	60.00	-9.0	2.09	1.25	5.74	41.38	1.32	0.18	0.34	231.72	7.00	17.01	46.92	17.65	0.43	0.26	0.09
Fruit juice	28.11	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shrimp	0.01	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other fish	5.94	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eggs	5.78	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beans	13.85	28.00	102.2	1.24	0.09	3.89	20.21	1.34	1.20	0.03	0.10	0.00	6.16	69.73	14.94	0.00	0.14	0.04
Red meat	12.31	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
White meat	18.57	51.00	174.6	9.72	4.27	4.76	95.23	0.42	0.23	1.44	11.75	1.09	5.25	265.40	30.07	0.51	0.71	0.19
Meat alternatives	1.66	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Milk	54.04	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cheese	7.08	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yoghurt	9.3	120.00	1190.3	4.87	1.93	19.01	108.34	0.25	9.62	1.19	21.34	0.43	2.19	82.24	168.34	0.17	0.60	0.21
Butter , Oil	10.65	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crisps , sweets	25.31	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total				27.32	16.01	80.12	557.00	6.08	14.72	5.75	352.67	20.99	74.62	698.33	305.23	2.56	2.76	0.73
Current nutrients				18.47	16.26	70.45	485.95	4.76	14.06	6.15	332.79	23.05	63.19	528.71	202.38	2.34	2.14	0.72

Figure 7.3 Weight (g) of different food groups in current meals and modelled primary school meals meal optimised for GHGE and new food based primary school meal standards

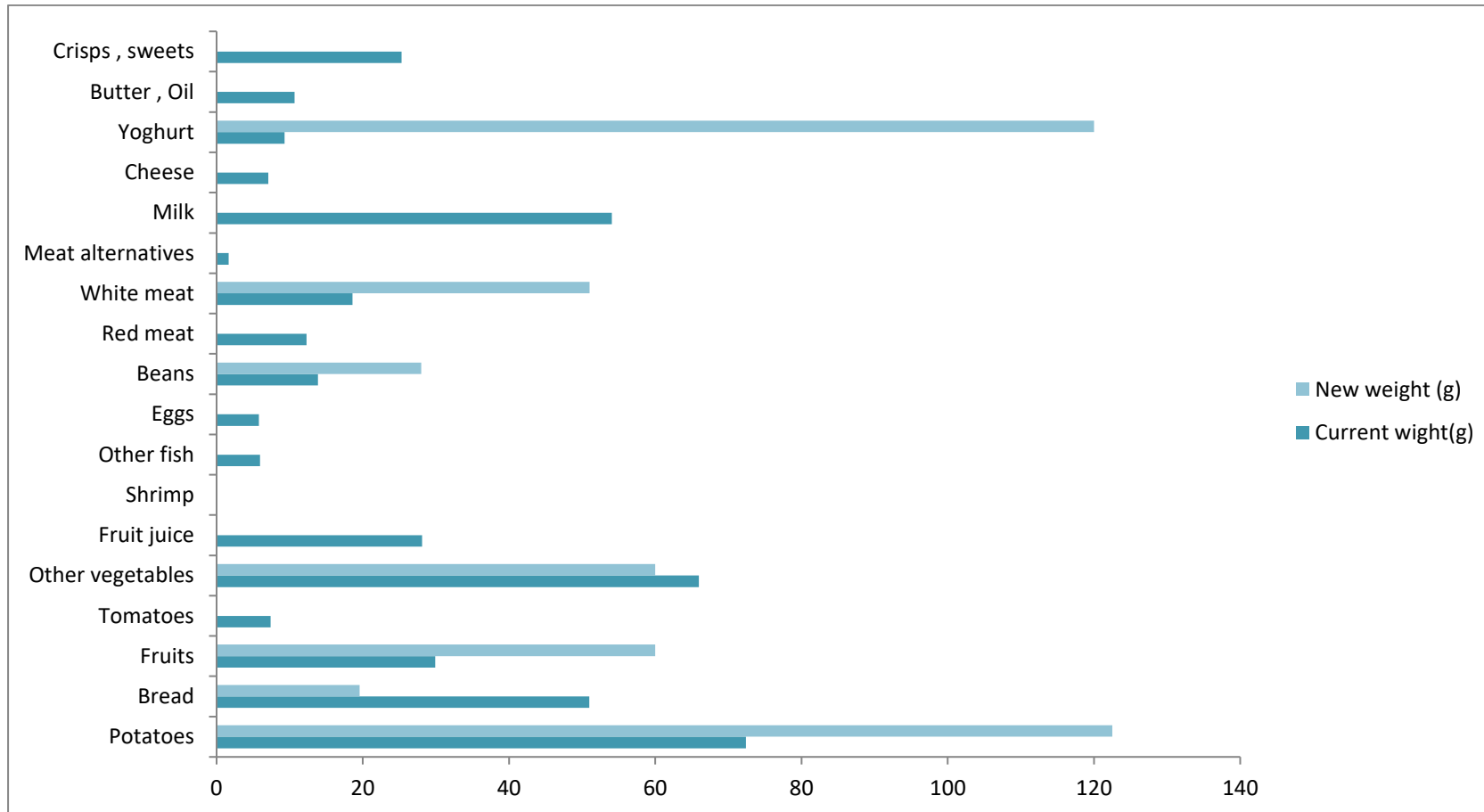
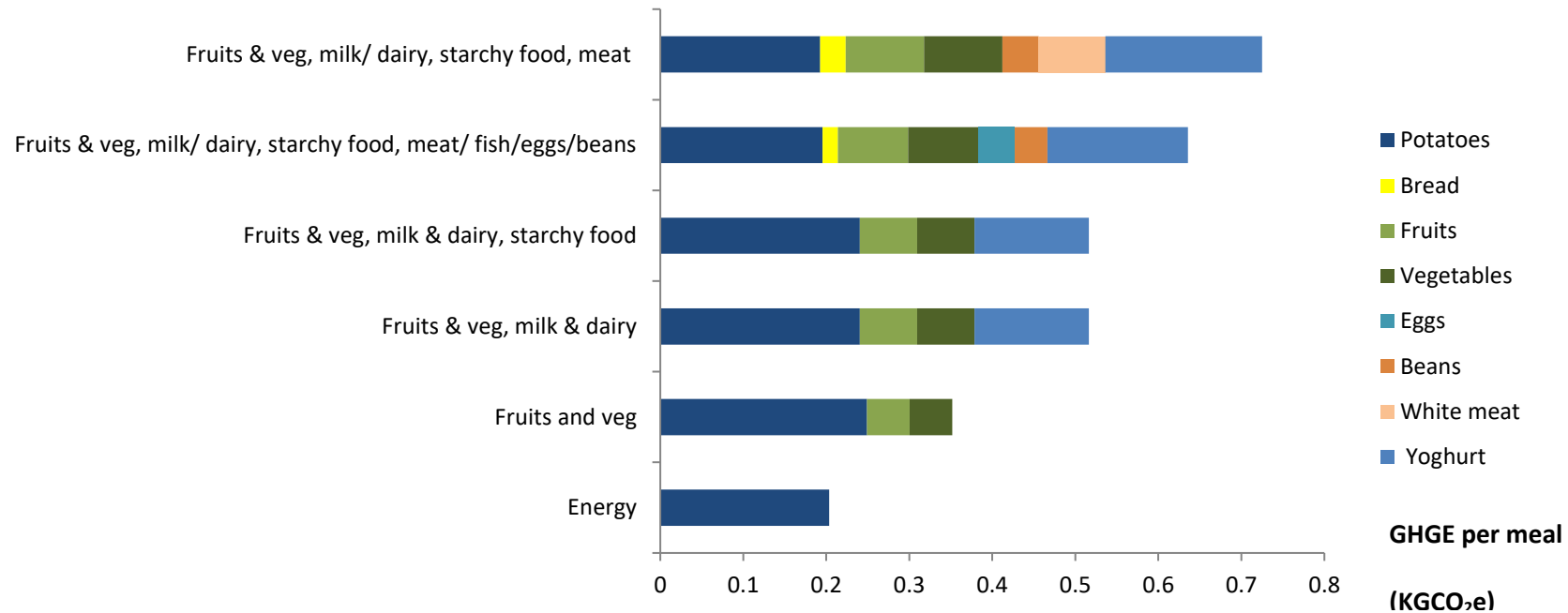


Figure 7.4 Proportion of different food groups in the outputs of the model with each set of food based constraints



Step by step changes in the model output meal is shown in Figure 7.2. Each bar represents the total GHGEs of the individual meal and the proportion of weight contribution from each food group. Fifth scenario allows the model to pick any food item from the meat, fish, eggs, beans or meat alternative group. The final scenario (meat) makes it compulsory to have a portion of meat or poultry on three or more days each week.

The meal shown in the Table 7.5 is based on the new food based standards. But the final meal met all nutrient based standards for a primary school meal.

One of the problems with the meals shown in Tables 7.4 and 7.5 is that they are significantly different to currently consumed meals. In both analyses, meal is optimised for GHGEs and achieves certain nutrient or food based standards. In the next analysis (Method 2) the aim was to create a school meal which allows primary school food sector to reach the GHGE reduction target (40% from consumed food) with minimal deviation from the current meal. An extra constraint was introduced to the model which looks at the difference between current consumption and proposed consumption of each food group and the model is optimised by reducing the sum of the difference between current and modelled consumption, squared for each food group.

The average GHGE value of a school lunch was 0.72 KgCO₂e and a 40% reduction means the new meal should be 0.43 KgCO₂e.

Tables 7.6 to 7.10 show step by step reduction of GHGE of a primary school meal from the current value to 5%, 10%, 20% ,30%and 40%. In these scenarios GHGE is reduced and no nutrients constraints were provided except energy. The energy value for a primary school meal was provided to create comparable and meaningful meals by the model. It shows what happens if we just reduce GHGE without thinking about nutrients. The overall nutritional quality of the proposed meal in each scenario and the mean values of current school meals are provided for comparison.

Table 7-6 Primary school meal created by the model with 5% reduction in GHGE and minimal changes to current consumption *

Food group	Current weight (g)	Weight (g)	Change (%)	Protein (g)	Fat (g)	Carbohydrate (g)	Energy (kcal)	Fibre (g)	NMES (g)	SFA (g)	Vitamin A (µg)	Vitamin C (mg)	Folate (µg)	Sodium (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	GHGE (KgCO2e)
Potatoes	72.4	72.16	-0.3	2.99	2.44	15.87	94.92	0.91	0.04	0.67	6.11	5.27	17.27	42.18	12.98	0.46	0.33	0.04
Bread	50.99	50.34	-1.3	3.52	4.16	21.48	131.97	1.04	3.09	1.50	32.43	0.40	11.14	165.93	50.36	0.67	0.43	0.07
Fruits	29.91	29.10	-2.7	1.43	1.32	5.55	38.52	0.39	1.08	0.49	31.43	1.63	5.03	47.51	15.83	0.20	0.16	0.05
Tomatoes	7.4	5.25	-29.1	0.06	0.04	0.27	1.57	0.06	0.00	0.01	4.99	0.79	1.05	1.48	0.64	0.03	0.01	0.02
Other vegetables	65.96	65.26	-1.1	2.28	1.36	6.24	45.01	1.43	0.20	0.37	252.02	7.62	18.50	51.03	19.20	0.47	0.28	0.10
Fruit juice	28.11	27.66	-1.6	0.16	0.05	2.28	9.60	0.02	2.24	0.03	1.16	3.81	1.79	1.96	2.35	0.05	0.00	0.03
Shrimp	0.01	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other fish	5.94	5.06	-14.8	0.55	0.32	1.06	9.18	0.07	0.01	0.09	1.47	0.07	0.88	15.13	2.12	0.05	0.03	0.01
Eggs	5.78	4.35	-24.7	0.24	0.53	1.87	12.75	0.05	1.00	0.18	5.34	0.11	0.44	12.49	2.79	0.04	0.03	0.01
Beans	13.85	13.16	-5.0	0.58	0.04	1.83	9.50	0.63	0.56	0.01	0.05	0.00	2.89	32.78	7.02	0.00	0.07	0.02
Red meat	12.31	4.42	-64.1	0.59	0.45	0.55	8.51	0.03	0.00	0.19	3.24	0.09	0.73	11.88	1.43	0.06	0.10	0.08
White meat	18.57	16.90	-9.0	3.22	1.42	1.58	31.56	0.14	0.08	0.48	3.89	0.36	1.74	87.95	9.97	0.17	0.23	0.06
Meat alternatives	1.66	0.78	-53.0	0.08	0.05	0.11	1.14	0.02	0.00	0.02	0.57	0.03	0.25	3.44	0.67	0.01	0.01	0.00
Milk	54.04	53.25	-1.5	2.42	1.57	6.80	49.32	0.17	1.54	0.81	22.91	1.24	4.60	44.53	58.96	0.15	0.33	0.09
Cheese	7.08	1.87	-73.6	0.42	0.57	0.05	6.97	0.00	0.01	0.36	6.28	0.00	0.50	13.31	12.38	0.01	0.06	0.02
Yoghurt	9.3	8.50	-8.6	0.34	0.14	1.35	7.67	0.02	0.68	0.08	1.51	0.03	0.15	5.83	11.92	0.01	0.04	0.01
Butter , Oil margarine	10.65	9.50	-10.8	0.38	2.04	4.66	37.40	0.09	2.61	0.63	14.64	0.12	2.22	34.75	4.55	0.15	0.05	0.02
Crisps , sweets	25.31	24.58	-2.9	0.68	1.40	5.81	37.07	0.15	2.74	0.64	10.12	0.24	2.45	72.52	11.51	0.16	0.06	0.04
Total				19.96	17.88	77.34	532.67	5.21	15.88	6.57	398.16	21.82	71.65	644.71	224.66	2.68	2.23	0.68
Current nutrients				18.47	16.26	70.45	485.95	4.76	14.06	6.15	332.79	23.05	63.19	528.71	202.38	2.34	2.14	0.72
* only energy values provided as nutrient constraints.																		

Table 7-7 Primary school meal created by the model with 10% reduction in GHGE and minimal changes to current consumption*

Food group	Current weight (g)	Weight (g)	Change (%)	Protein (g)	Fat (g)	Carbohydrate (g)	Energy (kcal)	Fibre (g)	NMES (g)	SFA (g)	Vitamin A (µg)	Vitamin C (mg)	Folate (µg)	Sodium (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	GHGE (KgCO2e)
Potatoes	72.4	72.12	-0.39	2.99	2.43	15.86	94.87	0.91	0.04	0.67	6.11	5.27	17.26	42.16	12.97	0.45	0.33	0.04
Bread	50.99	50.24	-1.47	3.51	4.15	21.43	131.70	1.04	3.08	1.49	32.36	0.40	11.12	165.60	50.26	0.67	0.43	0.07
Fruits	29.91	28.98	-3.11	1.43	1.31	5.53	38.35	0.39	1.07	0.49	31.29	1.63	5.00	47.30	15.76	0.20	0.16	0.05
Tomatoes	7.4	4.92	-33.51	0.05	0.03	0.25	1.47	0.05	0.00	0.01	4.67	0.74	0.98	1.39	0.60	0.02	0.01	0.02
Other vegetables	65.96	65.15	-1.23	2.27	1.36	6.23	44.93	1.43	0.20	0.37	251.60	7.61	18.47	50.95	19.16	0.47	0.28	0.10
Fruit juice	28.11	27.59	-1.85	0.16	0.05	2.27	9.57	0.02	2.23	0.03	1.15	3.80	1.79	1.96	2.34	0.05	0.00	0.03
Shrimp	0.01	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other fish	5.94	4.92	-17.17	0.54	0.31	1.03	8.93	0.07	0.01	0.09	1.43	0.07	0.86	14.72	2.06	0.05	0.03	0.01
Eggs	5.78	4.13	-28.55	0.23	0.50	1.78	12.10	0.05	0.95	0.17	5.07	0.11	0.42	11.85	2.64	0.04	0.02	0.01
Beans	13.85	13.06	-5.70	0.58	0.04	1.81	9.42	0.62	0.56	0.01	0.05	0.00	2.87	32.51	6.96	0.00	0.07	0.02
Red meat	12.31	3.19	-74.09	0.43	0.32	0.40	6.14	0.02	0.00	0.14	2.34	0.06	0.53	8.57	1.03	0.05	0.07	0.05
White meat	18.57	16.64	-10.39	3.17	1.39	1.55	31.07	0.14	0.08	0.47	3.83	0.36	1.71	86.59	9.81	0.17	0.23	0.06
Meat alternatives	1.66	0.64	-61.45	0.06	0.04	0.09	0.94	0.02	0.00	0.01	0.47	0.02	0.21	2.83	0.55	0.01	0.01	0.00
Milk	54.04	53.12	-1.70	2.42	1.57	6.78	49.20	0.17	1.53	0.81	22.86	1.24	4.59	44.43	58.82	0.15	0.33	0.09
Cheese	7.08	1.06	-85.03	0.24	0.32	0.03	3.94	0.00	0.00	0.20	3.54	0.00	0.28	7.51	6.99	0.00	0.04	0.01
Yoghurt	9.3	8.38	-9.89	0.34	0.13	1.33	7.56	0.02	0.67	0.08	1.49	0.03	0.15	5.74	11.75	0.01	0.04	0.01
Butter , Oil margarine	10.65	9.32	-12.49	0.37	2.00	4.57	36.69	0.09	2.56	0.62	14.36	0.11	2.18	34.09	4.46	0.15	0.05	0.02
Crisps , sweets	25.31	24.47	-3.32	0.68	1.39	5.78	36.90	0.15	2.72	0.64	10.07	0.24	2.44	72.18	11.45	0.15	0.06	0.04
Total				19.47	17.37	76.72	523.79	5.17	15.72	6.31	392.69	21.68	70.87	630.37	217.62	2.64	2.16	0.65
Current nutrients				18.47	16.26	70.45	485.95	4.76	14.06	6.15	332.79	23.05	63.19	528.71	202.38	2.34	2.14	0.72
*only energy values provided as nutrient constraints.																		

Table 7-8 Primary school meal created by the model with 20% reduction in GHGE and minimal changes to current consumption*

Food group	Current weight (g)	Weight (g)	Change (%)	Protein (g)	Fat (g)	Carbohydrate (g)	Energy (kcal)	Fibre (g)	NMES (g)	SFA (g)	Vitamin A (µg)	Vitamin C (mg)	Folate (µg)	Sodium (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	GHGE (KgCO2e)	
Potatoes	72.4	72.03	-0.51	2.99	2.43	15.84	94.76	0.91	0.04	0.67	6.10	5.26	17.24	42.11	12.95	0.45	0.33	0.04	
Bread	50.99	50.01	-1.92	3.49	4.13	21.33	131.11	1.03	3.07	1.49	32.21	0.40	11.07	164.85	50.03	0.66	0.43	0.07	
Fruits	29.91	28.69	-4.08	1.41	1.30	5.47	37.98	0.39	1.06	0.49	30.98	1.61	4.96	46.84	15.61	0.20	0.16	0.05	
Tomatoes	7.4	4.16	-43.78	0.05	0.03	0.22	1.25	0.04	0.00	0.01	3.96	0.62	0.83	1.18	0.51	0.02	0.01	0.02	
Other vegetables	65.96	64.90	-1.61	2.26	1.35	6.21	44.76	1.43	0.20	0.37	250.65	7.58	18.40	50.76	19.09	0.47	0.28	0.10	
Fruit juice	28.11	27.44	-2.38	0.16	0.05	2.26	9.52	0.02	2.22	0.03	1.15	3.78	1.78	1.94	2.33	0.05	0.00	0.03	
Shrimp	0.01	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other fish	5.94	4.61	-22.39	0.50	0.29	0.96	8.37	0.07	0.01	0.08	1.34	0.07	0.80	13.79	1.93	0.05	0.03	0.01	
Eggs	5.78	3.63	-37.20	0.20	0.44	1.56	10.64	0.04	0.83	0.15	4.45	0.09	0.37	10.42	2.32	0.04	0.02	0.01	
Beans	13.85	12.81	-7.51	0.57	0.04	1.78	9.25	0.61	0.55	0.01	0.05	0.00	2.82	31.91	6.84	0.00	0.06	0.02	
Red meat	12.31	0.42	-96.59	0.06	0.04	0.05	0.82	0.00	0.00	0.02	0.31	0.01	0.07	1.14	0.14	0.01	0.01	0.01	
White meat	18.57	16.05	-13.57	3.06	1.35	1.50	29.98	0.13	0.07	0.45	3.70	0.34	1.65	83.54	9.47	0.16	0.22	0.06	
Meat alternatives	1.66	0.33	-80.12	0.03	0.02	0.05	0.48	0.01	0.00	0.01	0.24	0.01	0.11	1.45	0.28	0.01	0.01	0.00	
Milk	54.04	52.85	-2.20	2.41	1.56	6.75	48.94	0.16	1.53	0.80	22.74	1.23	4.57	44.19	58.51	0.15	0.32	0.09	
Cheese	7.08	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Yoghurt	9.3	8.10	-12.90	0.33	0.13	1.28	7.31	0.02	0.65	0.08	1.44	0.03	0.15	5.55	11.36	0.01	0.04	0.01	
Butter , Oil margarine	10.65	8.91	-16.34	0.36	1.92	4.37	35.10	0.08	2.45	0.59	13.74	0.11	2.08	32.62	4.27	0.14	0.05	0.02	
Crisps , sweets	25.31	24.22	-4.31	0.67	1.38	5.72	36.52	0.15	2.69	0.63	9.97	0.24	2.41	71.43	11.33	0.15	0.06	0.04	
Total				18.55	16.46	75.36	506.76	5.08	15.38	5.88	383.02	21.38	69.31	603.71	206.96	2.56	2.03	0.58	
Current nutrients				18.47	16.26	70.45	485.95	4.76	14.06	6.15	332.79	23.05	63.19	528.71	202.38	2.34	2.14	0.72	
* only energy values provided as nutrient constraints.																			

Table 7-9 Primary school meal created by the model with 30% reduction in GHGE and minimal changes to current consumption*

Food group	Current weight (g)	Weight (g)	Change (%)	Protein (g)	Fat (g)	Carbohydrate (g)	Energy (kcal)	Fibre (g)	NMES (g)	SFA (g)	VitaminA (µg)	VitaminC (mg)	Folate (µg)	Sodium (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	GHGE (KgCO2e)
Potatoes	72.4	75.10	3.73	3.12	2.54	16.52	98.80	0.95	0.04	0.70	6.36	5.49	17.98	43.90	13.50	0.47	0.34	0.04
Bread	50.99	54.61	7.10	3.82	4.51	23.30	143.16	1.13	3.35	1.62	35.18	0.43	12.09	180.01	54.63	0.73	0.47	0.08
Fruits	29.91	26.55	-11.23	1.31	1.20	5.06	35.14	0.36	0.98	0.45	28.67	1.49	4.58	43.34	14.44	0.18	0.15	0.05
Tomatoes	7.4	0.00	-100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other vegetables	65.96	61.17	-7.26	2.13	1.28	5.85	42.18	1.34	0.18	0.35	236.22	7.14	17.34	47.83	17.99	0.44	0.26	0.09
Fruit juice	28.11	24.70	-12.13	0.14	0.05	2.03	8.57	0.01	2.00	0.03	1.03	3.40	1.60	1.75	2.09	0.04	0.00	0.02
Shrimp	0.01	0.00	-100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other fish	5.94	3.75	-36.87	0.41	0.24	0.78	6.81	0.05	0.01	0.07	1.09	0.05	0.65	11.23	1.57	0.04	0.03	0.01
Eggs	5.78	2.25	-61.07	0.12	0.27	0.97	6.59	0.02	0.52	0.09	2.76	0.06	0.23	6.46	1.44	0.02	0.01	0.01
Beans	13.85	9.35	-32.49	0.41	0.03	1.30	6.75	0.45	0.40	0.01	0.03	0.00	2.06	23.28	4.99	0.00	0.05	0.01
Red meat	12.31	0.00	-100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
White meat	18.57	8.10	-56.38	1.54	0.68	0.76	15.13	0.07	0.04	0.23	1.87	0.17	0.83	42.17	4.78	0.08	0.11	0.03
Meat alternatives	1.66	0.00	-100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Milk	54.04	49.24	-8.88	2.24	1.45	6.29	45.61	0.15	1.42	0.75	21.19	1.15	4.26	41.18	54.52	0.14	0.30	0.08
Cheese	7.08	0.00	-100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yoghurt	9.3	4.32	-53.55	0.18	0.07	0.68	3.90	0.01	0.35	0.04	0.77	0.02	0.08	2.96	6.06	0.01	0.02	0.01
Butter , Oil margarine	10.65	14.18	33.15	0.57	3.05	6.95	55.81	0.13	3.90	0.94	21.85	0.17	3.31	51.86	6.79	0.22	0.08	0.04
Crisps , sweets	25.31	23.58	3.73	0.65	1.34	5.57	35.56	0.14	2.62	0.62	9.70	0.23	2.35	69.55	11.04	0.15	0.06	0.04
Total				16.65	16.70	76.06	504.00	4.82	15.81	5.90	366.72	19.80	67.36	565.51	193.84	2.52	1.88	0.50
Current nutrients				18.47	16.26	70.45	485.95	4.76	14.06	6.15	332.79	23.05	63.19	528.71	202.38	2.34	2.14	0.72
* only energy values provided as nutrient constraints.																		

Table 7-10 Primary school meal created by the model with 40% reduction in GHGE and minimal changes to current consumption*

Food group	Current weight (g)	Weight (g)	Change (%)	Protein (g)	Fat (g)	Carbohydrate (g)	Energy (kcal)	Fibre (g)	NMES (g)	SFA (g)	Vitamin A (µg)	Vitamin C (mg)	Folate (µg)	Sodium (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	GHGE (KgCO2e)
Potatoes	72.4	81.05	11.95	3.36	2.74	17.82	106.62	1.02	0.04	0.76	6.86	5.92	19.40	47.38	14.57	0.51	0.37	0.04
Bread	50.99	63.06	23.67	4.41	5.21	26.90	165.32	1.30	3.87	1.88	40.62	0.50	13.96	207.86	63.08	0.84	0.54	0.09
Fruits	29.91	20.77	-30.56	1.02	0.94	3.96	27.49	0.28	0.77	0.35	22.43	1.17	3.59	33.91	11.30	0.14	0.12	0.04
Tomatoes	7.4	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other vegetables	65.96	52.28	-20.74	1.82	1.09	5.00	36.05	1.15	0.16	0.30	201.89	6.10	14.82	40.88	15.38	0.38	0.22	0.08
Fruit juice	28.11	18.30	-34.90	0.11	0.04	1.51	6.35	0.01	1.48	0.02	0.76	2.52	1.19	1.30	1.55	0.03	0.00	0.02
Shrimp	0.01	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other fish	5.94	0.52	-91.25	0.06	0.03	0.11	0.95	0.01	0.00	0.01	0.15	0.01	0.09	1.56	0.22	0.01	0.00	0.00
Eggs	5.78	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Beans	13.85	1.05	-92.42	0.05	0.00	0.15	0.75	0.05	0.04	0.00	0.00	0.00	0.23	2.60	0.56	0.00	0.01	0.00
Red meat	12.31	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
White meat	18.57	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Meat alternatives	1.66	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Milk	54.04	40.48	-25.09	1.84	1.19	5.17	37.49	0.13	1.17	0.62	17.42	0.94	3.50	33.85	44.81	0.11	0.25	0.07
Cheese	7.08	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Yoghurt	9.3	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Butter , Oil margarine	10.65	23.17	117.56	0.93	4.98	11.36	91.22	0.21	6.37	1.53	35.72	0.28	5.41	84.77	11.10	0.36	0.12	0.06
Crisps , sweets	25.31	21.06	-16.79	0.58	1.20	4.98	31.76	0.13	2.34	0.55	8.67	0.21	2.10	62.12	9.86	0.13	0.05	0.03
Total				14.18	17.42	76.95	504.00	4.29	16.25	6.01	334.52	17.65	64.28	516.23	172.43	2.52	1.68	0.43
Current nutrients				18.47	16.26	70.45	485.95	4.76	14.06	6.15	332.79	23.05	63.19	528.71	202.38	2.34	2.14	0.72
* only energy values provided as nutrient constraints.																		

Changes in the amount of different food groups and nutrient levels in each of the above scenarios are summarised in Table 7.11 and 7.12. Table 7.11 shows that amount of potatoes and bread does not change much with reductions of GHGEs from the primary school meal plate. With a 40% reduction of GHGEs the amount of potatoes increased to 81g compared to the current value of 72g. The amount of fruits and vegetables shows a steady decrease with each step of cutting down GHGEs. Dairy products such as milk, cheese and yoghurt also decreased with the reduction of GHGEs from the primary school meal plate. Change in the amount of meat is shown in Figure 7.3.

Table 7-11 Changes in the amount (g) of food groups and percentage (%) change with GHGE reduction

Food group	Current weight (g)	5% reduction		10% reduction		20% reduction		30% reduction		40% reduction	
		New weight (g)	Change (%)	New weight (g)	Change (%)	New weight (g)	Change (%)	New weight (g)	Change (%)	New weight (g)	Change (%)
Potatoes	72.4	72.16	-0.33	72.12	-0.39	72.03	-0.51	75.1	3.73	81.05	11.95
Bread	50.99	50.34	-1.27	50.24	-1.47	50.01	-1.92	54.61	7.10	63.06	23.67
Fruits	29.91	29.1	-2.71	28.98	-3.11	28.69	-4.08	26.55	-11.23	20.77	-30.56
Tomatoes	7.4	5.25	-29.05	4.92	-33.51	4.16	-43.78	0	-100.00	0	-100.00
Other vegetables	65.96	65.26	-1.06	65.15	-1.23	64.9	-1.61	61.17	-7.26	52.28	-20.74
Fruit juice	28.11	27.66	-1.60	27.59	-1.85	27.44	-2.38	24.7	-12.13	18.3	-34.90
Shrimp	0.01	0	-100.00	0	-100.00	0	-100.00	0	-100.00	0	-100.00
Other fish	5.94	5.06	-14.81	4.92	-17.17	4.61	-22.39	3.75	-36.87	0.52	-91.25
Eggs	5.78	4.35	-24.74	4.13	-28.55	3.63	-37.20	2.25	-61.07	0	-100.00
Beans	13.85	13.16	-4.98	13.06	-5.70	12.81	-7.51	9.35	-32.49	1.05	-92.42
Red meat	12.31	4.42	-64.09	3.19	-74.09	0.42	-96.59	0	-100.00	0	-100.00
White meat	18.57	16.9	-8.99	16.64	-10.39	16.05	-13.57	8.1	-56.38	0	-100.00
Meat alternatives	1.66	0.78	-53.01	0.64	-61.45	0.33	-80.12	0	-100.00	0	-100.00
Milk	54.04	53.25	-1.46	53.12	-1.70	52.85	-2.20	49.24	-8.88	40.48	-25.09
Cheese	7.08	1.87	-73.59	1.06	-85.03	0	-100.00	0	-100.00	0	-100.00
Yoghurt	9.3	8.5	-8.60	8.38	-9.89	8.1	-12.90	4.32	-53.55	0	-100.00
Butter , Oil margarine	10.65	9.5	-10.80	9.32	-12.49	8.91	-16.34	14.18	33.15	23.17	117.56
Crisps , sweets	25.31	24.58	-2.88	24.47	-3.32	24.22	-4.31	23.58	-6.84	21.06	-16.79
GHGE	0.72	0.68	-5.56	0.65	-9.72	0.58	-19.44	0.5	-30.56	0.43	-40.28

Figure 7.5 Reduction in meat content while cutting down GHGE from primary school meals

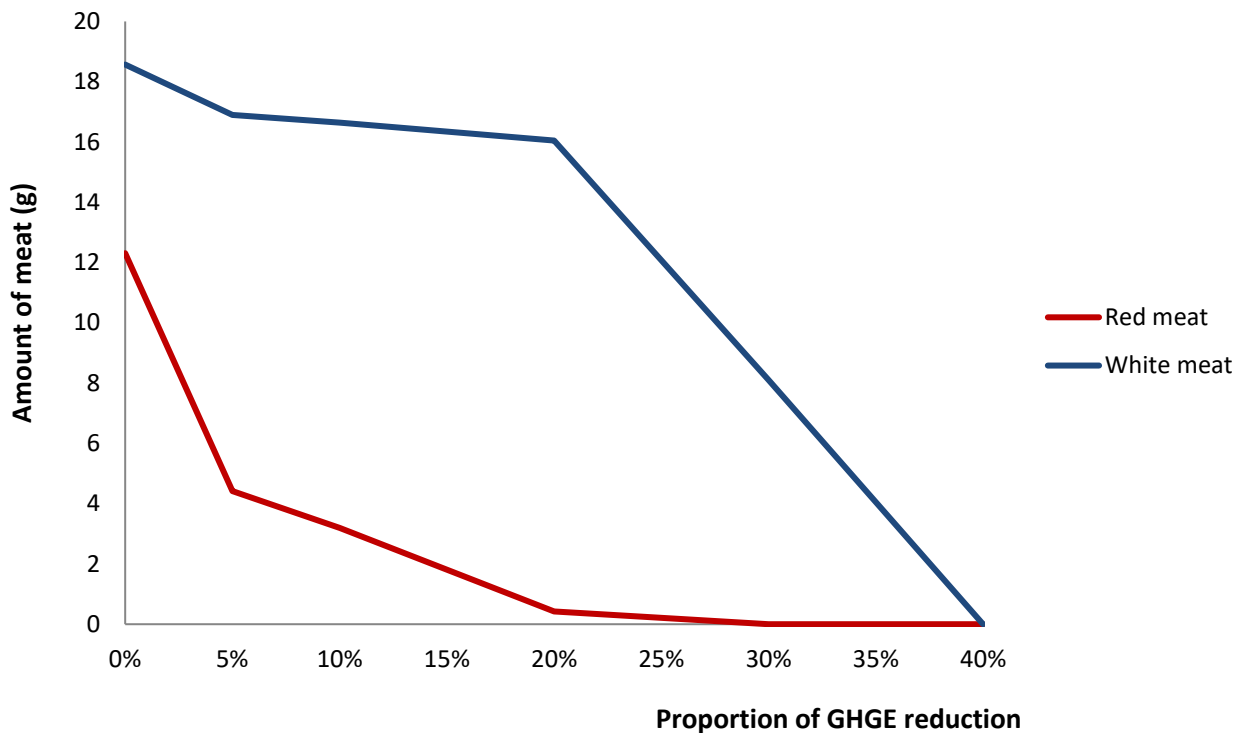


Figure 7.3 shows that if you just reduce GHGE from primary school meals, even with a small reduction like 5% we can see significant reduction in the amount of red meat. It is impossible to maintain red meat with more than a 20% reduction. But white meat only changed by about 2g with a 20% reduction of GHGE values and after that started falling rapidly. It is impossible to maintain any meat if we want to cut down GHGE more than 40% from current primary school meals.

As shown in Table 7.12 the nutrient levels have not changed significantly and it is possible to cut down 40% of GHGE with little changes to nutrient levels of current primary school meals.

Table 7-12 Change in nutrient levels in GHGE reduction scenarios

Nutrient	Current value	5% reduction	10% reduction	20% reduction	30% reduction	40% reduction
Protein (g)	18.47	19.96	19.47	18.55	16.65	14.18
Fat (g)	16.26	17.88	17.37	16.46	16.70	17.42
Carbohydrate (g)	70.45	77.34	76.72	75.36	76.06	76.95
Energy (kcal)	485.95	532.67	523.79	506.76	504.00	504.00
Fibre (g)	4.76	5.21	5.17	5.08	4.82	4.29
NMES (g)	14.06	15.88	15.72	15.38	15.81	16.25
SFA (g)	6.15	6.57	6.31	5.88	5.90	6.01
VitaminA (µg)	332.79	398.16	392.69	383.02	366.72	334.52
VitaminC (mg)	23.05	21.82	21.68	21.38	19.80	17.65
Folate (µg)	63.19	71.65	70.87	69.31	67.36	64.28
Sodium (mg)	528.71	644.71	630.37	603.71	565.51	516.23
Calcium (mg)	202.38	224.66	217.62	206.96	193.84	172.43
Iron (mg)	2.34	2.68	2.64	2.56	2.52	2.52
Zinc (mg)	2.14	2.23	2.16	2.03	1.88	1.68

Table 7.13 shows the constructed meal to achieve this GHGE reduction (40%) while achieving all the nutrient based constraints with minimal changes to the current consumption. All the nutrient based standards described in Table 7.3 were introduced to the model as constraints to maintain the healthiness of this school meal. This final meal contains:

Potatoes	85g
Bread	69g
Fruits	17g
Vegetables	46g
Milk	49g
Yogurt	10g
butter/oil/margarine	19g
crisps and sweets	11g
Fruit juice	15g

Table 7.13 and Figure 7.4 shows the distribution by weight of food groups in the current primary school meals and the new meal constructed by the linear programme model to achieve a 40% reduction in GHGE with minimal changes to the current primary school meal.

The crisps and sweets category contains most of the desserts included in primary school meals.

Table 7-13 Primary school meal created by the model with 40% reduction in GHGE, all nutritional constrains and minimal changes to current consumption

Food group	Current Wight (g)	Weight (g)	Change (%)	Protein (g)	Fat (g)	Carbohydrate (g)	Energy (kcal)	Fibre (g)	NMES (g)	SFA (g)	Vitamin A (µg)	Vitamin C (mg)	Folate (µg)	Sodium (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	GHGE (KgCO2e)
Potatoes	72.4	85.71	-0.33	3.56	2.89	18.85	112.75	1.08	0.05	0.80	7.26	6.26	20.51	50.10	15.41	0.54	0.39	0.046
Bread	50.99	69.59	-1.27	4.86	5.74	29.69	182.44	1.43	4.27	2.07	44.83	0.55	15.41	229.40	69.62	0.92	0.59	0.098
Fruits	29.91	17.61	-2.71	0.87	0.80	3.36	23.31	0.24	0.65	0.30	19.02	0.99	3.04	28.75	9.58	0.12	0.10	0.031
Tomatoes	7.4	0.00	-29.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Other vegetables	65.96	46.91	-1.06	1.64	0.98	4.49	32.35	1.03	0.14	0.27	181.16	5.48	13.30	36.69	13.80	0.34	0.20	0.072
Fruit juice	28.11	14.83	-1.60	0.09	0.03	1.22	5.15	0.01	1.20	0.02	0.62	2.04	0.96	1.05	1.26	0.03	0.00	0.014
Shrimp	0.01	0.00	-100.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Other fish	5.94	0.00	-14.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Eggs	5.78	0.00	-24.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Beans	13.85	0.00	-4.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Red meat	12.31	0.00	-64.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
White meat	18.57	0.00	-8.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Meat alternatives	1.66	0.00	-53.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Milk	54.04	49.40	-1.46	2.25	1.46	6.31	45.76	0.15	1.43	0.75	21.26	1.15	4.27	41.31	54.70	0.14	0.30	0.085
Cheese	7.08	0.00	-73.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
Yoghurt	9.3	9.94	-8.60	0.40	0.16	1.57	8.97	0.02	0.80	0.10	1.77	0.04	0.18	6.81	13.94	0.01	0.05	0.017
Butter , Oil	10.65	19.19	-10.80	0.77	4.13	9.40	75.53	0.18	5.28	1.27	29.57	0.24	4.48	70.19	9.19	0.30	0.10	0.048
Crisps , sweets	25.31	11.76	-2.88	0.33	0.67	2.78	17.74	0.07	1.31	0.31	4.84	0.12	1.17	34.70	5.51	0.07	0.03	0.019
Total				14.76	16.86	77.67	504.00	4.21	15.12	5.88	310.33	16.86	63.33	499.00	193.00	2.48	1.77	0.430

Figure 7.6 Current primary school meal and modelled new primary school meal plates with eatwell plate food groups

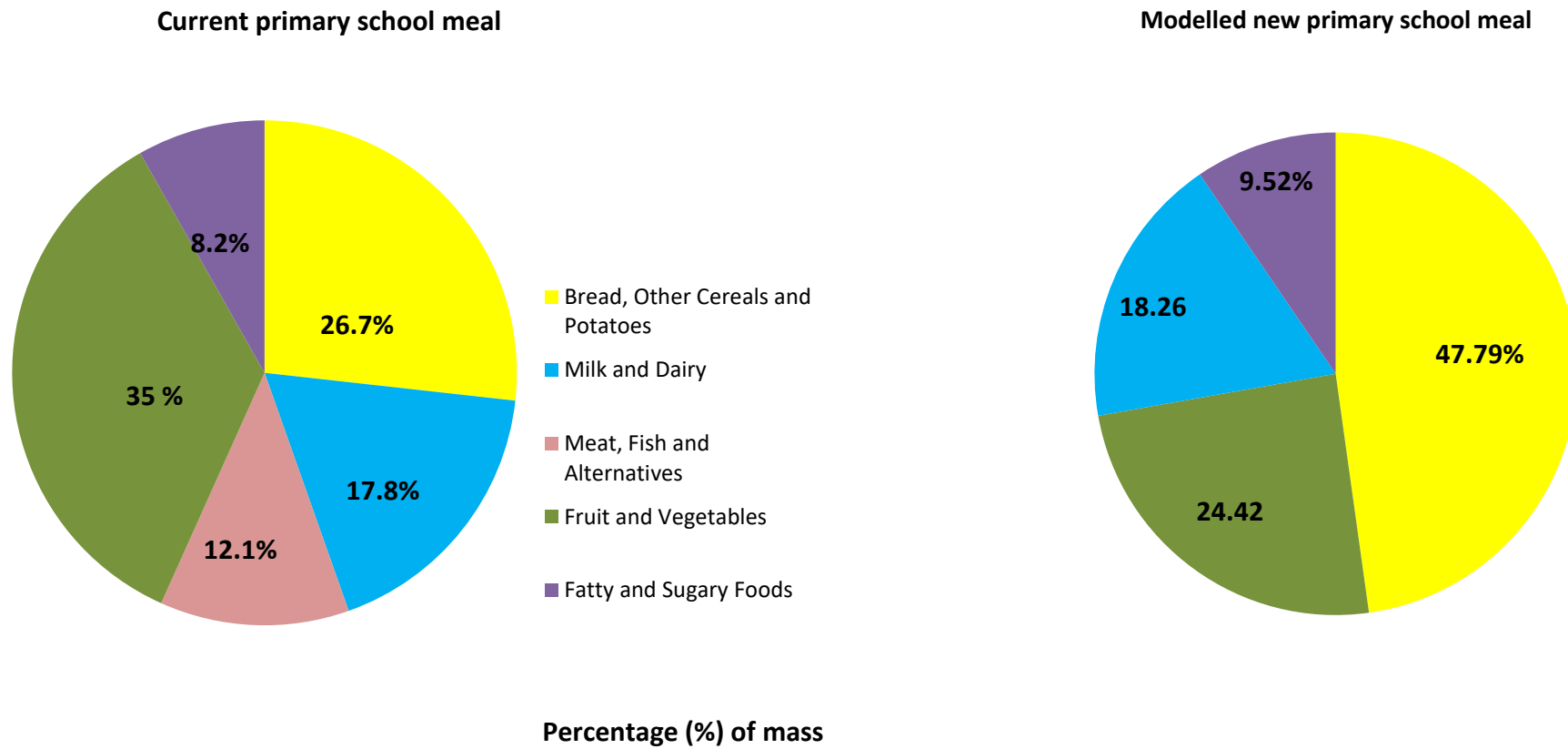


Table 7-14 Primary school meal created by the model with 40% reduction in GHGE, all nutritional constrains and (relative) minimal changes to current consumption*

Food group	Current Wight(g)	Weight (g)	Change (%)	Protein (g)	Fat (g)	Carbohydrate (g)	Energy (kcal)	Fibre (g)	NMES (g)	SFA (g)	Vitamin A (µg)	Vitamin C (mg)	Folate (µg)	Sodium (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	GHGE (KgCO2e)
Potatoes	72.4	55.39	-0.33	2.30	1.87	12.18	72.87	0.70	0.03	0.52	4.69	4.05	13.26	32.38	9.96	0.35	0.25	0.029
Bread	50.99	28.55	-1.27	2.00	2.36	12.18	74.85	0.59	1.75	0.85	18.39	0.23	6.32	94.11	28.56	0.38	0.24	0.040
Fruits	29.91	20.29	-2.71	1.00	0.92	3.87	26.86	0.27	0.75	0.34	21.92	1.14	3.51	33.13	11.04	0.14	0.11	0.036
Tomatoes	7.4	5.84	-29.05	0.06	0.04	0.30	1.75	0.06	0.00	0.01	5.55	0.87	1.17	1.65	0.71	0.03	0.01	0.027
Other vegetables	65.96	25.31	-1.06	0.88	0.53	2.42	17.45	0.56	0.08	0.14	97.74	2.95	7.17	19.79	7.45	0.18	0.11	0.039
Fruit juice	28.11	23.42	-1.60	0.14	0.05	1.93	8.13	0.01	1.89	0.03	0.98	3.22	1.52	1.66	1.99	0.04	0.00	0.023
Shrimp	0.01	0.01	-100.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.000
Other fish	5.94	5.53	-14.81	0.60	0.35	1.16	10.03	0.08	0.02	0.10	1.61	0.08	0.96	16.53	2.31	0.06	0.04	0.011
Eggs	5.78	5.15	-24.74	0.28	0.63	2.21	15.08	0.06	1.18	0.21	6.31	0.13	0.52	14.77	3.29	0.05	0.03	0.016
Beans	13.85	12.10	-4.98	0.53	0.04	1.68	8.73	0.58	0.52	0.01	0.04	0.00	2.66	30.13	6.45	0.00	0.06	0.018
Red meat	12.31	0.00	-64.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000
White meat	18.57	10.91	-8.99	2.08	0.91	1.02	20.38	0.09	0.05	0.31	2.51	0.23	1.12	56.79	6.44	0.11	0.15	0.040
Meat alternatives	1.66	1.63	-53.01	0.16	0.09	0.24	2.40	0.04	0.01	0.03	1.19	0.06	0.53	7.21	1.41	0.03	0.03	0.003
Milk	54.04	23.29	-1.46	1.06	0.69	2.97	21.57	0.07	0.67	0.35	10.02	0.54	2.01	19.48	25.79	0.07	0.14	0.040
Cheese	7.08	3.61	-73.59	0.80	1.10	0.09	13.45	0.00	0.02	0.69	12.11	0.01	0.97	25.66	23.87	0.01	0.13	0.041
Yoghurt	9.3	8.38	-8.60	0.34	0.13	1.33	7.57	0.02	0.67	0.08	1.49	0.03	0.15	5.74	11.76	0.01	0.04	0.015
Butter , Oil	10.65	8.91	-10.80	0.36	1.92	4.37	35.09	0.08	2.45	0.59	13.74	0.11	2.08	32.61	4.27	0.14	0.05	0.022
Crisps , sweets	25.31	19.12	-2.88	0.53	1.09	4.52	28.84	0.12	2.13	0.50	7.87	0.19	1.91	56.40	8.95	0.12	0.05	0.030
Total				13.13	12.71	52.47	365.05	3.32	12.22	4.77	206.17	13.85	45.87	448.06	154.24	1.71	1.45	0.430

*only GHGE values provided as a constraint

As described in the methods section, another option in linear programming model is to use relative change in amount of food (not absolute change) when you optimise to construct a meal similar to current primary school meal plates. Table 7.14 shows an example of an output which used the relative change and constructed a meal with minimal changes to current meal to achieve 40% reduction in GHGE values. It shows that there are no significant changes based on this method (compared to Table 7.13) and still the red meat was removed completely and white meat was reduced in this scenario.

7.5 Discussion

7.5.1 Main findings

The meal which was optimised for GHGEs has a mean of 0.39 KgCO₂e compared to the current level of 0.72 KgCO₂e. This is a 46% reduction in GHGEs while meeting all nutrient based standards. This value represents the absolute minimum GHGE level, whilst achieving nutritional recommendations. This therefore sets a plausible benchmark that could not be lowered without a) compromising on nutrition, or b) changing the types of foods that are available for consumption (and hence changing the mean nutrient levels in table 7.2). Once food based standards were introduced the minimum GHGE value was 0.64 KgCO₂e for vegetarian meals and for meal with meat, no reduction in GHGEs was possible. Tables 7.6 to 7.10 show the amount of meat reduction with each step of reducing GHGE from current school meals. These results show that it is possible to make meals healthier and sustainable, but the modelled meals were very different from current patterns of consumption. The analysis which minimised differences to current meals shows that main changes involved in reducing GHGE is reduction of meat content. But all nutritional standards were achieved while making primary school meals more sustainable.

7.5.2 Implication of findings

The methods used in this chapter could be applied to develop healthy and sustainable meals with any specific nutritional requirements or to any specific population groups. The promotion of healthy diets and promotion of sustainable diets has mostly taken standalone approaches; this technique shows the co-benefits and how to align these two tasks.

The final nutritional quality of the meal is estimated, and these results can be used to link with other existing models, such as the PRIME model (Scarborough, Harrington et al. 2014) to predict the long term population level health impacts of this new diet. The changes in GHGE can be used to assess the changes on environmental impact. Therefore these methods could be used to quantify the health and environmental impacts of a diet, outlined in a new policy.

The need for a rational approach where all sectors could contribute to the reduction in GHGEs is highlighted in the literature (Mikkola 2009, Wahlen, Heiskanen et al. 2012). Results from this chapter show one approach on how to create a more evidence-based discussion to get the involvement of different partners, including the catering industry to develop these meals.

7.5.3 Comparison with current literature

The Livewell report used a similar modelling approach to create a sustainable and a healthy plate for the UK population. This report presented a 2020 plate with 25% of GHGE reduction

and 2050 plate with a 70% reduction of GHGE (Macdiarmid, Kyle et al. 2011). It was possible to create a meal which met dietary recommendations and those GHGE reduction targets. The key message was to rebalance the diet and reduce meat based proteins to achieve these targets. This reports showed that it is not necessary to eliminate meat in a diet to meet nutrition and GHGE targets. In this chapter results Figure 7.3 shows that it is possible to reduce GHGE and maintain some meat in primary school meals, but beyond a 20% reduction in GHGE all meat consumption would need to reduce substantially.

The Livewell report also shows this is a starting point for creating sustainable and healthy diets. More work is needed to carefully improve this basic plate, to make it more acceptable and meet cultural, religious and individual dietary needs and preferences. The Livewell for Life report shows that it is possible to adopt this principal to other countries in Europe (Thompson, Gower et al. 2011). All these diets showed a reduction in red meat consumption, to achieve set targets. It is inevitable as red meat contains high GHGEs.

This chapter is the only analysis, which attempted to create a sustainable healthy meal for primary school meals using linear programming technique. My methods took a similar approach to the methods used in the Livewell report published by the WWF-UK.

7.5.4 Strengths and limitations

In order to estimate the GHGE reduction in food sector to achieve GHGE targets by 2015, we need to consider population growth. But this analysis is not adjusted for population growth. Population level food intake is based on dietary energy needs per person and if it is adjusted with the expected population growth actual overall savings would be less than estimated.

The main food groups included in the analysis were derived from the atwell plate. Food groups that showed significant changes in the systematic review of GHGE were sub-divided. For example shrimps and prawns had a significantly higher value compared to other fish groups. And Red meat had a significant higher value compared to other food items in the category. Food groups could be further sub-divided to provide more details. Fruits and vegetables could be listed separately to consider the seasonality or the region in the UK when creating menus.

Economic cost is not included in the model. When implementing policies or changing individual level behaviour, the cost is likely to play a major role (Carrillo, Varela et al. 2010)). But WWF reports shows the cost of the sustainable plates is not necessarily an expensive option (Macdiarmid, Kyle et al. 2011).

In the analysis, some food-based standards cannot be applied to the dataset. For example one of the standards say bread with no added fat or oil must be available every day. For children who consumed a meal which didn't require bread, this would not be applicable. Another standard says at least three different fruits and three different vegetables each

week. The dataset only includes one day per student. Therefore even when different fruits were available on the menu, it is not possible to identify whether each student consumed them over the week. This analysis applies standards to food consumed by children, rather than for available food items on the menu.

This analysis assumes that the nutritional quality of foods within each of the 20 food groups will remain constant. This is not necessarily the case, as the types of potatoes that are served could be altered (for example). This could have a big impact on the nutritional quality of the diets that are produced, and to the GHGE of the modelled meals.

7.6 Conclusion

A healthy meal can be more environmentally sustainable. It is possible to quantify both nutritional data and GHGE data to come up with sustainable healthy meals. It is possible to achieve more than 40% reduction in GHGEs compared to current primary school meals while achieving nutritional standards. This work provides the first step to build sustainable and healthy primary school meals using a linear programming technique.

8 Discussion

This chapter provides an overall summary of results and a comparison with current literature. It also discusses how these findings could inform future dialogues around promoting sustainable healthy diets. This chapter also includes strengths and weaknesses of this study and final conclusions.

8.1 Summary of findings

This study conducted a systematic review to compile estimates of GHGE for different food groups in a commonly used food frequency questionnaire (FFQ). Total GHGE was recorded in global warming potential (GWP) in KgCO₂e. From the food groups included in the review, beef (28.00) and lamb (15.52) had the highest values per Kg of food and, bread (0.56), fruits (0.53) and potatoes (0.21) were among the lowest values. This shows that there are substantial differences in GHGE values between food groups.

Estimates of GHGE within a food group also differ substantially depending on the system boundary considered by authors, farming methods and location of production. Estimates of the GHG emissions associated with 1Kg of beef ranges from 8.1- 150 of KgCO₂e. Organic production methods do not always give lower GHG emission values and for products such as pork, chicken, eggs, potatoes and tomatoes it was higher than for conventional methods. These results show that production systems should be considered when comparing GHGE values of a food item.

Some of these differences of GHGE could be attributed to the different system boundaries considered by authors in estimating the GHGE of a food item. Current data are inadequate to quantify the relative contributions of system boundary, production method and production location to explain these differences in final estimates of a food group.

The findings of this systematic review were used to estimate the GHGE of different primary school meals in England. The GHGE values of individual school meals had a wide range, 0.04 to 5.59 KgCO_{2e} for school lunches (IQR 0.40 – 0.80) and from 0.34 to 10.99 KgCO_{2e} for packed lunches (IQR 0.46 – 0.86) . Results show that the meat, fish, eggs, beans and other non-dairy protein source category of primary school meals is responsible for only 12% of the weight but associated with over 40% of GHGE. The fruit and vegetables category showed the highest contribution to the weight (35%), but is associated with only 23% of GHGEs.

The mean GHGE value per school lunch was estimated at 0.72 and per packed lunch was estimated as 0.70 KgCO_{2e}. Total GHGE from primary school meals (school lunches and packed lunches combined) is 578 million (95% confidence interval: 455 – 892) KgCO_{2e} per year.

The mean GHGE values of healthy vs unhealthy school meals were compared using two different criteria to define “healthy” . Use of any seven out of all 14 common nutrients to define healthy meals provided a different answer to the analysis which used only salt, sugar and saturated fat to define healthy meals with regard to whether healthy meals have lower GHGE values. The results suggest that achieving sustainable school lunches and packed

lunches may reduce salt, saturated fat and sugar but could compromise micronutrient levels. However, due to large uncertainty around the GHGE parameters for food groups in the current literature, the difference between healthy and unhealthy school meals are within the uncertainty intervals, so the results must be treated with caution.

Two different scenarios related to healthy and sustainable school meals were then analysed. The first scenario was aimed at understanding the changes in nutritional quality and GHGE of school meals if the new School Food Plan (SFP) standards were introduced. The proportion of meals meeting the protein standard will increase slightly in the SFP scenario. However, the SFP scenario showed a decline in the proportion of meals achieving fat, saturated fat, sugar and sodium indicating that foods that meet the new SFP standards are less likely to meet these nutrient-based criteria. When salt, saturated fat and sugar were used to define a “healthy meal” almost 32% of current school meals were classified as “healthy”. Out of the meals which met SFP criteria only 23% of meals met these three standards. The mean GHGE value of meals which meets the SFP criteria is 0.81 (0.78 – 0.83) KgCO₂e compared to 0.72 (0.70 – 0.73) KgCO₂e for current school meals. If we assume the total number of primary school children taking the school lunches would remain the same, shifting from current school meals to a SFP scenario would increase the total emissions by 27,989,844 KgCO₂e, which is 12.5% higher than current primary school meal emissions.

The second scenario examined what environmental and nutrition changes we can expect if we change the current primary school meal menus to introduce Meat Free Mondays (MFM).

Using the same cut-off value of achieving 7 or more standards (out of 14) to define healthy meals, I found the following. In current school meals around 65% of primary school meals are “healthy” and the in the MFM scenario this percentage will increase. However, the proportion of meals achieving sugar, salt and saturated fat standards would reduce from the current value of 32% to 15% in the MFM scenario. The mean GHGE of a school lunch in the MFM scenario is 0.68 (0.66 – 0.69) compared to the current value of 0.72 (0.70 – 0.73) KgCO₂e. If we assume the uptake of primary school meals would remain the same, this new policy will save around 12,439,931 KgCO₂e per year.

This study also developed a linear programming model to construct meals which meet nutritional requirements while minimising the GHGE value. It showed that the minimum GHGE value of a primary school meal which achieves all 14 nutrient based standards would be 0.39 KgCO₂e. Further reduction in GHGE values would have to compromise with the reduction in nutritional quality of meals. The meal constructed by the model which achieves all the School Food Plan food based standards could not reduce the GHGE to lower than current values. Further analysis, where deviations from current school meal provision are minimised, showed that if you just reduce GHGE from primary school meals, even with a small reduction such as 5% we can expect significant reductions in the amount of red meat consumed. Reduction of GHGE by 20% results in red meat consumption being removed from the meal. But white meat only changed by about 2g with a 20% reduction of GHGE values, but with further reductions fell rapidly. It is implausible to maintain any meat if we want to cut down GHGE more than 40% from current primary school meals.

8.2 Implication of findings

This study shows how to use GHGE data for individual food products to estimate the total GHGE of a meal and then total emissions of a specific sector (in this example the primary school meal sector). The method of calculation is straightforward, but the accuracy of the estimates depends on the original estimates of life cycle analysis (LCA). The systematic review shows that there is no uniform method to report LCA and comparable system boundaries for food items would increase the precision of GHGE estimates of meals. Also the systematic review shows that locally produced food or organic food does not always have the lowest GHGE values and overarching statements should be made with caution when we promote local or organic food to improve the sustainability of meals.

The analysis in this thesis shows that if all primary school children adopt a meal similar to the current healthy school lunch (based on salt, fat and sugar), we could reduce GHGEs by around 137 million KgCO₂e per year. It shows that without adopting extreme meals, currently available dietary patterns can make meals healthier and sustainable. Improving sustainability of meals provides an opportunity to change current dietary patterns and improve the nutritional quality of meals. Although the difference in GHGE per school meal between more and less healthy meals is only 0.2 KgCO₂e, it contributes to a large decrease in the amount of overall emissions due to the size of the primary school food sector (however, caution is needed as this small difference was within the large uncertainty intervals that were mainly generated from uncertainty in GHGE parameters derived from the systematic review). Similarly as everyone consumes food every day, reducing GHGE

associated with meals has the potential of saving a large proportion of emissions. Climate change action plans should prioritise tackling the food sector to make it more sustainable.

This study also showed how to estimate the uncertainty around GHGE values of meals. The GHGEs associated with a food item have different values in different studies due to factors such as production systems and locations. Therefore single point estimates for the GHGE of a meal are unrepresentative of the uncertainty reported in the literature. This study demonstrated a method to address the uncertainty and provide estimates accordingly.

Vieux et al estimated 95% confidence intervals around GHGE values of diets using the mean and standard deviation of the sample. More specifically, this estimate was based on a GHGE values assigned to 391 foods using LCAs as recommended by the International Organisation for Standardisation. The mean diet-related GHGE values were based on these single estimates of food items (Vieux, Soler et al. 2013). One of the limitations of this approach is that it does not account for the fact that LCA studies conducted as recommended by the International Organisation for Standardisation have been shown to provide different values for the same items produced in the same country, a point that was discussed in my systematic review chapter. My approach varies from the methods of Vieux et al in that I used original estimates from the literature to create 1000 different datasets to estimate the uncertainty of GHGE values per school meal, which allowed me to account for the uncertainty of GHGE values reported in the literature.

A similar issue could be raised regarding the nutritional data of food items. E.g. the salt content of bread is recorded as a point estimate from a food composition database, and this point estimate is applied to all bread consumption within the PSFS. However, there are

different varieties of bread available with different amounts of salt (Brinsden, He et al. 2013). If we could record the different salt values estimated by different studies, uncertainty analysis could be conducted for salt values in bread in a similar method as that used here for GHGE. This could be applied to any other nutritional variables in future nutritional research to provide more meaningful results. Most studies using food composition tables do not take account of the variability in the reported values from chemical analysis of foods, but a few do (Friedman 1996, Dangour, Dodhia et al. 2009) . This practice of not considering the variability implies that differences in the nutritional quality of the diet between different subgroups of the population may have been exaggerated.

The new School Food Plan and its food based standards for primary school meals would increase the GHGE associated with primary school meals if implemented in their entirety. The inadequacy of measures to improve the sustainability of school meals have been highlighted by various groups before (Wickramasinghe 2013, CFC 2014). These findings would support for such calls to improve the sustainability of school meals, for example by introducing an upper limit for food groups such as red meat.

Meat Free Mondays (MFMs) is promoted as a policy option to improve the sustainability and healthiness of meals by reducing the meat in school (and other) meals (MFM 2014). This analysis shows that MFMs help to reduce GHGE of school meals and improves a series of nutrient based standards. But it does not reduce the saturated fat, salt and sugar level if we just replace Monday meat containing meals with non-meat food items that are currently

served as vegetarian options in primary schools. This policy should be accompanied with more specific guidance and alternative menus to ensure improved nutritional outcomes.

This study also showed how to use linear programming to construct primary school meals with minimal GHGEs while achieving nutritional constraints. This could be applied to construct healthy and sustainable meals for any other sector or population group. The step by step reduction of GHGE from school meals shows at which point the drastic reduction of meat starts when you make meals more sustainable. This information could be used in policy development as it shows that even small reduction of 5% of GHGE results in about two thirds of reduction in red meat in meals. White meat could be included in meals in minimal changes to current levels and achieve 20% reduction in GHGE of meals. Any committees developing new guidelines and recommendations can use this information to improve the nutritional quality and sustainability of meals.

Scientific evidence will help to call for stronger measures to make school meals more sustainable. Wahelen et al showed that policy makers, catering professionals and consumers are three main actors to promote sustainable public catering (Wahlen, Heiskanen et al. 2012). Mikkola (2009) showed the need for future orientation for more informed evidence-based policies regarding promotion of sustainability aspects along the food supply chains in Finnish public catering. The paper shows the different responses from the catering industry and how the situation grew more dissonant, as improving sustainability was politically attractive but didn't have allocated funding or follow up mechanisms. Also the paper shows that local catering suppliers showed less interest in co-operation with these attempts to improve the sustainability of public food supply chains

(Mikkola 2009). Findings, similar to results of this study could be used to get these different stakeholders to understand the issues and to bring them together to discuss practical solutions to improve the sustainability and healthiness of meals.

In comparison to other food groups, it is clear that the environmental impact of beef and lamb is very high. But nutritionists and most government health departments globally have not advised their populations to reduce red meat consumption. There are several reasons for not reaching consensus among policymakers about reducing red meat consumption. In developed countries it is clear that reduction of red meat consumption would provide health benefits (Friel, Dangour et al. 2009). There are several studies which examined the association between meat consumption and different health outcomes. A meta-analysis by Larsson and Orsini shows a dose-response relationship between meat consumption and all-cause mortality (Larsson and Orsini 2014). Consumption of processed meat is associated with higher incidence of coronary heart diseases and diabetes mellitus (Micha, Wallace et al. 2010). Pan et al also showed that an increase in red meat intake of more than 0.50 servings per day is associated with an elevated risk of developing diabetes in the subsequent 4-year period (Pan, Sun et al. 2013). Reducing dietary meat shows clear health benefits at population level in developed countries and public health experts and charities call for policies to reduce red meat consumption (Astrup, Dyerberg et al. 2011).

In low and middle income countries (LMICs), hunger and undernourishment give rise to a major health burden and different programmes have been implemented to address them, in accordance with the first millennium development goals to “reduce extreme poverty and

hunger". These programmes have promoted livestock production as a livelihood and as an intervention to promote nutrition (Fanzo, Remans et al. 2011). Red meat is promoted as a protein source and also as a food item which could reduce the overall disease burden (McNeill and Van Elswyk 2012). In LMICs maternal and child health programmes make a great effort to reduce the proportion of underweight children. Primary healthcare workers have traditionally taken the role of educating mothers on how to provide energy-dense meals. Adding butter, fish and meat is commonly promoted in these settings to increase the energy intake of children (UN 2009). In these LMICs public health experts do not promote the message of reducing red meat as it may confuse the public and have a negative impact on their efforts to reduce the proportion of under-weight children. Therefore red meat is considered as a very useful food item in these countries and policies are often aimed at increasing the availability and access. There has been a steady increase in the consumption of red meat in developing countries (WHO 2014).

In addition to these health and environmental impacts, changes in red meat consumption will have impact on broader global issues such as rural development and poverty elevation. According to the Food and Agriculture Organization of the United Nations, about 1.3 billion people live on less than US\$ 1 a day. About 50%-70% of these extreme poor people depend on agriculture as part of their livelihood and livestock has been an important contributor to sustainable rural development (FAO 2014).

One of the policies adopted in these developing countries is providing livestock through rural development programmes under micro-finance plans or as donations. It is expected that income of these families and communities would improve while increasing food

availability and access. The World Bank implement large development programmes to utilise livestock as a pathway out of poverty (World Bank 2013). Any advice on reducing red meat consumption may have an impact on these rural communities, as their livelihood is mainly dependent on livestock management. These issues show complexities around forming a universal message about red meat consumption.

A study conducted in the Netherlands compared factors influencing sustainable and healthy dietary choices among native and migrant citizens. It shows that there are significant differences in dietary patterns due to religious and cultural reasons. It argued that cultural backgrounds should be given a central attention if we try to promote healthier and sustainable food choices in multi-ethnic communities (Schösler 2014). These are important lessons for the UK which has a diverse community with immigrants from different parts of the world.

8.3 Comparison with current literature

Most UK-based studies of the GHGE impact of diets and dietary scenarios obtain GHGE values of different food groups from the *How low can we go* report by the WWF-UK (Audsley, Brander et al. 2009, Briggs, Kehlbacher et al. 2013, Scarborough, Appleby et al. 2014). The GHGE values used in this report were not identified from a systematic review. The findings from my systematic review are consistent with those of the above report and most of the previously published reports and studies which claimed livestock products such as beef and lamb have a higher GHG emission per unit of production compared to fruits and vegetables and other crops (Basset-Mens and van der Werf 2005, Casey and Holden 2006, Williams, Audsley et al. 2006, Garnett 2008). Table 8.1 shows the GHGE value per Kg of

selected food groups from the systematic review and comparison with values from other (non-systematic) reviews of GHGE from different food groups. Most of the mean values in my systematic review are closer to values found in other reviews and reports. My GHGE value for beef is higher than the other studies. My analysis includes a paper which considered emissions from the loss of rainforests and this study reported a value around 5 times higher than other studies.

GHGE is not the only indicator of environmental sustainability, but as described in the introduction and the systematic review it is the most commonly reported measure. Garnett and Godfray say sustainability needs to be viewed over space and time in order to include the indirect effects and consequences of different policies that may impact on different regions and future generations (Garnett and Godfray 2012). They concluded that more work is needed to translate this thinking into the development of metrics that are relevant to different stakeholders in different contexts, to assist them in implementing appropriate strategies.

Table 8-1 Comparison of systematic review GHGE estimates with other literature

Food group	Mean(min-max) GHGE value per Kg. from the systematic review	Other values from selected (non-systematic) reviews
Beef	28 (8.1 – 156)	23.97 (Williams 2008) 19.6 (Casey 2006) 12.14 (WWF 2008)
Lamb	15.52 (0.66 – 56.7)	17.5 (Williams 2006) 18.8 (Biswas 2010)
Chicken	3.10 (0.80 – 6.68)	2.84 (WWF 2008) 4.57 (Williams 2006) 5.56 (Biswas 2010)

Pork	4.93 (3.54 – 8.26)	3.45 (Basset-Mens 2005) 4.87 ((Philippe and Nicks 2014)
Potatoes	0.21 (0.13 – 0.48)	0.26 (WWF 2008)
Milk	1.14 (0.54 -2.92)	1.19 (WWF 2008) 1.5 (Casey 2005)
Tomatoes	5.00 (0.22 – 17.80)	3.79 (WWF 2008) 9.4 (Williams 2006)
Onions	0.14 (0.042 -0.2)	0.37 (WWF 2008) 0.21 (Maraseni 2010)
Apple	0.29 (0.06-0.87)	0.32 (WWF 2008) 0.35(Williams 2008)

A study conducted by Saxe et al showed that GHGE of meals could be reduced by 27% compared to current average Danish meal by mainly reducing beef and substituting meat with legumes, dairy products and eggs (Saxe, Larsen et al. 2013). This study considered emissions from transport of food. It concluded that, especially for animal products transportation is less important as GHGE due to transportation is much smaller than the GHGE from production. My review also showed that sea transport would not change the final GHGE values by more than 0.01 KgCO₂e per Kg of any product and did not include it the analysis. This study showed that adoption of a diet based on nutritional recommendations would reduce the GHGE than current diets. Therefore both my results and this study show that there are opportunities to improve the nutritional quality of current diets while reducing the GHGE. This study also showed that reduction of red meat is an essential first step to reduce GHGE of meals. If the population adopt a diet with less red meat it will result in positive achievements for public health, mainly by reducing the morbidity and mortality related to non-communicable diseases (NCDs) (Scarborough, Allender et al. 2012).

The WWF- Livewell report estimated that the GHGE of UK adult diet per day is 3.99 KgCO₂e. My results show that GHGE of a primary school lunch is around 0.7 KgCO₂e. My GHGE value is for one meal (around a third of daily intake) and the energy requirement per primary school meal is only around 500Kcal. Compared to the Livewell report, my GHGE value per meal could be an underestimate. The GHGE values in the Livewell report are up to the regional distribution centre (RDC), in the life cycle analysis. Since these estimates came from a single source, they could be more comparable than those used in this thesis, as they have been calculated with the same system boundary. The authors corrected the estimate for 25% under-reporting of intake in the National Diet and Nutrition Survey, and to estimate the total GHGE per day, 44% of total value of GHGE was added as post RDC value to calculate the final figure of 6.05 KgCO₂e. Estimates in the systematic review used in my study come from different sources and stages were not comparable. Therefore we did not add any values to final estimates of GHGE and all the calculations are based on the original GHGE values reported in individual studies.

For the Livewell report composite dishes such as lasagne or shepherd's pie were included within the meat group. This would overestimate the amount of meat and underestimate other food groups such as vegetables and potatoes. But in my dataset, the composite dishes were disaggregated using a recipe and each ingredient was included in the correct eatwell plate food group.

The Livewell report and this study used linear programming and nutrient requirements were taken from respective dietary reference values to use as constraints. In the Livewell report as a precaution minimum intake of protein (53g/day) was used as a constraint. In my model in some scenarios, where nutrients were not provided as constraints, only energy value was provided to construct meaningful meals for primary school children. The Livewell model provided this series of food and nutrient constraints based on dietary guidelines and the final model was setup so that the diet also had to try and meet the eatwell plate proportions. In addition to that they included some food items (by imposing lower and /or upper limits) in the model as an indicator of acceptability. In my model the final model was setup so that the meal had to try and meet current primary school meal proportions for different food groups. My model tried to construct a meal that met the constraints and is closest to currently consumed plate. In both analyses some attempt has taken to make the modelled meals acceptable to the population.

The 2020 diet modelled in the Livewell project was able to achieve 25% reduction in GHGE and that plate included following proportions for each eat well plate category. (These results are without introducing any minimum weights for any of the eatwell food groups).

Table 8-2 Proportion of eatwell food groups in Livewell 2020 diet and school meal plate in this project

Eatwell plate food group		Eatwell plate proportions	
		Livewell 2020 diet (25% reduction in GHGE)	My results (20% reduction in GHGE)
1	Bread, rice, potatoes, pasta and other starchy foods	43%	35%
2	Fruits and vegetables	48%	28%
3	Meat, fish, eggs, beans and other non-dairy sources of protein	5%	10 %
4	Milk and dairy foods	0%	17%
5	Foods and drinks high in fat and /or sugar	4%	9%

Even with a 25% reduction in the 2020 Livewell diet the meat , fish , eggs, beans and other non-dairy sources of protein category contained only 5% of the mass. This is similar to my results and when I aimed for 20% reduction, proportion of weight from this group started to fall. In my analysis, 20% reduction in GHGE from consumption is comparable to the 2050 diet modelled in the Livewell report. Both eatwell food groups; Bread, rice, potatoes, pasta and other starchy foods group and the fruits and vegetables group are known to consist of food items with low GHGE values. In the Livewell 2020 diet these two groups accounted for 91% of the plate and in my results these two groups accounted for 63% of the plate. My plate consisted only 28% of the fruits and vegetables, compared to 48% in the Livewell 2020 diet. The eatwell plate recommends this should be around 33% of the plate.

Both these analyses show that to achieve this level of GHGE reduction, a significant shift is required from current diets. Both analysis showed it is possible to keep some meat (white

meat) and reduced amount of dairy products while reducing GHGE by 20- 25% compared to current meals (Macdiarmid, Kyle et al. 2011).

A similar approach was identified in an Australian case study, which shows how to change the current typical shopping basket to a more healthy and sustainable one. One of the key changes was to reduce the GHGE associated with animal proteins by replacing red meat with less GHGE intensive meat (chicken and kangaroo) and increasing plant derived items (Friel, Barosh et al. 2014). As show in my results an essential step in improving the sustainability is reducing the GHGE associated with red meat.

This study did not include the economic cost of food and it did not compare the price of healthy and sustainable school meals with the cost of the average observed meal. Literature shows that improving the nutritional quality of meals could increase the cost. In January 2012, the U.S Department of Agriculture implemented new regulations to improve the healthiness of school meals. It estimated that implementation of these new standards would increase the cost by around 8% (CSPI 2013) . In the UK also more healthy foods have been consistently more expensive than less healthy items and recent analysis of trends from 2002 shows that the gap is likely to grow in the future (Jones, Conklin et al. 2014). There are few studies which compared the price of healthy and sustainable diets. Barosh et al showed that the cost of a healthy and sustainable food basket would increase the cost in Australia (Barosh, Friel et al. 2014). Macdiarmid et al showed that the healthy and sustainable diet they created with modelling would not cost more than an average UK diet. This could be partly due to a drastic reduction in red meat and an increase in fruits and vegetables in the

modelled diet (Macdiarmid, Kyle et al. 2012). Wilson et al quantified the health outcomes, cost and GHGE of several dietary patterns. They found that some simplified Mediterranean-style and simplified Asian-style diets could provide health benefits while reducing cost and the GHGE, but further optimisation of GHGE increased the cost. (Wilson, Nghiem et al. 2013). Monsivais et al showed that greater accordance with the Dietary Approaches to Stop Hypertension (DASH) diet (a proven way to prevent and control hypertension and other chronic disease) is associated with lower GHGEs and higher dietary costs (Monsivais, Scarborough et al. 2015). Therefore improving the nutritional quality and sustainability of school meals could increase the overall cost of meals. The evidence linking sustainability, nutrition and economic cost of school meals is still emerging and further research to look at these issues in school meals in the UK could improve our understanding.

8.4 Strengths and limitations

This project uses GHGE values from a systematic review. Integration of GHGE values with nutritional data is a relatively new concept and one common query is how robust are GHGE data? There are different sources with GHGE data and some are created by academics and some are created by the food industry. Previous reviews of GHGE of different food groups have not been conducted systematically and this issue is a main concern for researchers working in this new discipline. This thesis includes the first systematic review of GHGE from different food groups, which should alleviate concerns about biases introduced by selectively choosing GHGE parameters for sustainability analyses.

To integrate environmental sustainability with nutrition research and policy discussions we need to demonstrate how we could use environmental sustainability data alongside routine nutritional data. This project uses a nutrition survey database (primary school meal database) and demonstrates how to estimate GHGE data for each food item in the database and how to estimate the GHGE per plate. Additionally, it introduces a novel approach to incorporating uncertainty around GHGE parameters with the uncertainty associated with sampling error from nutrition surveys. This is an important addition to the literature, and shows how ignoring uncertainty around GHGE results in a substantial under-estimation of the uncertainty in food sustainability analyses. The developed method could also be applied to standard nutrition research in order to capture uncertainty around nutrient levels in foods.

In this thesis, I have disaggregated composite foods into their constituent food groups, in order to include composite foods within estimates of the impact of different elements of the food system to GHG emissions. This also allowed me to include composite foods in the linear programming analyses reported in chapter 7. This is important as 31% of school food items and 58% of packed lunch items in primary school lunches are composite.

Conclusions regarding the sustainability of “healthy” vs “unhealthy” meals depend on the definition of such terms. This analysis shows the issues arising as a result of different definitions and why researchers should not rely on a single definition and importance of taking precautions when they generalise findings. This is a limitation of the study. Most of the previous studies and reports have tried to define healthiness of individual food items,

rather than meals (Lobstein and Davies 2009). Various approaches have been used to define healthy school lunches including: nutrient assessment of menus, list of recommended foods and checklists provided for caterers (Rayner, Scarborough et al. 2004). In this analysis, the conclusion is sensitive to the definition I used to define “healthy primary school meals”. The first definition used in this analysis is based on the primary school nutrient standards, used in the Primary School Food Survey report. The definition which includes all 14 items considers both negative (sugar, salt, saturated fat) and positive (Vit A, fibre etc.) nutrients. The second definition considers only negative (harmful) nutrients in the meal. These are two main approaches in defining “healthy” meals. This is a common limitation and I have attempted to address this issue by using more than one definition.

This study only provides GHGE values to show the environmental impact and policy makers may want to get an overall idea with other metrics such as land use and water use etc.

Changes in food consumption will have impacts on areas other than health and environment. Food and agriculture industry provides livelihood for many people in the UK and globally (Marsden 2010, Dethier and Effenberger 2011). It has direct impacts on the economy and employment. These socio-economic impacts are not quantified in this study and they will also play an important role when formulating policies.

This study used 504-557 Kcal as the energy range for primary school meals. In all the chapters when I had to construct a new primary school meal or to define a healthy primary school meal, this value was used from the nutrient based primary school meal standards.

In chapter 6, when I analysed different policy scenarios, there were two main stages. For example in the MFM scenario, first when I replaced meat containing meals with non-meat containing meals, I used average nutritional values of a non-meat containing meal. After that to define healthy meals, 504 – 557 Kcal energy value was used with other nutrient based standards.

There are true differences in energy between meals which contain meat and meals which do not contain meat. But according to the nutrient based standards a primary school meal should have this required amount of energy. The new School Food Plan standards are based purely on food and do not provide any energy standards. But for the purpose of comparing with previous scenarios, we used the same energy values to define healthy and non-healthy from the meals which met these new food based SFP standards.

8.5 Future research

Since these meals are computer generated (based on a list of food items provided), a key concern is how likely they are to be accepted in real settings. The WWF Livewell report says that important next steps are to tackle key social and economic challenges while developing public policy options to facilitate sustainable healthy diets (Macdiarmid, Kyle et al. 2011).

Australian Dietary Guidelines shows that adoption of healthy and sustainable concepts in public food, is a good first step to take the population in that direction (NHMRC 2011).

Government Food Procurement Policy or Buying Standards can play a key role to set these standards. Other guidelines such as school meals and hospital meals guides can explicitly state both health and sustainability measures. This methodology could be adopted by researchers and policy makers to estimate the quantifiable outcomes of such policies.

The need for a method to link food, nutrition/health and sustainability has been highlighted in the literature previously. An evaluation of the Food for Life Partnership by Jones (2012) et al showed the complexity of rolling out some current multi-level programmes to promote nutrition and sustainability. Sometimes measures to promote sustainability of school foods such as locally produced, organic food do not have a “necessary” connection to promote dietary standards. The paper highlights the need to conceptualize food-health-sustainability links in design of such programmes and their evaluations (Jones, Dailami et al. 2012). Having a method that could simultaneously link both sustainability aspect and nutritional aspect of school food would provide that connection and help to design such programmes in the future.

Our dietary patterns are influenced by the society and eating patterns of people around us (Conger, Conger et al. 1980). Health or nutritional quality is not the only concern when people make dietary choices. It is widely recognized that people seek the things they like and that give them pleasure, and that they take action to obtain these things. People process messages in accordance with their existing values, beliefs, and behaviour (Rudd and Glanz 1990). Lessons from other public policies such as smoking show that disapproval by the society is an important factor to change behaviour. Introduction of smoking regulation policies have moved societies from an initial no-consideration status to very concerned status and social norms have changed after the introduction of laws (Nyborg and Rege 2003). But sometimes if policymakers try to introduce policies without changing social norms they get criticised for creating a “nanny state”(DW 2014). Therefore, despite good

evidence, policymakers might wait for change in social norms first, to introduce any policies to change behaviours such as dietary patterns. This shows changes in social norms and grassroots level campaigns are equally important as introducing policies to promote sustainable healthy diets.

One of the key changes in diets which was modelled to reduce GHGE is that amount of red meat is reduced significantly. Other animal proteins such as white meat and dairy products could remain in reduced amounts. Therefore any discussion about acceptability would mainly focus on red meat in the diet. Reynolds (2014) et al say, reduced animal protein diets would be unpalatable to much of the global population for many cultural, nutritional, and economic reasons (Reynolds, Buckley et al. 2014). More evidence from schools and communities which adopted these new diets would be extremely useful to inform this policy discussion.

8.6 Conclusion

This thesis allows, for the first time, a simultaneous assessment of the impact of changes in primary school food policy on nutrition and sustainability. The results suggest that new food based primary school food standards will increase the GHGE of meals and introduction of Meat Free Mondays will reduce the GHGE of meals, but may increase levels of saturated fat, sugar and salt. Reduction of meat will not automatically improve the healthiness of current school meals and substitution should be done carefully. Current primary school meals can reduce GHGE further, while improving the nutritional quality of meals which will provide co-benefits to public health and to the planet. Primary school meals could reduce GHGE by up

to 20% without compromising nutritional quality and still maintaining a substantial amount of meat.

It is essential that we continue to explore policies that can implement sustainable, healthy diets. This thesis demonstrates how the impact of such policies can be estimated, in order to help policy makers define credible healthy sustainable diets.

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