Campden BRI
food and drink innovation

Understanding the greenhouse gas impacts of food preparation and consumption in the home

2009

R&D report no. 285

R&D report no. 285

Understanding the greenhouse gas impacts of food preparation and consumption in the home

A Fendler, D Simons, V Swain and G Tucker

2009

Station Road, Chipping Campden, Gloucestershire, GL55 6LD. UK
Tel: 01386 842000

www.campden.co.uk

Understanding the greenhouse gas impacts of food preparation and consumption in the home

A Fendler[†], V Swain[‡], D Simons[≠], G Tucker[†]

[†] Campden BRI
[‡] FRPERC, University of Bristol
[≠] FPIU, Cardiff University

SUMMARY

The objective of the research presented in this report was to evaluate the methodology of the newly developed Publicly Available Specification PAS 2050 by assessing the greenhouse gas (GHG) emissions associated with the use phase and disposal of several food products.

A literature review found little published research regarding actual energy consumption and resulting GHG emissions of activities involved in the preparation of food in the home. To obtain baseline data of consumer GHG emissions, the use phase of several meals was assessed. The overall GHG emissions associated with the use phase and waste disposal of a cottage pie were between 93g CO_2e per functional unit for a ready meal reheated by microwave and 630g CO_2e per functional unit for a home made cottage pie. Similar results were found for a ready meal and a home made apple crumble. Data was also generated for the preparation of home baked bread and home made apple juice.

To gain an understanding of the variability of consumer GHG emissions, the energy consumption and the GHG emissions associated with preparing a variety of meals were assessed using a range of different cooking appliances. The data indicated that overall, using a microwave oven resulted in the lowest GHG emissions, and emissions associated with the use of a gas hob were substantially lower than those associated

with the use of several electric hobs. Appliances used for preparing dishes in the oven showed a similar pattern.

Finally, the observation of various food preparation processes and two focus group discussions showed the influence of consumer behaviour in the domestic food preparation process. The study indicated that the process in the home was only approximately 50% effective, with losses due to under utilised appliances and food waste.

The methodology of PAS 2050 could be applied to the assessment of the GHG emissions associated with the use phase of food products. However, adjustments regarding boundary conditions and allocation methods had to be made.

CONTENTS

1 EXECUTIVE SUMMARY

The British Standards Institution, together with Defra and The Carbon Trust, has developed a Publicly Available Specification, PAS 2050, to help manufacturers assess, reduce and report the greenhouse gas (GHG) emissions of their products. Defra has funded a consortium of researchers, including Campden BRI, to inform Defra's response to the BSI consultation process by assessing the applicability of this standard to food products, and to report on a range of typical footprints of these products.

In phase 1 (FO 0406) of the project "Understanding the GHG impacts of food preparation and consumption in the home", Campden BRI in collaboration with FRPERC of the University of Bristol and FPIU of Cardiff University have evaluated the methodology of the proposed PAS by assessing the GHG emissions associated with the use phase and disposal of two food products: a home made and a ready meal cottage pie.

The overall GHG emissions associated with the use phase and waste disposal of the food products were between 93g CO_2e per functional unit for the microwaved ready meal to 630g CO_2e per functional unit for the home made cottage pie. Differences in the method of preparation were responsible for these differences in the GHG emissions associated with the two food products.

In the second phase (FO 0409) of the project a literature review was carried out to find available published data on food storage and preparation in the home, as well as on consumer behaviour regarding food and food packaging waste and the associated GHG emissions. Whilst there are some existing studies available regarding life-cycle analysis (LCA) of various food products, some including the consumer use phase in their assessment, little has been published looking at specific dishes in the home situation and particularly investigating actual energy consumption and resulting GHG emissions when preparing meals.

In this study, the use phase GHG emissions of several additional food products, such as a ready meal, a home made apple crumble, home baked bread and home made apple juice, were assessed to obtain a wider base of data of consumer GHG emissions.

GHG emissions associated with the use phase and disposal of the apple crumble meals were very similar to those found for the cottage pie in phase 1 of the project. The preparation of the home made apple crumble was much more energy intensive than reheating the ready meal, and this shows in the associated GHG emissions (276g CO_2e per functional unit for the ready meal versus 525g CO_2e per functional unit for the home made meal). GHG emissions were also assessed for bread prepared in a bread-maker (219g CO_2e per functional unit) and bread prepared by hand (626g CO_2e per functional unit). GHG emissions associated with the preparation of 1L of home made apple juice were found to be 234g CO_2e per functional unit.

The preparation step (cooking, baking, etc). made the biggest contribution to the use phase GHG emissions for cottage pie, apple crumble and bread. In the case of the apple juice, however, the juicing of apples (i.e. the preparation step) contributed only 5% to the GHG emissions, whilst washing up and waste disposals made the biggest contribution (38% and 55%).

In order to gain a better understanding of the variability of GHG emissions when preparing meals with different cooking appliances, researchers at FRPERC studied the energy consumption and resulting GHG emissions of cooking a ready prepared meal (the cottage pie from phase 1 of the project) using a range of domestic microwaves and ovens. Other trials carried out included the assessment of the energy consumption of boiling vegetables and of cooking various meat dishes using a range of cooking appliances.

The energy consumption was measured and GHG emissions were calculated for boiling of new potatoes and carrots and for preparation of a chicken stir-fry. The data indicated that the gas hob had the highest energy consumption of all hobs used. However, when calculating the GHG emissions, the impact of cooking with gas was much smaller than for the electric hobs. Overall, the microwave oven had the lowest GHG emissions, followed by the gas hob. The highest amount of GHG emissions was associated with the use of an electric ceramic and a ring hob. The value for the induction hob was lower than for the electric hobs, but higher than for the gas hob.

Appliances used for preparing dishes in the oven showed a similar pattern. The results obtained for the GHG emissions of preparing the ready meal cottage pie showed that the microwave ovens had by far the lowest GHG emissions per functional unit. The combination microwave and the gas ovens had similar GHG emissions per functional unit. Both the convection oven and the fan-assisted oven showed substantially higher associated GHG emissions. These patterns were also confirmed for the preparation of roast chicken and for chicken stew.

The researchers at FPIU investigated the influence of the consumer in the domestic food preparation process for home made and ready meals. Four food preparations were observed and two focus groups used to test the observations and identify further potential issues. This initial study indicated that the process in the home was approximately 50% effective, with losses due to wasted unopened ingredients, under utilised appliances and unconsumed cooked food. Packaging and pack size entering the home were found to be key external drivers of household waste, whilst internally wasted energy of unused appliances such as ovens being left switched on were important factors.

Using data from phase 1 of this study, together with data gathered by two other Defra projects regarding the life cycle GHG emissions associated with food products, the overall life cycle GHG emissions of the cottage pie ready meal were assessed. The emissions from manufacturing, retail and the consumer use phase were of similar magnitude, while the production of raw materials, including agricultural operations, contributed over 60% to the life cycle GHG emissions of the ready meal. Cattle rearing was found to make the biggest impact on the overall carbon footprint of the cottage pie raw materials (70%).

The methodology of PAS 2050 was useful for the assessment of the GHG emissions associated with the use phase of food products. However, some adjustments mainly regarding boundary conditions and allocation methods had to be made in order to apply PAS 2050 to the use phase of food products. These issues were included in Defra's response to BSI, and were considered during the consultation process for the development of PAS2050.

2 INTRODUCTION

The British Standards Institution (BSI) has been working with the Carbon Trust and Defra to develop a new specification for the assessment of the life cycle greenhouse gas emissions of goods and services – PAS 2050[1].

The aim of this specification is to provide a method for assessing the life cycle greenhouse gas emissions of all kinds of products using a life cycle assessment (LCA) approach. By providing clear instructions as to how to perform this kind of assessment, one of the intentions of PAS 2050 is to allow for the comparison of GHG emissions between goods or services, and to enable the communication of this information.

Defra has funded a range of projects which assess the methodology of PAS 2050 for application in food products. Project FO 0404 ("Scenario building to test and inform the development of a BSI method for assessing GHG emissions from food") focused on the pre-farm gate and the manufacturing steps in the life cycle of a food product. However, further GHG impacts occur when the consumer takes the food home and stores, prepares and consumes it, although there is currently little data in this area on which sensible messages can be based. Evidence is needed, particularly on GHG emissions associated with energy use in storing and cooking different categories of food in the home, along with the impacts of various associated activities and the waste streams involved. Both the magnitude of such impacts (in absolute terms and in comparison to the impact of other stages in the food chain) and their causes/sources are of interest.

The aim of the project "Understanding the GHG impacts of food preparation and consumption in the home" was therefore to investigate the suitability of PAS 2050 for calculating GHG emissions for food use from the point of entry to the home, to its preparation, use, and waste disposal. At the same time, data regarding consumer behaviour and the associated GHG emissions of various foodstuffs was to be generated.

In the context of this study, food storage and preparation were taken to include refrigerated and ambient storage. In addition, a range of cooking methods such as gas and electric ovens, hobs, and microwaves were used. The study also took account of the impacts of associated energy requirements such as the use of kitchen equipment, the heating of water for washing up, etc. in GHG values.

In phase 1 of the project, the use-phase associated GHG emissions of two food products (a ready meal and a home made cottage pie) were assessed and compared. During this first phase, the work focused on assessing the difficulties in applying the methodology of PAS 2050 to the use-phase of food products. Feedback on the suitability of the draft PAS 2050 was provided to BSI via Defra.

For phase 2, the scope of the work was expanded to include the application of PAS 2050 to a wider range of foods and meal types and a variety of different cooking methods.

A literature review was carried out to obtain information on previous studies regarding in-home food storage behaviour, cooking practices and consumer waste practices and the implications of consumer behaviour for the associated GHG emissions.

The work of assessing the relative impacts of home preparation of meals from individual raw ingredients, compared to the purchase and home cooking of an equivalent ready meal, started in phase 1 with cottage pie, was complemented by data on home made and ready meal apple crumble.

Researchers at Campden BRI also assessed the GHG emissions associated with the preparation of bread in a commercial bread maker for the home, as well as in a fan assisted electric oven. At the same time, the preparation of fresh apple juice in a home juice extractor was assessed. The products were chosen to allow comparison with like industrially made food products studied in project FO 0404.

In order to assess the variability of data when preparing meals with different appliances, researchers at FRPERC prepared meals using a variety of cooking methods to generate data on the potential impacts of possible scenarios. As a first step, the energy consumption for the preparation of the ready meal cottage pie in a range of domestic ovens (electric, fan assisted, gas, microwave solo, microwave combination) was recorded. After finishing the trials of preparation of the cottage pie ready meal, the energy consumption for the preparation of a variety of vegetables (e.g. potatoes, carrots) on a range of hobs was assessed. Finally, various meat dishes were prepared to compare the influence of different cooking methods and appliances on the associated GHG emissions.

The experimental data obtained was complemented by work carried out at FPIU to obtain information on domestic storage, preparation and waste practices. In order to identify variations between the experimental set-up and real consumer behaviour, the preparation of ready made and home made cottage and apple pie was observed and differences to the findings from the laboratory environment were pointed out. Two focus groups were used to test the observations and identify further potential issues (e.g. effects of buying larger amounts of raw materials than required, treatment of plate waste, issues around types and sizes of food packaging).

The GHG emissions associated with the use-phase of the food products assessed are not to be taken as absolute numbers. However, they may provide useful insights into the relative contribution of different process steps to the overall GHG emissions in the use-phase of a food product, and can thus indicate where to focus attention to reduce consumer carbon emissions.

3 PAS 2050

PAS 2050 has been developed to provide a clear and consistent method for assessing the life cycle GHG emissions of goods and services. It builds on existing life cycle assessment methods established through EN ISO 14040[2] and EN ISO 14044[3]. PAS 2050 goes further than these two standards in that it focuses on goods and services, and in that it specifies requirements for identifying the system boundary, the sources of GHG emissions associated with products that fall inside the system boundary, the data requirements for carrying out the analysis, and the calculation of the results.

For consumers of goods and services, PAS 2050 provides an opportunity for greater understanding of life cycle GHG emissions when making purchasing decisions and using goods and services.

For organisations that supply goods and services, PAS 2050 allows for the internal assessment of the existing life cycle GHG emissions of goods and services and provides a benchmark for ongoing programmes aimed at reducing these emissions. This PAS may also facilitate the evaluation of alternative product configurations, sourcing and manufacturing methods, raw materials, etc. based on the life cycle GHG emissions associated with these options. Finally, PAS 2050 allows for a comparison of goods or services using a common, recognized and standardized approach to life cycle GHG emissions assessment.

3.1 Methodology for assessing GHG emissions using PAS 2050

During the work on project FO 0406/0409, a methodology for assessing greenhouse gas emissions according to PAS 2050 has been developed. This methodology has been used for the work carried out to assess the carbon footprints of the consumer use and disposal stages for the different food products. The Carbon Trust, Defra and BSI have published the "Guide to PAS 2050"[4] which also gives examples of how to apply PAS 2050.

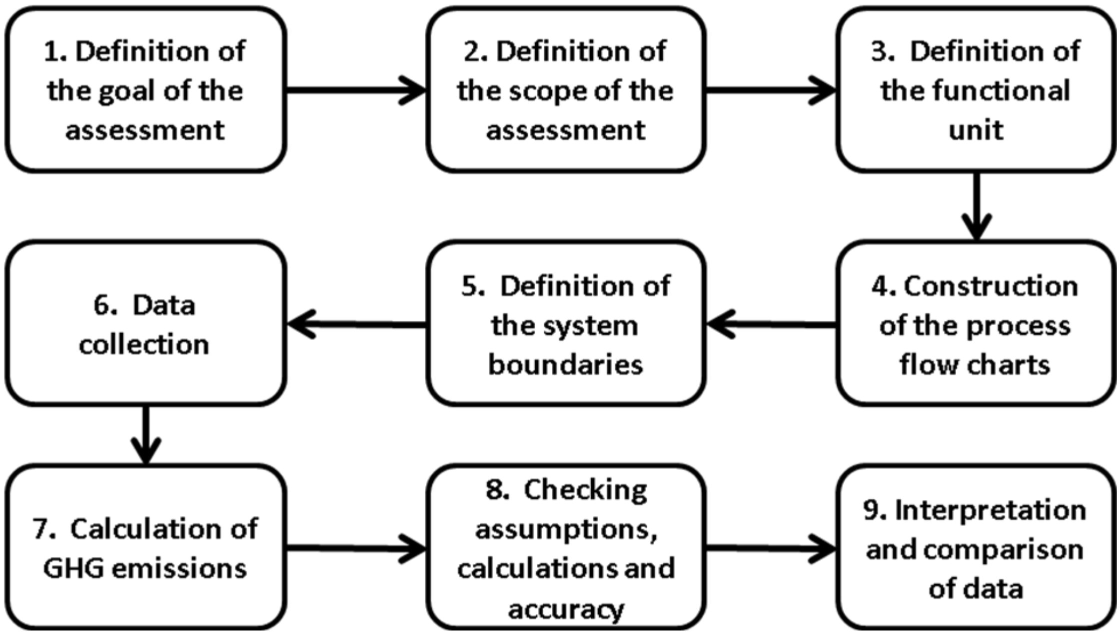


Figure 3-1: Steps of assessing a product carbon footprint according to PAS 2050

Figure 3-1 shows the steps of assessing the life cycle GHG emissions associated with a product, according to PAS 2050. As a first step, **the goal of the assessment should be defined**. It is important to clarify the purpose of the assessment and to decide what is going to be done with the results of the study. Thus, if the assessment is required only for internal use, the quality of primary and secondary data will not have to be as good as for a study intended for publication.

In a second step, **the scope of the assessment is defined**. If not all phases of the life cycle of the product are going to be studied, exclusions should be highlighted at this point. It is also important to ask if any special assumptions are being made, or if there are any restrictions to the study.

Step three is **the definition of the functional unit** on which the assessment will be based. This functional unit can be mass or volume based, such as 125g yoghurt, 1L ice cream, or activity based (e.g.: making ten cups of coffee).

One of the most important steps is the **construction of the process flow charts**. Process flow charts should be drawn up as detailed as possible. At a later stage, boundary conditions will be defined, and/or some parts of the process may be assumed to be negligible. Process flow charts could include:

- **A simplified life cycle process map:** this process map can be used to make stakeholders understand the life cycle of the product to be analysed. At the same time, it can be used to highlight the process steps that are going to be assessed. Life cycle steps to be included could be: Raw materials production, Manufacture of product, Distribution, Use, Disposal

- **Detailed process maps for life cycle steps:** For the steps of the life cycle of a product which are to be taken into account in the assessment, detailed process maps should be drawn up. The process steps in these process maps should relate directly to the mass balance steps drawn up in a later step. Process steps to be mapped include all steps of the life cycle of the product, including co-products and waste and all input and output streams.

Once the flow chart(s) is/are drawn up, **the system boundaries are defined**, following the rules laid out in PAS 2050. If there are any inputs, outputs or process steps which are to be excluded from or included in the assessment, which are not mentioned in PAS 2050, the reasons for the decision to include or exclude these should be written down. A note should also be made regarding input/output streams or process steps which are going to be considered negligible at this point.

Step six is **the collection of data**. As much primary activity data as possible should be collected for each process step. This may include: measured direct GHG emissions, measured energy consumption (gas, electricity, etc.), miles travelled and vehicle used, mass of product produced, etc. For process steps where it is impossible to obtain primary activity data, secondary data from sources recognised by PAS 2050 should be used instead.

The calculation of the GHG emissions requires several operations. First, the mass balances for each process step have to be drawn up (for an example see Figure 3-2). PAS 2050 states that mass balances have to be constructed for all process steps which have more than one input and/or output.

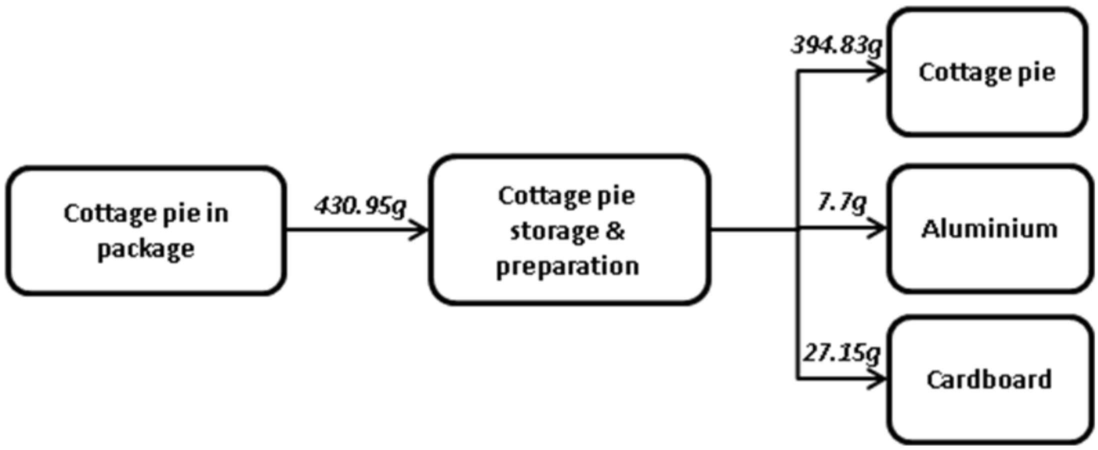


Figure 3-2: Mass balance for the calculation of GHG emissions

After drawing up the mass balance, CO_2 equivalents per functional unit are calculated. Data type, data source and appliance or site for which the data was collected should be recorded. The operation carried out, along with the fuel type used, as well as its quantity, and the unit in which it was measured are also recorded. For these purposes, direct emissions of greenhouse gases are to be treated as "fuel". Emission factors for the fuel types used are collected, along with the units (example: emission factor for electricity: 0.523 kg CO_2/kWh). Emission factors for most fuel types can be found in Defra's Greenhouse Gas Conversion Factors for Company Reporting[5,6]. For direct GHG emissions, the global warming potential (GWP) is used instead of emission factors. GWP is annexed to PAS 2050. The PAS requires that the GWP used in calculations is the latest available from the IPPC (currently, a document published in 2007[7]). Now, the overall emission factor for each process step is calculated. In order to do so, the quantity of each fuel type used is multiplied by its emission factor, and the results for the process step are added. The mass of the product being processed at the relevant process step is taken into account (see example in Figure 3-2).

Example 1: **Calculation of the process step emission factor**

In order to process 1.5 tonnes of material, 0.931 kg diesel and 22.8 kWh electricity are consumed. The emission factor for diesel is $3.164\frac{kgCO_2e}{kgdiesel}$, while the emission factor for electricity is $0.523\frac{kgCO_2e}{kWhelectricity}$. Thus, the process step emission factor(PEF) is:

$$PEF = \frac{0.931kgDiesel \times 3.164\frac{kgCO_2e}{kgDiesel} + 22.8kWhElectricity \times 0.523\frac{kgCO_2e}{kWhElectricity}}{1.5tonnesMaterial}$$

$$= 9.91\frac{kgCO_ee}{tonneMaterial}$$

Allocation: If a process step has more than one output, the associated GHG emissions have to be allocated to the co-products. PAS 2050 states that allocation is to be carried out either by dividing the unit processes to be allocated into sub-processes, or by expanding the product system, or according to the economic value of the co-products. The approach taken to allocate emissions to co-products has to be recorded. If the co-product is a waste stream, its associated GHG emissions are included in the life cycle GHG emissions of the assessed product.

<u>Example 2:</u> **Allocation according to economic value**

The process step has two outputs: a precursor of the product for which the lifecycle GHG emissions are being assessed (Material A), and a co-product, which is sold (Material B). The economic value of Material A is £ 50 per tonne, and the economic value of Material B is £ 30 per tonne. The output streams are: 0.6 tonnes of Material A and 0.9 tonnes of Material B.

Thus, Material A contributes with $\frac{£50}{tonne} \times 0.6 tonnes = £30$ to the total price, while Material B contributes with $\frac{£30}{tonne} \times 0.9 tonnes = £27$ to the total price of £57 for one tonne of processed material.

This means that $\frac{£30}{£57} = 0.53 \Rightarrow 53\%$ of the emissions of the process step are to be allocated to Material A, and $\frac{£27}{£57} = 0.47 \Rightarrow 47\%$ of the emissions are allocated to Material B.

Finally, calculate the mass of CO_2 equivalents per functional unit for each process step, and add all process steps to obtain the lifecycle GHG emissions of the product in CO_2 equivalents (see example in Figure 3-3).

Process step No.	**Data type**	**Data source**	**Appliance/ site**	**Operatio n**	**Fuel type**	**Quantity**	**Unit**	**Emission factors**	**EF unit**	**Process step EF**	**Process step EF unit**	**Mass CO_2e/FU**
1	Primary	Direct Measurement			Diesel	0.931	kg	3.164	kgCO_2e/ kg diesel	9.91	kg CO_2e per tonne	5.25
					Elec- tricity	22.8	kWh	0.523	kgCO_2e/ kWh			
2	...	...	...	...	...	...	...	...	...	...	...	7.22
Life cycle GHG emissions:												**12.47**

Figure 3-3: Table for calculation of product life cycle GHG emissions

In step 8, **the assumptions and the calculations and their accuracy are checked**. The assessment of the GHG emissions of a product is an iterative process. A first assessment may be carried out with data that is readily available, making assumptions for data which is not available. The conclusions of this first assessment will provide an idea of where to focus the attention in the following, more detailed assessment. It is important to check that the final assessment is in line with PAS 2050.

The final step in carrying out a product carbon footprint assessment in line with PAS 2050 is the **interpretation and comparison of data.** When interpreting data, it is important to bear in mind the assumptions (for example regarding boundary conditions) made during the assessment.

Finally, comparing the results of a life cycle GHG assessment for two products is very complicated. The data may only be compared if the same functional unit has been applied for both products and if the assessments for both products have been carried out with the same boundary conditions and making the same assumptions. Ideally, the life cycle GHG assessments for the products to be compared with each other will have been carried out in the same study.

4 REVIEW: GHG EMISSIONS FOR CONSUMER PREPARATION OF FOODS

A literature review was carried out to obtain information on previous studies regarding in-home food storage behaviour, cooking practices, and consumer waste practices and their implications for the associated GHG emissions.

The challenges we face because of climate change are well known. To deal with these challenges, the UK Government's Energy White Paper[8] (Department for Trade and Industry, 2003) set a goal to reduce carbon dioxide emissions by 60 per cent by 2050 with real progress by 2020, and in 2008, the UK's Climate Change Bill[9] committed to cut CO_2 emissions by 80% from 1990 levels by 2050.

Energy consumption is closely related to GHG emissions, and a report by the United Nations Department of Economic and Social Affairs[10] shows that in 11 OECD countries, household energy consumption increased by about 10% from 1990 to 1998. A study carried out for the Danish Ministry of the Environment[11] concluded that food related activities including refrigeration, cooking and cleaning amount to 7 - 12 % of total household energy use in European countries.

The Office for National Statistics[12] underlines that while for some industrial sectors greenhouse gas emissions are declining, emissions from households continue to rise. Overall UK greenhouse gas emissions decreased by 7.6% from 1990 to 2001, while emissions directly generated by UK households (emissions generated through cooking, heating and using own vehicles) rose by 12.4% in the same time period.

Information is widely available on the carbon emissions associated with different industries, and also on the potential of those industries to reduce carbon emissions. It is less well understood how those emissions translate into the carbon impact of the products and services ultimately delivered to the UK consumer. A study initiated by the Carbon Trust[13], and carried out by the Centre for Environmental Strategy at the University of Surrey and Enviros Consulting attributed all carbon emissions associated with different industries to final product and service categories. According to the study, in the UK, the category "Food and Catering" has emissions of 22.4 million tonnes of carbon per year, equivalent to 82.1 million tonnes of CO_2e.

A review published by Defra[14] shows that there is an abundance of data regarding the impacts of the use of water, energy and pesticides in food production. At the same time, the energy consumed in food storage, distribution and retail also has considerable environmental impact and is the subject of increasing research. However, according to this review and in agreement with our own research, there are many foods for which the environmental impacts at household level have not been considered. In the following subchapters, we will explore the research carried out on contributions that consumer storage of food, consumer preparation of foods and consumer waste practices make to greenhouse gas emissions, and if consumers are aware of these issues.

4.1 Storage

Depending on the length of storage time, chilled and frozen storage of food can contribute significantly to the carbon footprint of the consumer use of a food product.

Energy consumption of refrigerated appliances

Substantial research has been carried out regarding the energy efficiency of domestic refrigeration appliances. According to a briefing note by Defra's Market Transformation Programme[15], refrigerated appliances in the UK currently consume an estimated 14.4 TWh of electricity annually (MTP Reference scenario) and account for around 17% of domestic energy consumption.

There have been significant reductions in the energy used by domestic refrigerated appliances as a result of the EU Energy Label scheme. The first Energy Label, defining the classes A to G, was introduced in 1994. In 1997, a minimum standard was imposed which withdrew the least efficient models, and in 2004, the classes A+ and A++ were introduced[16]. The Ecodesign for Energy-Using Products Regulations 2007 specifies maximum consumption values for new refrigeration appliances sold on the market[17].

The majority of sales of refrigerated appliances in the UK now fall into the A class, with around 63% of all sales in the six months to December 2005. However, to reach significant levels of reduction in energy use, in order to reach the target for reduction in carbon dioxide emissions laid out in the UK's Climate Change Bill, the majority of future appliances will have to be rated A++ or better.

Since 1990, average annual unit energy consumption of new refrigerated appliances has fallen by between 29% and 36%, depending on appliance type. However, the reduction since 1999 is less. This is partially due to the change in consumer food purchasing patterns away from small, regular purchases to larger bulk purchases from supermarkets, which has led to a perceived need for larger or multiple refrigerated appliances. There has been a move away from under-counter fridge models towards upright fridge-freezers, and also towards larger side-by-side American-style models, which now account for around 10% of all fridge-freezers sold in the UK. These are significantly larger and consume more energy than standard fridge-freezers (over 500 kWh per year compared to 350 kWh or less). Frost-free models are also popular, with over 50% of the fridge-freezer market being this type since 2004, and having a frost-free freezer typically adds 10% to the energy consumption compared with a standard model.

The lifespan of refrigeration appliances in the home is assumed to be between 12.8 and 17.5 years[18], so that sales data can give an impression of how energy consumption of these appliances will evolve in the future, but consumer studies are necessary to give a picture of the actual energy consumption of refrigeration appliances in the home. GfK[18] data suggests that in 2008 65% of households owned a fridge-freezer, 16% of households owned a chest freezer and 29.8% an upright freezer; 43% of households owned a simple fridge. Numbers over 100% suggest that most households own several of these appliances.

For energy label declarations, the energy consumption of all types of domestic cold appliances is measured in accordance with test standards (BS) EN 153/ EN ISO 15502. However, these tests are criticised because real use situations like door opening and insertion of warmer food are not taken into account[19,20].

Several studies have been carried out monitoring in-home energy consumption of refrigerated appliances during everyday use. MTP monitored the energy consumption of 19 domestic refrigerated appliances ranging from 1 to 19 years old[20]. Of the 19 appliances, 14 had an energy class which could be calculated and none of these performed worse than an 'E' energy label rating. For the 10 appliances where the original energy label data for the model was known, all but one operated as well as, or better than, the stated energy consumption value plus 15%.

A study in France[21] used metered appliances in around 98 households to monitor the effect of external conditions on the operation and energy consumption of domestic cold appliances. The study found that most freezers were operating at temperatures on average 3.1°C colder than the recommended storage temperature (-18°C), leading to an increase of 17.6% in energy consumption levels. On the other hand, keeping a cold appliance in a non-heated storeroom rather than a kitchen gave an average energy saving of 36%.

The Lothian and Edinburgh Environmental Partnership (LEEP) bill savers project[22] measured the consumption of domestic refrigerators in the homes of a hundred low income and a hundred middle income households and then replaced the existing appliances with new ones, while continuing to meter consumption, which allowed accurate estimates of the savings achieved and the cost effectiveness of these measures. The information was deduced from research in the early 1990s, before energy labelling, and the original appliances were selected for replacement because they were faulty or of high consumption. They therefore represent the worst examples of appliance stock at the time (see Table 1).

Original appliances		**Replacement appliances**	
Sample	**In Use consumption**	**Sample**	**In Use consumption**
8 fridge-freezers	1.98 kWh/24h 723 kWh/year	8 fridge-freezers	1.36 kWh/24h 496 kWh/year
11 fridge-freezers	2.08 kWh/24h 759 kWh/year	11 fridge-freezers	1.45 kWh/24h 529 kWh/year
1 refrigerator	1.36 kWh/24h 496 kWh/year	6 refrigerators	0.65 kWh/24h 237 kWh/year

Table 1: Energy consumption of refrigerated appliances

Finally, in a study on the impact of household food consumption on resource and energy management, Faist et al.[23] used material flux analysis to assess material and energy fluxes of the entire system of food production and consumption. Their results show that agricultural production and private households account for most of the system's energy requirements, and the results reveal an astonishing optimisation potential of cooling devices in private households.

GHG emissions associated with food storage in the home

While little information is available on the actual average energy consumption of refrigerated appliances in the home, less research has been carried out regarding GHG emissions due to energy consumption but also due to the leakage of refrigerant gases from refrigeration appliances in the home.

A very thoroughly researched working paper regarding food refrigeration and its contribution to greenhouse gas emissions was published by Garnett[24]. She states that figures for the refrigeration at the food manufacturing, retailing and domestic stages total about 2.4% of UK greenhouse gas emissions. According to data provided by the MTP[25], domestic refrigeration results in 1.9 million tonnes of carbon emissions, contributing 1.24% to the UK's overall CO_2 emissions.

Interestingly, Garnett[24] also points out the relation between food refrigeration and food waste. Thus, while refrigeration entails the release of greenhouse gases it can also help save GHG emissions by reducing food waste. Refrigerated food lasts longer and as such is less likely to go rotten and need to be thrown away. If one takes into account that wasted food represents a waste of all the embedded GHG emissions released when producing, processing, transporting, storing and retailing the food, the extra greenhouse gases released when refrigerating may well be worth it.

4.2 Food preparation

Little has been published looking at specific dishes in the home situation, and particularly investigation regarding actual energy consumption and resulting GHG emissions when preparing meals is scarce.

Energy consumption of domestic cooking

Swain[26] carried out a short review of energy consumption information in domestic refrigeration and cooking. She found that detailed energy-consumption data for domestic appliances, particularly for cooking activities in real situations (by type of meal or by appliance), is scarce.

Sidler et al.[21] carried out an investigation into cooking, drying, and refrigeration in 100 homes in France. They found that the combined cooking-related energy consumption accounted for 14% of the total electricity-specific energy consumption of the households surveyed. The average annual household energy consumption of all electric cooking appliances was 568 kWh/year.

A study by Wood and Newborough[27] looked at ways of saving energy when using cooking appliances in 44 households in the UK. They monitored these households for a period of 12 months and found that the average daily energy consumption for electric cooking was 1.30 kWh. A case study of the energy requirements of household consumption in the Netherlands has been carried out by Biesiot and Norman[28]. Total energy consumption and related CO_2 emission data were calculated as a function of household income and family type. However, these reports were based on assumptions only.

Defra´s Market Transformation Programme[29,30] reported about assumptions underlying the energy projections of cooking appliances and compared the energy use in microwave ovens with more traditional electric cooking methods. The briefing note informs the consumer of the most energy efficient way of cooking different foods.

Sonesson et al.[31] modelled the energy consumption of various food preparation methods such as boiling in water on a hotplate, boiling of water in electric kettles, frying in a frying pan, oven cooking, etc.. Cold storage was also modelled. The researchers present general models to calculate the energy needed for food preparation and cold storage in households, to be used in LCA or other similar environmental analyses for food systems.

Collison[32] carried out an analysis of the energy consumed in the cooking of a number of different foods (Small sponge cakes, Yorkshire pudding, Pork sausages, Cod, Potatoes) in an electric forced-convection oven. He found that the total energy use for cooking 1 kg of food amounted to 1.4 - 1.7 MJ. Of this, 0.43 to 0.72 MJ was absorbed by the food. Blenkhorn and Wnuk[33] investigated the energy consumption of using a microwave oven compared to traditional cooking methods (fan-assisted oven). They measured the energy consumption of cooking a whole chicken. Gas ovens were not considered in this study.

Life cycle assessment of food products

Other surveys considered the life-cycle impact of different kinds of food. Carlsson-Kanyama[34,35] investigated the energy consumption and greenhouse gas emissions associated with the life-cycle of carrots, tomatoes, potatoes, pork, rice and dry peas consumed in Sweden. She went on to estimate the energy requirements in the food sector, reporting on the energy required for crop farming, animal husbandry, food processing, storage, transportation and food preparation. In 2001, Carlsson-Kanyama[36] reported about the electricity use for cooking wheat, spaghetti, pasta, barley, rice, potatoes, couscous and mashed potatoes and another report was also published by Carlsson-Kanyama[37] about food life cycle energy inputs. All reports present data about the energy consumption for producing different kind of foods but do not focus on energy consumption and CO_2 emission for cooking in the home.

Sonesson et al.[38] reported on the difference between industrial processing and home cooking in Sweden. They used life cycle assessment to quantify the environmental impact of homemade, semi-prepared, and ready-to-eat meals. Overall, the differences in environmental impact between the meals were small. However, the energy consumption data from industrial ready-to-eat meals relied on values provided by manufacturers rather than measured values, while some of the information for home prepared meals was obtained by measurement and some was taken from published data.

4.3 Food and packaging waste

It is important to shed light on consumer behaviour related to food and packaging waste for two reasons. On the one hand, studies of the life cycle emissions of food products should take the percentage of waste produced, and the GHG emissions associated with this waste, into account in their calculations. On the other hand, strategies to influence consumer behaviour to reduce food and packaging waste should be based on findings from consumer research.

Food waste - Consumer behaviour

Apart from domestic food preparation and storage, wastage plays an important part in consumer related GHG emissions. However, very little is known about consumers' actual activities: How much is eaten of the food purchased? How much is wasted? Why is food thrown away?

Waste sorting analyses performed in Austria indicate that food disposed of in its original packaging or partly used accounts for 6 to 12% of residual household waste[39,40].

Sonesson et al.[41] surveyed Swedish households by questionnaire, diary, and interviews. One of the objectives of the study was to quantify domestic food wastage for an average Swedish household. The researchers found that wastage of prepared food ranged between 0 and 34% for different food categories, and wastage from storing between 0 and 164% (where more food was discarded than consumed, e.g. by cleaning out a cupboard). In both cases dairy products scored highest. The report also makes recommendations for possible improvements regarding the environmental impact of foods. Thus, increased shelf life of foods as well as an increased awareness among consumers could lead to less wastage. Smaller packages would decrease the risk for foods to be spoiled during storage, just as specialized packaging could increase the shelf life.

Andersson and Ohlsson[42] questioned 41 people concerning their bread wasted at home, in order to assess bread losses on household level. This restricted survey indicated that approximately 25% of bread is lost in households.

WRAP has published several reports on very comprehensive research looking into food waste behaviour of UK consumers. A study carried out in 2007[43] consisted of a detailed survey of over 2000 households and a physical analysis of their rubbish. It was designed to quantify the amounts and types of food waste being produced and to make links between this and the attitudes displayed by the households.

The study came to the conclusion that UK households waste 6.7 million tonnes, or around one third of the 21.7 million tonnes of food purchased. Most of this food waste is collected by local authorities and goes to landfill.

According to this research, 4.1 million tonnes or 61% of the food waste could have been avoided if the food had been managed better. Truly unavoidable food waste, like vegetable peelings, meat carcasses and teabags, accounts for 1.3 million tonnes a year or 19% of the total, with the remainder being 'possibly avoidable' food waste - items such as bread crusts that some people choose not to eat and potato skins which can be eaten when food is prepared in certain ways but not in others.

Figure 4-1 shows that, of the avoidable food waste, 2.5 million tonnes or 61% is left unused, almost a million tonnes of food is thrown away unopened or whole (24% of avoidable food waste), and at least 340 thousand tonnes of food are still in date (8% of avoidable food waste). Cooking and preparing too much food results in 1.6 million tonnes of food waste a year or 39% of avoidable food waste.

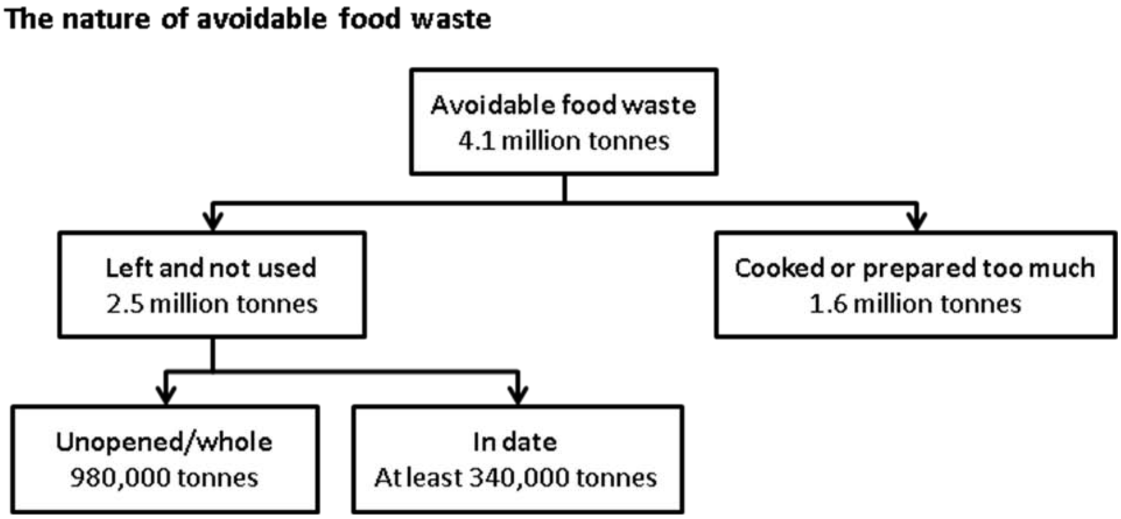


Figure 4-1: The nature of avoidable food waste [from ref. 43]

There appeared to be little difference between age groups in the amounts of avoidable food thrown away, each age group throwing away 1.2 to 1.5 kg of avoidable food waste per head per week.

40% (by weight) of avoidable food waste is made up of fruit & vegetables[44]. Almost 90% of this fruit & vegetable waste consists of fresh produce, and most is thrown away as a result of not being used before going off or out of date. Research showed that only 40% of fruit and 75% of vegetables (by weight) are stored in the fridge. Fruit is mainly stored in a fruit bowl (56%). A literature survey on data available on commercial storage of fresh produce as well as storage trials at different temperatures found, however, that for most types of fruits and vegetables refrigeration is vitally important in maintaining freshness and extending storage life.

WRAP research[45] indicates that many people don't appreciate the quantity of food they waste. 90% claim that little food is wasted in their household. However, if that is true, the other 10% must be wasting almost all the food they buy, given the 6.7 million tonnes of food waste generated. The study discovered that people believe more food is thrown away after it has been prepared than as raw ingredients. However, other evidence suggests that there is more raw food in the bin than cooked food. This is partially explained by the inedible elements of food waste such as peelings, offcuts and tea bags not being perceived as 'a waste' in the same way as waste from food prepared but not eaten.

Consumers mentioned different reasons for throwing food away[43]. The main reasons for throwing away food that could have been eaten if it had been managed better were: the food looked, smelt or tasted bad or went mouldy (30% of avoidable food waste), it had passed its date (20%), it was left on the plate after a meal (30%), or it was left over from cooking (9%).

Temptation by special offers like 'buy one, get one free', buying more perishable food as the result of trying to eat more healthily in combination with poor storage management (spontaneous shopping, 'spring cleaning') and high sensitivity to food hygiene (1 in 5 say they won't take a chance with food close to its 'best before' date, even if it looks fine) all lead to consumers buying more than they need and throwing away food that is still perfectly edible[45].

The research also found evidence of a lack of awareness and understanding of the environmental implications of food waste. Consumers do not recognise that greenhouse gas emissions are generated from the growing, transport, processing and storage of food before purchase and that, if food is thrown away, all this effort - and environmental impact - goes to waste too. They are much more sensitive to packaging waste than food waste, with most consumers concerned about throwing away plastic and other waste perceived of as non-biodegradable but less so about biodegradable waste. Almost three-quarters believe that 'discarded food packaging is a greater environmental issue than food thrown away'.

GHG emissions associated with food waste disposal

Waste management makes a significant contribution to UK emissions of greenhouse gases, through transport, processing, treatment and, of particular importance, releases of methane from degrading wastes in landfill. Other forms of waste management have the potential to result in net reductions in GHG emissions, by recovering materials or energy and avoiding the requirement for, and the production of, primary resources.

Over 36 million tonnes of Municipal Solid Waste (MSW) are generated annually in the UK[46]. The management of this waste is estimated to produce greenhouse gas emissions equivalent to 4 million tonnes of CO_2 per year, 90% of which is attributable to the use of landfill for disposal[47]. Food waste represents about one fifth of domestic waste, and in the UK, the vast majority of food waste ends up in landfill[45]. In landfill, biodegradable food waste generates methane, with a global warming potential of 25, a much more powerful greenhouse gas than carbon dioxide. Landfill sites can thus contribute significantly to UK greenhouse gas emissions through their uncontrolled release of methane emissions to atmosphere.

Even more important are the significant amounts of greenhouse gases emitted by producing, processing and transporting food which is wasted. According to WRAP, every tonne of food waste is responsible for 4.5 tonnes of CO_2[43] if these previous steps are taken into account. In total, at least 15 million tonnes of carbon dioxide are associated with food that was thrown away but could have been eaten[48].

To divert appropriate biowastes like food and garden waste from landfill at the lowest financial and environmental cost, home composting should be promoted according to a WRAP report[49].

For packaging materials, most studies reviewed by WRAP[50] show that recycling offers more environmental benefits and lower environmental impacts than other waste management options. Thus, the UK's current recycling of those materials was found to save between 10-15 million tonnes of CO_2 equivalents per year compared to applying the current mix of landfill and incineration with energy recovery to the same materials.

5 EMBODIED GHG EMISSIONS OF SEVERAL FOOD PRODUCTS

The assessment of the relative impacts of home preparation of meals from individual raw materials, compared to the purchase and home cooking of an equivalent ready meal, started in phase 1 of this project with cottage pie. This was complemented by data on home made and ready meal apple crumble in phase 2. Researchers at Campden BRI also assessed the GHG emissions associated with the preparation of bread in the home and the preparation of fresh apple juice in a home juice extractor. The products were chosen to allow comparison with industrially made food products studied in Defra project FO 0404.

5.1 Method and assumptions

The methodology used for the assessment of the GHG emissions of the food products during the use-phase and disposal is that proposed by PAS 2050. Measurement of primary data and research regarding secondary data for the meal examples were carried out while PAS 2050 was still under development. However, as the later drafts and the final version of PAS 2050 became available in the later stages of this project, we have tried to incorporate the new assessment principles wherever possible.

Scope of the study and definition of the functional unit

For this assessment, only the use-phase and disposal were studied. Primary data for the use-phase was produced. We decided to consider packaging materials as waste, which arises during the consumption of the food products. Organic waste came from cuttings of raw materials used for the preparation of the homemade meals. We considered that the foods prepared were fully eaten and that no food waste was generated. Waste treatment and water use, as well as wastewater treatment, are included in the study. Secondary data for these parts of the study came from a variety of sources[46,47,51,55]. Differences in consumer behaviour were ignored.

For the purposes of this study, the functional units were defined individually for each product group (see relevant sub-chapters).

Construction of the process flow charts

Process flow charts were constructed including the use-phase of the food products in the home, as well as the waste transport and disposal stage. The basic steps for the use phase of the products were drawn up according to the experimental set-up for primary data collection.

Data collection

Where possible, primary experimental data was collected for the use-phase of the food products. In this part of the study, only one or two main preparation options were carried out for each product, in order to first establish values for each process step and to identify the material contributions of each process step to the overall life cycle GHG emissions of the food products. Trials carried out to assess the influence of different cooking methods are presented in Chapter 6.

For the ready meals, preparation was carried out following the instructions given on the package. The homemade meals were prepared according to family recipes. During the preparation of the meals, energy consumption of the kitchen appliances was recorded. Three trials were performed for each preparation method.

Secondary data was used for the assessment of the GHG emissions related to food product waste transport and disposal. As waste disposal routes are very specific for very small regions, assumptions for average waste management routes had to be made for the UK. Assumptions and data for waste management were taken from two Defra studies on waste arisings and waste management[47,51] . Data in these studies comes mainly from recognised databases[52,53] and government statistics.

Definition of the system boundaries

The system boundaries were defined according to PAS 2050. However, all process steps before the food products enter the home of the consumer were outside the system boundary for this project, as they are considered in other studies. The only exception is water supply for washing up, where the associated GHG emissions were taken into account.

Following the approach of PAS 2050, the GHG emissions arising from the production of appliances are outside of the system boundaries. Thus, the GHG emissions from the production of appliances such as microwave, electric hob & oven, pots & plates, used for preparation of the meals were not included in the study.

While refrigerated storage was included in the study, where appropriate, the heating of a home was not taken into account in the calculations.

The GHG emissions of all process steps for which data was found were included in the overall values for the use-phase. At this point, no contributions were considered "non-material". However, waste treatment options contributing less than 1 wt. % to overall waste management were considered negligible.

Allocation

Product functional units have to be chosen carefully to avoid allocation issues. For example, for homemade meals, the usual size is of 4 to 6 portions, while the standard size of ready meals is usually 1 to 2 portions. If a functional unit of one portion is chosen, bigger size homemade meals would have lower GHG emissions per functional unit than small size homemade meals.

PAS 2050 states that the preferred approach to allocation of emissions to co-products is dividing the processes to be allocated into sub-processes, expanding the product system to include additional functions related to the co-products, or, if neither of these two approaches is suitable, to allocate emissions according to the economic value of the co-products. However, for refrigerated storage, an allocation of energy-consumption to the co-products by economic value is impossible. A fridge may be half-empty, or the economic value of all other products in the storage is not known. Instead, we allocated energy consumption of the refrigerator to the food products studied according to the volume of the stored products per total volume of the fridge/freezer, following the approach laid out in PAS 2050 for emissions from transport.

For washing up, no allocation was necessary for this part of the study, as dishes needed for the preparation of the food products were washed up by hand. However, we would think that for a dishwasher, an allocation would have to be made according to the volume fraction of the dishes used.

Interpretation and comparison of data

Primary data was collected via direct measurement of energy consumption of kitchen appliances, and was then transformed into CO_2 equivalents, using the relevant emission factors published by Defra[54]. The quality of the data is good, with a good repeatability.

This data has been collected for one specific set of appliances (one specific fridge/freezer, one electric hob/oven, one microwave). The approach reflects the collection of primary data in a manufacturing context. However, in order to obtain relevant data for the use phase of a food product, the range of GHG emissions of various different appliances should be tested. The variability of energy consumption when using different kitchen appliances was a focus of the work presented in Chapter 6.

Secondary data was collected for water supply and treatment as well as for waste management. The emission factors relating to water supply and treatment were taken from a collection of UK water industry sustainability indicators[55]. The authors of this publication classify their confidence in the accuracy of the emission factors as "low". Emission factors relating to waste management were taken from two Defra funded studies[47,51].

In conclusion, the data collected for the meals will allow for identification of the material inputs for GHG emissions associated with the use phase. However, any comparisons between the "carbon footprint" of the food products should be made with caution, as the calculated values are not to be taken as absolute values.

5.2 Ready-meal and home made cottage pie: Comparison of GHG emissions

Ready-meal cottage pie

The ready-meal cottage pie was supplied by a ready meal producer. It was a single portion meal of approximately 400g. The exact composition of the meal was not disclosed, as it was not relevant for this study.

The ready meal was assumed to be stored in a refrigerator in the household for 24 hours before preparation of the meal. The preparation was carried out according to the two different methods described on the ready meal package; the cottage pie was prepared in a preheated electric fan oven at 170°C for 25 minutes, while other samples were cooked for 5 minutes in a microwave of Cat E (850W).

Washing up of plates and cutlery was assumed to be done by hand. We assumed that 1 L of water was used at a temperature of 55°C (heated from a temperature of 15°C). Waste arisings were measured and the associated GHG emissions were calculated as explained in the appendix.

Home made cottage pie

The home made cottage pie was prepared from ingredients. The portion size was held as close as possible to 400g in order to compare results with the ready meal product.

Ingredients needing refrigeration (minced beef, milk, butter) were assumed to be stored in a refrigerator in the household for 24 hours before preparation of the meal. For preparation of the mashed potatoes and the meat sauce, an electric hob was used, and the cottage pie was then baked in a preheated electric fan oven at 200°C for 15 minutes.

Washing up of pots, plates and cutlery was done by hand. For home cooking, a greater amount of water was assumed to be used (about 6 L). As for the ready meal, calculations were carried out to evaluate the energy consumption associated with heating water from 15 to 55°C.

Waste arose mainly from containers of the raw materials (plastic bags, etc.) and from vegetable cut-offs (kitchen waste). As almost all ingredients had to be purchased in a greater amount than actually used, waste was allocated to the ingredients by weight. Waste arisings were measured and the associated GHG emissions were calculated as explained in the appendix.

Comparison and discussion of results

For comparison of the two meals, one portion of 400g cottage pie was chosen as the functional unit. GHG emission values were calculated for both the ready meal cottage pie and the home made cottage pie. GHG emissions associated with the use phase and disposal of the ready meal were found to be between 93g and 362g CO_2e per functional unit, depending on the method of preparation. GHG emissions per functional unit of home made cottage pie were found to be much higher at 630g CO_2e per functional unit (see Table 2 and Figure 5-1).

For both meals, preparation (cooking) was found to be the most influential process step. Thus, in the case of the home made meal, preparation accounted for 85% of use phase GHG emissions, while it was 65 - 91% for the ready meal.

There were great differences in energy consumption and consequently in GHG emissions between the different methods of preparation. The microwave proved to be the most energy efficient appliance, at least for the small portion size studied. The preparation of the home made meal in the electric fan oven was more energy intensive than the preparation of the ready meal for two reasons: firstly, the home made meal was prepared at a higher oven temperature (200°C vs. 170°C), and secondly, for the home made meal, mash and sauce were prepared on an electric hob prior to baking.

For both meals the GHG emissions of the storage of the ingredients/meal was very similar and virtually irrelevant. However, the assumption made was storage for 24 hours; if the ingredients or the meal are stored for a longer time, the contribution of storage can become more relevant. If the ready meal is stored for 14 days instead of only 24 hours, the associated emissions rise by more than a factor 10 to 27g CO_2e per functional unit.

Washing up makes a relatively small contribution to the overall GHG emissions associated with the use phase and disposal of the meals studied. However, there are great differences in energy consumption depending on the amount of water used. Other important factors that are not considered in this study are the temperature of washing up (if water is initially colder, or if water is used at ambient temperature) and a comparison of washing up by hand or using a dishwasher.

Finally, disposal of waste associated with the preparation of the cottage pie meals makes a small contribution to the GHG emissions when compared to the much bigger impacts of the preparation steps. Values are very similar for both products and account for 2% (home made meal) to 19% (microwaved ready meal) of GHG emissions.

<table>
<tr><th colspan="2">Process step</th><th colspan="2">kg CO_2e/PU</th></tr>
<tr><td colspan="2"></td><td>ready meal</td><td>home made</td></tr>
<tr><td colspan="2">Storage</td><td>0.002</td><td>0.004</td></tr>
<tr><td rowspan="3">Preparation</td><td>microwave</td><td>0.060</td><td>--</td></tr>
<tr><td>electric fan oven</td><td>0.329</td><td>--</td></tr>
<tr><td>electric hob/fan oven</td><td>--</td><td>0.537</td></tr>
<tr><td colspan="2">Washing Up</td><td>0.013</td><td>0.075</td></tr>
<tr><td colspan="2">Waste Disposal</td><td>0.018</td><td>0.014</td></tr>
<tr><td colspan="2">Total</td><td>0.093 - 0.362</td><td>0.630</td></tr>
</table>

Table 2: Cottage pie: Contribution of process steps to the overall GHG emissions of the use phase

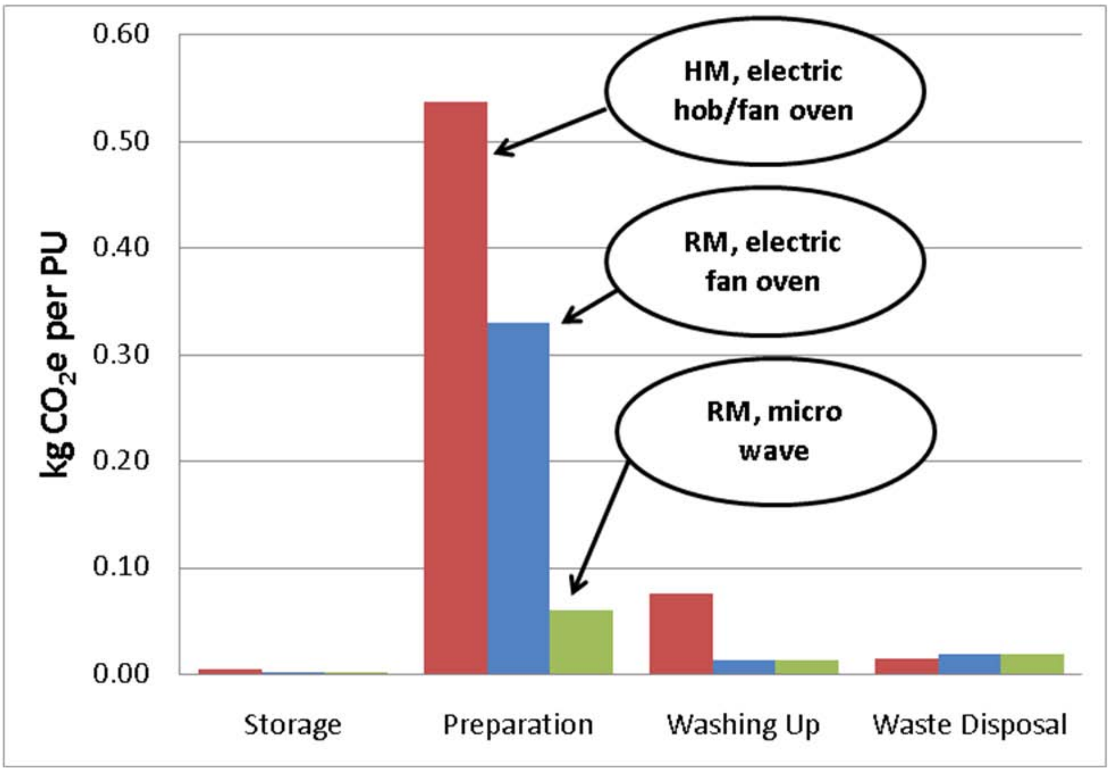


Figure 5-1: Cottage pie: Importance of process steps for overall GHG emissions (red: home made meal, blue: ready meal in electric fan oven, green: ready meal in microwave)

5.3 Ready-meal and a home made apple crumble: Comparison of GHG emissions

Ready-meal apple crumble

The ready-meal apple crumble was bought at a local retailer. According to the manufacturer, this was a six portion meal of approximately 360g. However, calculations were carried out for a theoretical functional unit of 400g, in order to be able to compare the results with those obtained from the cottage pie study. The exact composition of the meal was not disclosed, as it was not relevant for this study.

The ready meal was assumed to be stored at ambient temperature. The apple crumble was prepared in a preheated electric fan oven at 180^{o}C for 10 minutes according to the method described on the ready meal package.

Washing up of plates and cutlery was assumed to be done by hand. We assumed that 1 L of water was used at a temperature of 55^{o}C (heated from a temperature of 15^{o}C).

Waste arisings were measured and the associated GHG emissions were calculated as explained in the appendix.

Home made apple crumble

The home made apple crumble was prepared from ingredients. The portion size was held as close as possible to 400g.

Ingredients needing refrigeration (apples, butter) were assumed to be stored in a refrigerator in the household for 24 hours before preparation of the meal. For preparation of the apple mix, an electric hob was used, and the apple crumble was then baked in a preheated electric fan oven at 180°C for 30 minutes.

Washing up of pots, plates and cutlery was done by hand. For home cooking, a greater amount of water was assumed to be used (about 3 L). As for the ready meal, calculations were carried out to evaluate the energy consumption associated with heating water from 15 to 55°C.

Waste arose mainly from containers of the raw materials (plastic bags, etc.) and from fruit cut-offs (kitchen waste). As almost all ingredients had to be purchased in a greater amount than actually used, waste was allocated to the ingredients by weight. Waste arisings were measured and the associated GHG emissions were calculated as explained in the appendix.

Comparison and discussion of results

GHG emissions associated with the use phase and disposal of the ready meal were found to be approximately 276g CO_2e per functional unit, while GHG emissions per functional unit of home made apple crumble were almost double at 525g CO_2e (see Table 3 and Figure 5-2).

For both meals, preparation (cooking) was found to be the most important process step. Thus, in the case of the home made meal, preparation accounted for 87% of use phase GHG emissions, while it was 95% for the ready meal.

There were differences in energy consumption and consequently in GHG emissions between the home made and the ready meal. The preparation of the home made meal was more energy intensive than the preparation of the ready meal for two reasons: firstly, for the home made meal, the apple mix was prepared on an electric hob prior to baking, and secondly, the home made meal was baked for 30 minutes at 180°C, while the ready meal was only heated for 10 minutes (at the same temperature).

While the ready meal could be stored at ambient temperature, butter and apples for the home made apple crumble were taken to be stored in a refrigerator for 24 hours. Still, the GHG emissions of the storage of these ingredients were very small.

Washing up also made a relatively small contribution to the overall GHG emissions associated with the use phase and disposal of the meals studied. However, there are great differences in energy consumption depending on the amount of water used. Other important factors that are not considered in this study are the temperature of washing up (if water is initially colder, or if water is used at ambient temperature) and a comparison of washing up by hand or using a dishwasher.

Finally, disposal of waste associated with the preparation of the ready meal is virtually irrelevant (<1% of use phase emissions), while for the home made meal, waste disposal makes up a total of 5% of the use phase emissions (mainly caused by kitchen waste such as apple peelings).

Process step		**kg CO_2e/PU**	
		ready meal	home made
Storage		0	0.002
Preparation	electric fan oven	0.262	--
	electric hob/fan oven	--	0.459
Washing Up		0.013	0.039
Waste Disposal		0.002	0.026
Total		**0.276**	**0.525**

Table 3: Apple crumble: Contribution of process steps to the overall GHG emissions of the use phase

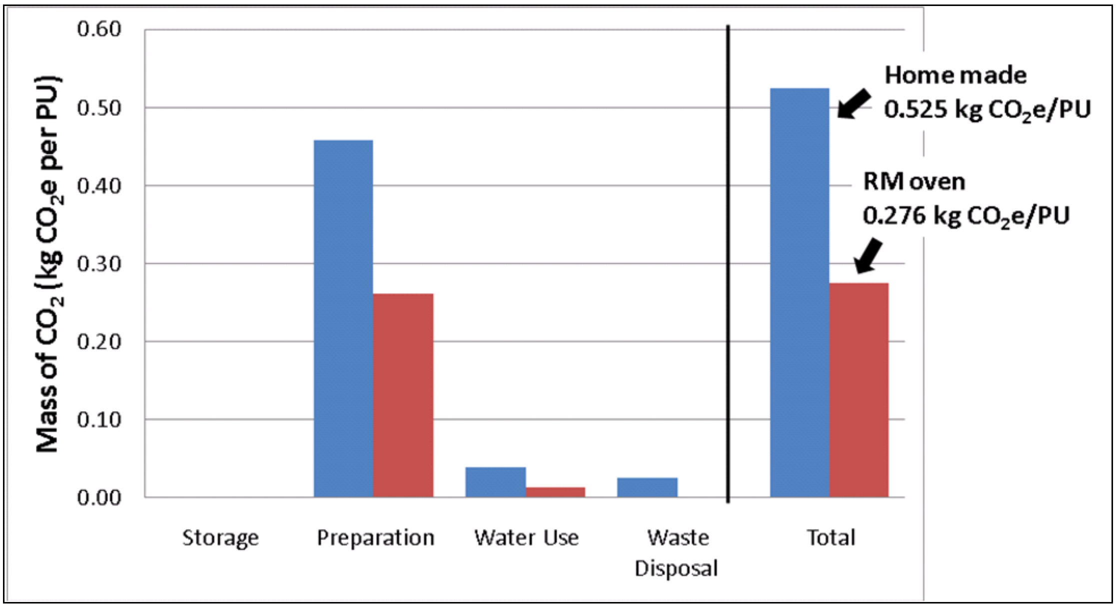


Figure 5-2: Apple crumble: Importance of process steps for overall GHG emissions (blue: home made meal, red: ready meal in electric fan oven)

5.4 GHG emissions associated with the preparation of home baked bread

Bread was made in two different ways using a household bread-maker and made by hand and baked in an electric fan oven. The functional unit was chosen to be 800g (one standard loaf of bread). The recipe for bread made in the bread-maker was taken from the equipment manual, while the recipe for the hand made bread was a family recipe.

Only butter was assumed to be stored in a refrigerator in the household for 24 hours before preparation of the bread, all other ingredients were stored at ambient temperature. The bread-maker was programmed for a bread of size "L" and a standard preparation time of 4 hours. Hand made bread was prepared and then baked in a preheated electric fan oven at 210°C for 45 minutes.

Washing up of baking tins, etc. was done by hand. For bread made by hand in the oven, a slightly bigger amount of water was assumed to be used (about 1.75 L as compared to 1 L of water for the bread-maker utensils). Calculations were carried out to evaluate the energy consumption associated with heating water from 15 to 55°C.

Waste arose from containers of the raw materials (plastic bags, etc.). As almost all ingredients had to be purchased in a greater amount than actually used, waste was allocated to the ingredients by weight. Waste arisings were measured and the associated GHG emissions were calculated as explained in the appendix.

Comparison and discussion of results

GHG emissions associated with the use phase and disposal of the bread made in the bread-maker were found to be approximately 219g CO_2e per functional unit. This value is in line with unpublished research carried out previously at FRPERC. GHG emissions of home made bread baked in an electric fan oven were much higher at 626g CO_2e per functional unit (see Table 4 and Figure 5-3).

For both types of bread, preparation (baking) was found to be the most important process step. Thus, in the case of the bread made in the bread-maker, preparation accounted for 93% of use phase GHG emissions, while it was 96% for the hand made bread.

While all the ingredients for the hand made bread could be stored at ambient temperature, butter for the bread made in the bread-maker was taken to be stored in a refrigerator for 24 hours. The GHG emissions related to the storage of this ingredient remain negligible.

Washing up also made a relatively small contribution to the overall GHG emissions associated with the use phase and disposal of the types of bread studied. However, there are great differences in energy consumption depending on the amount of water used. Other important factors that are not considered in this study are the temperature of washing up (if water is initially colder, or if water is used at ambient temperature) and a comparison of washing up by hand or using a dishwasher.

Finally, disposal of waste associated with the preparation of the two types of bread is virtually irrelevant (<1% of use phase emissions).

Process step		**kg CO_2e/PU**	
		breadmaker	hand made
Storage		0	0
Preparation	electric fan oven	--	0.602
	bread-maker	0.204	--
Washing Up		0.014	0.023
Waste Disposal		0.001	0.001
Total		**0.219**	**0.626**

Table 4: Bread: Contribution of process steps to the overall GHG emissions of the use phase

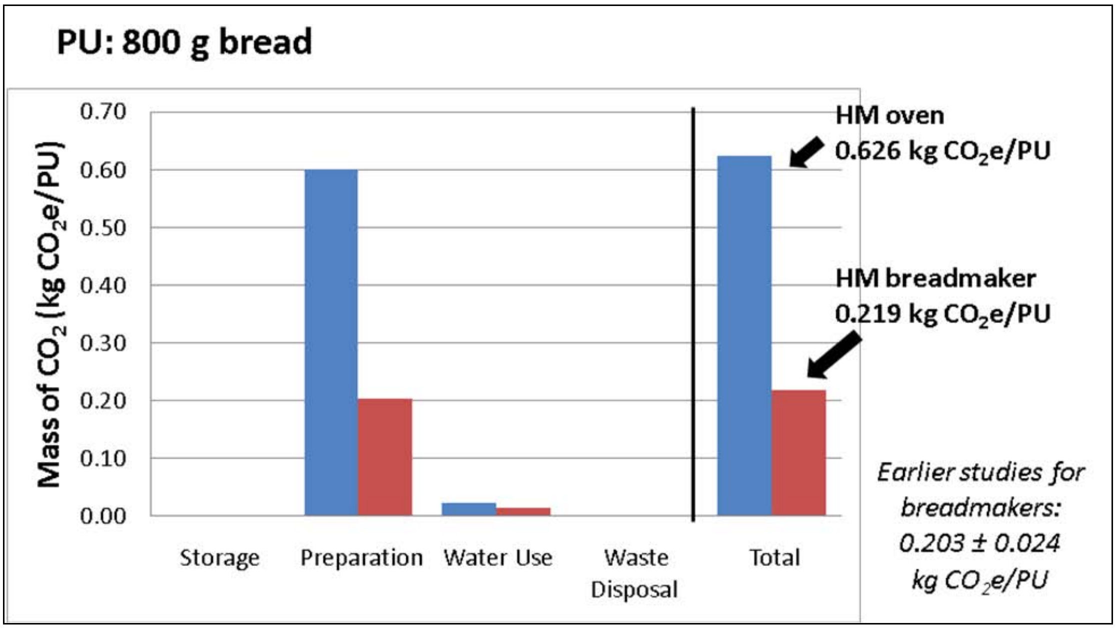


Figure 5-3: Bread: Importance of process steps for overall GHG emissions (blue: hand made bread, red: bread made in bread-maker)

5.5 GHG emissions associated with the preparation of home made apple juice

The only ingredients for home made apple juice were apples. The functional unit was defined as 1 L of apple juice. Apples were assumed to be stored in a refrigerator in the household for 24 hours before juicing. The juice was prepared using a household fruit juicer.

Washing up of the removable parts of the juicer was done by hand. The amount of water used was assumed to be about 7 L. As for the two previous meals, calculations were carried out to evaluate the energy consumption associated with heating water from 15 to 55°C. Waste arose from apple pulp (kitchen waste) and from the retail plastic bags the apples were sold in. Waste arisings were measured and the associated GHG emissions were calculated as explained in the appendix.

Discussion of results

GHG emissions associated with the preparation of 1 L of home made apple juice were found to be approximately 234g CO_2e per functional unit (see Table 5 and Figure 5-4).

Unlike for the cottage pie and the apple crumble meals discussed above, the preparation of the apple juice (juicing of apples) contributed relatively little to the use phase GHG emissions (about 5%). The contribution of chilled storage of the apples was even smaller, contributing about 2% to the total use phase emissions.

Washing up made a significant contribution to the overall GHG emissions associated with the use phase (around 38%). As pointed out for the first two meal examples, there are great differences in energy consumption depending on the amount of water used. Other important factors that are not considered in this study are the temperature of washing up (if water is initially colder, or if water is used at ambient temperature) and a comparison of washing up by hand or using a dishwasher.

Finally, the biggest impact on the use phase GHG emissions is the disposal of waste associated with the preparation of home made apple juice. This makes up 55% of the GHG emissions of the use phase, and is mainly due to the waste disposal of the apple pulp (kitchen waste).

Home made apple juice	
Process step	**kg CO_2e/PU**
Storage	0.005
Preparation	0.011
Washing Up	0.090
Waste Disposal	0.128
Total	**0.234**

Table 5: Apple juice: Contribution of process steps to the overall GHG emissions of the use phase

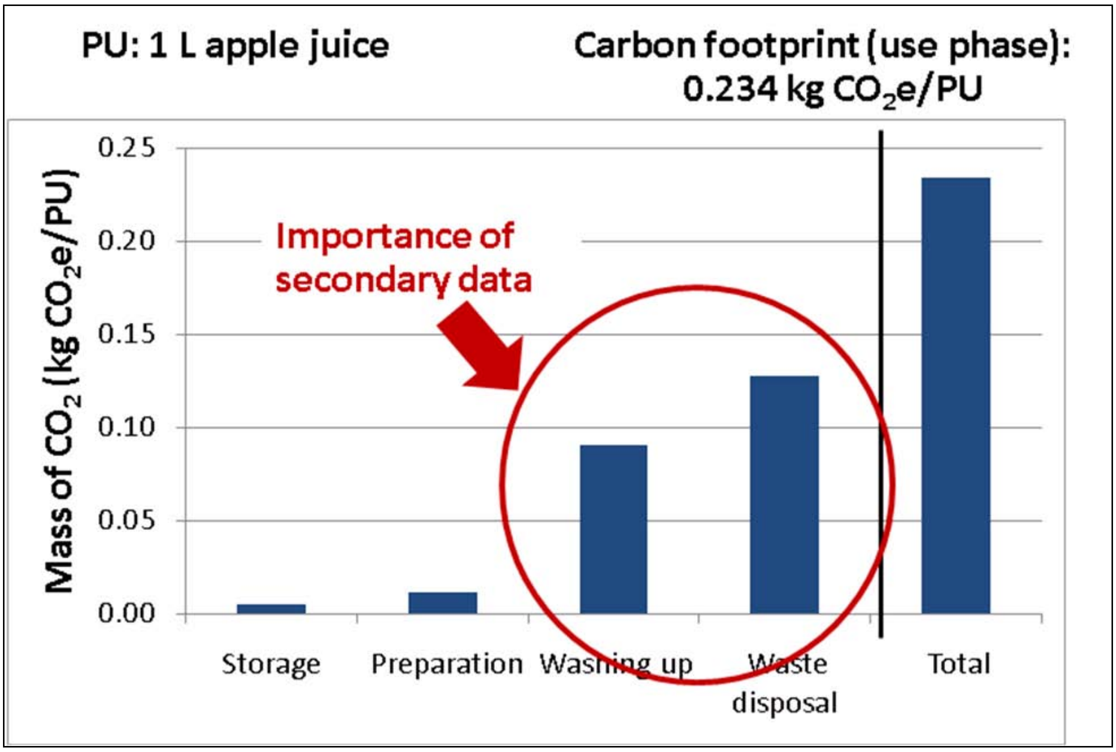


Figure 5-4: Apple juice: Importance of process steps for overall GHG emissions

Comparison of data quality

It is important to point out that for the meal examples discussed above the biggest contribution to the GHG emissions of the use phase was made by the preparation of the foods (between 65% and 96% of the use phase emissions). Even though there will be some experimental error and uncertainty linked to the energy consumption data obtained from cooking trials (depending on trial set up, number of different appliances used, number of repetitions, etc.) it is relatively straightforward to obtain good quality primary data for this part of the use phase. Only emission factors for the conversion from gas or electricity consumption to CO_2 equivalents are needed, and there are reliable sources for these[5,6].

For the apple juice example, on the other hand, the important contributors to the GHG emissions of the use phase are found in washing up and waste disposal associated with the preparation of the juice. A much bigger margin of error may be associated with the experimental data gathered for these two steps, as subjective behaviour will influence these measurements to a greater extent. At the same time, the emission factors needed to calculate the GHG emissions associated with washing up and waste disposal are not as reliable as those used for gas and electricity. The emission factors relating to water supply and treatment were taken from a collection of UK water industry sustainability indicators[55]. The authors of this publication classify their confidence in the accuracy of the emission factors as "low". Emission factors relating to waste management were taken from two Defra funded studies[47,51], and are based on several assumptions regarding consumer disposal behaviour and municipal waste management.

6 COMPARISON OF VARIOUS METHODS OF FOOD PREPARATION

Researchers at FRPERC prepared meals using a variety of cooking methods to generate data on the potential impacts of possible scenarios. As a first step, the energy consumption of the preparation of a ready meal cottage pie in a range of domestic ovens (electric, fan assisted, gas, microwave solo, microwave combination) was recorded. After finishing the trials in preparing the cottage pie ready meal, the energy consumption for the preparation of a variety of vegetables (e.g. potatoes, carrots) on a range of hobs was assessed. Finally, various meat dishes were prepared to compare the influence of different cooking methods and appliances on the associated GHG emissions.

6.1 Cooking a ready prepared meal (cottage pie) in a range of domestic ovens

This task aimed to measure the energy consumption of cooking the ready meal cottage pie, discussed in Chapter 5, in a range of domestic ovens. The trials were carried out in order to obtain more data on the variability associated with the preparation of a specific meal in a range of cooking appliances.

Cooking instructions, oven temperatures, and pre-heating and cooking times were followed as per on-pack instructions. In the case of the microwave combination oven, the automatic oven pre-heating function was used. A cold oven was used for all tests. The total energy consumption for each oven, including any pre-heating required, was measured. A pre-heating period of 20 minutes, the same as used at Campden BRI (trials discussed in Chapter 5), was used for all electric standard ovens. Five replicates were carried out in each oven.

Results and discussion

Table 6 shows the results obtained for the energy consumption (pre-heat and cooking) and GHG emissions of preparing the ready meal cottage pie. Figure 6-1 shows the average GHG emission values with the variation among the replicates on all ovens tested. The microwave ovens had by far the lowest amount of energy consumption and hence the lowest GHG emissions per functional unit. The combination microwave and the gas ovens had similar energy consumption and GHG emissions per functional unit, with the gas oven having a slightly higher value. The convection oven had the highest energy consumption with the fan-assisted oven not far behind.

Oven	Mode		Pre-heating energy (kWh)	Cooking energy (kWh)	GHG emissions (kg CO_2e/PU)
Whirpool	Fan-assisted	***Av.***	**0.43**	**0.72**	**0.3766**
		St. dev.	*0.007*	*0.004*	*0.0037*
Miele	Convection	***Av.***	**0.49**	**0.76**	**0.3954**
		St. dev.	*0.011*	*0.0112*	*0.0079*
Sharp	MW combi	***Av.***	**0.19**	**0.53**	**0.2594**
		St. dev.	*0*	*0.035*	*0.0191*
Panasonic	MW solo	***Av.***	**N/A**	**0.09**	**0.0471**
		St. dev.	*N/A*	*0.0*	*0.0000*
Sanyo	MW solo	***Av.***	**N/A**	**0.11**	**0.0575**
		St. dev.	*N/A*	*0.0*	*0.0000*
Cannon	Gas	***Av.***	**0.72**	**1.43**	**0.2651**
		St. dev.	*0.020*	*0.024*	*0.0045*

Table 6: Energy consumption and GHG emission data for cooking ready prepared cottage pie using different domestic ovens.

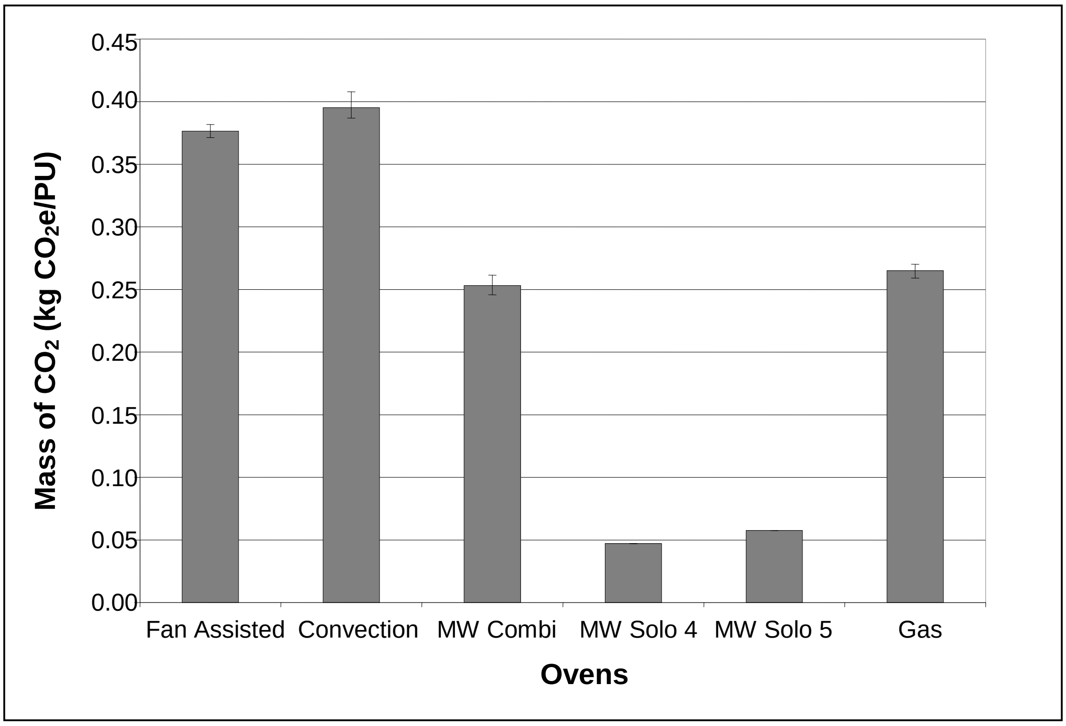


Figure 6-1: Calculated GHG emissions per functional unit of cottage pie

For the two 900 W solo microwave ovens used, the time on the pack instructions produced an over-heated product, so 1 minute was removed from the suggested heating time.

In the case of the gas oven, the suggested heat setting (gas mark 6) produced an over-heated product due to the fact that the oven had a large temperature gradient inside the cavity, varying from 170ºC at the bottom to 240ºC at the top, with the centre temperature around 220ºC. For this particular oven, less time would be required to heat this product without over heating and hence would require less energy. However, all the heating times used were those specified by the product on-pack instructions and are likely to be those used by the consumers.

It should be noted that although 5 replicates were used for each oven tested, the results only considered one example of each type of oven. From experience there is a considerable difference between oven manufacturers/models and this should be considered when using these results. Therefore the conclusion based on such a limited sample of ovens will have a high degree of uncertainty.

6.2 Boiling vegetables using a range of domestic hobs and a microwave

This task aimed to measure the energy consumption of boiling vegetables using a range of domestic hobs and a solo microwave oven. Tests were also performed using an electric kettle to boil 500g of water and finishing the cooking process using the hobs. Vegetables used for the trials were new potatoes and carrots.

Standard cooking instructions for boiling vegetables for one person were followed: for hobs 150g of vegetables with 500g of water, and for the microwave 150g of vegetables with 30g of water. The vegetables were boiled using the highest setting, then the setting was turned down to the minimum and the vegetables were simmered untill cooked. This took approximately 16 minutes for the new potatoes, and 12.5 minutes for the carrots. Cold hobs were used for all tests. The total energy consumption for each hob, including energy required for boiling and for cooking, was measured. At least 2 replicates were carried out on each hob.

Table 7 shows the energy consumption measured and the calculated GHG emissions for boiling 150g of new potato and carrots. The data indicates that although the gas hob has the highest energy consumption of all hobs used, when calculating the GHG emissions the impact of cooking with gas is much smaller than for the electric hobs. When energy consumption is transformed into GHG emissions for both types of vegetables, the microwave oven had the lowest GHG emissions, followed by the gas hob for both types of vegetables. The highest amount of GHG emission was associated with the use of an electric ceramic and a ring hob. The value for the induction hob was lower than for the electrics but higher than for the gas hob.

Vegetables	Stages	Units	Ring	Ceramic	Induction	Gas	Microwave
Potatoes	Energy to boil	(kWh)	0.11	0.14	0.09	0.16	N/A
	GHG emissions	(kg CO_2e/PU)	0.05753	0.07322	0.04707	0.03012	N/A
	Energy to cook	(kWh)	0.09	0.07	0.07	0.10	0.08
	GHG emissions	(kg CO_2e/PU)	0.04707	0.03400	0.15500	0.01850	0.04184
	Total energy	**(kWh)**	**0.20**	**0.21**	**0.16**	**0.27**	**0.08**
	Total GHG emissions	**(kg CO_2e/PU)**	**0.1046**	**0.10722**	**0.08107**	**0.04951**	**0.04184**
Carrots	Energy to boil	(kWh)	0.12	0.14	0.09	0.15	N/A
	GHG emissions	(kg CO_2e/PU)	0.060145	0.07	0.04707	0.02867	N/A
	Energy to cook	(kWh)	0.06	0.05	0.03	0.07	0.07
	GHG emissions	(kg CO_2e/PU)	0.03138	0.02	0.01569	0.01382	0.03661
	Total energy	**(kWh)**	**0.18**	**0.19**	**0.13**	**0.23**	**0.07**
	Total GHG emissions	**(kg CO_2e/PU)**	**0.091525**	**0.09676**	**0.06538**	**0.04249**	**0.03661**

Table 7: Energy consumption and GHG emissions for cooking one portion (150g) of new potatoes or carrots in a saucepan with lid

Table 8 shows the results of trials for cooking vegetables when using an electric kettle to boil water and then boil/simmer on the hob until cooked. The results indicate that although the cooking time was decreased, there was little difference in energy consumption when using a kettle compared to using cold water for the electric hobs (Figure 6-2). However, the CO_2 emission increased in the case of the gas hob when using the kettle.

Vegetables	Stages	Units	Ring	Ceramic	Induction	Gas
Potatoes	Energy to boil	(kWh)	0.06	0.06	0.06	0.06
	GHG emissions	(kg CO_2e/PU)	0.03138	0.03138	0.03138	0.03138
	Energy to cook	(kWh)	0.075	0.07	0.05	0.19
	GHG emissions	(kg CO_2e/PU)	0.03923	0.03400	0.02615	0.03424
	Total energy	**(kWh)**	**0.195**	**0.20**	**0.15**	**0.25**
	Total GHG emissions	**(kg CO_2e/PU)**	**0.10199**	**0.10460**	**0.07584**	**0.06562**
Carrots	Energy to boil	(kWh)	0.06	0.06	0.06	0.06
	GHG emissions	(kg CO_2e/PU)	0.03138	0.03138	0.03138	0.03138
	Energy to cook	(kWh)	0.12	0.12	0.07	0.19
	GHG emissions	(kg CO_2e/PU)	0.05753	0.06276	0.03661	0.03515
	Total energy	**(kWh)**	**0.18**	**0.18**	**0.13**	**0.25**
	Total GHG emissions	**(kg CO_2e/PU)**	**0.09153**	**0.09414**	**0.06799**	**0.06653**

Table 8: Energy consumption and GHG emissions for cooking one portion (150g) of new potatoes or carrots, using a kettle to boil the water

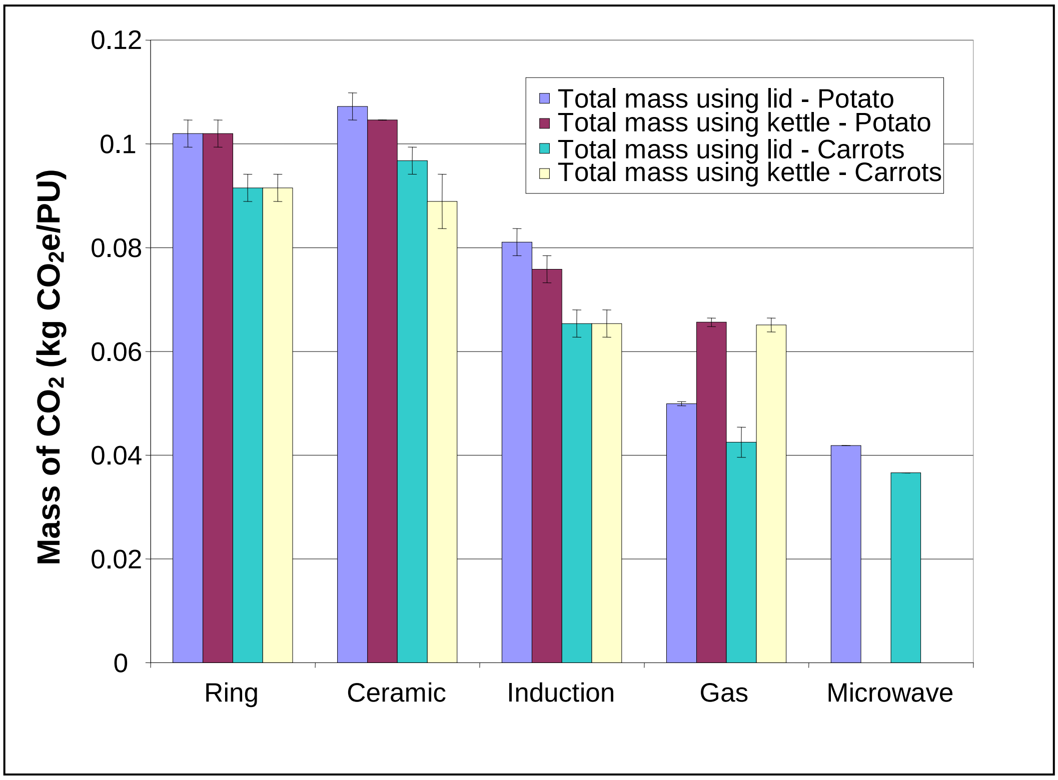


Figure 6-2: Difference in GHG emissions when using cold water or a kettle to cook new potatoes and carrots

It should be noted that although 3 replicates were used for each hob tested, the results only considered one example of each type of hob/microwave. From experience there is a considerable difference between hob manufacturers/models and this should be considered when using these results. Therefore the conclusion based on such a limited sample of hobs will have a high degree of uncertainty.

However, the above results of the tests showed that, in summary, microwave ovens required the lowest amount of energy consumption and hence resulted in the lowest mass of CO_2 emitted per unit of product. Although the gas hob had the highest energy consumption of all hobs tested, once the emission factor was taken into account, it had the second lowest GHG emissions per functional unit, after microwave ovens. The induction hob had lower energy consumption and GHG emissions when compared to the ceramic and ring hobs.

6.3 Cooking different meat dishes using a range of domestic hobs and ovens

This task aimed to measure the energy consumption of cooking different chicken dishes using a range of domestic ovens and a combination microwave oven.

Several chicken dishes were prepared using different hobs and/or ovens. Figure 6-3 shows the cooking methods and types of appliances used for these tests.

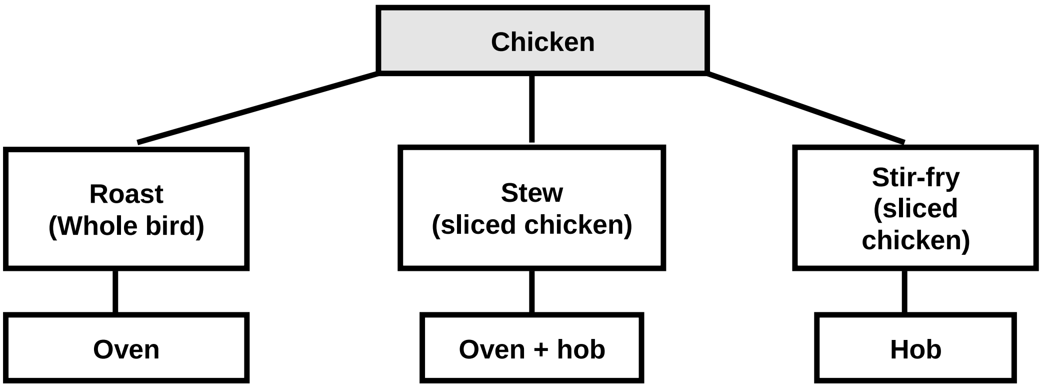


Figure 6-3: Cooking methods and appliances used for cooking the chicken dishes

Typical chicken stew and stir-fry recipes were found using cookery books or internet cookery sites. The instructions for cooking a roast chicken were followed using the food packaging guidelines; for the combination microwave ovens the auto roast button was used.

Roast chicken

For roasting the chicken a range of ovens were used: One gas oven, five different models of fan assisted electric ovens, one natural convection electric oven (no fan mode) and eight different models of combination microwaves. The chickens had a weight range of 1.2 to 1.3 kg. They were purchased in a supermarket and stored at 5°C in a refrigerator overnight for temperature equalisation. The cooking time was calculated using recommendations on the chicken packaging for weight/time ratio.

The ovens were pre-heated using the thermostat light indicator (once the light is off, the oven is ready for use) for the fan-assisted and conventional oven and 15 minutes for the gas oven as recommended by the oven manufacturer. No pre-heating was required for the combination ovens. Instructions for the auto chicken roast program were followed. Table 9 shows the average energy consumed and the calculated GHG emissions for roasting a whole chicken for all appliances used.

Average values (minimum 3 reps)	Units	Gas oven	Combination Microwave	Fan - assisted	Natural convection
Energy consumption	kWh	**2.49**	**0.94**	**1.37**	**1.31**
Min		2.45	0.65	1.21	1.25
Max		2.52	1.20	1.44	1.36
GHG emissions	kg CO_2e/PU	**0.4605**	**0.4934**	**0.7186**	**0.6825**
Min		0.4542	0.3400	0.6328	0.6538
Max		0.4662	0.6293	0.7531	0.7113

Table 9: Energy consumption and GHG emissions for roasting chickens

Figure 6-4 illustrates the variation in the energy consumed and Figure 6-5 the variation in the calculated GHG emissions for the appliances used. The gas oven had the highest average energy consumption when compared with the other ovens, however, when calculating the GHG emissions, the gas ovens was the lowest. Of all electric appliances, on average the combination microwaves had the lowest energy consumption (av. 0.94 kWh) followed by the natural convection (av. 1.31 kWh) and then fan-assisted (av. 1.37 kWh) ovens. However, it is important to note that there is a large variation between the ovens tested (8 different microwave ovens models and 5 different fan-assisted models) with some combination microwaves consuming as much energy (1.20 kWh) as the lowest value for a fan-assisted oven (1.21 kWh). When considering the amount of GHGs associated with the use of each model, the gas oven had the lowest emission (av. 0.4605 kg CO_2e/PU) and the fan-assisted ovens the highest (av. 0.7186 kg CO_2e/PU).

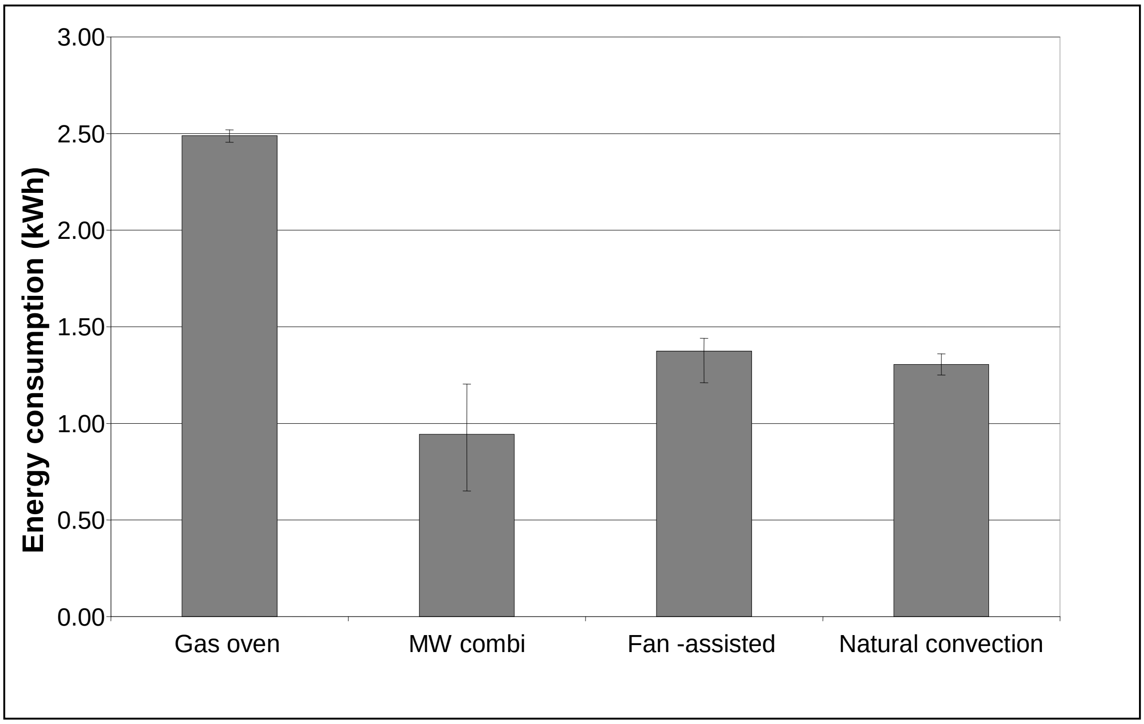


Figure 6-4: Energy consumption of roasting chickens using different appliances

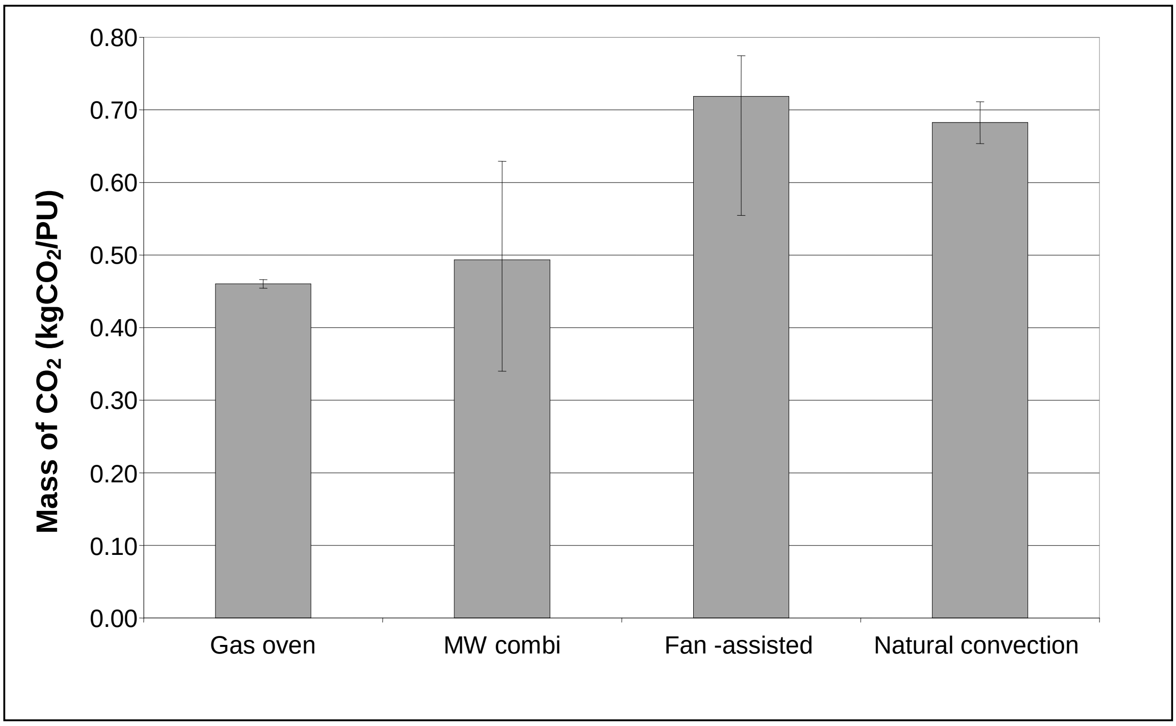


Figure 6-5: GHG emissions for roasting chickens using different appliances

Chicken stew

Vegetables and chicken pieces were fried before the stew was cooked in the gas oven, a fan assisted electric oven, a conventional electric oven or a combination microwave. Figure 6-6 shows the type of ovens and the cooking settings which were used for cooking the stew. The basic recipe for the stew was found in the Sharp Combination Oven cookery book and was then adapted to cooking when using normal ovens.

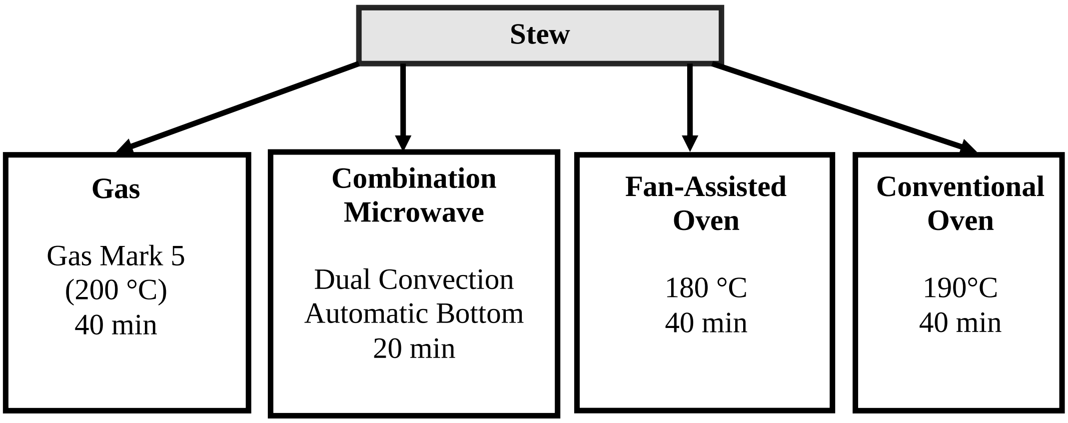


Figure 6-6: Ovens and cooking settings for cooking the chicken stew

Table 10 shows the data for the energy consumption and the GHG emissions associated with cooking a stew with different domestic appliances. The data shows that the energy consumption for preparing a stew in a fan-assisted oven is highest at 1.225 kWh (equivalent to 0.641 kg of CO_2e), followed by the conventional oven at 1.125 kWh (equivalent to 0.588 kg of CO_2e). Although the gas oven showed the highest energy consumption, when considering the emission factor, the GHG emissions were the lowest of all ovens (Figure 6-7).

Average values	Units	Gas	Combination Microwave	Fan-assisted Oven	Conventional Oven
Energy consumption	(kWh)	1.9914	0.840	1.225	1.125
GHG emissions	(kgCO_2e/PU)	0.3684	0.439	0.641	0.588

Table 10: Energy consumption and GHG emissions for cooking a chicken stew

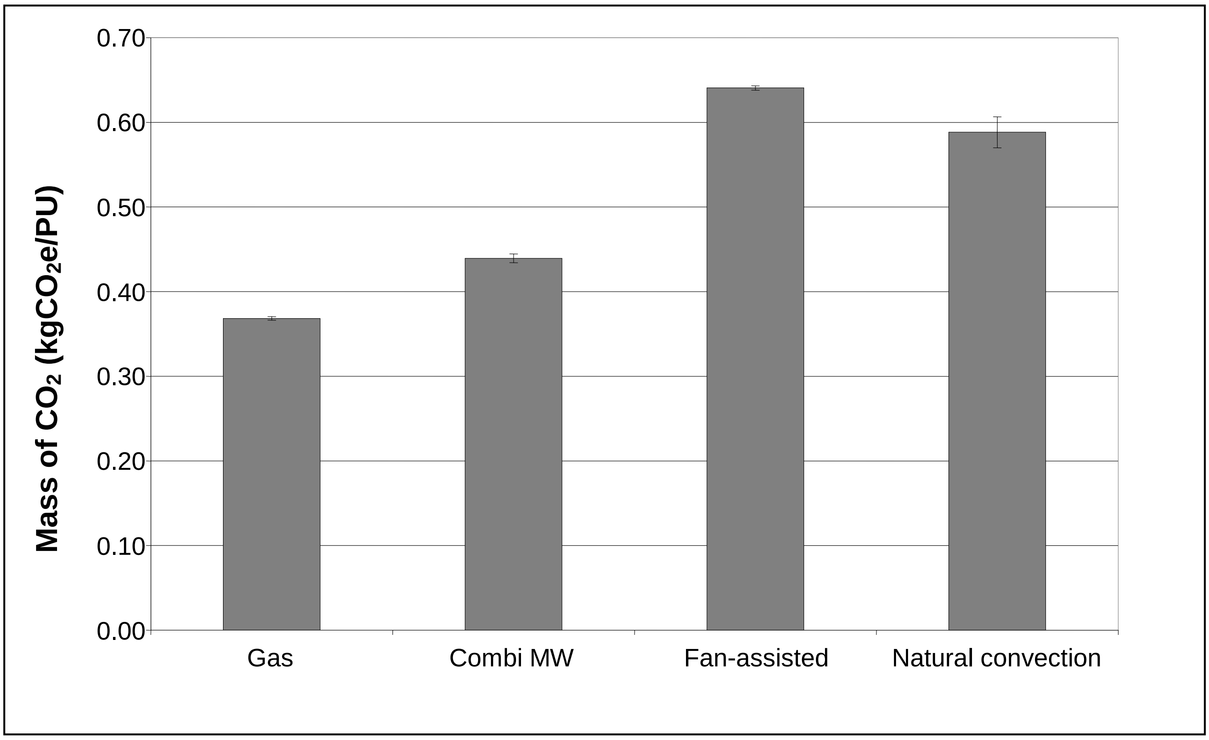


Figure 6-7: GHG emissions for cooking chicken stew using different appliances

Chicken stir-fry

The stir-fried chicken was cooked using a gas hob, induction hob and electric ceramic hob. A basic recipe for stir-fry found on the internet was used.

Values for the energy consumption and the GHG emissions obtained for cooking a stir-fry chicken dish are given in Table 11.

Average values	Units	Gas	Ceramic hob	Induction
Energy consumption	(kWh)	0.67	0.39	0.32
GHG emissions	($kgCO_2e/PU$)	0.1231	0.2040	0.1674

Table 11: Energy consumption and GHG emissions for cooking stir-fried chicken

Results show that when using the gas hob for stir-frying a chicken dish, the energy consumption was more than twice as high as for the induction hob. However, when considering the GHG emissions, the gas hob had the lowest value with associated emissions of 0.1231 kg for cooking the whole dish. The highest GHG emission was associated with the use of the ceramic hob (Figure 6-8).

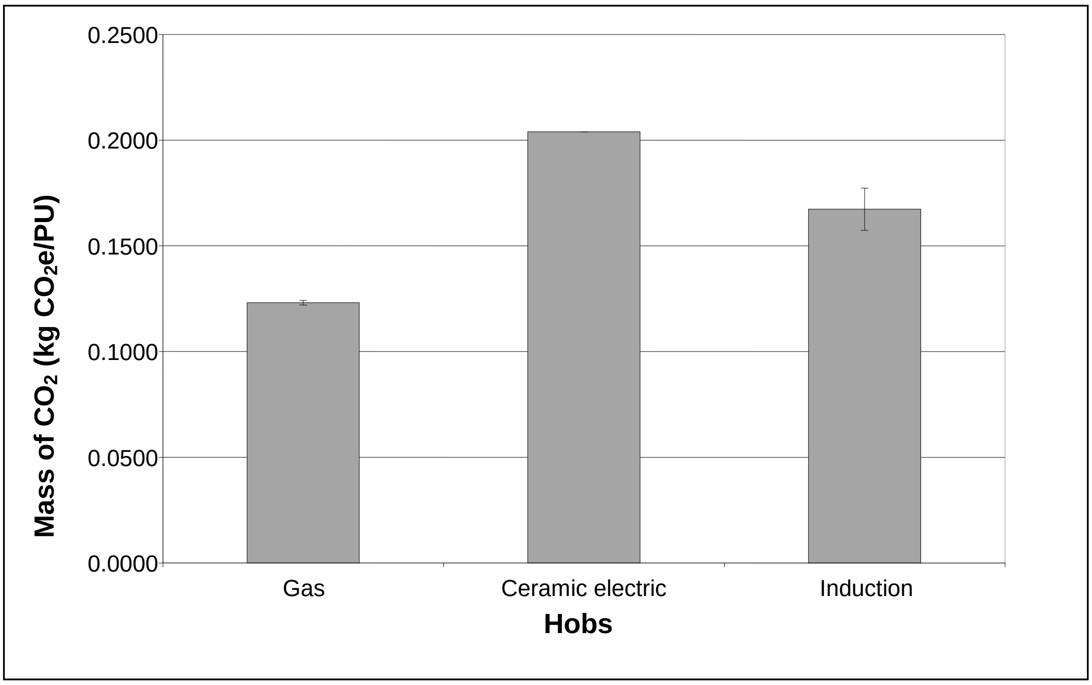


Figure 6-8: GHG emissions for stir-frying chicken when using different appliances

Conclusions from cooking of meat dishes

Trials for roasting chicken were carried out as close as possible to that used in a home situation. A pre-heating period was used for all ovens; however, most pre-heating used the automatic thermostat control built-in on each oven, except for the gas appliance where the oven manufacturer's instructions were followed. Cooking time for roasting chickens in the combination microwave oven varied from 30 to 55 minutes, in the gas oven it was 1 hour 15 minutes, fan-assisted ovens ranged from 58 minutes, to 1 hour and in 18 minutes and the natural convection oven it was 1 hour and 25 minutes.

Overall the results indicated that, although the gas oven had the highest average energy consumption values, when the emissions were taken into consideration it provided the lowest amount of greenhouse gases (0.4605 kgCO_2e/PU), followed by the combination microwave (0.4934 kgCO_2e/PU), the natural convection oven (0.6825 kg CO_2e/PU) and the fan-assisted oven (0.7186 kg CO_2e/PU). However, although the average values for combination microwave ovens were much lower than for fan-assisted ovens, the variation between microwave combination models (8 different microwave ovens models) was large and in some cases the GHG emissions were as high as those measured for fan-assisted ovens. It should be noted that only one gas and one natural convection oven were used in these trials and variation within different models was therefore not considered here. In the case of combination microwaves (8 different models) and fan-assisted ovens (5 different models), data from previous tests was also considered and hence variation between models.

The CO_2 emissions when cooking a chicken stew had a similar pattern as when roasting chicken, with the gas oven producing the least GHG emissions (0.3684 kg CO_2e/PU) followed closely by the combination microwave oven (0.439 kg CO_2e/PU). The natural convection and the fan-assisted ovens had the highest emissions, 0.588 and 0.641 kg CO_2e/PU respectively. In the case of the stew the hob was also used for preparation of frying vegetables and browning the chicken (about 5 minutes) before finishing cooking the dish in the oven (40 minutes); this was taken into consideration when assessing the total energy consumption for cooking a stew dish.

In the case of the chicken stir-fry the emissions were lowest for the gas hob (0.1231 kg CO_2e/PU) followed by the induction (0.2040 kg CO_2e/PU) and electric ceramic hob (0.01674 kg CO_2e/PU). Cooking time for the stir-fry varied from 11min 30 s with the gas and induction hobs to 12 min 50 s with the ceramic hob.

7 CONSUMER BEHAVIOUR

The experimental data obtained was complemented by work carried out at FPIU to gather information on domestic storage, preparation and waste practices. A review of the literature found no study focussing on a method to assess GHG emissions from food preparation, while taking account of the interaction between the person preparing the meal and the appliance used. The objective of this part of the study was to build on the appliance studies described in Chapter 6, to assess how effectively process and equipment interact. The analogy for this interaction is based on an Overall Equipment Effectiveness measure.

Overall Equipment Effectiveness = Availability x Performance x Quality

For an appliance such a measure could be:

Availability: The amount of time the appliance is used as a proportion of the time it is switched on. Losses occur when the appliance is switched on too early, or left on when no longer needed.

Performance: This is the proportion of the equipment capacity used. In this case, losses occur through wasted space in the oven or fridge.

Quality: The amount of food that is actually consumed as a proportion of the food prepared. Losses occur when prepared food is not used (e.g. thrown away).

Example

An oven was switched on for 100 minutes.

The oven was used for 90 minutes and left switched on for 10 more minutes:

→ 90% available.

Half the oven cavity was used (by using only one shelf): → 50% performance.

Four out of five portions of cooked food were consumed: → 80% quality.

OEE = 90% x 50% x 80% = **36%**

In order to identify variations between the experimental set-up and real consumer behaviour, the preparation of ready made and home made cottage and apple pies was observed. Differences to the findings from the laboratory environment were pointed out. Two focus groups were used to test the observations and to identify further potential issues (e.g. effects of buying larger amounts of raw materials than required, treatment of plate waste, issues around types and sizes of food packaging).

7.1 Mapping of several cooking processes

Four standard cooking processes were observed with the purpose of discovering how home preparation/cooking deviated from the ideal process. The ethical terms of the study were explained to the participants, but they were not briefed on the environmental nature of the study, to minimise a possible impact on their practices. The brief was that the objective of the study was to observe how people cooked in real life situations.

Table 12 shows the FRPERC emissions data used, and Table 13 shows a summary of each of the cooking processes. The FRPERC data was used to provide values of mass of CO_2e per minute for each appliance by dividing the cooking emissions per unit by the cooking time. This was used to convert the observed cooking times to environmental outputs. For each type of meal, the total times for all appliances and the time for each individual appliance (hob, oven etc) were recorded. Each time recorded was analysed in terms of value added and waste.

Appliance	**kg CO_2e/minute**	**FRPERC reference**
Gas Hob	0.0034	See chapter 6
Electric Fan Oven	0.0084	
Gas Oven	0.0059	
Microwave	0.0118	

Table 12: Emission rates of domestic appliances

During the cooking process, the cottage pie ready meal emitted approximately 60% less CO_2 than the home prepared meal, while values for the preparation of the apple pies were quite similar for the ready meal and the home prepared meal. These findings are limited to the preparation part of the process and do not include GHG emissions arising from packaging or other parts of the chain. Heating plates, switching the oven on too early or leaving it on too long, oven capacity loss by using only one shelf, storage and reheating, and throwing part of the prepared food away were five areas of waste observed outside the core process considered in previous chapters.

	Family Cottage Pie	**RM Cottage Pie**	**Family Apple Pie**	**RM Apple Pie**
Appliance time (mins)	181	63	71	36
Waste time (mins)	37.35	6.05	18.7	5
Value Add % (mins)	**79.36%**	**90.40%**	**73.66%**	**86.11%**
Gas Hob (mins)	52	23	7	0
Gas Hob Waste (mins)	11.7	5.75	0	0
Hob CO_2e	0.1768	0.0782	0.0238	0
Hob Waste CO_2e	0.03978	0.01955	0	0
Oven (mins)	103	37	44	35
Oven Waste (mins)	25.65	0	15	4.375
Type	Elec	Elec	Gas	Elec
Oven CO_2e	0.8620	0.3096	0.2592	0.2929
Oven Waste CO_2e	0.2147	0.0000	0.0884	0.0366
Microwave (mins)	0	0	6	1
Microwave Waste (mins)	0	0	3	0.625
MW CO_2e	0	0	0.07065	0.011775
MW Waste CO_2e	0	0	0.035325	0.007359375
Other appliances (mins)	0	3	0	1
Total kg CO_2e	**1.0388**	**0.3878**	**0.35365**	**0.304675**
Waste CO_2e	**0.25448**	**0.01955**	**0.123725**	**0.04396**
Value Add % (CO_2e)	**75.50%**	**94.95%**	**65.01%**	**85.57%**

Table 13: Mapping summary

7.2 Focus Groups

Participant Selection

Groups were sought based on two factors: socio-economic background[56] and age.

Class	Label
1	Managerial and professional occupations
2	Intermediate occupations
3	Small employers and own account workers
4	Lower supervisory and technical occupations
5	Semi-routine and routine occupations

Table 14 - Socio economic classifications

The aim was to achieve a qualitative insight, via focus groups of both factors, into how prevalent the issues identified in the mapping were, to uncover further issues, and to investigate how GHG emissions could be reduced. Group 1 covered the Over 40's non-professionals, and group 2 covered professionals for a wide age range. As seen in Table 15, there is an opportunity for further research with the lower ages across all socio economic groups.

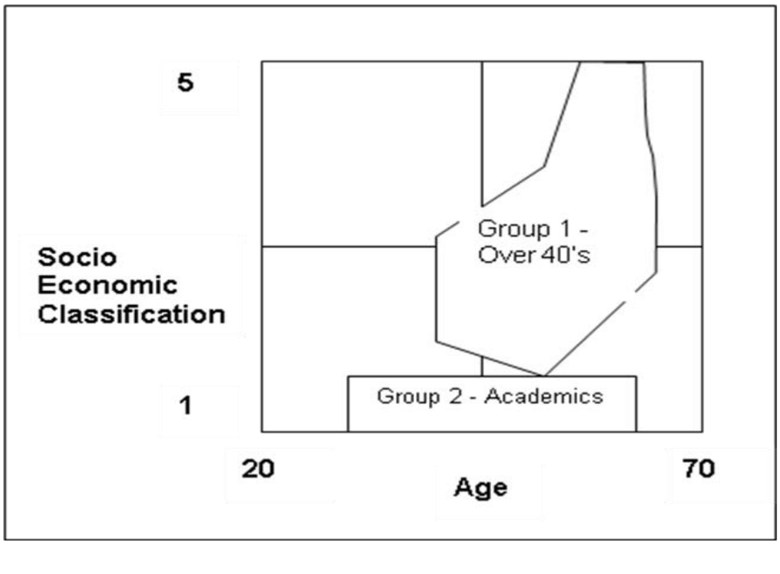


Figure 7-1: Focus group overview

Group 1: Over 40’s

The focus group was planned for 1 hour but actually ran to 1.5 hours. All of the seven participants were known to the researcher and their backgrounds in the table below are based on the researcher’s opinion:

Household No. (Opinion No. in text)	**Gender**	**Age**	**Socio economic group**
1	M	60-70	3
1	F	50-60	4
2	M	50-60	3
2	F	40-50	2
3	F	40-50	2
4	M	60-70	3
4	F	60-70	5

Table 15 - Focus Group 1 Participants

A. Storage and Waste

Initial process of buying the product and storing it until needed for a meal

The participants generally shopped weekly, with occasional top-up shops in between. Supermarket pack sizes were identified as a major source of waste, with BOGOFs highlighted as a particular issue. For one participant (4), this required packs to be broken down for immediate use and storage in the freezer (requiring a freezer bag). Other more 'time poor' participants (2&3) said the extra portions were often wasted. Over cautious code life and use- by dates were cited as a major form of waste. (1) stated that they applied common sense to these whilst their daughter’s household abided strictly to the dates, leading to large amounts of waste. (3) also adhered strictly to dates. Supermarket fruit and vegetables were stated as having shorter life than in previous generations (4). This was agreed by the group as a further major cause of waste. In response, the researcher stated that studies had shown waste of 20% or more, which was seen as conservative by the group.

All participants had two freezers: a large stand alone freezer and a smaller one integrated with a fridge. Two participants (1&2) said they kept their freezer as full as possible as this gave maximum efficiency. (1) cleared their freezer out every six months, and the other participants at intervals up to several years, governed by when the frost built up too much. Some foods were left in the freezer for a considerable unknown time, and were disposed of during clear outs because of uncertainty of code life. (1) had started writing dates on freezer bags of undated food including left-overs to reduce this waste.

Cooking and consumption waste

Cleaning product proliferation was identified as a form of waste and carbon emissions. There were a variety of opinions around dishwashers versus hand washing. (3) had seen an article saying that dishwashing was more efficient. (1&2) used handwash/dishwasher according to batch size for convenience.

Restorage and final waste

Whilst all respondents put unused portions in the fridge, these were often forgotten about. After a few days these are often thrown away.

B. Cooking

Modes of cooking: Gas/Electric, Oven/Micro

All participants had gas hobs and microwaves. All participants had gas ovens except one (who had three electric ovens). Non-fan assisted ovens only had one shelf that reached the correct temperature (1) so the other shelves were felt to be largely redundant anyway. For fan assisted ovens, only one shelf was in general use but everyone wanted the flexibility of multiple shelves. The researcher asked if anyone planned cooking to maximise oven capacity utilisation – no one did.

Heating plates

On almost all meal occasions plates were heated (including take-aways). This was usually done under the grill, but one participant (1) sometimes placed the plates under a hot tap. Another participant (2) mentioned that a previous microwave that they owned had a plate warming setting and probably used less energy.

Appliance switched on too early/too long

All participants switched on an appliance for longer than necessary to ensure safety and quality. (See query below regarding gas oven temperature indicator.)

Disposal/Recycling

All members of the group (except (3)) had bought into recycling schemes provided by local authorities and fully utilised them.

C. Awareness

How do greenhouse gases occur in the home food preparation process?

This question was addressed with a great deal of passion, starting with the wider context. The participants agreed that global warming is a reality but the balance of opinion was that this was principally part of the evolution of the earth due to the solar cycle and other external factors rather than human activity. However, there was limited acceptance that human beings were not helping to mitigate global warming and a certain percentage of global warming could be due to human activity.

(1) stated a target of 20% reduction of carbon by 2015 but there was no awareness of any 2050 target. The whole group were aware of the general concept of reduction, but did not see personal benefit within their life expectancy. Technology would make it possible to achieve massive improvements (2). The key point that everyone made was that the UK was a relatively small polluter and that the USA and China had not bought into the process. Without everyone signing up, the UK initiative would have little impact and was not relevant. Another perception was that of moving GHG emissions through 'deindustrialisation' as Western industry redeployed to the developing world. There was general cynicism towards government taxation (an excuse to raise taxes) and regulation of industry (industry spending millions (4)). Everything is carbon footprint (1).

The perception of where carbon emissions occurred in the home food process was ozone depletion through refrigeration. The cooking and waste processes were estimated to be low by comparison.

Perceived forms of mitigation?

The group identified three decision factors relating to consumer acceptance of government regulation and advice concerning mitigation. These were quality, time and energy. Five out of seven participants rated quality of cooking as the most important factor whilst the other two rated time (convenience) as most important. Lower energy processes would only be used where they delivered the same quality and convenience. The key to government advice being followed was energy/emissions savings that improved, or at least did not reduce, quality and time. This message would have to be communicated in a way that did not lead to the perception that 'we were being told how to look after our own food' (1).

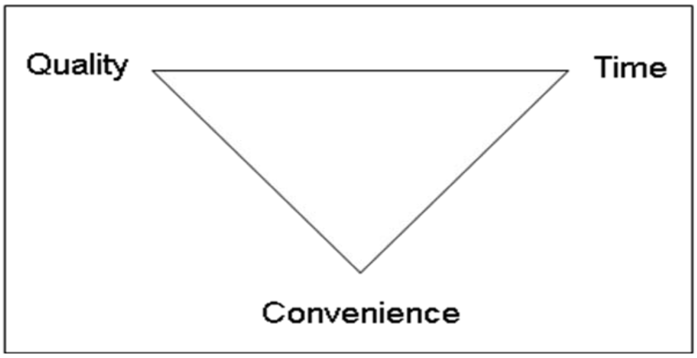


Figure 7-2: Observation group 1 priorities

All participants left the cookers on standby to keep their clocks running. The question asked was: what % of energy did this use? Pressure cookers were proposed as the most effective way of saving energy by five of the seven participants. One of the other participants (2) agreed this was a good idea and would probably purchase one but had concerns regarding safety with regard to the weight of the vessel and steam produced. The gas ovens of six of the participant had no temperature indicator. The question was raised as to why such an indicator was not commonly available and if it was, if it would help with pre-heating.

Group 2 - Academics

Focus group 2 consisted of the participants described in Table 16. This group discussed the same issues as focus group 1: storage and waste, cooking, and awareness. Results from the discussion of focus group 2 are shown below.

Household No. (Opinion No. in text)	**Gender**	**Age**	**Socio economic group**
1	M	50-60	1
2	F	30-40	1
3	F	20-30	1

Table 16: Focus group 2 participants

A. **Storage and Waste**

Initial process of buying the product and storing it until needed for a meal

The participants shopped weekly or fortnightly at a supermarket with top-up trips to local stores as frequently as every other day. One participant (2) used a box scheme for a fortnightly shop for vegetables. This was stated to be economically and environmentally better than supermarket produce with minimum recyclable cardboard packaging. Packaging and particularly supermarket packs were identified as the main form of waste. Over-cautious observation of code life and use by dates, especially with younger members of households, was considered wasteful (1).

All participants had fridges and freezers, with a maximum of three fridges and a freezer (1). Fridge management was an issue that led to wasted food. There was no accountability for cleaning and it happened about once every six weeks "when it gets smelly" (1). The general perception was that up to 10 percent of food is thrown away without ever being opened.

Cooking and consumption waste

Portion control was identified as an issue in home cooking, especially with rice and pasta (2). Portion lines on pasta packages are not commonly found any more.

Restorage and final waste

Fridge management was identified as a key source of waste, with vegetables being the greatest area of waste. Participant (3) stored vegetables in a cool area of the garage, making the fridge less cluttered and easier to manage. At least 10% of food is wasted in this way (All).

B. Cooking

Modes of cooking: Gas/Electric, Oven/Micro

All participants had gas hobs and microwaves. All participants had gas ovens except one. Whilst no participant attempted to maximise oven utilisation on a daily basis, participants 1 & 2 were aware of this and did increase utilisation on some occasions. Participant 1 cooked meals in a full oven to freeze for the following one to two weeks with the implicit trade-off of freezing and reheating energy. Participant 2 would sometimes cook fresh fruit from the garden to fill up the oven.

Heating plates

On some meal occasions, principally Sunday lunch, plates were heated.

Appliance switched on too early/too long

Safety was key in ensuring that pre-heat was established and sometime appliances were left switched on for too long. One participant (1) sometimes had a plate warming drawer which had no warning light so could easily be left switched on.

Disposal/Recycling

All members of the group fully utilised recycling and participant (3) composted unused vegetables.

C. Awareness

How do greenhouse gas emissions occur in the home food preparation process?

The group were aware of government targets on carbon reduction. There was no consensus or specific knowledge on energy use and emissions in cooking. The perception (2) was that most energy and emissions were embedded in the food.

Perceived forms of mitigation?

The main form of mitigation suggested was awareness in terms of the economic costs of wasted appliance energy through publication of ‘how much it cost’ to leave appliances on, and the promotion of energy monitors and technological solutions to prevent overuse. The greatest impact was perceived to be from supermarkets selling products in right sized packs.

7.3 Analysis and Discussion

The focus group issues were assessed by the researcher on a scale of 0 (no issue) to 5 (very important issue) for both focus groups. For both groups, product entering the home had issues concerning supermarket pack size (too big) and use-by dates. Fridge management was considered a vital issue, especially for vegetables, with the consensus that at least 20% of food was disposed of. In the cooking cycle, the key issue was remembering to switch appliances off. Recycling of product leaving the home was seen as essential, with a high level of support.

Waste Issues	**Group 1**	**Group 2**
Supermarket BOGOFS and pack size	5	3
Sell by dates	4	3
Vegetables	5	5
Left-overs in fridge forgotten	5	5
Waste > 20% (10% before opening and 10% unconsumed)	5	5
Portion control of rice/pasta	0	4
Too much packaging	0	4

Energy Issues	Group 1	Group 2
Multiple fridges/freezers	5	3
Cleaning product proliferation	5	0
Plate heating oven/tap/heater (all/Sunday roast)	5	2
Appliances switched on too early/long	4	4
Cookers on standby	4	0
Mitigation Issues	**Group 1**	**Group 2**
Better fridge/freezer housekeeping	4	4
Dates on freezer bags	4	3
Gas oven temperature sensors/bleepers	4	2
Recycling	5	5
Pressure cookers	5	0
Oven utilisation (weekly cooks for freezer/fruit from garden)	0	2
Compost	0	4
Lines on rice/pasta packets	0	4
Vegetable storage in cool area	0	2
Green suppliers with less packaging	0	3
Awareness and Advice	**Group 1**	**Group 2**
Carbon reduction targets	1	4
Ozone depletion refrigeration	3	0
Cooking emissions	1	2
Waste disposal	1	2
Packaging (reduction)	0	5
Quality and cost (electricity monitors)	5	2

Table 17: Issues discussed in the focus groups

Estimation of overall equipment effectiveness

The overall equipment effectiveness assessment was estimated to be as follows:

OEE = 80% x 70% x 90% = **50%**

with:

Availability = 80%: Losses are 10% of food not opened and 10% of time where appliances are switched on too early or left on when no longer needed.

Performance = 70%: Fridges had high levels of utilisation but incurred losses of availability and quality. Cooking appliances were generally only partially utilised (one shelf). The estimate is 30% of appliance energy lost, but this would need further study to understand the proportion of energy used between refrigeration and cooking.

Quantity = 90%: At least 10% of food prepared is not consumed.

The tentative conclusion from this section of the report is that the domestic procurement, refrigeration, and cooking process is just 50% efficient. This is clearly a twelve day pilot study and further research could more accurately define this issue, as it is likely to be as important, if not more important, than appliance choice in reducing household energy consumption and GHG emissions during the cooking process. Ingredient packaging and pack size are a key driver of waste in the home.

8 THE LIFECYCLE GHG EMISSIONS OF A RM COTTAGE PIE

DEFRA has funded a series of projects to assess the carbon footprints of several food products over all stages of the food supply chain, from raw materials production through to disposal (see Figure 8-1).

Figure 8-1: Stages required in the GHG assessment of a food product

The work presented on the life cycle GHG emissions of a ready meal cottage pie links together the findings from three different DEFRA-funded projects. ADAS and Campden BRI looked at the impact of the agricultural and manufacturing stages of the cottage pie in FO0404 "Scenario Building to Test the PAS", while researchers from Brunel University studied the contributions of the retail sector to the carbon footprint of the cottage pie in FO0405 "Greenhouse Gas Impacts of Food Retailing". Finally, the impact of consumer use and final disposal of the ready meal was assessed by Campden BRI in this project: FO0406/0409 "Understanding the GHG Impacts of Food Preparation and Consumption in the Home".

As seen in the previous chapters, the ready meal cottage pie assessed is a complex product with over 20 different ingredients, some of which are present in very small quantities. The main ingredients of the cottage pie are mashed potato and cooked beef, which together make up over 70% of the cottage pie (in mass). Figure 8-2 shows a flow diagram of the life cycle of this ready meal, grouped in the life cycle steps Raw Materials, Manufacture, Distribution and Retail, Consumer Use and Disposal/

Recycling as shown in Figure 8-1.

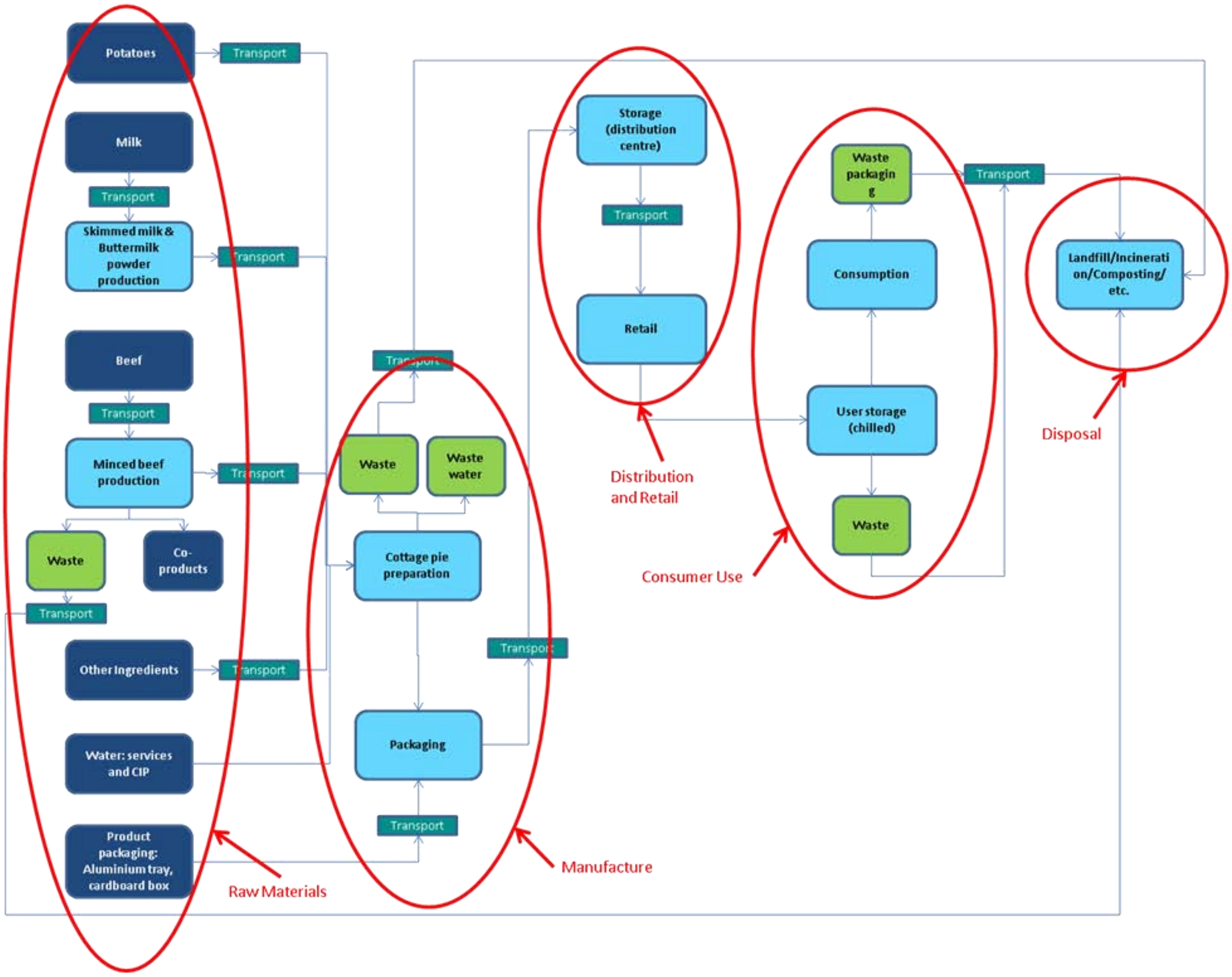


Figure 8-2: Flow diagram of the life cycle stages of a cottage pie ready meal

The impact of all life cycle stages on the overall carbon footprint of the ready meal is shown in Figure 8-3. Even though the actual figures may change depending on the assumptions made, general trends are clear: the influence of manufacturing, retail and the consumer use phase are about equally important, while the production of raw materials, including agricultural operations, is the "emission hot-spot", contributing over 60% to the life cycle GHG emissions of the ready meal.

Although final disposal of the cottage pie and of the meal itself (in case it is not eaten) contributes only a small amount to the carbon footprint of the cottage pie, it is important to stress that wasting the product in its entirety results in unnecessary emissions up the supply chain.

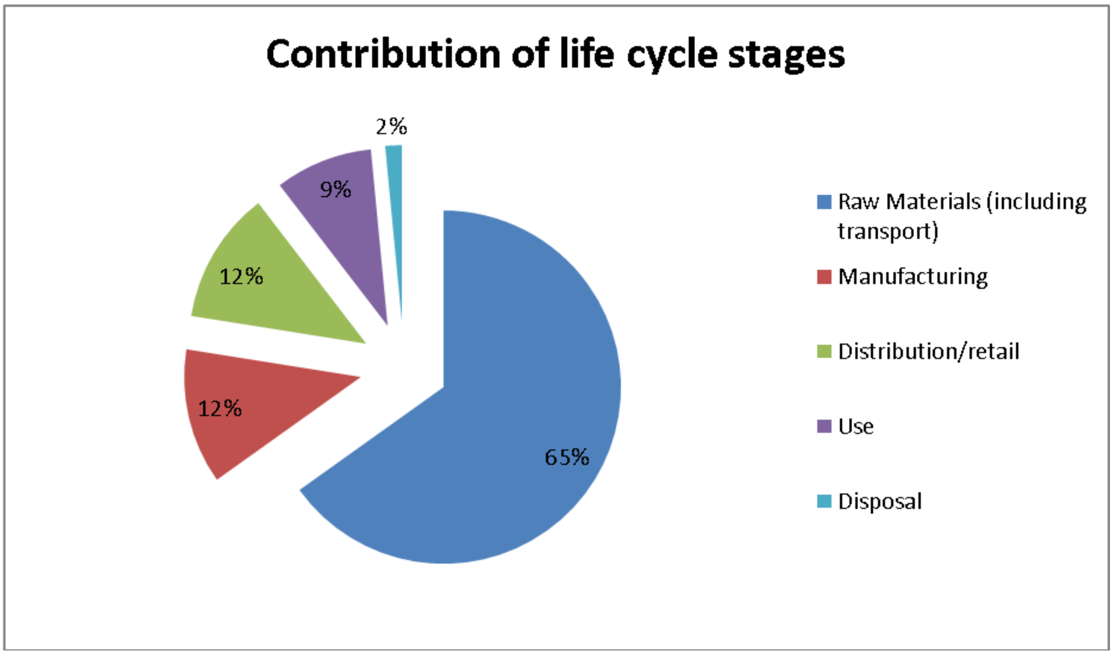


Figure 8-3: Impact of the life cycle stages on the carbon footprint of a cottage pie ready meal

ADAS has worked together with farmers and growers to assess the impact of the agricultural stage, and Campden BRI has estimated the GHG emissions associated with the production of other raw materials. In Figure 8-4, the contributions to the GHG emissions of the raw materials are shown.

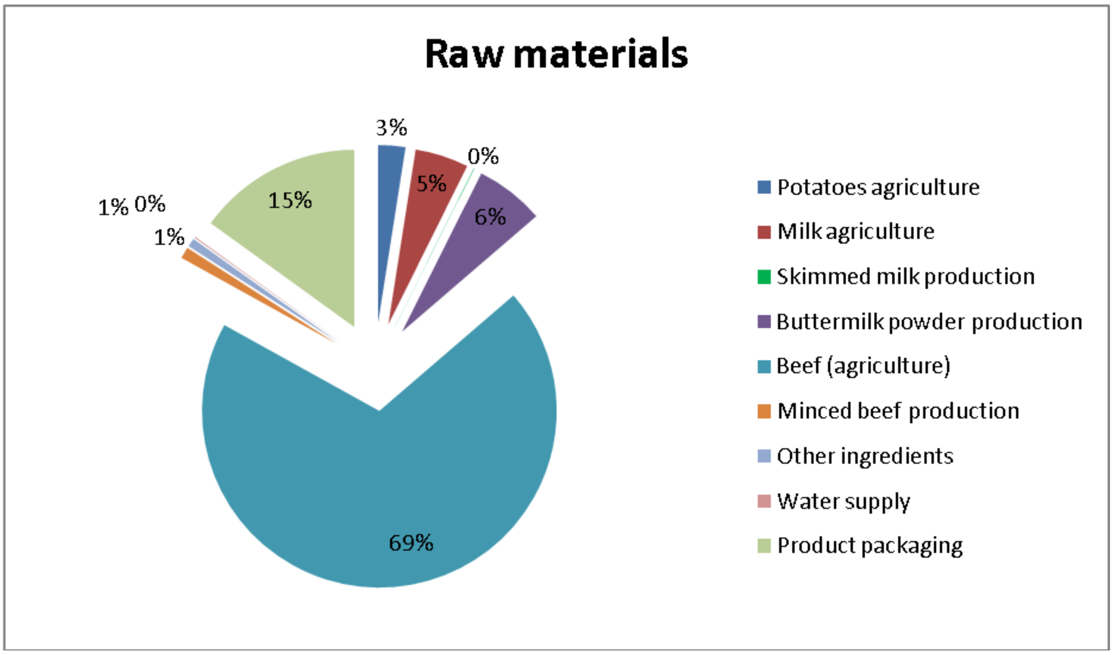


Figure 8-4: Contribution of the different raw materials to the GHG emissions of this life cycle step

As shown in Figure 8-4, cattle rearing (Beef agriculture) makes the biggest impact on the overall carbon footprint of cottage pie raw materials. Cattle manure releases carbon and nitrogen gases, which contribute to the carbon footprint. Also, fertilisers used on grass or for the growing of fodder for winter feed release nitrous oxide, which is almost 300 times as damaging as carbon dioxide (global warming potential (GWP) of N_2O: 298[7]). The main factor, however, is that ruminants generate methane as they digest their feed.

This project has shown that the method of preparation of the cottage pie has a big impact on the contribution of this life cycle stage to the overall life cycle of the ready meal. Calculations for Figure 8-3 were carried out assuming that the ready meal was heated in an electric fan oven. Figure 8-5 shows that if a microwave is used instead to reheat the cottage pie, the carbon footprint of this stage drops dramatically, from 9% to 2% of the total GHG emissions.

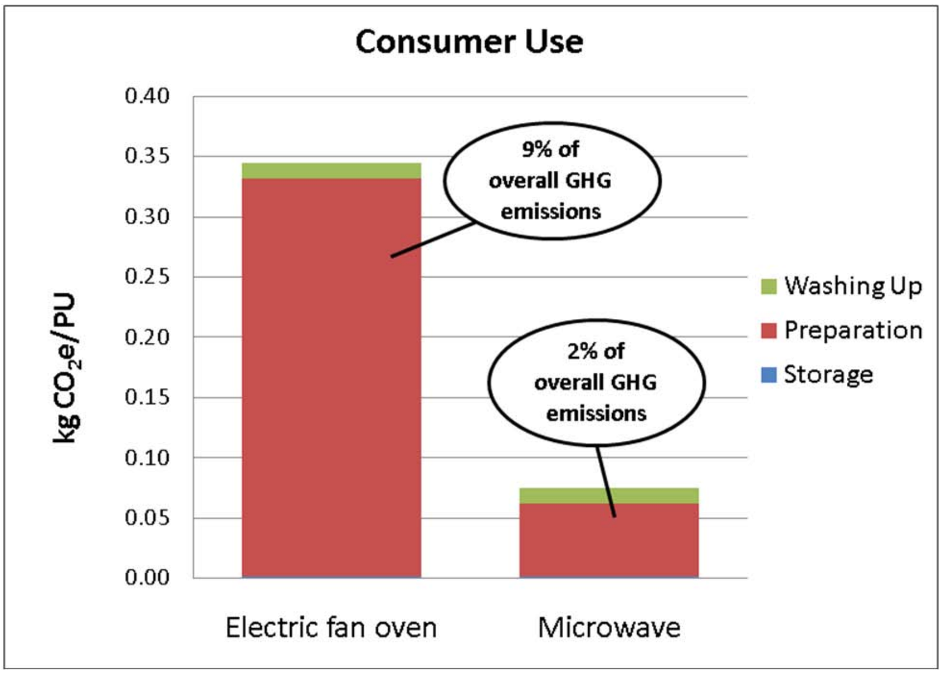


Figure 8-5: Impact of method of preparation on the carbon footprint of the consumer use phase

The study shows that it is possible to carry out a product carbon footprint following the methodology of PAS 2050. Because this is one of the first products assessed in accordance with the new specification, there is not a great deal of secondary data available for the calculations. Hopefully this will change, as the GHG emissions of more products are assessed.

The above findings have also been published as a Defra publication leaflet[57].

9 CONCLUSIONS AND OUTLOOK

A literature review showed that few studies linking consumer storage and preparation of foods with the associated GHG emissions have been carried out to date. The aim of the work presented in this report was to provide data on the carbon footprint of the use phase of various food products as well as to compare the impact of several ready meals and their home made equivalents during their use phase. Further, the influence of choice of appliances and cooking methods on the GHG emissions associated to the use phase of several foods were assessed. Finally, a study combining process mapping and focus groups was intended to explore the understanding that consumers have of the issues and to highlight aspects of consumer behaviour which might contribute to increased GHG emissions during the use phase of food products.

Data regarding the carbon footprint of the use phase was gathered for a cottage pie, an apple crumble, home baked bread and home prepared apple juice. For home baked bread, both manual preparation of bread from the ingredients (including baking in the oven) and preparation using a bread-maker were assessed. Using a bread maker led to a smaller carbon footprint as compared to using an oven to bake the bread.

For both cottage pie and apple crumble, the GHG emissions associated with the preparation of a ready meal were compared to those of the equivalent home made meal. In both cases, the carbon footprint of the use phase of the ready meal was substantially lower than that of the meal prepared from the ingredients. The data collected in this study is not sufficient to compare the overall life cycle emissions of the two meal types. There might be substantial differences between the two meals regarding the amount of GHG emissions associated with the life cycle steps not included in this study. For example, the manufacturing of ready meals will include a "pre-cooking" step, which might lead to added GHG emissions.

The previous chapters show that it is not straightforward to assess the GHG emissions associated with the consumer use phase of food products. Investigation carried out by researchers at FRPERC shows that the carbon footprint of the use phase of a food product (here: a ready meal cottage pie) can vary greatly depending on the energy efficiency of the appliance used to prepare the dish, and also depending on the form of energy used. This was confirmed for the cooking of vegetables using different hobs, and also for the preparation of various meat products. In very general terms, and for the products studied, using a microwave to prepare a given food will lead to the least GHG emissions, followed by using a gas hob or oven. Electrical hobs or ovens generally show the highest GHG emissions for the preparation of a given food product.

At the same time, the choice of preparation method for a certain food, e.g. chicken, has a big impact on its carbon footprint. The use of an oven during preparation of the food will increase the GHG emissions of a certain dish as compared to a dish prepared on the hob alone. For example, the chicken stir fry assessed in this work will have a lower carbon footprint per functional unit than a chicken stew prepared in the oven, regardless of the type of appliance used.

Consumer behaviour regarding food storage, preparation and waste issues varies. While a general awareness of climate change seemed to exist, the consumers who took part in the focus groups were not very aware of their own impact on GHG emissions and what action they could take to reduce their impact.

Mapping of the process of preparation of several meals revealed energy use and food waste as major issues, and the consumer focus groups confirmed these findings. Thus, under-utilisation of appliances (e.g. only using one shelf of an oven), forgetting to turn appliances off, and plate warming were factors which contributed to an increased use of energy. The consumers taking part in the study agreed that they threw away about 20% of the food they purchased, unopened ingredients as well as unconsumed cooked food, and pointed out that they thought this waste issue was due mainly to excess packaging and oversized packs of food.

9.1 Recommendations to lower the GHG impact of food preparation in the home

A few sensible messages to the consumer could be based on the findings of this study:

- **Use the microwave when preparing small portions of food**

Due to the short time required for the preparation of food in the microwave, and to its relative energy efficiency, GHG emissions will be reduced as compared to the use of conventional hobs and ovens. The energy required to prepare food in the microwave increases when bigger amounts of food are prepared at the same time. Theoretically, this could lead to a situation where preparation of big amounts of food in an oven uses less energy than preparation of the same amount of food in the microwave. This aspect was not investigated in the present study. However, it is safe to say that the microwave is the most efficient appliance for single portions.

- **If possible choose gas fired hobs over electric hobs**

Gas fired appliances are generally less energy efficient than electric appliances. However, electricity has to be generated (currently, the UK grid mix includes electricity generated in coal or gas fired power stations, as well as from other sources), which entails a loss in energy efficiency. Gas is a primary source of energy, and thus, overall, its use results in lower GHG emissions.

- **Avoid the use of the oven for preparing meals**

As pointed out in previous chapters, the use of an oven is especially energy intensive and results in greater GHG emissions when compared to other methods of food preparation. Thus, the preparation of a chicken stir fry will result in less GHG emissions per portion than the preparation of a chicken stew in the oven.

If the oven is the appliance of choice for the preparation of a specific meal, use of the oven space should be maximised. Less GHGs are emitted per portion if the oven is used to prepare a family meal rather than a single portion.

- **Try to make the best use of bought ingredients and unconsumed cooked food**

It is important to stress that when food is thrown away, this does not only result in GHG emissions from the disposal of the food product, but also in unnecessary GHG emissions from all the previous life cycle steps (e.g. extraction of raw materials, agriculture, manufacturing, etc.). Making shopping lists and meal plans may help to avoid throwing away unused food, while there are plenty of recipes for reusing unconsumed cooked food.

9.2 Opportunities for future work

As seen, currently there is little data regarding the use phase of food products and associated GHG emissions available. More investigation into the GHG impact of the use phase of additional food products could shed more light on the question of how the consumption of different foods affects climate change. Messages to the consumer regarding changes to more environmentally friendly behaviour should be based on a substantial amount of good quality data. Ideally, this use phase data for food products could be freely available in a database.

This research shows that depending on the assumptions made regarding the use phase of a food product - storage, preparation and disposal - the GHG emissions associated with the use phase of a product can vary substantially. In order to reduce the uncertainties related to these calculations, PAS 2050 demands that a use profile, consisting of criteria against which the GHG emissions arising from the use phase are determined, be recorded for each food product. To allow comparison with other products belonging to the same product category (e.g. ready meal cottage pies from different manufacturers), ideally the use profile should be based on Product Category Rules (PCR), international standards, national guidelines or published industry guidelines that specify a use phase for the product being assessed. At the moment, there are approved PCRs for only 4 different food products. Future research should have an input into the development of use profiles and finally PCRs for a wide range of other foods.

Finally, the emission of GHGs is not the only environmental impact of food consumption. The use phase of food products also affects water use (water footprint), ozone depletion, eco-toxicity, and other impact factors commonly used in life cycle analysis (LCA). Future research into the consumer use phase of foods could explore these aspects further.

10 REFERENCES

1. PAS 2050 - "Specification for the assessment of the life cycle greenhouse gas emissions of goods and services", BSI, 2008.
2. BS EN ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and framework.
3. BS EN ISO 14044:2006 - Environmental management - Life cycle assessment - Requirements and guidelines.
4. Guide to PAS 2050 - How to assess the carbon footprint of goods and services, Crown, 2008 and Carbon Trust, 2008.
5. Guidelines to Defra's GHG conversion factors for company reporting, Defra, 2008.
6. Guidelines to Defra's GHG conversion factors - Annexes, Defra, 2008.
7. Climate Change 2007 - The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S. et. al.. Chapter 2, Table 2.14, IPPC, 2007.
8. UK Government's Energy White Paper. http://stats.berr.gov.uk/ewp/index.asp (accessed on 03/02/2009).
9. UK's Climate Change Bill: http://www.opsi.gov.uk/acts/acts2008/pdf/ukpga_20080027_en.pdf (accessed on 03/02/2009).
10. United Nations Department of Economic and Social Affairs - "Sustainable consumption and production." 2007.
11. Michaelis, L. and Lorek, S. Consumption and the Environment In Europe: Trends and Futures, Environmental Project No. 904, Danish Ministry of the Environment, 2004.
12. Office for National Statistics - "The impact of UK households on the environment through direct and indirect generation of greenhouse gases." 2004.
13. Carbon Trust - "The carbon emissions generated in all that we consume." Carbon Trust, 2006.
14. Defra - "Critical Review of Data for Environmental Impacts of Household Activities: Executive Summary Report." Defra, 2006.
15. MTP - IBNC16: Innovation Briefing Note: Vacuum insulated panels for refrigerated appliances. Updated: 2008.
16. Statutory Instrument 2004 No. 1468: Energy Conservation: The Energy Information (Household Refrigerators and Freezers) Regulations 2004.
17. Statutory Instrument 2007 No. 2037: Energy Conservation: The Ecodesign for Energy-Using Products Regulations 2007.
18. (http://www.gfk.com) from: MTP - BNC08: Assumptions underlying the energy projections for domestic cold appliances. Last reviewed: 2008.

19. MTP - BNC10: Energy efficiency test methodologies for domestic cold appliances. Updated: 2008.

20. MTP - BNC11: Domestic refrigerator test standard vs real-use energy consumption. Updated: 2007.

21. Sidler, O. Waide, P. and Lebot, B.: "An experimental investigation of cooking, refrigeration and drying endues in 100 households." Presented at the summer study on energy efficiency in buildings for the American Council for an Energy-Efficient Economy (ACEEE) meeting, 2000.

22. DECADE Transforming the UK Cold Market 1997 Environment Change Unit.

23. Faist, M.; Kytzia, S.; Baccini,P.: The impact of household food consumption on resource and energy management. International Journal of Environment and Pollution, 15 (2), 183-199, 2001.

24. Garnett, T.: "Food refrigeration: what is the contribution to greenhouse gas emissions and how might emissions be reduced?". FCRN working paper, 2007.

25. Sustainable Products 2006: Policy Analysis and Projections, MTP, 2006.

26. Swain, V.: "A short review of energy information in domestic refrigeration and cooking." FRPERC internet article, 2008. Accessed 16/01/2009. http://www.frperc.bris.ac.uk/home/projcts/whtgdsen/whtgdsen.htm

27. Wood, G. and Newborough, M.: "Dynamic energy-consumption indicators for domestic appliances: environment, behaviour and design." Energy and Building, 35, 821-841, 2003.

28. Biesiot, W. and Norman, K.: "Energy requirements of household consumption: a case study of The Netherlands." Ecological Economics 28, 367-368, 1998.

29. BNCK01 - Assumptions underlying the energy projections of cooking appliances. Market Transformation Programme, Last updated: 20/08/2007. Accessed 16/01/2009. www.mtprog.com/spm/download/document/id/581

30. BNCK07: Comparing energy use in microwave ovens with traditional electric fuelled methods, Market Transformation Programme Last updated: 10/11/2006. Accessed 16/01/2009. www.mtprog.com/spm/download/document/id/675

31. Sonesson, U.; Janestad, H.; Raaholt, B.: Energy for preparation and storing of food - models for calculation of energy use for cooking and cold storage in households. SIK-Rapport Nr. 709 2003.

32. Collison, R.: "Energy consumption during cooking." Food Technology, 14, 173-179,1979.

33. Blenkhorn, C. and Wnuk, G. - MTP Cooking Energy Use. Intertek ETL SEMKO; Research & Performance Testing; 2006.

34. Carlsson-Kanyama, A.: "Climate change and dietary choices - how can emissions of greenhouse gases from food consumption be reduced?" Food Policy, 23 (3/4), 277-293, 1998.

35. Carlsson-Kanyama, A.: "Energy use in the food sector." University of Stockholm (Environmental Strategies Research Group) and Swiss Federal Institute of Technology (ETH Zürich, Department of Civil and Environmental Engineering); 1999.

36. Carlsson-Kanyama, A.: "Energy use for cooking and other stages in the life cycle of food - A study of wheat, spaghetti, pasta, barley, rice, potatoes, couscous and mashed potatoes." Stockholms Universitet/Systemekologi, ISBN 91-7056-105-2, 2001.

37. Carlsson-Kanyama, A.: "food and life cycle energy inputs." Ecological Economics, 44, 293-307, 1999.

38. Sonesson, U., Mattsson, B., Nybrant, T. and Ohlsson, T.: "Industrial processing versus home cooking". Ambio, 34 (4-5), 2005.

39. Wassermann G., Schneider F. (2005): Edibles in Household Waste. In: Cossu R., Stegmann R. (Ed.): SARDINIA 2005 Tenth International Waste Management and Landfill Symposium, Proceedings, CISA Environmental Sanitary Engineering Centre, pp. 913-914.

40. Schneider F., Obersteiner G. (2007): Food waste in residual waste of households - regional and socio-economic differences. In: Cossu R., Stegmann R. (Ed.): SARDINIA 2007 International Waste Management and Landfill Symposium. Proceedings, CISA Environmental Sanitary Engineering Centre, in preparation.

41. Sonesson, U.; Anteson, F.; Davis, J.; Sjödén, P.-O.: "Home transport and wastage: environmentally relevant household activities in the life cycle of food". AMBIO: A Journal of the Human Environment, 34 (4), 371-375, 2005.

42. Andersson K., Ohlsson T. (1999): Life cycle assessment of bread produced on different scales. International Journal of LCA 4 (1), 25-40.

43. WRAP, 2008. "The food we waste - A study of the amount, types and nature of the food we throw away in UK households". Food Waste Report v2. ISBN: 1-84405-383-0.

44. WRAP, 2008. "Helping Consumers Reduce Fruit and Vegetable Waste: Interim Report. http://www.wrap.org.uk/downloads/Helping_Consumers_reduce_fruit_veg_waste_Apr_08.184693bb.5286.pdf (accessed on: 12/12/2008).

45. WRAP - Understanding Food Waste - Research Summary. ISBN: 1-84405-310-5. WRAP, 2007.

46. Defra, 2007: Municipal Waste Arisings. http://www.defra.gov.uk/environment/statistics/waste/kf/wrkf19.htm (accessed on: 03/02/2009).

47. WR0609 Final Report - Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions. Defra, 2006.

48. WRAP, 2008. "Minimisation of Household Food Waste". Presentation. http://www.wrap.org.uk/downloads/WRAP_Food_Waste_Minimisation_adp_-_27_10_071.025c8498.4672.pdf (accessed on: 12/12/2008).

49. WRAP - Summary Report: Sustainable ways of dealing with household food and garden waste in the UK. WRAP, 2007.

50. WRAP - Environmental benefits of recycling - An international review of life cycle comparisons for key materials in the UK recycling sector. ISBN: 1-84405-263-X. WRAP, 2006.

51. WR0602: Carbon Balances and Energy Impacts of the Management of UK Waste Streams. Defra, 2006.

52. Ecoinvent. Version 1.1. http://ecoinvent.ch/

53. WRATE. Life cycle assessment tool of the Environment Agency.

54. Guidelines to Defra's GHG conversion factors for company reporting, Defra, 2007.

55. Water UK - Towards Sustainability 2005 - 2006. UK Water Industry Sustainability Indicators 2005/2006.

56. Self-coded version of the NS-SEC, Office of National Statistics, 2008. Accessed 16/01/2009. http://www.ons.gov.uk/about-statistics/classifications/current/ns-sec/self-coded/index.html

57. "PAS2050 CASE STUDY - Applying PAS2050 to a complex product: Cottage Pie Ready Meal", PB13179, Defra, 2008.

11 APPENDIX

11.1 Secondary data for waste disposal

Most of the secondary data is common for all meals discussed in Chapter 5, and the data is therefore presented together.

Emission factors for fuel conversion

Emission factors for fuel conversion were taken from the Defra 2007 Guidelines to GHG conversion factors for company reporting[54]. Emission factors are calculated on a Gross Calorific Value basis. For electricity, the newest available rolling average (2001 - 2005) was used.

Fuel type	Units	kg CO_2e/unit
Electricity	kWh	0.523
Natural Gas	kWh	0.185
Diesel	kg	3.164

Table A1: Emission factors for fuel conversion

Waste composition, transport and treatment

Waste composition

The waste generated for the preparation of both the ready meal and the home made cottage pie may be split up into separate waste fractions. Values for the percentages of the following treatment options for each one of these waste fractions were taken from a Defra report[51]: Recycling and re-use, in-vessel composting (IVC), anaerobic digestion (AD), mechanical biological treatment (MBT), combustion, landfill and landspread/recovery/reclamation.

Waste Fraction	Recycling & reuse	IVC	AD	MBT	Combus tion	Landfill	Landspread/ recovery/ reclamation	Total
Paper & Card	6.4 **(46.6%)**			0.04 **(0.3%)**	0.9 **(6.6%)**	6.4 **(46.6%)**		13.7 **(100.1%)**
Kitchen/ Food waste	0.2 **(1.7%)**	0.6 **(5.1%)**	0.05 **(0.4%)**	0.07 **(0.6%)**	1.6 **(13.5%)**	9.2 **(77.8%)**	0.1 **(0.8%)**	11.8 **(99.9%)**
Plastic (dense)	0.1 **(3.7%)**			0.01 **(0.4%)**	0.2 **(7.4%)**	2.4 **(88.6%)**		2.7 **(100.1%)**
Plastic (film)	0.3 **(9.6%)**			0.01 **(0.3%)**	0.2 **(6.4%)**	2.6 **(83.6%)**		3.1 **(99.9%)**
Ferrous	2.4 **(58.4%)**			0.01 **(0.2%)**	0.2 **(4.9%)**	1.5 **(36.5%)**	Min	4.1 **(100%)**
Non-ferrous metal	1.5 **(73.8%)**			0.002 **(0.1%)**	0.03 **(1.5%)**	0.5 **(24.6%)**	Min	2.0 **(100%)**

Table A2: Waste management for each waste fraction (million tonnes (%))

Waste Fraction	Recycling & reuse	IVC	Combustion	Landfill	Total
Paper & Card	6.4 **(46.7%)**		0.9 **(6.6%)**	6.4 **(46.7%)**	13.7 **(100%)**
Kitchen/ Food waste	0.2 **(1.7%)**	0.6 **(5.2%)**	1.6 **(13.8%)**	9.2 **(79.3%)**	11.6 **(100%)**
Plastic (dense)	0.1 **(3.7%)**		0.2 **(7.4%)**	2.4 **(88.9%)**	2.7 **(100%)**
Plastic (film)	0.3 **(9.7%)**		0.2 **(6.5%)**	2.6 **(83.9%)**	3.1 **(100.1%)**
Ferrous	2.4 **(58.5%)**		0.2 **(4.9%)**	1.5 **(36.6%)**	4.1 **(100%)**
Non-ferrous metal	1.5 **(73.9%)**		0.03 **(1.5%)**	0.5 **(24.6%)**	2.0 **(100%)**

Table A3: Major waste fractions and management options (million tonnes (%))

Waste management options contributing less than 1 wt. % to the total management of one particular waste fraction were considered negligible, and percentages were adjusted for the remaining waste treatment options (see table above).

Waste transport: Assumptions

The model of a standard waste management system was taken from a Defra report[47]. It assumes that all separately collected dry recyclables are source-separated and passed via a material recovery facility (MRF) before recycling/reprocessing. All other residual wastes pass via a transfer station before reaching their final treatment facility.

Thus, recyclables are transported from the household to a material recovery facility, sorted there, and then transported in bulk to the reprocessor. Residual waste is also collected at kerbside, but is then brought to a waste transfer site, where it is bulked before being transported to the final treatment facility or landfill.

For the transport of waste, it has been assumed that all waste fractions cause the same emissions per km travelled (through vehicle use), so that only the mass of waste transported is a variable. It has also been assumed that all transport of waste is via road.

The assumptions made for the typical distances travelled by wastes according to the Defra report[47] appear in the relevant sub-points.

Waste recollection from the household, transport to MRF

Waste recollected for recycling is assumed to travel an average distance of 2 km from the household to a material recovery facility (MRF).

The emission factor for this process step was calculated by the authors of the Defra report[47] using data for the operation of refuse collection vehicles sourced from Ecoinvent[52].

EF refuse collection vehicle: transport from household to MRF: **0.64 kg CO_2e/tonne waste transported**.

Processing of waste via a MRF

Once the recyclable waste has reached a material recovery facility, it is separated into the relevant material fractions and bulked, before being transported on to the reprocessor. Both diesel and electricity are used for this operation. The emission factor for this process step was calculated using available data for diesel and electricity consumption (*Source: ERM & Environment Agency Data (2003 - 2005) - Mechanical Semi-Automated MRF*), and using emission factors for diesel and electricity generation[54].

Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit
Diesel	0.931	kg	3.164	kg CO_2e/kg diesel	14.870	kg CO_2e/tonne waste
Electricity	22.8	kWh	0.523	kg CO_2e/kWh		

Table A4: Calculation of the EF for a MRF

Transport of waste from MRF to reprocessor

Bulked and separated recyclable waste is assumed to travel an average distance of 100 km from the material recovery facility to the reprocessor.

The emission factor for this process step was calculated[47]. The authors of this report used data for the operation of bulk transport vehicles sourced from Ecoinvent[52].

EF bulk transport: transport from MRF to reprocessor: **14.87 kg CO_2e/tonne waste transported.**

Waste recollection from the household, transport to a transfer station

Residual waste that is not collected for recycling is assumed to travel an average of 1.5 km to a transfer station.

The emission factor for this process step was calculated[47]. The authors of this report used data for the operation of refuse collection vehicles sourced from Ecoinvent[52].

EF refuse collection vehicle: transport from household to transfer station: **0.48 kg CO_2e/tonne waste transported**.

Processing of waste via a transfer station

At the transfer station, residual waste is bulked, before being transported to its final treatment destination. Data for the fuel and electricity requirements to process waste via transfer stations was sourced from a Defra report[47] (*Data collected by the Environment Agency (2003 - 2005) for the development of the waste management life-cycle assessment tool WRATE: Transfer Station (road) - with compaction*).

Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit
Diesel	0.32	kg	3.164	kg CO_2e/kg diesel	2.027	kg CO_2e/tonne waste
Electricity	1.94	kWh	0.523	kg CO_2e/kWh		

Table A5: Calculation of the EF for a transfer station

Transport of waste from transfer station to treatment facility

Bulked residual waste is assumed to travel an average distance of 30 km from the transfer station to its final treatment facility.

The emission factor for this process step was calculated[47]. The authors used data for the operation of bulk transport vehicles sourced from Ecoinvent[52].

EF bulk transport: transport from transfer station to treatment facility: **4.46 kg CO_2e/tonne waste transported.**

Waste treatment

Emission factors for waste treatment were calculated. These EF represent GHG emissions resulting from the production and use of fuels and from the generation of electricity, as well as direct GHG emissions resulting from the particular treatment process. Offset emissions through materials recycling and energy recovery are not included in the calculated emission factors, as they lie outside the system boundary stipulated by PAS 2050.

For some treatment processes, the intrinsic properties of the material fractions become relevant.

The amount of biogenic carbon content vs. fossil carbon content of a material fraction becomes important because direct CO_2 emissions resulting from the biogenic carbon content do not fall inside the system boundary, while CO_2 emissions resulting from the fossil carbon content have to be taken into account.

In other treatment processes such as in-vessel composting (IVC) and landfill, only the biogenic carbon fraction of a material is assumed to break down and release methane (CH_4), which contributes to the overall GHG emissions of the particular treatment process.

Waste Fraction	Biogenic Carbon Content [%]	Fossil Carbon Content [%]
Paper & Card	31.87	--
Kitchen Waste	13.46	--
Ferrous Metal	--	--
Non-ferrous Metal	--	--
Glass	0.28	--
Plastic (film)	--	47.81

Table A6: Waste Fraction Carbon Content[47]

In-vessel composting (IVC)

The emission factor for in-vessel composting of kitchen/food waste was calculated using data on fuel and electricity consumption, as well as on direct GHG emissions (*ERM & Environment Agency Data (2003 - 2005) - In-Vessel Batch Mobile with Enclosed Windrow Composting*).

Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit
CH_4	0.0178	kg	21	kg CO_2e/kg CH_4	17.60706	kg CO_2e/tonne waste
N_2O	0.00989	kg	310	kg CO_2e/kg N2O		
Diesel	2.99	kg	3.164	kg CO_2e/kg diesel		
Electricity	9	kWh	0.523	kg CO_2e/kWh		

Table A7: EF for IVC of kitchen/food waste

Incineration

Data for calculation of the emission factors associated with the combustion of waste was taken from a Defra report[47]. This data was collected by the Environment Agency (2003 - 2005) for the development of their LCA tool WRATE[53]. Data was presented for an energy from waste (EfW) facility (Mass Burn - New Moving Grate). However, for the purposes of this study outputs of ash and offset emissions for energy recovery were not included in the calculations.

As explained above, the process emissions of carbon dioxide are based on the fossil carbon content of each individual waste fraction, as direct CO_2 emissions resulting from the biogenic carbon content are not considered.

Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit
Paper & Card	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/tonne waste
	Diesel	0.118	kg	3.164	kg CO_2e/kg diesel		
	Electricity	3.91	kWh	0.523	kg CO_2e/kWh		
Kitchen waste	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/tonne waste
	Diesel	0.118	kg	3.164	kg CO_2e/kg diesel		
	Electricity	3.91	kWh	0.523	kg CO_2e/kWh		
Plastic (film)	Direct CO_2	1753	kg	0	kg CO_2	1755.41	kg CO_2e/tonne waste
	Diesel	0.118	kg	3.164	kg CO_2e/kg diesel		
	Electricity	3.91	kWh	0.523	kg CO_2e/kWh		
Ferrous metal	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/tonne waste
	Diesel	0.118	kg	3.164	kg CO_2e/kg diesel		
	Electricity	3.91	kWh	0.523	kg CO_2e/kWh		
Non-ferrous metal	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/tonne waste
	Diesel	0.118	kg	3.164	kg CO_2e/kg diesel		
	Electricity	3.91	kWh	0.523	kg CO_2e/kWh		

Table A8: EF for incineration of different waste fractions

Landfill

Data for calculation of the emission factors associated with the landfill of waste was taken from a Defra report[47]. This data was collected by the Environment Agency (2003 - 2005) for the development of their LCA tool WRATE. GHG emission offsets for energy recovery through generation of electricity were not taken into account. However, the landfill gas was assumed to be flared, and emissions of nitrous oxide from flaring of the landfill gas were sourced (*UK Greenhouse Gas Inventory (1990 - 2003)*).

The landfill process emissions of methane are based on the biogenic carbon content of each waste fraction.

Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit
Paper & Card	CH_4	17.4	kg	21	kg CO_2e/kg CH_4	368.319	kg CO_2e/tonne waste
	N_2O	0.000189	kg	310	kg CO_2e/kg N_2O		
	Diesel	0.904	kg	3.164	kg CO_2e/kg diesel		
Kitchen waste	CH_4	7.68	kg	21	kg CO_2e/kg CH_4	164.199	kg CO_2e/tonne waste
	N_2O	0.000189	kg	310	kg CO_2e/kg N_2O		
	Diesel	0.904	kg	3.164	kg CO_2e/kg diesel		
Plastic (film)	CH_4	0	kg	21	kg CO_2e/kg CH_4	2.919	kg CO_2e/tonne waste
	N_2O	0.000189	kg	310	kg CO_2e/kg N_2O		
	Diesel	0.904	kg	3.164	kg CO_2e/kg diesel		
Ferrous metal	CH_4	0	kg	21	kg CO_2e/kg CH_4	2.919	kg CO_2e/tonne waste
	N_2O	0.000189	kg	310	kg CO_2e/kg N_2O		
	Diesel	0.904	kg	3.164	kg CO_2e/kg diesel		
Non-ferrous metal	CH_4	0	kg	21	kg CO_2e/kg CH_4	2.919	kg CO_2e/tonne waste
	N_2O	0.000189	kg	310	kg CO_2e/kg N_2O		
	Diesel	0.904	kg	3.164	kg CO_2e/kg diesel		
Glass	CH_4	0.18	kg	21	kg CO_2e/kg CH_4	6.699	kg CO_2e/tonne waste
	N_2O	0.000189	kg	310	kg CO_2e/kg N_2O		
	Diesel	0.904	kg	3.164	kg CO_2e/kg diesel		

Table A9: EF for landfill of different waste fractions

11.2 Additional data for the assessment of GHG emissions of various food products

11.2.1 Ready meal cottage pie

List of ingredients

Mashed Potato (61%), Beef Stock, Cooked Beef (11%), Leeks, Carrots, Onions, Celery, Cornflour, Wheatflour, Chicken Stock, Tomato Paste, Sea Salt, Natural Colour: Plain Caramel, Vegetable Oil, Red Wine, Garlic Puree, Horseradish Puree, White Pepper.

Mashed Potato contains: Cooked Potato (89%), Skimmed Milk, Dried Buttermilk, Salt, Pepper Extract (contains Anticaking Agent: E551).

Beef Stock contains: Water, Beef, Salt.

Chicken Stock contains: Chicken, Water, Salt, Carrots, Onions, Leeks, Mushrooms, Garlic, Bay Leaf, Thyme, Cloves.

Preparation instructions

Method 1:

OVEN For best results conventional oven - Preheat oven. Remove carton. Place on baking tray. Oven 200°C, Fan 170°C, 400°F, Gas 6. Time: 25 mins

Method 2:

MICROWAVE The foil container must not be used in the microwave. Place product in a microwaveable dish of similar dimensions. Microwave ovens vary. The following is a guide only. Cover with microwaveable film. Pierce film. Cook on high (100%).

MW Cat D 750w: Time: 5 1/2 mins; MW Cat E 850w: Time: 5 mins

<u>Process flow chart</u>

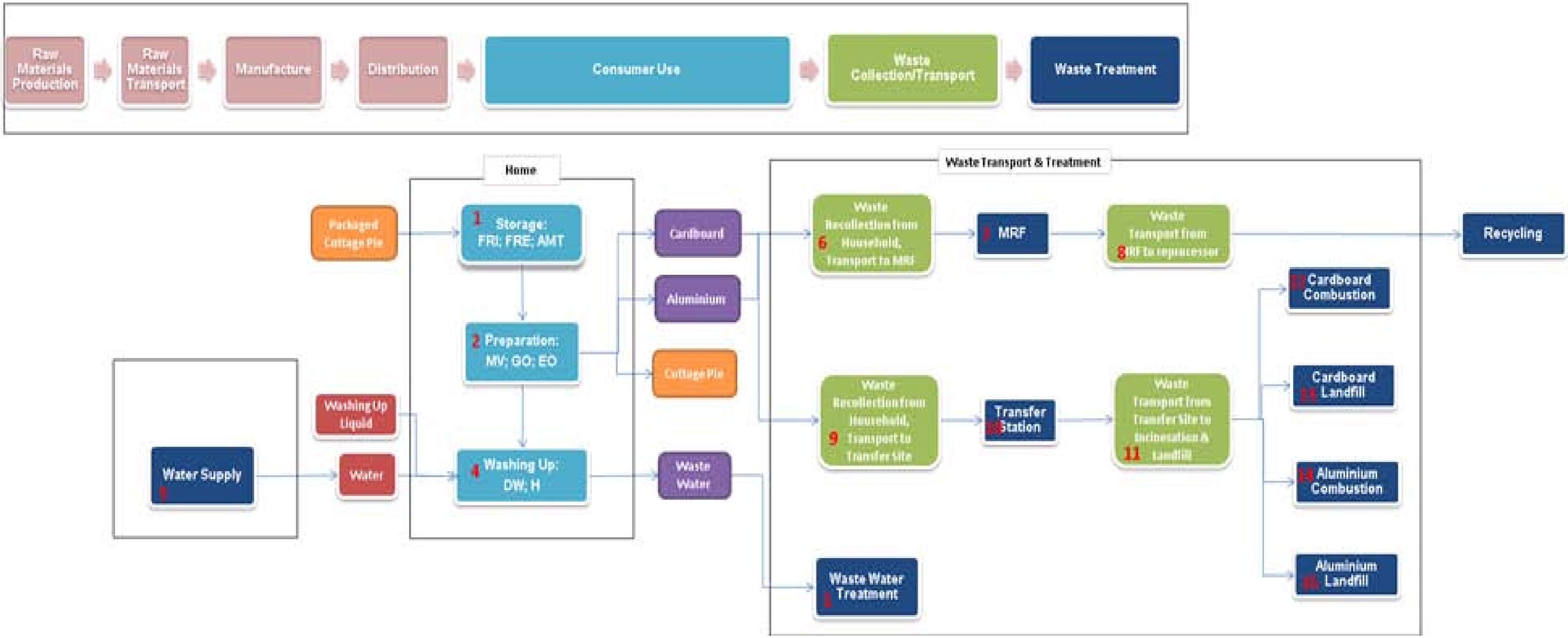


Figure 11-1: Flow chart of process steps for use phase and disposal of 1 product unit of ready meal cottage pie

Mass balances

As stipulated in PAS 2050, mass balances were drawn up for each process step.

Process step No.	Input	Input mass [g]	Output	Output mass [g]
1	Packaged Cottage Pie	430.95	Packaged Cottage Pie	430.95
2	Packaged Cottage Pie	430.95	Cottage Pie	394.83
			Cardboard	27.15
			Aluminium	7.7
3	Water	1000	Water	1000
4	Water	1000	Water	1000
5	Water	1000	Water	1000
6	Packaging Waste A = 46.7% of cardboard + 73.9% of aluminium	18.37	Packaging Waste A	18.37
7	Packaging Waste A	18.37	Packaging Waste A	18.37
8	Packaging Waste A	18.37	Packaging Waste A	18.37
9	Packaging Waste B = 53.3% of cardboard + 26.1% of aluminium	16.48	Packaging Waste B	16.48
10	Packaging Waste B	16.48	Packaging Waste B	16.48
11	Packaging Waste B	16.48	Cardboard to Incineration	1.79
			Cardboard to Landfill	12.68
			Aluminium to Landfill	1.89
12	Cardboard to Incineration	1.79	Cardboard in Incineration	1.79
13	Cardboard to Landfill	12.68	Cardboard in Landfill	12.68
14	Aluminium to Incineration	0.12	Aluminium in Incineration	0.12
15	Aluminium to Landfill	1.89	Aluminium in Landfill	1.89

Table A10: Mass balances for the process steps of preparing the ready meal cottage pie

Primary data on energy consumption

Primary data on energy consumption was measured for the storage and the preparation of the ready meal cottage pie.

It was assumed that, once bought, the ready meal would be stored in the refrigerator for 24 hours before preparation and consumption. Energy consumption of the storage process step was measured for one specific fridge/freezer combination.

According to the manufacturer is instructions, the ready meal cottage pie could be prepared either in an oven (in this example, one specific electric fan oven was tested), or in a microwave (again, measurements were carried out for one specific appliance). Preparation was carried out following the manufacturer's instructions for each preparation method. All energy consumption measurements were carried out in triplicate.

Process step No.	Appliance	Operation	Fuel type	Amount	Unit
1	Fridge/Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh
2a	Electric Fan Oven A	Temperature: 170°C, time: 20 mins preheating + 25 mins	Electricity	0.63	kWh
2b	Microwave A	Power: High (100%), time: 5 mins	Electricity	0.115	kWh

Table A11: Energy consumption of the storage and preparation of a ready meal cottage pie

<u>Calculation of CO_2e per product unit</u>

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/ PU
1	Primary	measured energy consumption	Fridge/ Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh	0.523	kg CO_2e/ kWh	0.322	kg CO_2e/24h whole fridge	**1.93E-03**
2a	Primary	measured energy consumption	Electric Fan Oven A	Temperature: 170°C, time: 20 mins preheating + 25 mins	Electricity	0.63	kWh	0.523	kg CO_2e/ kWh	0.329	kg CO_2e/ heating step	**3.29E-01**
2b	Primary	measured energy consumption	Micro wave A	Power: High (100%), time: 5 mins	Electricity	0.115	kWh	0.523	kg CO_2e/ kWh	0.060	kg CO_2e/ heating step	**6.02E-02**
3	Secondary	Water UK	--	--	--	--	--	--	--	0.289	tonnes CO_2e/ML water supplied	2.89E-04
4	Secondary	MTP - BNW16	Gas boiler	heating 1L water from 15°C to 55°C	Natural Gas	0.0665	kWh	0.185	kg CO_2e/ kWh	0.012	kg CO_2e/L water heated	**1.23E-02**
5	Secondary	Water UK	--	--	--	--	--	--	--	0.406	t CO_2e/ ML wastewater treated	4.06E-04
6	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to MRF: 2km	--	--	--	--	--	0.64	kg CO_2e/ tonne waste	1.18E-05
7	Secondary	Defra 2006a,b	MRF	Waste sorting and bulking	Diesel	0.931	kg	3.164	kg CO_2e/ kg diesel	14.870	kg CO_2e/ tonne waste	2.73E-04
					Electricity	22.8	kWh	0.523	kg CO_2e/ kWh			

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
8	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from MRF to reprocessor: 100 km	--	--	--	--	--	14.87	kg CO_2e/ tonne waste	2.73E-04
9	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to transfer station: 1.5km	--	--	--	--	--	0.48	kg CO_2e/ tonne waste	7.91E-06
10	Secondary	Defra 2006a,b	Transfer station	Waste bulking	Diesel	0.32	kg	3.164	kg CO_2e/ kg diesel	2.027	kg CO_2e/ tonne waste	3.34E-05
					Electricity	1.94	kWh	0.523	kg CO_2e/ kWh			
11	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from transfer station to treatment facility: 30 km	--	--	--	--	--	4.46	kg CO_2e/ tonne waste	7.35E-05
12	Secondary	Defra 2006a,b	Incineration plant (mass burn - new moving grate)	Incineration	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/ tonne waste	4.33E-06
					Diesel	0.118	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/ kWh			
13	Secondary	Defra 2006a,b	Landfill site	Landfill	CH_4	17.4	kg	21	kg CO_2e/ kg CH_4	368.319	kg CO_2e/ tonne waste	**4.67E-03**
					N_2O	0.000189	kg	310	kg CO_2e/ kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2/ kg diesel			
14	Secondary	Defra 2006a,b	Incineration plant (mass burn - new moving grate)	Incineration	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/ tonne waste	2.79E-07
					Diesel	0.118	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/ kWh			

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/ PU
15	Secondary	Defra 2006a,b	Landfill site	Landfill	CH_4	0	kg	21	kg CO_2e/ kg CH_4	2.919	kg CO_2e/ tonne waste	5.53E-06
					N_2O	0.000189	kg	310	kg CO_2e/ kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2/ kg diesel			

Table A12: Calculation of the GHG emissions in CO_2 equivalents for each process step (material inputs to the life cycle GHG emissions of the product are denoted in bold).

Contributions to the overall GHG emissions of use phase and disposal of a ready meal cottage pie

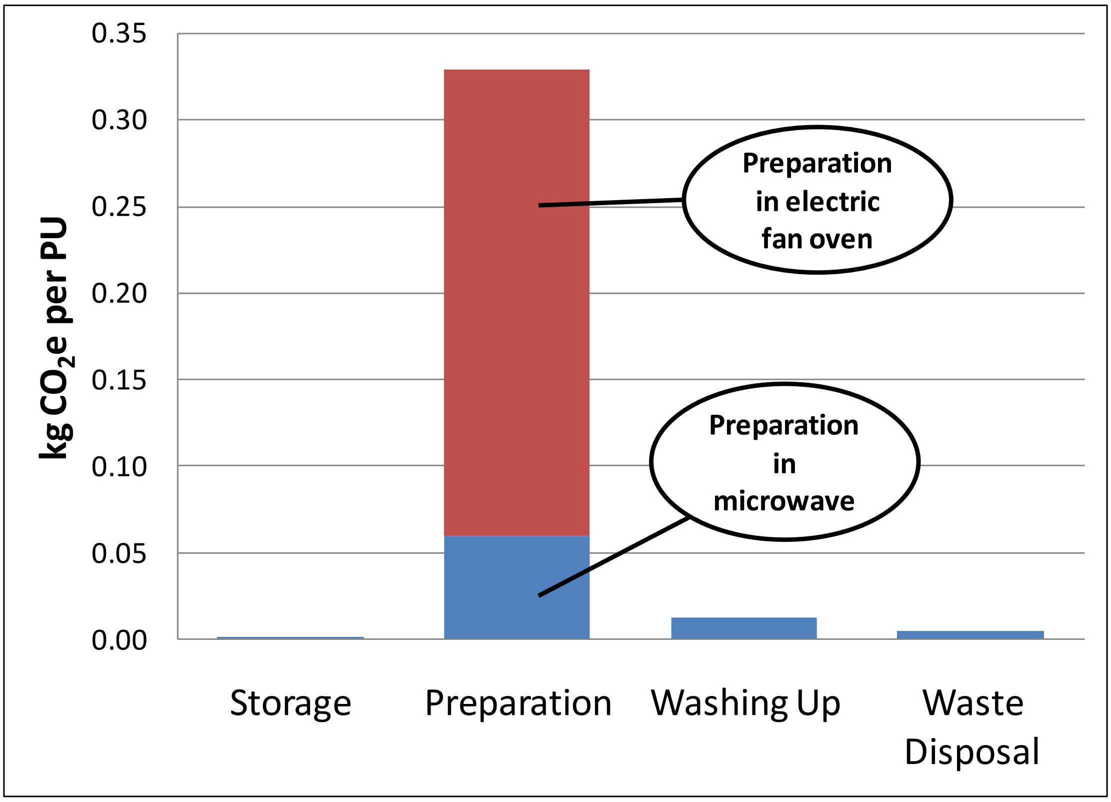


Figure 11-2: Contribution of process steps to the overall GHG emissions of the use phase of a ready meal cottage pie

11.2.2 Home made cottage pie

List of ingredients

Potatoes, minced beef, carrots, onion, tomatoes (canned, with juice), milk, butter, garlic, salt, mixed herbs.

Process flow chart

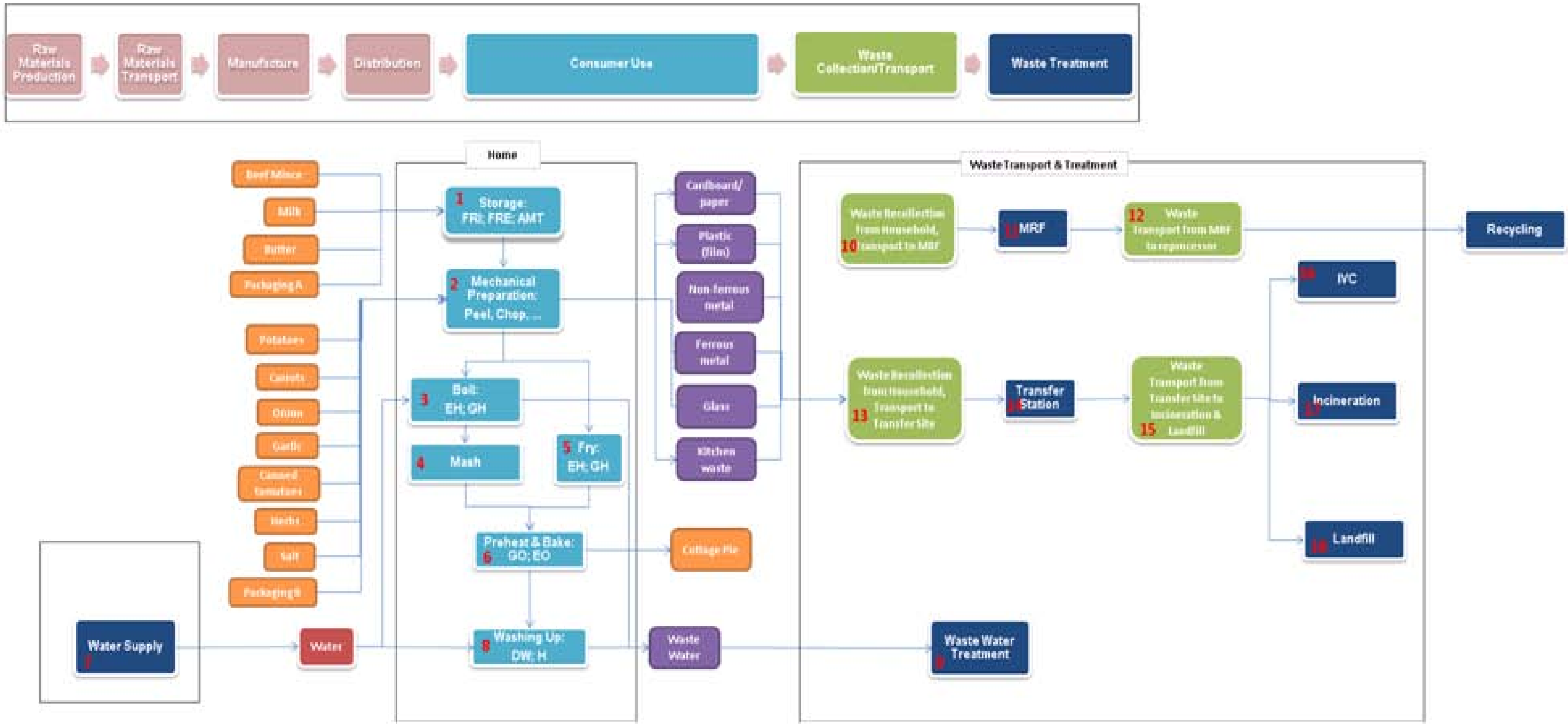


Figure 11-3: Flow chart of process steps for use phase and disposal of 1 product unit of home made cottage pie

An experimental flow chart for the process steps of preparation and disposal was drawn up for the home made cottage pie. This initial process map was checked at FPIU through observation of a cooking process by a consumer. A meal was cooked for six people and times and practices were recorded. The only additional step to the original process map identified was the warming of plates.

Excluding preparation of raw materials, the cooking and consumption time of the meal was 181 minutes for all processes with parallel activities giving a reduced elapsed time of 120 minutes. Two areas of waste were identified: warming of plates and portion control (15% was not served and was thrown away after 24 hours storage). The map shows that 79.4% of cooking time was adding value to the consumer with the remainder waste.

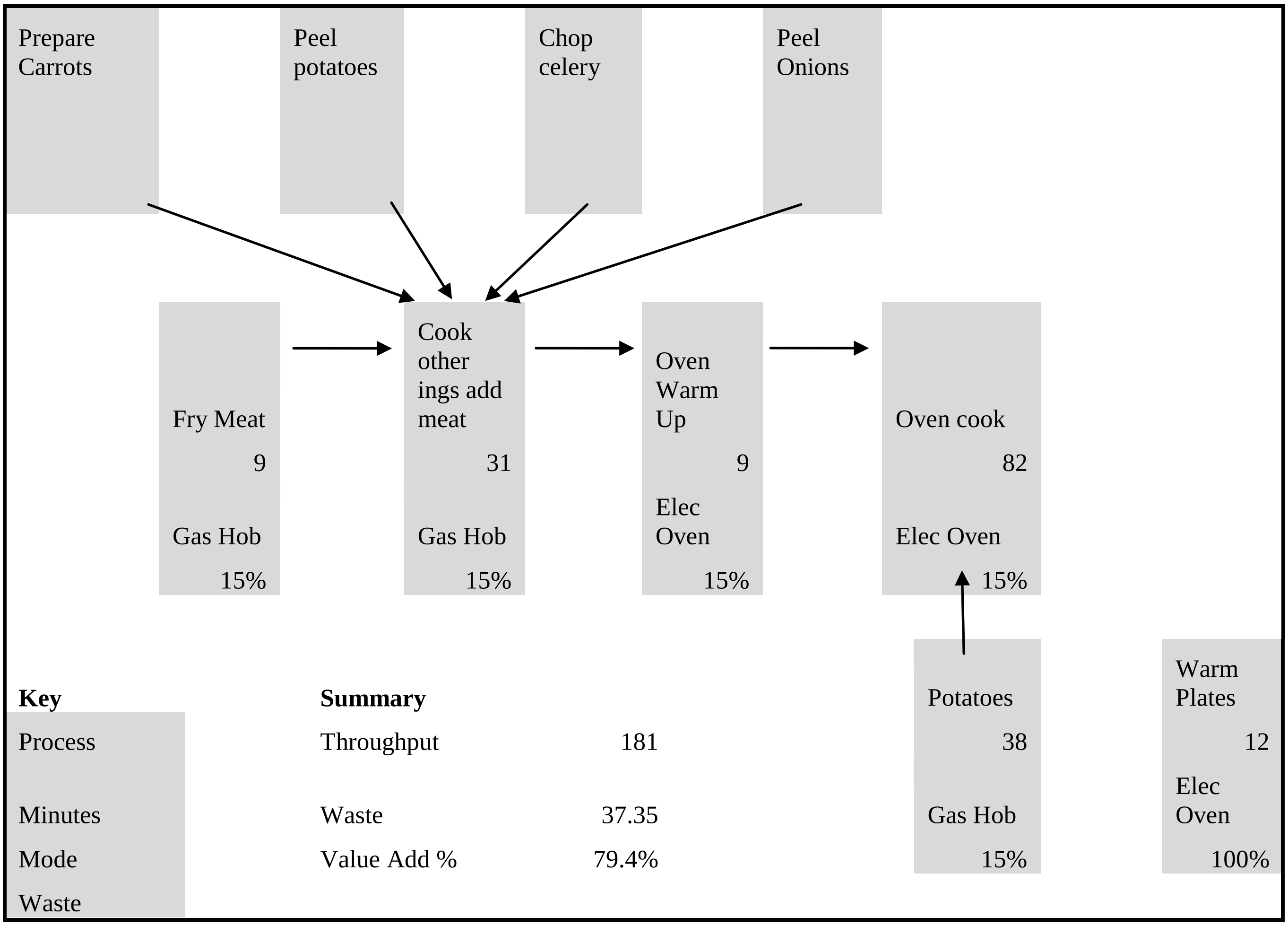


Figure 11-4: Process map (FPIU)

Preparation instructions

Peel and chop potatoes, carrots, onion and garlic.

Boil the potatoes until tender. Mash the cooked potatoes, incorporating the milk, half the butter and half the salt.

Put the rest of the butter in a pan and fry the beef mince with the chopped carrots, onion and garlic. When the mince starts to brown, add tomatoes, herbs and the rest of the salt.

Place the mince in an oven dish and top with the mashed potatoes. Preheat the oven to 200°C, then bake the cottage pie for 15 minutes at 200°C.

Mass balances

Process step No.	Input	Input mass [g]	Output	Output mass [g]
1	Beef mince	124.27	Beef mince	124.27
	Milk	32.77	Milk	32.77
	Butter	10.90	Butter	10.90
	Packaging A	2.6	Packaging A	2.6
2	Beef mince	124.27	Beef mince	124.27
	Milk	32.77	Milk	32.77
	Butter	10.90	Butter	10.90
	Potatoes	192.73	Peeled, chopped potatoes	161.00
	Carrots	89.77	Peeled, chopped Carrots	53.73
	Onion	73.33	Peeled, chopped onion	56.60
	Garlic	3.13	Peeled, chopped garlic	2.00
	Tomatoes (can)	63.20	Tomatoes	63.20
	Herbs	0.47	Herbs	0.47
	Salt	0.93	Salt	0.93
	Packaging	0.00	Kitchen waste	85.63
			Cardboard & Paper	0.30
			Plastic (film)	12.23
			Non-ferrous metal (Aluminium)	0.14
			Ferrous metal (Can)	7.93
			Glass	4.70

Process step No.	Input	Input mass [g]	Output	Output mass [g]
3	Peeled, chopped potatoes	161.00	Boiled potatoes	184.25
	Water	550.00	Waste water	548.55
4	Boiled potatoes	184.25	Mashed potatoes	193.47
	Butter	5.45		
	Milk	32.77		
	Salt	0.47		
5	Beef mince	124.27	Meat sauce	217.80
	Peeled, chopped Carrots	53.73	Water vapour	88.38
	Peeled, chopped onion	56.60		
	Peeled, chopped garlic	2.00		
	Tomatoes	63.20		
	Herbs	0.47		
	Butter	5.45		
	Salt	0.47		
6	Meat sauce	217.80	Cottage Pie	378.37
	Mashed potatoes	193.47	Water vapor	32.90
7	Water	6283.33	Water	6283.33
8	Washing up water	5733.33	Washing up water	5733.33
9	Waste water	6281.88	Waste water	6281.88
10	Waste A	9.69	Waste A	9.69
11	Waste A	9.69	Waste A	9.69
12	Waste A	9.69	Waste A	9.69
13	Waste B	101.25	Waste B	101.25
14	Waste B	101.25	Waste B	101.25
15	Waste B	101.25	Waste to IVC	4.45
			Waste to incineration	13.02
			Waste to landfill	84.45
16	Kitchen waste to IVC	4.45	Kitchen waste in IVC	4.45
17	Paper & card to incineration	0.02	Paper & card in incineration	0.02
	Kitchen waste to incineration	11.82	Kitchen waste in incineration	11.82
	Plastic (film) to incineration	0.80	Plastic (film) in incineration	0.80
	Ferrous metal to incineration	0.39	Ferrous metal in incineration	0.39
	Non-ferrous metal to incineration	0.00	Non-ferrous metal in incineration	0.00

Process step No.	Input	Input mass [g]	Output	Output mass [g]
18	Paper & card to landfill	0.14	Paper & card in landfill	0.14
	Kitchen waste to landfill	67.91	Kitchen waste in landfill	67.91
	Plastic (film) to landfill	10.26	Plastic (film) in landfill	10.26
	Ferrous metal to landfill	2.90	Ferrous metal in landfill	2.90
	Non-ferrous metal to landfill	0.04	Non-ferrous metal in landfill	0.04
	Glass to landfill	2.54	Glass in landfill	2.54

* Waste A = Waste for recycling

** Waste B = Waste for further treatment

Table A13: Mass balances for the preparation and disposal of the home made cottage pie

<u>Primary data on energy consumption</u>

Process step No.	Appliance	Operation	Fuel type	Quantity	Unit
1	Fridge/Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh
2	--	Mechanical preparation	None	0	--
3	Electric Hob A	Boiling of potatoes	Electricity	0.2576667	kWh
4	--	Mash	None	0	--
5	Electric Hob A	Frying of meat sauce	Electricity	0.1222667	kWh
6	Electric Fan Oven A	Temperature: 200°C, time: 20 mins preheating + 15 mins	Electricity	0.6472333	kWh

Table A14: Primary activity data for the use phase of the home made cottage pie

Calculation of CO_2e per product unit

Process step No.	Data type	Data source	Appliance/Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
1	Primary	measured energy consumption	Fridge/Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh	0.523	kg CO_2e/ kWh	0.322	kg CO_2e/24h whole fridge	3.75E-03
2	Primary	measured energy consumption	--	Mechanical preparation	None	0	--	--	--	--	--	--
3	Primary	measured energy consumption	Electric Hob A	Boiling of potatoes	Electricity	0.2576667	kWh	0.523	kg CO_2e/ kWh	0.135	kg CO_2e/ heating step	**1.35E-01**
4	Primary	measured energy consumption	--	Mash	None	0	--	--	--	--	--	--
5	Primary	measured energy consumption	Electric Hob A	Frying of meat sauce	Electricity	0.1222667	kWh	0.523	kg CO_2e/ kWh	0.064	kg CO_2e/ heating step	**6.39E-02**
6	Primary	measured energy consumption	Electric Fan Oven A	Temperature: 200^{0}C, time: 20 mins preheating + 15 mins	Electricity	0.6472333	kWh	0.523	kg CO_2e/ kWh	0.339	kg CO_2e/ heating step	**3.39E-01**
7	Secondary	Water UK	--	--	--	--	--	--	--	0.289	tonnes CO_2e/ML water supplied	1.82E-03
8	Secondary	MTP - BNW16	Gas boiler	heating water from 15 to 55^{0}C	Natural Gas	0.0665	kWh	0.185	kg CO_2e/ kWh	0.012	kg CO_2/L water heated	7.05E-02
9	Secondary	Water UK	--	--	--	--	--	--	--	0.406	t CO_2e/ML wastewater treated	2.55E-03
10	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to MRF: 2km	--	--	--	--	--	0.64	kg CO_2e/ tonne waste	6.20E-06

Process step No.	Data type	Data source	Appliance/Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
11	Secondary	Defra 2006a,b	MRF	Waste sorting and bulking	Diesel	0.931	kg	3.164	kg CO_2e/ kg diesel	14.870	kg CO_2e/ tonne waste	1.44E-04
					Electricity	22.8	kWh	0.523	kg CO_2e/ kWh			
12	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from MRF to reprocessor: 100 km	--	--	--	--	--	14.87	kg CO_2e/ tonne waste	1.44E-04
13	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to transfer station: 1.5km	--	--	--	--	--	0.48	kg CO_2e/ tonne waste	4.86E-05
14	Secondary	Defra 2006a,b	Transfer station	Waste bulking	Diesel	0.32	kg	3.164	kg CO_2e/ kg diesel	2.027	kg CO_2e/ tonne waste	2.05E-04
					Electricity	1.94	kWh	0.523	kg CO_2e/ kWh			
15	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from transfer station to treatment facility: 30 km	--	--	--	--	--	4.46	kg CO_2e/ tonne waste	4.52E-04
16	Secondary	Defra 2006a,b	IVC	Kitchen waste composting	CH_4	0.0178	kg	21	kg CO_2e/ kg CH_4	17.60706	kg CO_2e/tonne waste	7.84E-05
					N_2O	0.00989	kg	310	kg CO_2e/ kg N_2O			
					Diesel	2.99	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	9	kWh	0.523	kg CO_2e/ kWh			

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
17	Secondary	Defra 2006a,b	Incineration plant (mass burn - new moving grate)	Incineration of Paper & Card	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/tonne waste	4.75E-08
					Diesel	0.118	kg	3.164	kg CO_2e/kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/kWh			
				Incineration of Kitchen waste	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/ tonne waste	2.86E-05
					Diesel	0.118	kg	3.164	kg CO_2e/kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/kWh			
				Incineration of Plastic (film)	Direct CO_2	1753	kg	1	kg CO_2	1755.418	kg CO_2e/tonne waste	1.40E-03
					Diesel	0.118	kg	3.164	kg CO_2e/kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/kWh			
				Incineration of Ferrous metal	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/ tonne waste	9.40E-07
					Diesel	0.118	kg	3.164	kg CO_2e/kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/kWh			
				Incineration of Non-ferrous metal	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/tonne waste	5.23E-09
					Diesel	0.118	kg	3.164	kg CO_2e/kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/kWh			

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
18	Secondary	Defra 2006a,b	Landfill site	Landfill of Paper & card	CH_4	17.4	kg	21	kg CO_2e/kg CH_4	368.319	kg CO_2e/tonne waste	5.12E-05
					N_2O	0.000189	kg	310	kg CO_2e/kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/kg diesel			
				Landfill of Kitchen waste	CH_4	7.68	kg	21	kg CO_2e/kg CH_4	164.199	kg CO_2e/tonne waste	**1.12E-02**
					N_2O	0.000189	kg	310	kg CO_2e/kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/kg diesel			
				Landfill of Plastic (film)	CH_4	0	kg	21	kg CO_2e/kg CH_4	2.919	kg CO_2e/tonne waste	3.00E-05
					N_2O	0.000189	kg	310	kg CO_2e/kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/kg diesel			
				Landfill of Ferrous metal	CH_4	0	kg	21	kg CO_2e/kg CH_4	2.919	kg CO_2e/tonne waste	8.47E-06
					N_2O	0.000189	kg	310	kg CO_2e/kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/kg diesel			
				Landfill of Non-ferrous metal	CH_4	0	kg	21	kg CO_2e/kg CH_4	2.919	kg CO_2e/tonne waste	1.03E-07
					N_2O	0.000189	kg	310	kg CO_2e/kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/kg diesel			
				Landfill of Glass	CH_4	0.18	kg	21	kg CO_2e/kg CH_4	6.699	kg CO_2e/tonne waste	1.70E-05
					N_2O	0.000189	kg	310	kg CO_2e/kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2/kg diesel			

Table A15: Calculation of the GHG emissions in CO_2 equivalents for each process step (material inputs to the life cycle GHG emissions of the product are denoted in bold).

<u>Contribution of process steps to the overall GHG emission of a home made cottage pie</u>

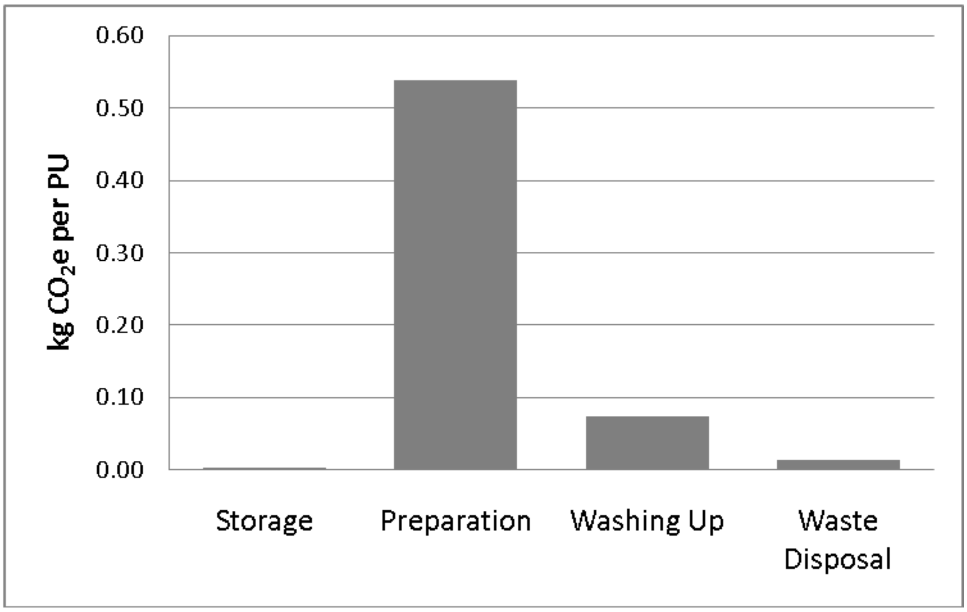


Figure 11-5: Contribution of process steps to the overall GHG emissions of the use phase of a home made cottage pie

11.2.3 Ready meal apple crumble

List of ingredients

Apple filling (40%), wheat flour, vegetable margarine, sugar, oats (5%), water, raising agents, salt.

Apple filling contains: rehydrated apples (32%), glucose-fructose syrup, glucose syrup, sucrose syrup, sugar, ground rice, apple pulp (7%), vegetable oil, modified maize starch, citric acid, flavouring, gelling agent [pectin], acidity regulator [trisodium citrate], preservatives [potassium sorbate, sulphur dioxide].

Vegetable margarine contains: vegetable oils, water, salt, emulsifier [polyglycerol esters of fatty acids], flavouring.

Raising agents contain: disodium diphosphate, sodium hydrogen carbonate.

Preparation instructions

To Heat:

Remove outer packaging, place foil on a baking tray in a pre-heated oven for 10 minutes on Gas Mark 4, 350^{o}F, 180^{o}C, adjust for fan assisted ovens.

__Process flow chart__

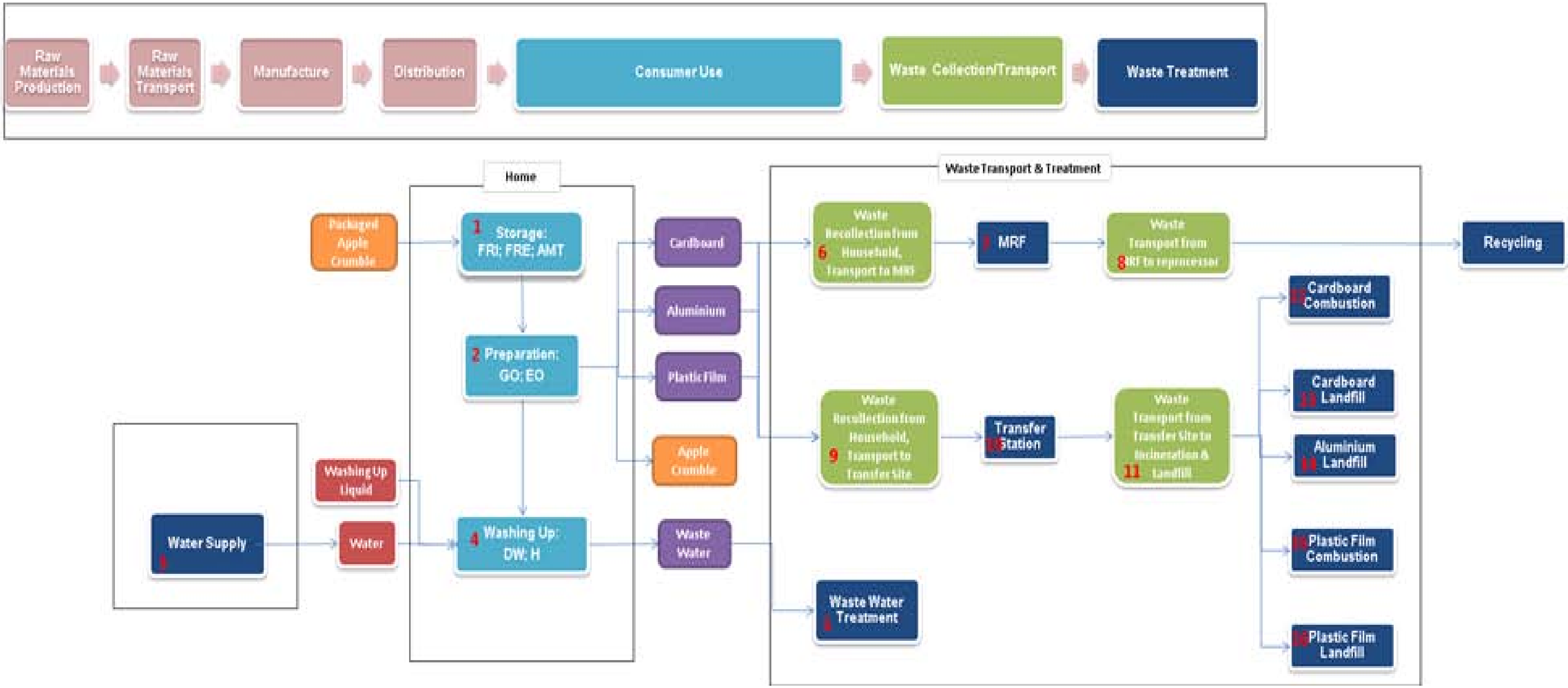


Figure 11-6: Flow chart of process steps for use phase and disposal of 1 product unit of a ready meal apple crumble

Mass balances

Process step No.	Input	Input mass [kg]	Output	Output mass [kg]
1	Packaged Apple crumble	0.434	Packaged Apple crumble	0.434
2	Packaged Apple crumble	0.434	Apple crumble	0.4
			Cardboard	0.0271
			Aluminium	0.00491
			Plastic (film)	0.00226
3	Water	1	Water	1
4	Water	1	Water	1
5	Water	1	Water	1
6	Packaging Waste A = 46.7% of paper & card + 73.9% of aluminium + 9.7% of plastic (film)	0.0165	Packaging Waste A	0.0165
7	Packaging Waste A	0.0165	Packaging Waste A	0.0165
8	Packaging Waste A	0.0165	Packaging Waste A	0.0165
9	Packaging Waste B = 53.3% of paper & card + 26.1% of aluminium + 90.4% of plastic (film)	0.0178	Packaging Waste B	0.0178
10	Packaging Waste B	0.0178	Packaging Waste B	0.0178
11	Packaging Waste B	0.0178	Paper & Card to Incineration	0.00179
			Paper & Card to Landfill	0.0127
			Aluminium to Landfill	0.00121
			Plastic (film) to Incineration	0.000147
			Plastic (film) to Landfill	0.00190
12	Paper & Card to Incineration	0.00179	Paper & Card in Incineration	0.00179
13	Paper & Card to Landfill	0.0127	Paper & Card in Landfill	0.0127
14	Aluminium to Landfill	0.00121	Aluminium in Landfill	0.00121
15	Plastic (film) to Incineration	0.000147	Plastic (film) in Incineration	0.000147
16	Plastic (film) to Landfill	0.00190	Plastic (film) in Landfill	0.00190

Table A16: Mass balances for the preparation and disposal of the ready meal apple crumble

Primary data on energy consumption

Process step No.	Appliance	Operation	Fuel type	Quantity	Unit
1	Fridge/Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh
2	Electric oven A	baking at 180°C for 20+10 mins	Electricity	0.500	kWh

Table A17: Primary activity data for the use phase of the ready meal apple crumble

Calculation of CO_2e per product unit

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
1	Primary	measured energy consumption	Fridge/ Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh	0.523	kg CO_2e/ kWh	0.322	kg CO_2e/ 24h whole fridge	0.00E+00
2	Primary	measured energy consumption	Electric oven A	baking at 180°C for 20+10 mins	Electricity	0.5003333	kWh	0.523	kg CO_2e/ kWh	0.262	kg CO_2e/ baking step	**2.62E-01**
3	Secondary	Water UK	--	--	--	--	--	--	--	0.289	tonnes CO_2e/ML water supplied	2.89E-04
4	Secondary	MTP - BNW16	Gas boiler	heating 1L water from 15°C to 55°C	Natural Gas	0.0665	kWh	0.185	kg CO_2e/ kWh	0.012	kg CO_2e/L water heated	**1.23E-02**
5	Secondary	Water UK	--	--	--	--	--	--	--	0.406	t CO_2e/ML wastewater treated	4.06E-04
6	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to MRF: 2km	--	--	--	--	--	0.64	kg CO_2e/ tonne waste	1.06E-05
7	Secondary	Defra 2006a,b	MRF	Waste sorting and bulking	Diesel	0.931	kg	3.164	kg CO_2e/ kg diesel	14.870	kg CO_2e/ tonne waste	2.46E-04
					Electricity	22.8	kWh	0.523	kg CO_2e/ kWh			
8	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from MRF to reprocessor: 100 km	--	--	--	--	--	14.87	kg CO_2e/ tonne waste	2.46E-04

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
9	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to transfer station: 1.5km	--	--	--	--	--	0.48	kg CO_2e/ tonne waste	8.53E-06
10	Secondary	Defra 2006a,b	Transfer station	Waste bulking	Diesel	0.32	kg	3.164	kg CO_2e/ kg diesel	2.027	kg CO_2e/ tonne waste	3.60E-05
					Electricity	1.94	kWh	0.523	kg CO_2e/ kWh			
11	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from transfer station to treatment facility: 30 km	--	--	--	--	--	4.46	kg CO_2e/ tonne waste	7.93E-05
12	Secondary	Defra 2006a,b	Incineration plant (mass burn - new moving grate)	Incineration of paper & card	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/ tonne waste	4.33E-06
					Diesel	0.118	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/ kWh			
13	Secondary	Defra 2006a,b	Landfill site	Landfill of paper & card	CH_4	17.4	kg	21	kg CO_2e/ kg CH_4	368.319	kg CO_2e/ tonne waste	8.75E-04
					N_2O	0.000189	kg	310	kg CO_2e/ kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/ kg diesel			

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
14	Secondary	Defra 2006a,b	Landfill site	Landfill of aluminium	CH_4	0	kg	21	kg CO_2e/ kg CH_4	2.919	kg CO_2e/ tonne waste	6.94E-06
					N_2O	0.000189	kg	310	kg CO_2e/ kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/ kg diesel			
15	Secondary	Defra 2006a,b	Incineration plant (mass burn - new moving grate)	Incineration of plastic (film)	Direct CO_2	1753	kg	1	kg CO_2	1755.41 8	kg CO_2e/ tonne waste	2.58E-04
					Diesel	0.118	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/ kWh			
16	Secondary	Defra 2006a,b	Landfill site	Landfill of plastic (film)	CH_4	0	kg	21	kg CO_2e/ kg CH_4	2.919	kg CO_2e/ tonne waste	5.53E-06
					N_2O	0.000189	kg	310	kg CO_2e/ kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/ kg diesel			

Table A18: Calculation of the GHG emissions in CO_2 equivalents for each process step (material inputs in bold).

Contributions to the overall GHG emissions of use phase and disposal of a ready meal apple crumble

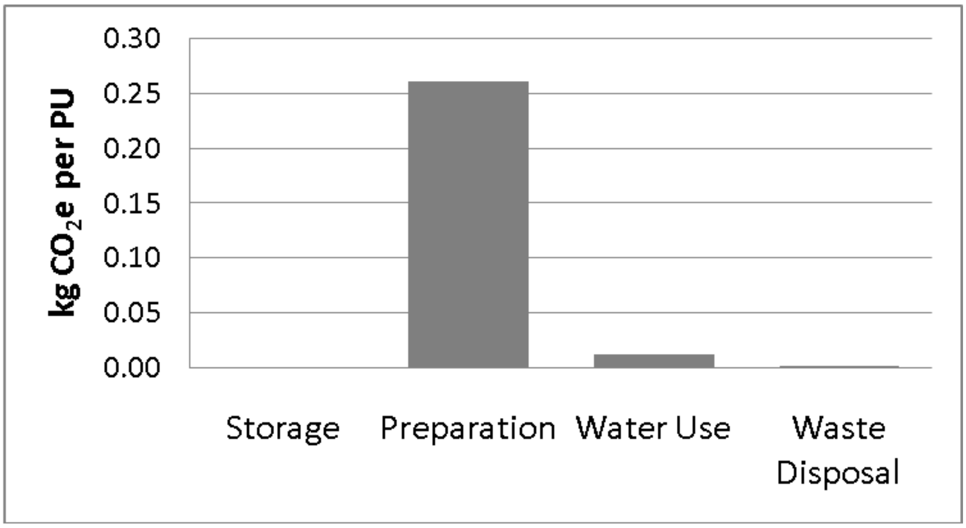


Figure 11-7: Contribution of process steps to the overall GHG emissions of the use phase of a ready meal apple crumble

11.2.4 Home made apple crumble

List of ingredients

Apples, butter, light brown sugar, flour.

Preparation instructions

Peel and core the apples; dice the apples about half an inch in size. Melt 50g of the butter in a saucepan on a high heat. Add the apples to the butter and cook for ten minutes, stirring all the time until slightly soft. Take off the heat, reserve and leave to cool.

Preheat the oven to 180°C. Meanwhile rub the remaining butter, flour and sugar between your fingers until fully mixed together.

Put the cooled apples in a baking dish and spread the crumble mixture on top until the apples are completely covered. Bake at 180°C for 30 minutes.

Process flow chart

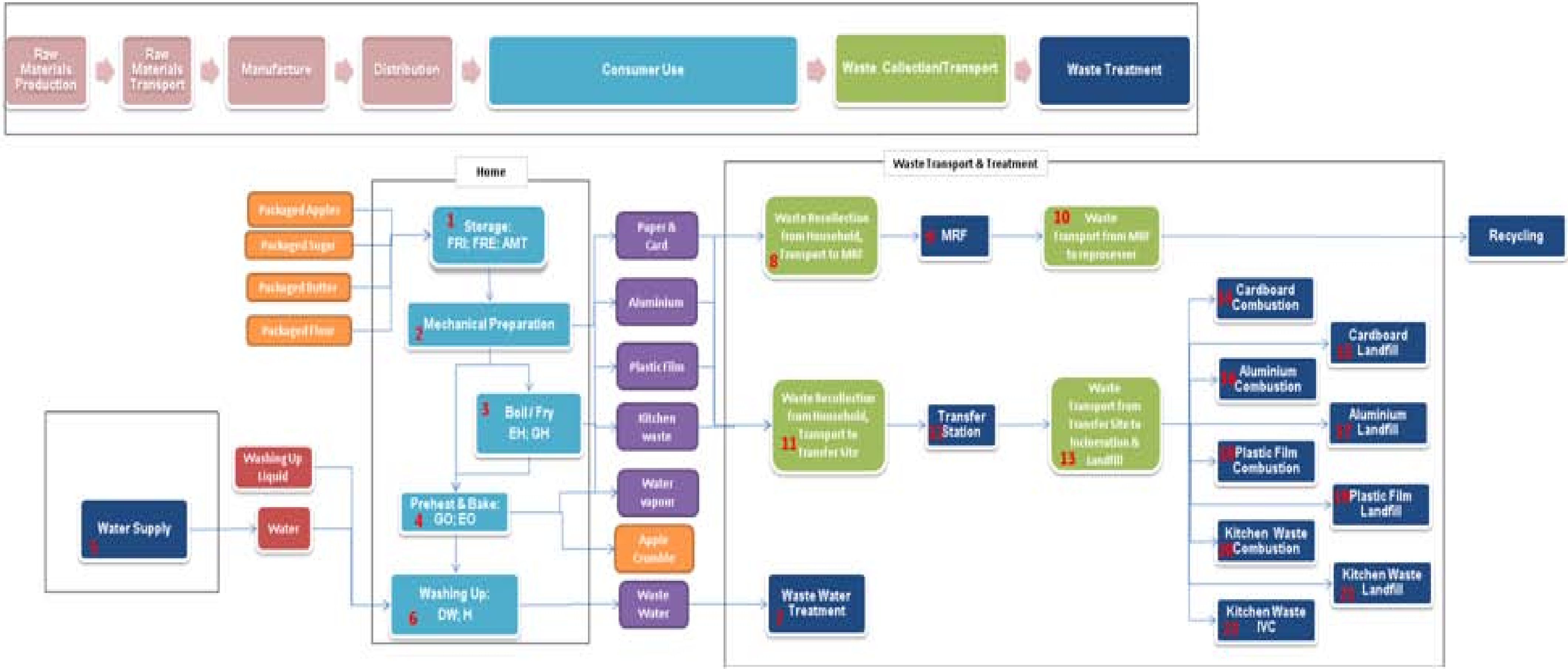


Figure 11-8: Flow chart of process steps for use phase and disposal of 1 product unit of a home made apple crumble

Mass balances

Process step No.	Input	Input mass [kg]	Output	Output mass [kg]
1	Packaged Apples	0.523	Packaged Apples	0.523
	Packaged Butter	0.045	Packaged Butter	0.045
	Packaged Sugar	0.026	Packaged Sugar	0.026
	Packaged Flour	0.079	Packaged Flour	0.079
2	Packaged Apples	0.523	Apples	0.519
	Packaged Butter	0.045	Butter	0.044
	Packaged Sugar	0.026	Sugar	0.026
	Packaged Flour	0.079	Flour	0.078
			Paper & Card	0.001
			Aluminium	0.001
			Plastic (film)	0.004
			Kitchen waste	0.180
3	Apples	0.519	Water vapour	0.098
	Butter	0.022	Apple mix	0.290
4	Apple mix	0.290	Water vapour	0.019
	Butter	0.022	Apple crumble	0.400
	Sugar	0.026		
	Flour	0.078		
5	Water	3.000	Water	3.000
6	Water	3.000	Water	3.000
7	Water	3.000	Water	3.000
8	Packaging Waste A = 46.7% of paper & card + 73.9% of aluminium + 9.7% of plastic (film) + 1.7% of kitchen waste	0.004	Packaging Waste A	0.004
9	Packaging Waste A	0.004	Packaging Waste A	0.004
10	Packaging Waste A	0.004	Packaging Waste A	0.004
11	Packaging Waste B = 53.3% of paper & card + 26.1% of aluminium + 90.4% of plastic (film) + 98.3% of kitchen waste	0.181	Packaging Waste B	0.181
12	Packaging Waste B	0.181	Packaging Waste B	0.181
13	Packaging Waste B	0.181	Paper & Card to Incineration	0.000
			Paper & Card to Landfill	0.000
			Aluminium to Incineration	0.000
			Aluminium to Landfill	0.000
			Plastic (film) to Incineration	0.000
			Plastic (film) to Landfill	0.003
			Kitchen waste to Incineration	0.025
			Kitchen waste to Landfill	0.143
			Kitchen waste to IVC	0.009

Process step No.	Input	Input mass [kg]	Output	Output mass [kg]
14	Paper & Card to Incineration	0.000	Paper & Card in Incineration	0.000
15	Paper & Card to Landfill	0.000	Paper & Card in Landfill	0.000
16	Aluminium to Incineration	0.000	Aluminium in Incineration	0.000
17	Aluminium to Landfill	0.000	Aluminium in Landfill	0.000
18	Plastic (film) to Incineration	0.000	Plastic (film) in Incineration	0.000
19	Plastic (film) to Landfill	0.003	Plastic (film) in Landfill	0.003
20	Kitchen waste to Incineration	0.025	Kitchen waste in Incineration	0.025
21	Kitchen waste to Landfill	0.143	Kitchen waste in Landfill	0.143
22	Kitchen waste to IVC	0.009	Kitchen waste in IVC	0.009

Table A19: Mass balances for the preparation and disposal of the home made apple crumble

<u>Primary data on energy consumption</u>

Process step No.	Appliance/Site	Operation	Fuel type	Quantity	Unit
1	Fridge/Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh
2	--	--	--	--	--
3	Electric hob A	cooking for 10 mins	Electricity	0.1718516	kWh
4	Electric oven A	baking at 180ºC for 20+30 mins	Electricity	0.7057	kWh

Table A20: Primary activity data for the use phase of the home made apple crumble

Calculation of CO_2e per product unit

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
1	Primary	measured energy consumption	Fridge/ Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh	0.523	kg CO_2e/ kWh	0.322	kg CO_2e/ 24h whole fridge	1.52E-03
2	--	--	--	--	--	--	--	--	--	--	--	0.00E+00
3	Primary	measured energy consumption	Electric hob A	cooking for 10 mins	Electricity	0.1718516	kWh	0.523	kg CO_2e/ kWh	0.090	kg CO_2e/ PU cooking step	**8.99E-02**
4	Primary	measured energy consumption	Electric oven A	baking at 180°C for 20+30 mins	Electricity	0.7057	kWh	0.523	kg CO_2e/ kWh	0.369	kg CO_2e/ baking step	**3.69E-01**
5	Secondary	Water UK	--	--	--	--	--	--	--	0.289	tonnes CO_2e/ ML water supplied	8.67E-04
6	Secondary	MTP - BNW16	Gas boiler	heating 1L water from 15°C to 55°C	Natural Gas	0.0665	kWh	0.185	kg CO_2e/ kWh	0.012	kg CO_2/ L water heated	**3.69E-02**
7	Secondary	Water UK	--	--	--	--	--	--	--	0.406	t CO_2e/ML wastewater treated	1.22E-03
8	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to MRF: 2km	--	--	--	--	--	0.64	kg CO_2e/ tonne waste	2.79E-06
9	Secondary	Defra 2006a,b	MRF	Waste sorting and bulking	Diesel	0.931	kg	3.164	kg CO_2e/ kg diesel	14.870	kg CO_2e/ tonne waste	6.49E-05
					Electricity	22.8	kWh	0.523	kg CO_2e/ kWh			

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
10	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from MRF to reprocessor: 100 km	--	--	--	--	--	14.87	kg CO_2e/ tonne waste	6.49E-05
11	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to transfer station: 1.5km	--	--	--	--	--	0.48	kg CO_2e/ tonne waste	8.67E-05
12	Secondary	Defra 2006a,b	Transfer station	Waste bulking	Diesel	0.32	kg	3.164	kg CO_2e/ kg diesel	2.027	kg CO_2e/ tonne waste	3.66E-04
					Electricity	1.94	kWh	0.523	kg CO_2e/ kWh			
13	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from transfer station to treatment facility: 30 km	--	--	--	--	--	4.46	kg CO_2e/ tonne waste	8.05E-04
14	Secondary	Defra 2006a,b	Incineration plant (mass burn - new moving grate)	Incineration of paper & card	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/ tonne waste	1.57E-07
					Diesel	0.118	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/ kWh			
15	Secondary	Defra 2006a,b	Landfill site	Landfill of paper & card	CH_4	17.4	kg	21	kg CO_2e/ kg CH_4	368.319	kg CO_2e/ tonne waste	1.69E-04
					N_2O	0.000189	kg	310	kg CO_2e/ kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/ kg diesel			
16	Secondary	Defra 2006a,b	Landfill site	Incineration of aluminium	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/ tonne waste	2.49E-08
					Diesel	0.118	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/ kWh			

Process step No.	**Data type**	**Data source**	**Appliance/ Site**	**Operation**	**Fuel type**	**Quantity**	**Unit**	**Emission factors**	**EF unit**	**Process step EF**	**Process step EF unit**	**Mass CO_2e/PU**
17	Secondary	Defra 2006a,b	Landfill site	Landfill of aluminium	CH_4	0	kg	21	kg CO_2e/ kg CH_4	2.919	kg CO_2e/ tonne waste	4.92E-07
					N_2O	0.000189	kg	310	kg CO_2e/ kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/ kg diesel			
18	Secondary	Defra 2006a,b	Incineration plant (mass burn - new moving grate)	Incineration of plastic (film)	Direct CO_2	1753	kg	1	kg CO_2	1755.418	kg CO_2e/ tonne waste	4.05E-04
					Diesel	0.118	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/ kWh			
19	Secondary	Defra 2006a,b	Landfill site	Landfill of plastic (film)	CH_4	0	kg	21	kg CO_2e/ kg CH_4	2.919	kg CO_2e/ tonne waste	8.70E-06
					N_2O	0.000189	kg	310	kg CO_2e/ kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/ kg diesel			
20	Secondary	Defra 2006a,b	Incineration plant (mass burn - new moving grate)	Incineration of kitchen waste	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/ tonne waste	6.00E-05
					Diesel	0.118	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/ kWh			
21	Secondary	Defra 2006a,b	Landfill site	Landfill of kitchen waste	CH_4	7.68	kg	21	kg CO_2e / kg CH_4	164.199	kg CO_2e/ tonne waste	**2.34E-02**
					N_2O	0.000189	kg	310	kg CO_2e/ kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/ kg diesel			

Process step No.	**Data type**	**Data source**	**Appliance/ Site**	**Operation**	**Fuel type**	**Quantity**	**Unit**	**Emission factors**	**EF unit**	**Process step EF**	**Process step EF unit**	**Mass CO_2e/PU**
22	Secondary	Defra 2006a,b	IVC	Kitchen waste composting	CH_4	0.0178	kg	21	kg CO_2e/ kg CH_4	17.60706	kg CO_2e/ tonne waste	1.65E-04
					N_2O	0.00989	kg	310	kg CO_2e/ kg N_2O			
					Diesel	2.99	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	9	kWh	0.523	kg CO_2e/ kWh			

Table A21: Calculation of the GHG emissions in CO_2 equivalents for each process step (material inputs in bold).

Contributions to the overall GHG emissions of use phase and disposal of a home made apple crumble

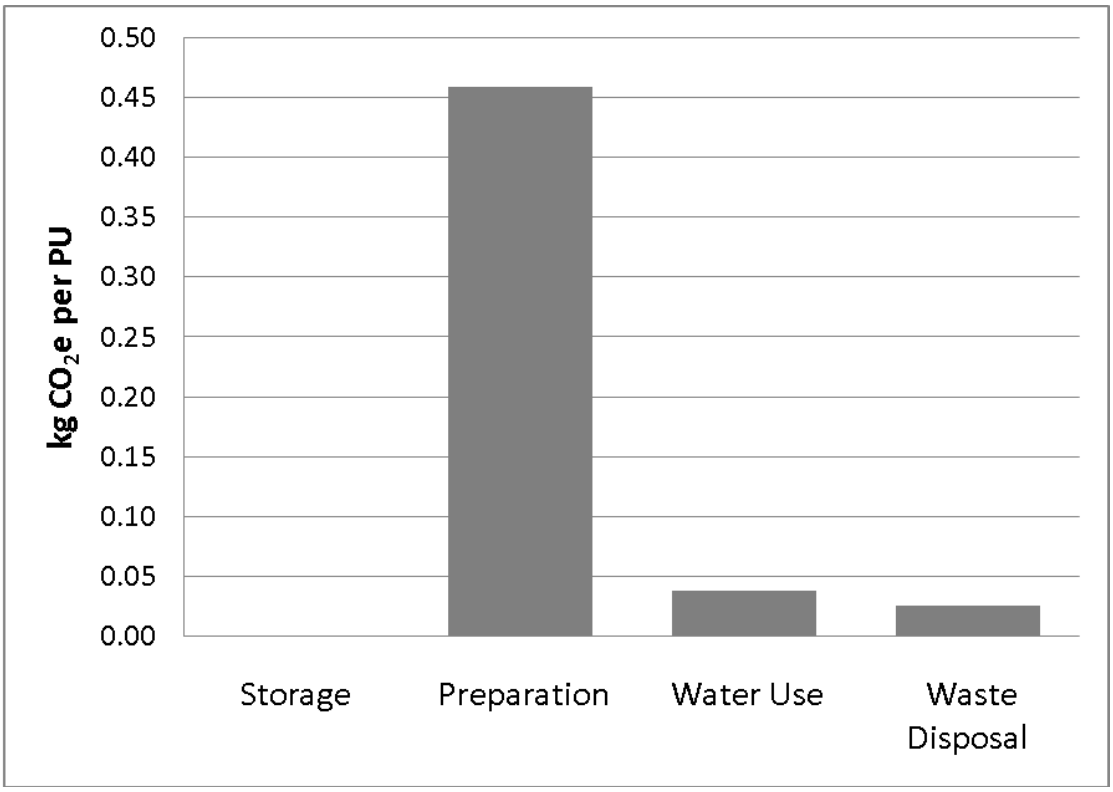


Figure 11-9: Contribution of process steps to the overall GHG emissions of the use phase of a home made apple crumble

11.2.5 Home made bread

List of ingredients

Flour, salt, yeast, sugar.

Preparation instructions

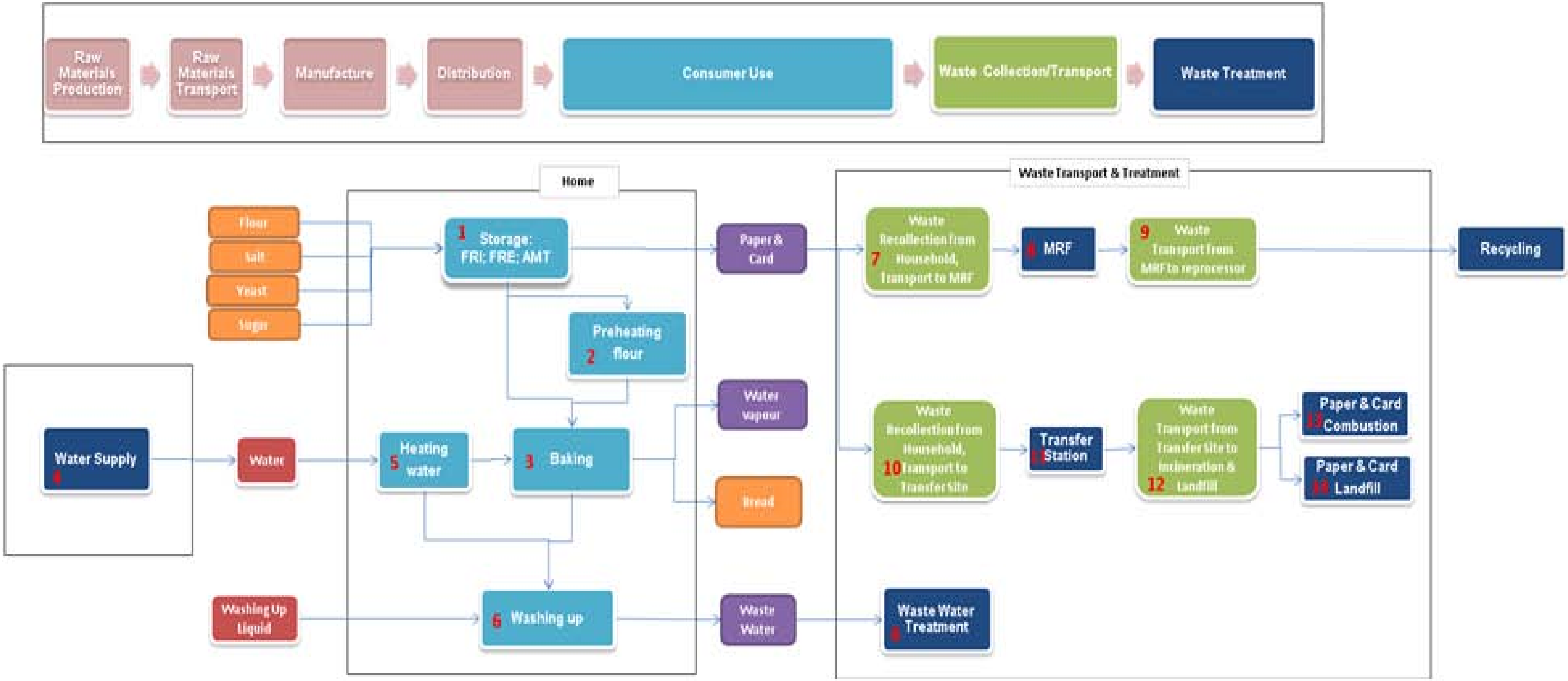
Warm the flour in the oven for 10 minutes (oven from cold, 50ºC), then turn the oven off.

Sift flour, salt, yeast and sugar into a bowl, make a well in the centre of the mixture, then add the water. Now mix to a dough, adding a spot more water if there are any dry bits. Wipe the bowl clean with the dough and transfer it to a flat work surface. Knead the dough for 3 minutes or until it develops a sheen and blisters under the surface (it should also be springy and elastic). Return the dough to the bowl and cover it with clingfilm. Leave about 2 hours at room temperature.

Knock the air out, then knead again for 2 minutes. Optionally divide the dough in half or use the whole at once. Pat each piece out to an oblong, then fold one end into the centre and the other in on top. Put each one into a buttered tin, sprinkle each with a dusting of flour and cover with clingfilm. Let the dough rise for about 1 hour at room temperature.

Preheat the oven to 210ºC, then bake the loaves on the centre shelf for 40 minutes until they sounds hollow when their base is tapped. Return them, out of their tins, upside-down to the oven to crisp the base and side crust for about 5 minutes, then cool on a wire rack.

Process flow chart



Mass balances

Process step No.	Input	Input mass [kg]	Output	Output mass [kg]
1	Packaged Yeast	0.003	Yeast	0.003
	Packaged Flour	0.561	Flour	0.556
	Packaged Sugar	0.007	Sugar	0.007
	Salt	0.006	Salt	0.006
2	Flour	0.556	Flour	0.556
3	Yeast	0.003	Bread	0.800
	Flour	0.561	Paper & Card packaging	0.005
	Sugar	0.007	Water vapour	0.142
	Salt	0.006		
	Water	0.365		
4	Water	2.115	Water	2.115
5	Water	1.750	Water	1.750
6	Water	1.750	Water	1.750
7	Packaging Waste A = 46.7% of paper & card	0.002	Packaging Waste A	0.002
8	Packaging Waste A	0.002	Packaging Waste A	0.002
9	Packaging Waste A	0.002	Packaging Waste A	0.002
10	Packaging Waste B = 53.3% of paper & card	0.003	Packaging Waste B	0.003
11	Packaging Waste B	0.003	Packaging Waste B	0.003
12	Packaging Waste B	0.003	Paper & Card to Incineration	0.000
			Paper & Card to Landfill	0.002
13	Paper & Card to Incineration	0.000	Paper & Card in Incineration	0.000
14	Paper & Card to Landfill	0.002	Paper & Card in Landfill	0.002

Table A22: Mass balances for the preparation and disposal of home made bread

Primary data on energy consumption

Process step No.	Appliance/Site	Operation	Fuel type	Quantity	Unit
1	Fridge/Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh
2	Electric oven A	preheating flour, 10 min at 50°C w/o preheating	Electricity	0.0550925	kWh
3	Electric oven A	baking process 20+40+5 min at 210°C	Electricity	1.0958	kWh

Table A23: Primary activity data for the use phase of the home made bread

Calculation of CO_2e per product unit

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
1	Primary	measured energy consumption	Fridge/ Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh	0.523	kg CO_2e/ kWh	0.322	kg CO_2e/ 24h whole fridge	0.00E+00
2	Primary	measured energy consumption	Electric oven A	preheating flour, 10 min at 50°C w/o preheating	Electricity	0.0550925	kWh	0.523	kg CO_2e/ kWh	0.029	kg CO_2e/ preheating step	**2.88E-02**
3	Primary	measured energy consumption	Electric oven A	baking process 20+40+5 min at 210°C	Electricity	1.0958	kWh	0.523	kg CO_2e/ kWh	0.573	kg CO_2e/ baking step	**5.73E-01**
4	Secondary	Water UK	--	--	--	--	--	--	--	0.289	tonnes CO_2e/ ML water supplied	6.11E-04
5	Secondary	MTP - BNW16	Gas boiler	heating 1L water from 15°C to 55°C	Natural Gas	0.0665	kWh	0.185	kg CO_2e/ kWh	0.012	kg CO_2e/ L water heated	**2.15E-02**
6	Secondary	Water UK	--	--	--	--	--	--	--	0.406	t CO_2e/ ML wastewater treated	7.11E-04
7	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to MRF: 2km	--	--	--	--	--	0.64	kg CO_2e/ tonne waste	1.46E-06
8	Secondary	Defra 2006a,b	MRF	Waste sorting and bulking	Diesel	0.931	kg	3.164	kg CO_2e/ kg diesel	14.870	kg CO_2e/ tonne waste	3.39E-05
					Electricity	22.8	kWh	0.523	kg CO_2e/ kWh			
9	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from MRF to reprocessor: 100 km	--	--	--	--	--	14.87	kg CO_2e/ tonne waste	3.39E-05

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
10	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to transfer station: 1.5km	--	--	--	--	--	0.48	kg CO_2e/ tonne waste	1.25E-06
11	Secondary	Defra 2006a,b	Transfer station	Waste bulking	Diesel	0.32	kg	3.164	kg CO_2e/ kg diesel	2.027	kg CO_2e/ tonne waste	5.28E-06
					Electricity	1.94	kWh	0.523	kg CO_2e/ kWh			
12	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from transfer station to treatment facility: 30 km	--	--	--	--	--	4.46	kg CO_2e/ tonne waste	1.16E-05
13	Secondary	Defra 2006a,b	Incineration plant (mass burn - new moving grate)	Incineration of paper & card	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/ tonne waste	7.80E-07
					Diesel	0.118	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/ kWh			
14	Secondary	Defra 2006a,b	Landfill site	Landfill of paper & card	CH_4	17.4	kg	21	kg CO_2e/ kg CH_4	368.319	kg CO_2e/ tonne waste	8.40E-04
					N_2O	0.000189	kg	310	kg CO_2e/ kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/ kg diesel			

Table A24: Calculation of the GHG emissions in CO_2 equivalents for each process step (material inputs in bold).

Contributions to the overall GHG emissions of use phase and disposal of a home made bread

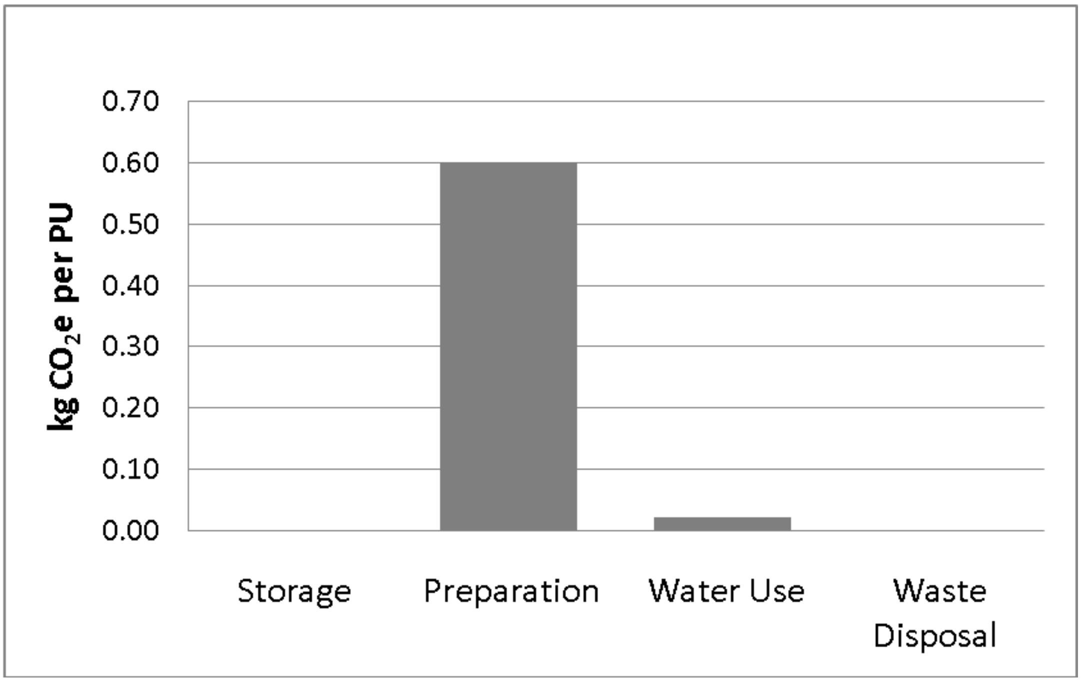


Figure 11-11: Contribution of process steps to the overall GHG emissions of the use phase of a home made bread

11.2.6 Bread made in bread-maker

List of ingredients

Flour, butter, milk powder, sugar, salt, yeast.

Preparation instructions

Weigh the ingredients and place in the bread-maker, then add water. Program the bread-maker for a bread of size "L". Use the standard baking programme (4 hours).

<u>**Process flow chart**</u>

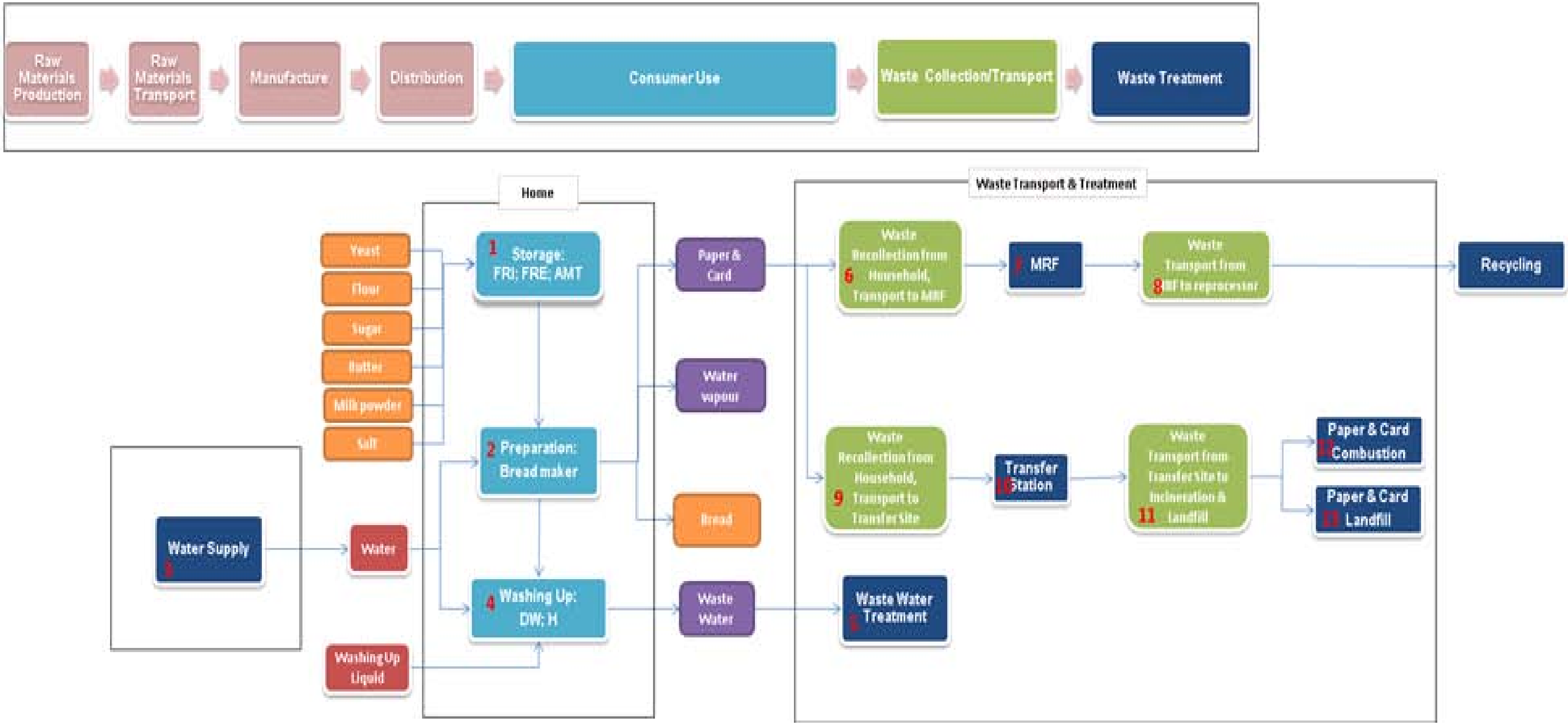


Figure 11-12: Flow chart of process steps for use phase and disposal of 1 product unit of bread made in a bread maker

Mass balances

Process step No.	Input	Input mass [kg]	Output	Output mass [kg]
1	Packaged Yeast	0.003	Packaged Yeast	0.003
	Packaged Flour	0.512	Packaged Flour	0.512
	Packaged Sugar	0.020	Packaged Sugar	0.020
	Packaged Butter	0.025	Packaged Butter	0.025
	Packaged Milk powder	0.015	Packaged Milk powder	0.015
	Salt	0.004	Salt	0.004
2	Packaged Yeast	0.003	Bread	0.800
	Packaged Flour	0.512	Paper & Card packaging	0.004
	Packaged Sugar	0.020	Water vapour	0.135
	Packaged Butter	0.025		
	Packaged Milk powder	0.015		
	Salt	0.004		
	Water	0.355		
3	Water	1.422	Water	1.422
4	Water	1.067	Water	1.067
5	Water	1.067	Water	1.067
6	Packaging Waste A = 46.7% of paper & card	0.002	Packaging Waste A	0.002
7	Packaging Waste A	0.002	Packaging Waste A	0.002
8	Packaging Waste A	0.002	Packaging Waste A	0.002
9	Packaging Waste B = 53.3% of paper & card	0.002	Packaging Waste B	0.002
10	Packaging Waste B	0.002	Packaging Waste B	0.002
11	Packaging Waste B	0.002	Paper & Card to Incineration	0.000
			Paper & Card to Landfill	0.002
12	Paper & Card to Incineration	0.000	Paper & Card in Incineration	0.000
13	Paper & Card to Landfill	0.002	Paper & Card in Landfill	0.002

Table A25: Mass balances for the preparation and disposal of bread made in a bread maker

Primary data on energy consumption

Process step No.	Appliance/Site	Operation	Fuel type	Quantity	Unit
1	Fridge/Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh
2	Bread maker A	baking process, 4h, size: L	Electricity	0.39038	kWh

Table A26: Primary activity data for the use phase of the bread made in a bread-maker

Calculation of CO_2e per product unit

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
1	Primary	measured energy consumption	Fridge/ Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh	0.523	kg CO_2e/ kWh	0.322	kg CO_2e/ 24h whole fridge	0.00E+00
2	Primary	measured energy consumption	Bread maker A	baking process, 4h, size: L	Electricity	0.39038	kWh	0.523	kg CO_2e/ kWh	0.204	kg CO_2e/ baking step	**2.04E-01**
3	Secondary	Water UK	--	--	--	--	--	--	--	0.289	tonnes CO_2e/ ML water supplied	4.11E-04
4	Secondary	MTP - BNW16	Gas boiler	heating 1L water from 15^{o}C to 55^{o}C	Natural Gas	0.0665	kWh	0.185	kg CO_2e/ kWh	0.012	kg CO_2/ L water heated	**1.31E-02**
5	Secondary	Water UK	--	--	--	--	--	--	--	0.406	t CO_2e/ ML wastewater treated	4.33E-04
6	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to MRF: 2km	--	--	--	--	--	0.64	kg CO_2e/ tonne waste	1.33E-06
7	Secondary	Defra 2006a,b	MRF	Waste sorting and bulking	Diesel	0.931	kg	3.164	kg CO_2e/ kg diesel	14.870	kg CO_2e/ tonne waste	3.10E-05
					Electricity	22.8	kWh	0.523	kg CO_2e/ kWh			
8	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from MRF to reprocessor: 100 km	--	--	--	--	--	14.87	kg CO_2e/ tonne waste	3.10E-05

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
9	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to transfer station: 1.5km	--	--	--	--	--	0.48	kg CO_2e/ tonne waste	1.14E-06
10	Secondary	Defra 2006a,b	Transfer station	Waste bulking	Diesel	0.32	kg	3.164	kg CO_2e/ kg diesel	2.027	kg CO_2e/ tonne waste	4.82E-06
					Electricity	1.94	kWh	0.523	kg CO_2e/ kWh			
11	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from transfer station to treatment facility: 30 km	--	--	--	--	--	4.46	kg CO_2e/ tonne waste	1.06E-05
12	Secondary	Defra 2006a,b	Incineration plant (mass burn - new moving grate)	Incineration of paper & card	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/ tonne waste	7.12E-07
					Diesel	0.118	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/ kWh			
13	Secondary	Defra 2006a,b	Landfill site	Landfill of paper & card	CH_4	17.4	kg	21	kg CO_2e/ kg CH_4	368.319	kg CO_2e/ tonne waste	7.67E-04
					N_2O	0.000189	kg	310	kg CO_2e/ kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/ kg diesel			

Table A27: Calculation of the GHG emissions in CO_2 equivalents for each process step (material inputs in bold).

Contributions to the overall GHG emissions of use phase and disposal of bread made in a bread-maker

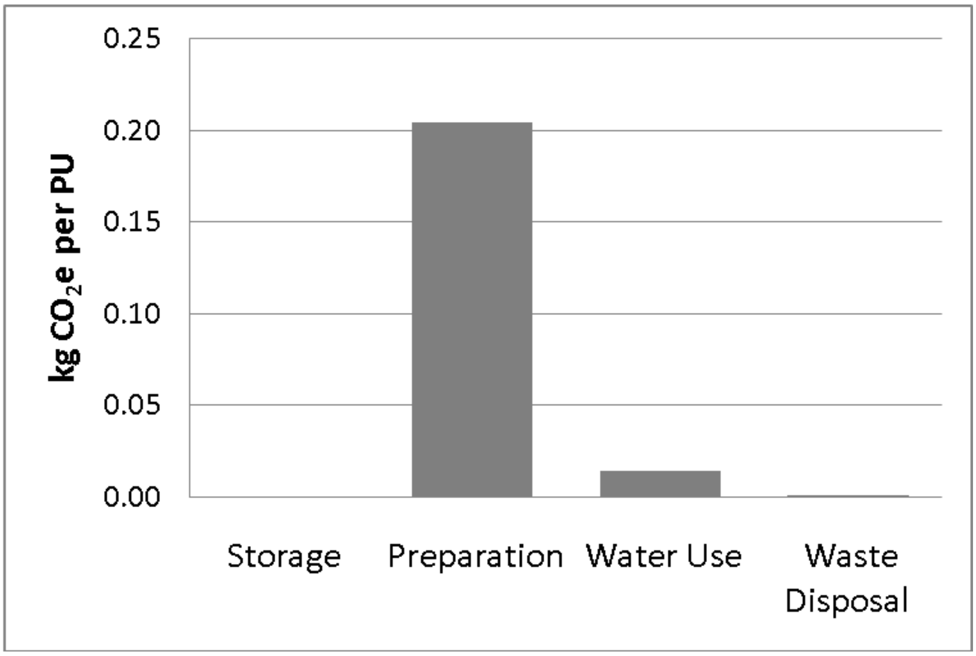


Figure 11-13: Contribution of process steps to the overall GHG emissions of the use phase of bread made in a bread maker

11.2.7 Home made apple juice

List of ingredients

Braeburn apples in a plastic film bag

Preparation instructions

Quarter and core the apples, then pass them through the juicer.

Process flow chart

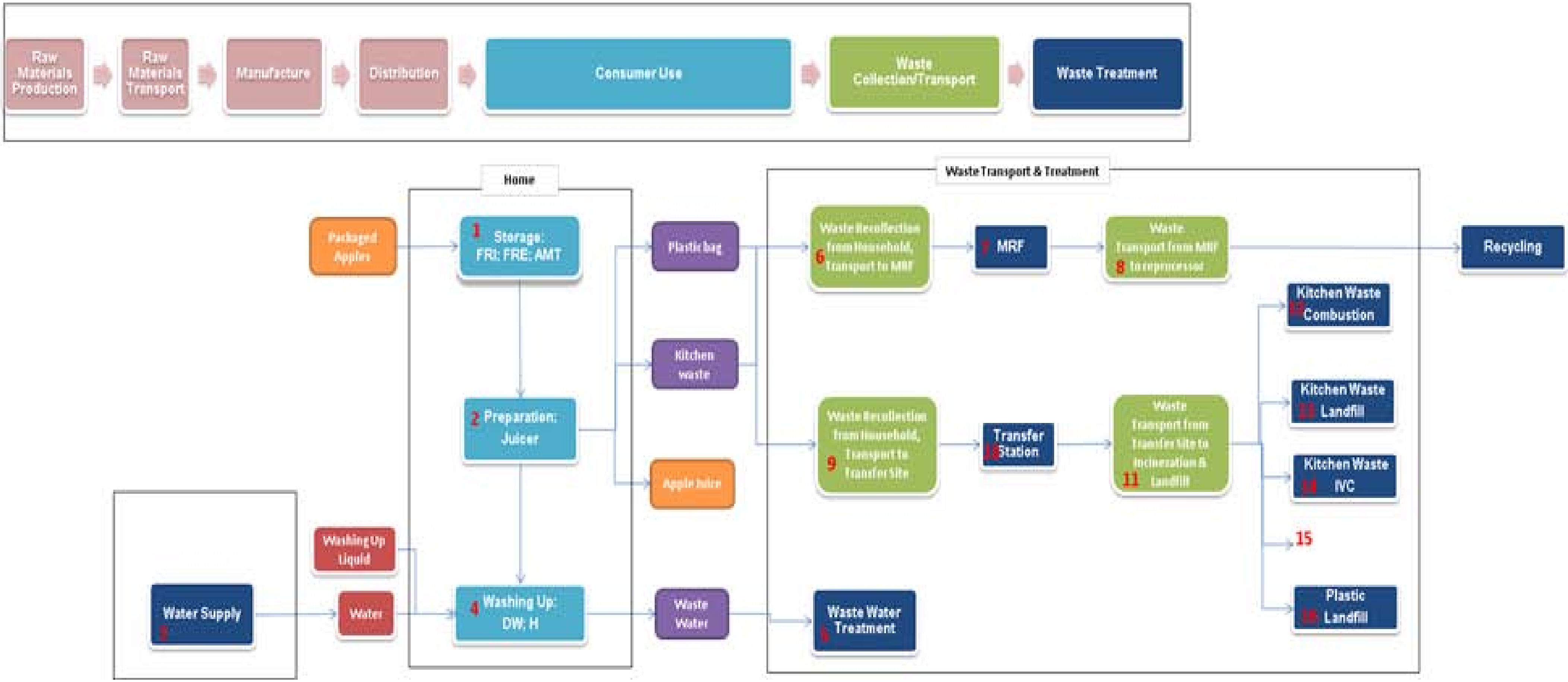


Figure 11-14: Flow chart of process steps for use phase and disposal of 1 product unit of home made apple juice

Mass balances

Process step No.	Input	Input mass [g]	Output	Output mass [g]
1	Packaged Apples	2.00	Packaged Apples	2.00
2	Packaged Apples	2.00	Apple Juice	1.07
			Kitchen waste	0.910
			Plastic bags	0.0107
3	Water	6.96	Water	6.96
4	Water	6.96	Water	6.96
5	Water	6.96	Water	6.96
6	Packaging Waste A = 1.7% of kitchen waste + 9.7% of plastic (film)	0.0165	Packaging Waste A	0.0165
7	Packaging Waste A	0.0165	Packaging Waste A	0.0165
8	Packaging Waste A	0.0165	Packaging Waste A	0.0165
9	Packaging Waste B = 98.3% of kitchen waste + 90.4% of plastic (film)	0.904	Packaging Waste B	0.904
10	Packaging Waste B	0.904	Packaging Waste B	0.904
11	Packaging Waste B	0.904	Kitchen Waste to Incineration	0.126
			Kitchen Waste to Landfill	0.721
			Kitchen Waste to IVC	0.0473
			Plastic (film) to Incineration	0.0007
			Plastic (film) to Landfill	0.009
12	Kitchen Waste to Incineration	0.126	Kitchen Waste in Incineration	0.126
13	Kitchen Waste to Landfill	0.721	Kitchen Waste in Landfill	0.721
14	Kitchen Waste to IVC	0.0473	Kitchen Waste in IVC	0.0473
15	Plastic (film) to Incineration	0.000697	Plastic (film) in Incineration	0.0007
16	Plastic (film) to Landfill	0.009	Plastic (film) in Landfill	0.009

Table A28: Mass balances for the process steps of preparing the home made apple juice

<u>Primary data on energy consumption</u>

Process step No.	Appliance	Operation	Fuel type	Quantity	Unit
1	Fridge/Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh
2	Juicer A	aprox. 5 mins "on"	Electricity	0.022	kWh

Table A29: Primary activity data for the use phase of the home made apple juice

<u>Calculation of CO_2e per product unit</u>

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
1	Primary	measured energy consumption	Fridge/ Freezer A	24h storage, fridge with energy rating "A", on "3"	Electricity	0.615	kWh	0.523	kg CO_2e/ kWh	0.322	kg CO_2e/ 24h whole fridge	**4.55E-03**
2	Primary	measured energy consumption	Juicer A	aprox. 5 mins "on"	Electricity	0.0216211	kWh	0.523	kg CO_2e/ kWh	0.011	kg CO_2e/ juicing step	**1.13E-02**
3	Secondary	Water UK	--	--	--	--	--	--	--	0.289	tonnes CO_2e/ ML water supplied	2.01E-03
4	Secondary	MTP - BNW16	Gas boiler	heating 1L water from 15^0C to 55^0C	Natural Gas	0.0665	kWh	0.185	kg CO_2e/ kWh	0.012	kg CO_2e/ L water heated	**8.55E-02**
5	Secondary	Water UK	--	--	--	--	--	--	--	0.406	t CO_2e/ ML wastewater treated	**2.82E-03**
6	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to MRF: 2km	--	--	--	--	--	0.64	kg CO_2e/ tonne waste	1.06E-05
7	Secondary	Defra 2006a,b	MRF	Waste sorting and bulking	Diesel	0.931	kg	3.164	kg CO_2e/ kg diesel	14.870	kg CO_2e/ tonne waste	2.45E-04
					Electricity	22.8	kWh	0.523	kg CO_2e/ kWh			
8	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from MRF to reprocessor: 100 km	--	--	--	--	--	14.87	kg CO_2e/ tonne waste	2.45E-04
9	Secondary	Defra 2006a,b	Refuse collection vehicle	Waste transport from household to transfer station: 1.5km	--	--	--	--	--	0.48	kg CO_2e/ tonne waste	4.34E-04
10	Secondary	Defra 2006a,b	Transfer station	Waste bulking	Diesel	0.32	kg	3.164	kg CO_2e/ kg diesel	2.027	kg CO_2e/ tonne waste	1.83E-03
					Electricity	1.94	kWh	0.523	kg CO_2e/ kWh			

Process step No.	Data type	Data source	Appliance/ Site	Operation	Fuel type	Quantity	Unit	Emission factors	EF unit	Process step EF	Process step EF unit	Mass CO_2e/PU
11	Secondary	Defra 2006a,b	Bulk transport vehicle (40-tonne truck)	Waste transport from transfer station to treatment facility: 30 km	--	--	--	--	--	4.46	kg CO_2e/ tonne waste	**4.03E-03**
12	Secondary	Defra 2006a,b	Incineration plant (mass burn - new moving grate)	Incineration of kitchen waste	Direct CO_2	0	kg	0	kg CO_2	2.418	kg CO_2e/ tonne waste	3.04E-04
					Diesel	0.118	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/ kWh			
13	Secondary	Defra 2006a,b	Landfill site	Landfill of kitchen waste	CH_4	7.68	kg	21	kg CO_2e/ kg CH_4	164.199	kg CO_2e/ tonne waste	**1.18E-01**
					N_2O	0.000189	kg	310	kg CO_2e/ kg N_2O			
					Diesel	0.904	kg	3.164	kg CO_2e/ kg diesel			
14	Secondary	Defra 2006a,b	IVC	Kitchen waste composting	CH_4	0.0178	kg	21	kg CO_2e/ kg CH_4	17.60706	kg CO_2e/ tonne waste	8.33E-04
					N_2O	0.00989	kg	310	kg CO2e/ kg N_2O			
					Diesel	2.99	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	9	kWh	0.523	kg CO_2e/ kWh			
15	Secondary	Defra 2006a,b	Incineration plant (mass burn - new moving grate)	Incineration of plastic (film)	Direct CO_2	1753	kg	1	kg CO_2	1755.418	kg CO_2e/ tonne waste	1.22E-03
					Diesel	0.118	kg	3.164	kg CO_2e/ kg diesel			
					Electricity	3.91	kWh	0.523	kg CO_2e/ kWh			
16	Secondary	Defra 2006a,b	Landfill site	Landfill of plastic (film)	CH_4	0	kg	21	kg CO_2e/ kg CH_4	2.919	kg CO_2e/ tonne waste	2.63E-05
					N_2O	0.000189	kg	310	kg CO_2e/ kg N2O			
					Diesel	0.904	kg	3.164	kg CO_2e/ kg diesel			

Table A30: Calculation of the GHG emissions in CO_2 equivalents for each process step (material inputs are denoted in bold).

Contributions to the overall GHG emissions of use phase and disposal of home made apple juice

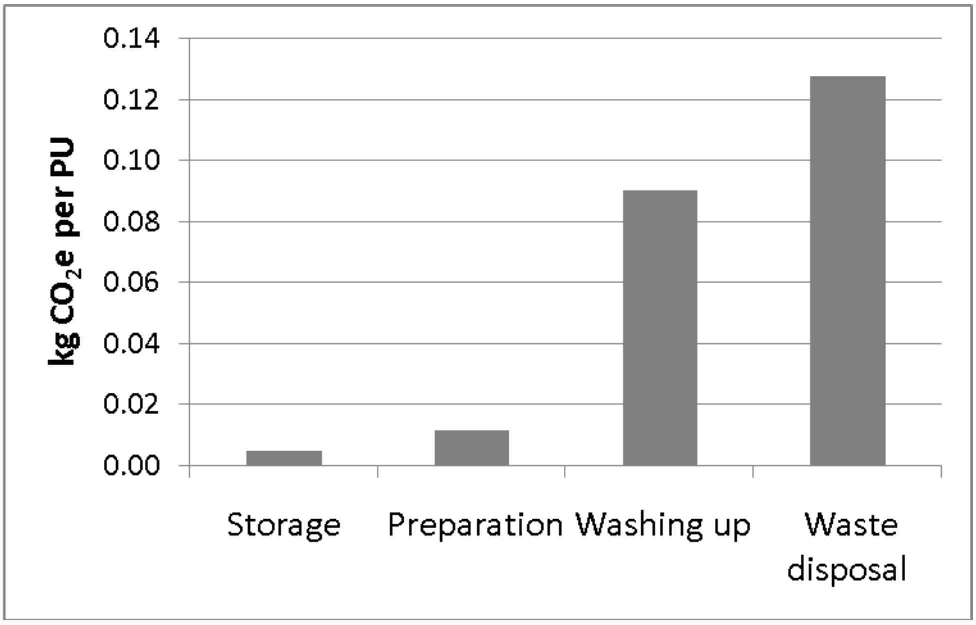


Figure 11-15: Contribution of process steps to the overall GHG emissions of the use phase of home made apple juice

11.3 Additional data for the preparation of food products using various methods

11.3.1 Ready meal cottage pie

Methodology

Conditions

All tests were carried out in an air conditioned test laboratory running at 20 ± 1°C and the power to the ovens was supplied via a voltage stabilizer (TS-3B RMS, Claude Lyons, Waltham Cross, UK) and a variable transformer (Regavolt 715-G2PE, Claude Lyons, Waltham Cross, UK) providing an input voltage of 240 V ± 1 %. A power meter was attached to each of the ovens to measure the energy consumption during the cooking process. For the gas oven a flow meter was fitted to enable the measurement of gas consumption required for the cooking process.

The following ovens were used for the trials:

Manufacturer	Model	Oven type	Cooking mode
WHIRLPOOL	AKZ650/IX	Electric	Fan-assisted
MIELE	H4250B	Electric	Convection
PANASONIC	NN-T553W	Microwave solo	100%
SANYO	EM-S3577	Microwave solo	100%
SHARP	R-95STM	Combination MW	50% MW + fan assisted
CANNON	10518G	Gas	Convection

Table A31: Ovens used for the trial

The ready prepared product (cottage pie) was collected from the manufacturer and stored frozen in a chest freezer at -20°C until required.

Method

Prior to the tests, samples were removed from frozen storage and placed in a refrigerator at 5°C for at least 24h before the cooking tests. Cooking instructions, oven temperature, and pre-heating and cooking time were followed as per on-pack instructions (see below). In the case of the microwave combination the automatic oven pre-heating was used.

Manufacturer	Oven type	Pre-heating time (min)	Cooking time (min)
WHIRLPOOL	Electric fan-assisted	20	25
MIELE	Electric convection	20	25
PANASONIC	100%	N/A	4
SANYO	100%	N/A	5
SHARP	50% MW + air	4.5 (auto pre-heat)	10
CANNON	Gas	20	25

Table A32: Trial method

For all tests a cold oven was used (at least 6 h between replicates), to allow the ovens to return to ambient conditions. Internal product temperature was measured at 9 different positions at the end of the cooking period using a hand held temperature sensor (Digitron). Visual assessment was also carried out at the end of each replicate. The total energy consumption for each oven, including any pre-heating required, was measured. A pre-heating period of 20min the same as used at Campden BRI, was used for all electric standard ovens. Five replicates were carried out in each oven.

Accuracy of control

The ovens were tested for accuracy of control based on BS EN 60350:1999 - clause 8.2, to check the temperature in the oven as set on the dial. A calibrated thermocouple (type T), used to measure temperature at 2 s intervals, was placed halfway between the top and the lowest shelf positions, equivalent to the geometric centre of the cooking zone. The ovens were set at three temperature points (150, 180 and 200ºC) and left to run until stable at each set temperature. Once stable, the average temperature in the oven was calculated and compared to that set at the dial.

Table A33 shows the average temperature in the geometric centre of the oven at each temperature setting and the deviation from the dial setting. Figures 11-16 to 11-19 show the time/temperature plots for the ovens used at specified set temperatures. As expected, the fan-assisted oven gave a very small deviation from the dial setting, showing a good control of temperature. The convection oven showed a larger deviation from that of the dial setting, around 10ºC higher at the temperature set at the dial. The gas ovens showed very large temperature deviations at all dial settings used, with gas mark 6 having the larger deviation, 26.57ºC above the expected 200ºC.

Oven	Set on dial (°C)	Average value once stable (°C)	Deviation (°C)
Fan-assisted	150	149.88	-0.12
	180	180.40	+0.40
	200	199.57	-0.43
Convection	150	137.67	-12.33
	180	170.51	-9.49
	200	190.56	-9.44
Gas	Mark 2 (150)	173.12	+23.12
	Mark 4 (180)	195.54	+15.54
	Mark 6 (200)	226.57	+26.57

Table A33: Accuracy of control temperature data

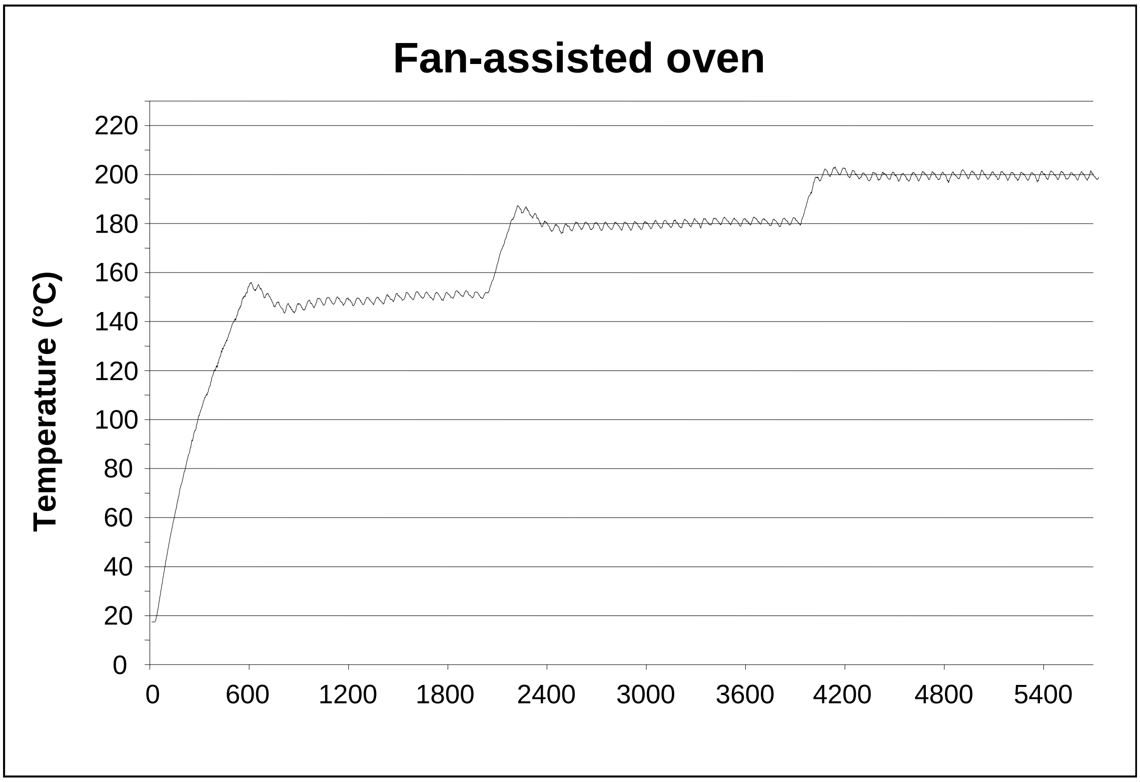


Figure 11-16: Temperature for the fan-assisted oven set at 150, 180 and 200ºC on the dial and run until stable temperatures at each setting.

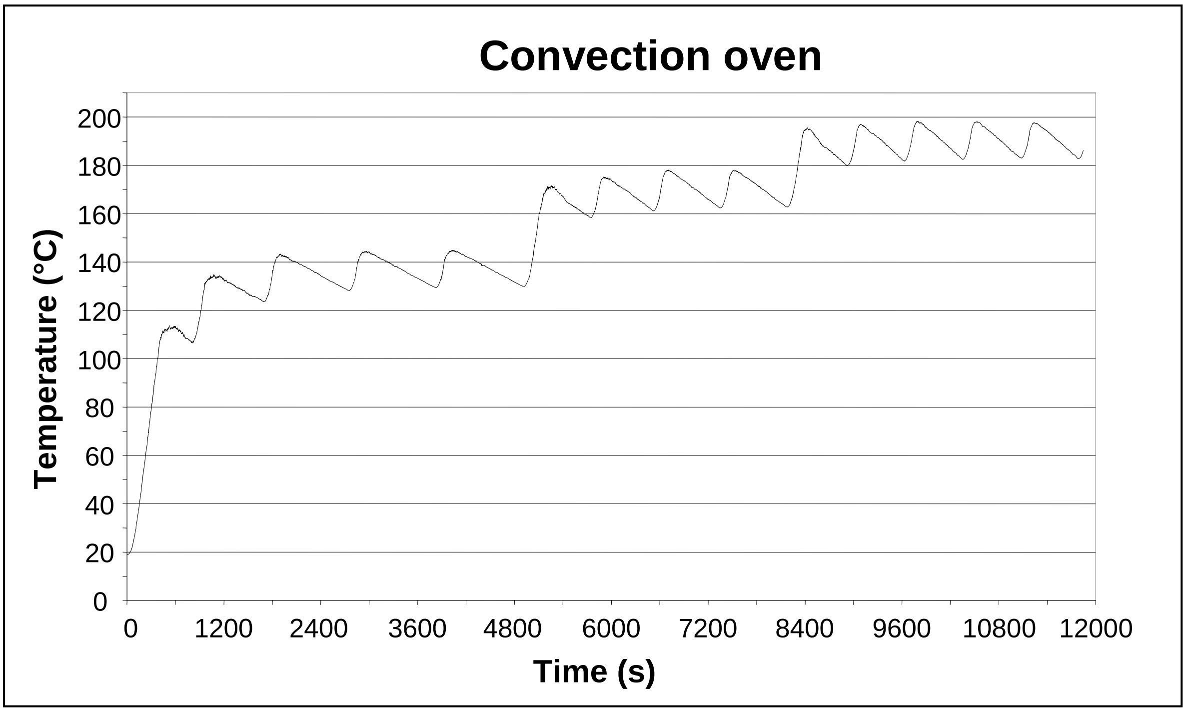


Figure 11-17: Temperature for the convection oven set at 150, 180 and 200ºC on the dial and run until stable temperatures at each setting.

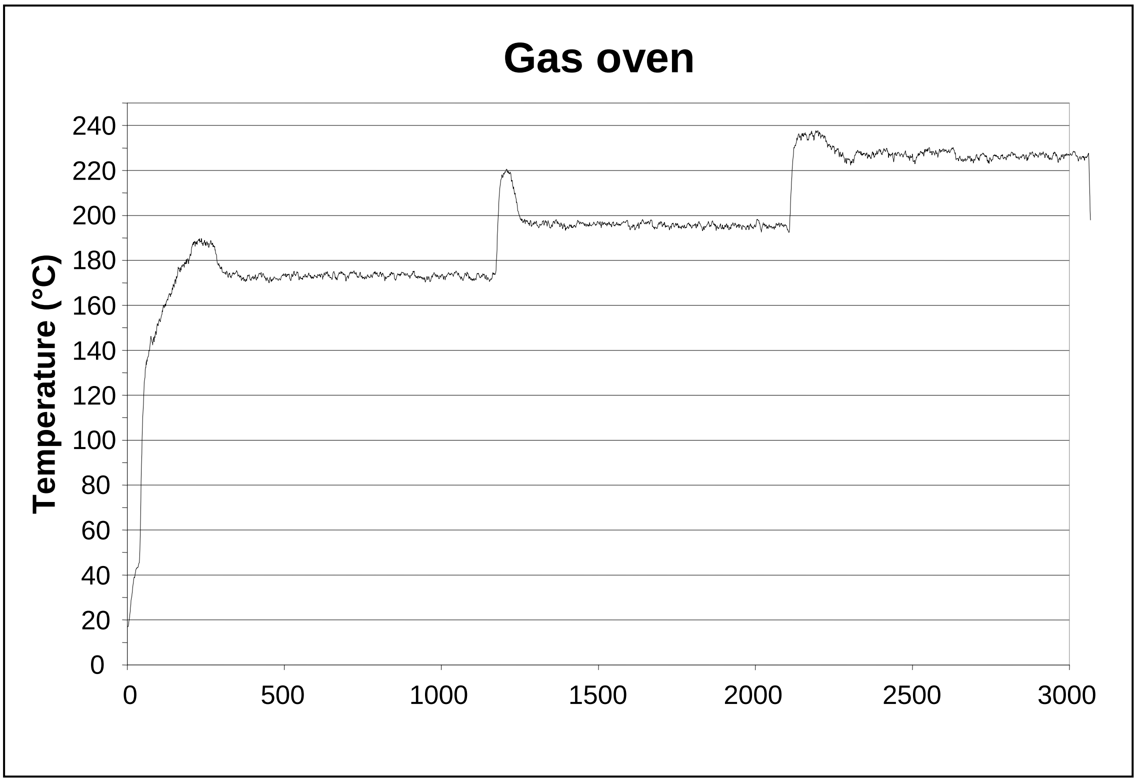


Figure 11-18: Temperature for the gas oven set at gas mark 2 (150ºC), 4(180ºC) and 6 (200ºC) on the dial and run until stable temperatures at each setting.

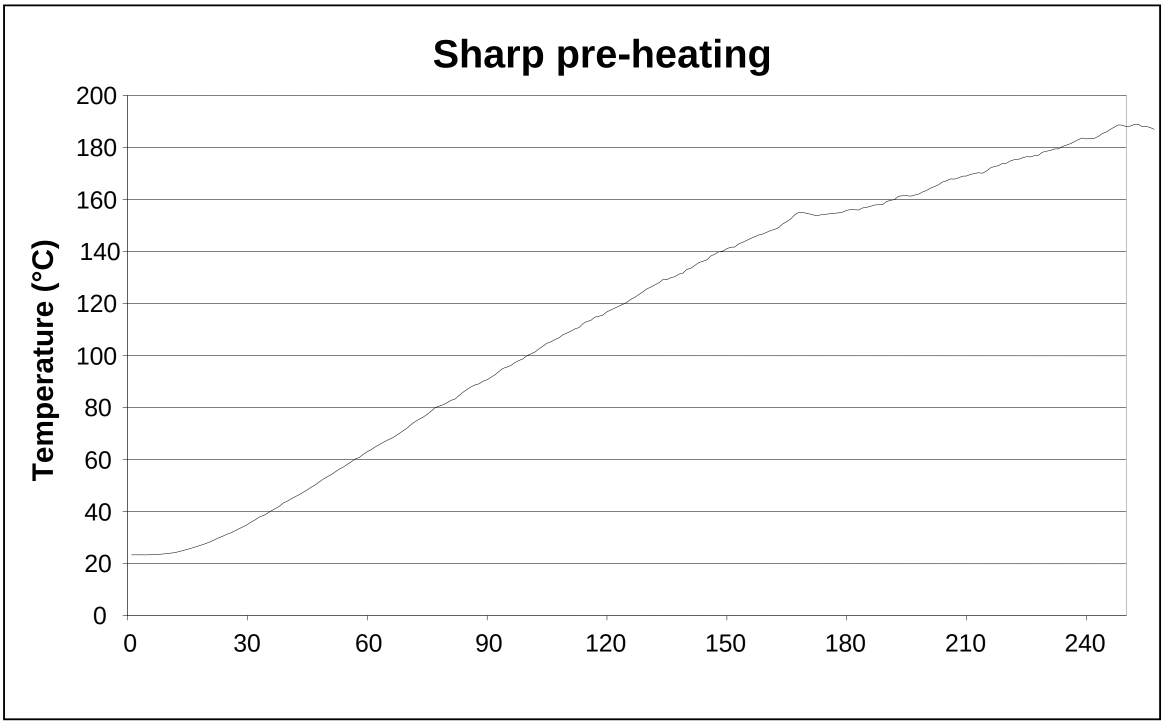


Figure 11-19: Auto pre-heating for the MW combination oven set at 180ºC on the convection mode.

Cottage pie tests

The first test carried out in the fan-assisted oven using a cottage pie, used the oven's preheating thermostat control, i.e. the oven was ready for use when the thermostat light went off. This however, produced an under heated meal and resulted in a need to increase the final cooking time. A short test was then carried out to check the temperature deviation after the pre-heating (Table A34). For the electric ovens, the temperature, time and energy consumption were recorded when the thermostat indicator light switched off. In the case of the gas oven, the gas consumption and temperature were recorded after 15 min pre-heating (the time recommended in the manufacturer's manual).

		Thermostat setting				**20min pre-heating**		
	Dial set (ºC)	**Measured (°C)**	**Deviation (°C)**	**Time (s)**	**Energy (kWh)**	**Measured (°C)**	**Deviation (°C)**	**Energy (kWh)**
Fan-assisted (Whirlpool)	170	161.4	-8.6	540	0.280	167.7	-2.3	0.434
Convection (Miele)	200	151	-49.0	540	0.352	171.7	-28.3	0.486
Gas (Cannon)	Gas 6	227.7	+27.7	900	0.570	225.5	+25.5	0.731
MW combination (Sharp)	180	187	+3.0	244	0.18	N/A	N/A	N/A

Table A34: Measured temperature, deviation from set temperature and energy consumption for the preheating of the electric, gas and microwave combination ovens.

11.3.2 Boiling vegetables

Methodology

Hob efficiency

This test is based on BS EN 60350:1999, clause 7.1. An uncoated stainless steel saucepan with a nominal diameter of 18 cm is filled with 1.5 l of water. The water is heated from 15 ± 2 °C to 90 °C and the time and energy consumption is measured. The efficiency is calculated according to the following formula:

$$\eta = \frac{4.187 * 75 * m}{W_m * 3600} * 100$$

Where:

η	efficiency
W_m	measured energy consumption (kWh)
75	temperature rise (K)
m	mass of water (kg)
3600	conversion (s/h)

This test was carried out before any trial could start to define the efficiency of all hobs used.

Figure 11-20 shows the calculated efficiency values for the hobs tested. It shows that the induction hob had the highest efficiency (77 %) and the gas hob had the lowest (31 %).

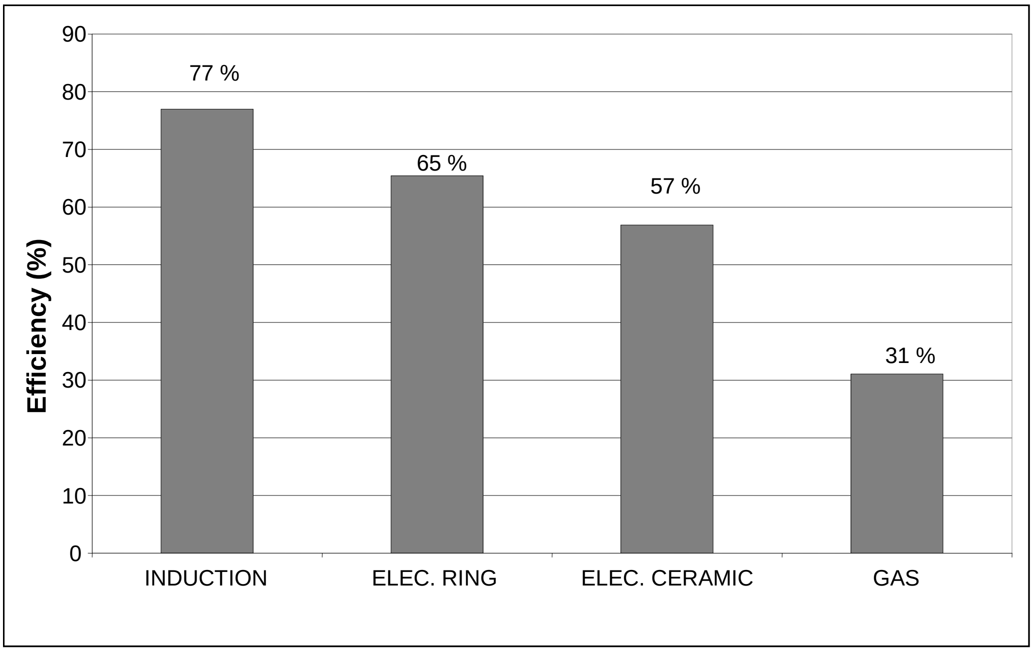


Figure 11-20: Efficiency values when heating a 1.5 litres water load.

Vegetable boiling trials

All tests were carried out in an air conditioned test laboratory running at 20 ± 1°C and the power to the electric appliances was supplied via a constant voltage stabilizer (TS-3B RMS, Claude Lyons, Waltham Cross, UK) and a variable transformer (Regavolt 715-G2PE, Claude Lyons, Waltham Cross, UK) providing an input voltage of 240 V ± 1 %. A power meter (Northern Design, Northern Design (Electronics) Ltd, Single Phase Multicube) was used to measure the energy consumption during each cooking process. For the gas hob a gas flow meter (Wizit Co. Ltd, KG-2, G1.6) was used.

A range of domestic hobs, shown in table below, were used for the tests. Tests were also performed using an electric kettle to boil 500 g of water and finishing the cooking process using the hobs. New potatoes and carrots were purchased by FRPERC from a local supermarket and were stored under chilled conditions until required.

Manufacturer	Model	Type of energy	Type	Diameter of the cooking zone (cm)
Jackson hallmark		Electric	Ring	16
Belling format	600XP2 BL	Electric	Ceramic	20
Palson	S2C-K	Electric	Induction	22
Cannon	10518G	Gas	Flame	10
Panasonic	NN-T553W	Microwave	Solo	-
Swan		Electric	Kettle	-

Table A35: Domestic hobs and other appliances used for tests

Cooking procedure

Prior to the tests samples of carrots were placed in a refrigerator at 8ºC for at least 24 hours before the cooking tests could begin. The samples of new potatoes were stored at ambient condition in a room at 20ºC for no more than 2 days. Standard cooking instructions for boiling vegetables for one person were followed: for hobs 150g of vegetables with 500 g of water and for the microwave 150 g of vegetable with 30 g of water. The vegetables were boiled using the highest setting, then the setting was turned down to the minimum and simmered until the vegetables were cooked. For all tests cold hobs were used, i.e. at least 6 h was allowed between replicates for the hobs to reach ambient conditions. The total energy consumption for each hob, including energy required for boiling and for cooking, was measured. At least 2 replicates were carried out on each hob.

11.3.3 Meat dishes

Methodology

Test conditions

The investigations were run under the same controlled conditions. The regulation of the air temperature in the laboratory was ensured by an air conditioner which kept the air temperature at 20 ± 1°C. The power to the ovens was supplied via a voltage stabilizer (TS-3B RMS, Claude Lyons, Waltham Cross, UK) and a variable transformer (Megavolt 715-G2PE, Claude Lyons, Waltham Cross, UK) providing an input voltage of 240 V ± 1 %. The energy consumption was determined using a power meter (Northern Design (Electronics) Ltd, Single Phase Multicube). For the gas oven a gas flow meter (Wizit Co. Ltd, KG-2, G1.6) measured the gas use for cooking the different chicken dishes (Figure 11-21).

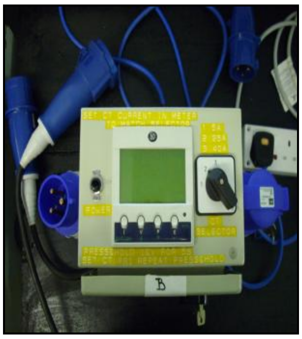
	
Power meter Northern Design (Electronics) Ltd Single Phase Multicube	**Gas meter Wizit Co. Ltd KG-2, G1.6**

Figure 11-21: Pictures showing the power meter and gas meter used to measure energy and gas consumption during the tests.

A wok with a diameter of 32 cm (Tefal) was used to stir-fry the chicken and a 28 cm frying pan (Tefal) was used for frying the vegetables and the chicken breast for the stew.

Table A36 provides information on the appliances used for the trials. Whole chicken, chicken products and the vegetables were purchased in a local supermarket and stored in a fridge at 5°C until required.

Manufacturer	Model	Appliance type	Energy type	Oven cooking mode	Dish
WHIRLPOOL	AKZ650/IX	Built-in oven	Electric	Fan-assisted	Stew, roast chicken
MIELE	H4250B	Built-in oven	Electric	Natural convection	Roast chicken
SHARP	R-95STM	Combination MW oven	-	50% MW + fan assisted	Stew, roast chicken
CANNON	10518G	Gas oven	Gas	Natural convection	Stew, roast chicken, Stir- fry
BELLING	600XP2 BL	Ceramic hob	Electric	-	Stew, Stir-fry
PALSON	S2C-K	Induction hob	Electric	-	Stir-fry

Table A36: Information on the appliances used for the tests.

Cooking procedure and recipes

Roast chicken

Table A37 summarises the sources from recipes used for the calculation of cooking time for roasting a chicken.

Type of oven	Source for recipe	Cooking time calculation
Gas	Chicken Package	20min/450g plus 20min
Combination Microwave	Auto roast button	Input bird weight
Fan-assisted	Chicken Package	15min/450g plus 15min
Natural convection	Chicken Package	20min/450g plus 20min

Table A37: Source of cooking instructions for roasting a chicken

The chicken had a weight range of 1.2 to 1.3 kg. They were purchased in a supermarket and stored at 5°C and left in refrigerator overnight for temperature equalisation. For roasting the chicken a range of ovens were used: one gas oven, 5 different models of fan assisted ovens, one natural convection oven (no fan mode) and 8 different models of combination microwaves.

The cooking time was calculated using the recommendations on the chicken packaging for weight:time ratio as shown in Table A37.

The ovens were pre-heated using the thermostat light indicator (once the light is off oven is ready for use) for the fan-assisted and conventional oven and 15 min for the gas oven as recommended by oven manufacturer. No pre-heating was required on the combination ovens, as instructions for the auto chicken roast program were followed.

Methods		
Combination Microwave	**Gas oven**	**Fan-assisted and natural convection ovens**
Weighing of raw bird (1.2-1.3 kg) The auto button for roasting a whole chicken was used, the weight of the whole chicken was input and the oven calculated the cooking time and mode of roasting	Weighing of raw bird (1.2-1.3 kg) The oven was pre-heated for 15 min recommended by oven manufacturer Chicken was placed uncovered in the centre of the oven and breast side up on a wire rack Cooking time was calculated (av. 1 h 15 min) and the chicken was cooked at 200 °C One minute after cooking the internal temperature was measured using 14 program-controlled thermocouples After the chicken was weighed to calculate the weigh loss	Weighing of raw bird (1.2-1.3 kg) The ovens were pre-heated using the Auto program Chicken was placed uncovered in the centre of the oven and breast side up on a wire rack Cooking time was calculated and the chicken was cooked at 190 °C in the natural convection oven and at 180 °C in the fan-assisted oven One minute after cooking the internal temperature was measured using 14 program-controlled thermocouples After the chicken was weighed to calculate the weigh loss

Table A38: Cooking methods for roasting chicken in different ovens

The chicken was placed uncovered in the centre of the oven and breast side up on a wire rack. This allowed the juices to run down. After cooking, the chicken was taken out of the oven. One minute after cooking, the internal temperature was measured using 14 program-controlled thermocouples in the positions illustrated in Figure 11-24. In chickens the recommendation given by the European Federation of WPSA branches is a minimum temperature of 85°C as a standardised method for sensory assessment of chicken. In all cases the chicken was cooked once the minimum temperature was 85ºC ±1ºC. The chicken was weighed afterwards and the weight loss was then calculated.

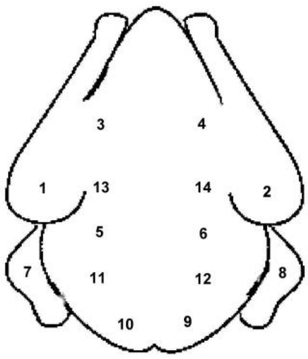


Figure 11-22: Thermocouple positions for temperature measurements 1min after cooking

Chicken stew

The stew was cooked in a gas oven, a fan assisted oven, a convectional oven and a combination microwave. Table A39 shows the recipe used to cook the chicken stew for each appliance. The basic recipe for the stew was found in the Sharp Combination Oven cookery book and was then adapted to cook using normal ovens (Table A39).

Ingredients		
2 tsp of oil; 200 g mushrooms, sliced; 125 g onion, chopped; 1 clove garlic; 450 g chicken; 60 ml tomato purée; 90 ml chicken stock; 1tsp dried oregano; 1tsp dried parsley; Salt and pepper to taste		
Methods		
Combination Microwave	**Gas oven**	**Built- in Fan-assisted oven & Natural convection oven**
Place the mushrooms, onion and garlic in casserole dish, Cook on 100 % for 4 min Preheat frying pan, add 2 tsp. oil and add chicken Fry for 4 min until chicken is no longer pink and get a brown skin Stir in remaining ingredients except the chicken, mix well Add chicken portions and turn to coat with the sauce Cook on Dual Convection,180 °C, 70 % for 20 min, stir and coat the chicken twice during cooking	Preheat frying pan, add 2 tsp. oil Add the onions and garlic into the frying pan, fry at maximum setting for 1:30 min, after add the mushrooms and fry for another 30 sec Put vegetables in a casserole dish After place the chicken breast into the pan and fry it for 2 min to get a brown skin on both sides Prepare the sauce, mix chicken stock with 90 ml water and tomato puree, herbs, salt and pepper, mix up Place chicken portions into casserole dish and coat with the sauce Cook for 40 min, Gas Mark 5 (200 °C)	Preheat frying pan, add 2 tsp. oil Add the onions and garlic into the frying pan, fry for 1:30 min, after add the mushrooms and fry for another 30 sec using setting 6 Put vegetables in a casserole dish After place the chicken breast into the frying pan and fry it for 2 min to get a brown skin on both sides Prepare the sauce, mix chicken stock with 90 ml water and tomato puree, herbs, salt and pepper, mix up Place chicken portions into casserole dish and coat with the sauce Cook for 40 min, at 180 °C with the fan-assisted oven and at 190 °C with the natural convection oven

Table A39: Information about the ingredients and procedure for cooking the chicken stew for the different appliances

Stir-fry chicken

The stir-fry chicken was cooked using a gas hob, induction hob and electric ceramic hob. A basic recipe for stir-fry was found on the internet and is described in Table A40.

Ingredients	Methods
	Gas hob, Ceramic and Induction hob
450 g of chicken	Slice chicken breast into small pieces
3 cups (150 g) of frozen vegetable mix	Preheat wok (using setting 6), add 2 tsp. oil and add chicken
40 ml soy – sauce	Stir-fry for 4 min until chicken is no longer pink and golden
2 tsp oil	Add the vegetables and stir-fry about 4 min
	Pour soy sauce into the wok and stir frequently for 2 min

Table A40: Cooking instruction for stir-fry chicken (www.chinesefood.about.com)