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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: FO 0409
2. Project title: Understanding the GHG impacts of food preparation and consumption in the home
3. Contractor organisation(s):
   Campden & Chorleywood Food Research Association

   Food Process Innovation Unit, Cardiff Business School

   Food Refrigeration & Process Engineerign Research Center, University of Bristol
4. Total Defra project costs (agreed fixed price): £ 34,428
5. Project: start date .... 01 April 2008

   end date .... 31 December 2008

6. It is Defra's intention to publish this form.
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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

The Carbon Trust and Defra co-sponsored the development of Publicly Available Specification 2050 (Specification for the assessment of the life cycle greenhouse gas emissions of goods and services), which was published by the British Standards Institution (BSI) in October 2009. Defra has also 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. This project report is concerned only with phase 2 (FO 0409) of the project "Understanding the GHG impacts of food preparation and consumption in the home".

A literature review was carried out to find available published data on food preparation in the home and the associated GHG emissions. Whereas there are some 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.

The use phase GHG emissions of several additional food products, such as a ready meal and 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 to 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 heating up the ready meal, and this shows in the associated GHG emissions. GHG emissions were also assessed for bread prepared in a bread-maker and bread prepared by hand, where the use of the bread-maker resulted in lower GHG emissions for the use phase. Finally, the GHG emissions associated to the preparation of 1L of home made apple juice were also assessed.

The step of preparation (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 very little to the GHG emissions, while washing up and waste disposals made the biggest contribution.

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 include the assessment of the energy consumption of boiling vegetables and of cooking various meat dishes using a range of 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 indicates that although the gas hob had the highest energy consumption of all hobs used, 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 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.

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 show 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 observations were also confirmed for the preparation of roast chicken and for chicken stew.

The researcher 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. Externally, packaging and pack size entering the home are key drivers of household waste, whilst internally wasted energy of unused appliances, such as ovens being left switched on, is an important factor.

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 were found to make the biggest impact on the overall carbon footprint of the cottage pie raw materials (approx. 70%).

The methodology of PAS 2050 was generally useful for the assessment of the GHG emissions associated to the use phase of food products, and data regarding the use phase GHG emissions of a range of food products was generated.

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:
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   - the main implications of the findings;
   - possible future work; and
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Introduction

The aim of the project "Understanding the GHG impacts of food preparation and consumption in the home" was to investigate the suitability of PAS 2050[1] 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. While phase 1 (FO 0406) focused on the assessment of the suitability of the drafts of PAS 2050 for the consumer use phase, phase 2 (FO 0409) was mainly concerned with obtaining data for the preparation of various food products as well as with obtaining insight into consumer behaviour.

Review: GHG emissions of 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 the implications of consumer behaviour for the associated GHG emissions. 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[2] 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 situation (by type of meal or by appliance) are very scarce. Sidler et al.[3] 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[4] looked at ways of saving energy when using cooking appliances in 44 households in 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[5]. Total energy consumption and related CO_2 emission data were calculated as a function of household income and family type. However, in these reports only assumptions have been considered. DEFRA´s Market Transformation Programme[6,7] 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.

Collison[8] carried out 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 out that the total energy use for cooking 1 kg of food amounts 1.4 to 1.7 MJ. Of this, 0.43 to 0.72 MJ was absorbed by the food. Blenkhorn and Wnuk[9] 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 energy life-cycle of different kinds of food. Carlsson-Kanyama[10,11] investigated the impact of greenhouse gas emissions and energy consumption during 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[12] 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[13] 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.[14] reported about the difference between industrial processing versus 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, some of the information for home prepared meals was obtained by measurement and some was taken from published data.

This review shows that a variety of studies regarding the energy consumption and the associated GHG emissions of the preparation of food products has been carried out previously. However, no literature focused on the consumer use phase, and linking consumer behaviour, energy consumption when using different preparation techniques and kitchen appliances, and the GHG emissions associated with the preparation of food in the home, has been found.

Embodied GHG emissions of several food products

The work of assessing 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 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 the home and the preparation of fresh apple juice in a home juice extractor. The products were chosen to allow comparison with like industrially made food products studied in project FO 0404.

<u>Ready-meal and home made apple crumble: Comparison of GHG emissions</u>

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. 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 ready meal was assumed to be stored at ambient temperature. The apple crumble was prepared in a preheated electric fan oven at 180ºC 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°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 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.

Comparison and discussion of results

GHG emission values were calculated for both the ready meal and the home made apple crumble. GHG emissions associated to 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 found to be almost double at 525g CO_2e per functional unit (see Table 1 and Figure 1).

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

For both meals, preparation (cooking) was found to be the most important process step. Thus, in the case of the home made meal, preparation was accountable 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 min 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 to 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 (apple peelings)).

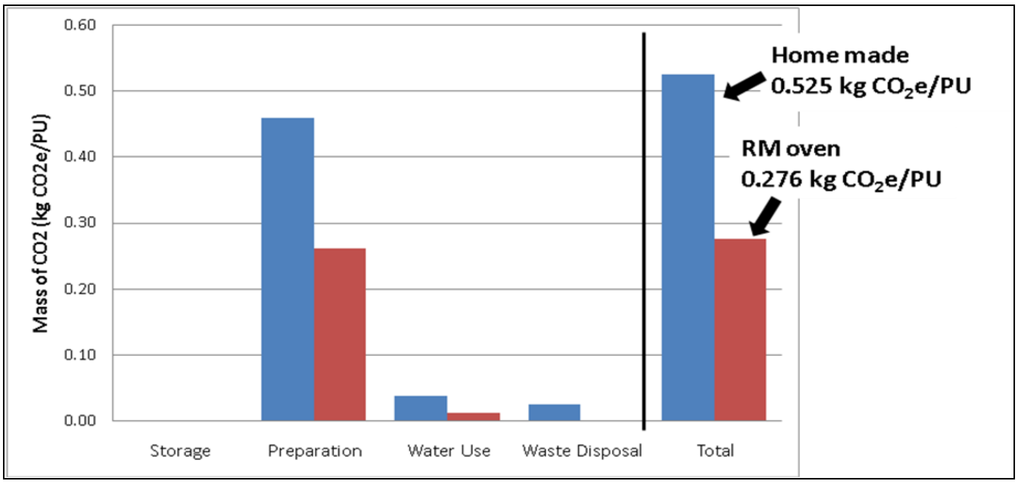

Figure 1: Apple crumble: Importance of process steps for overall GHG emissions (blue: home made meal, red: ready meal in electric fan oven)

GHG emissions associated with the preparation of home baked bread

Home made bread

Bread was made in two different ways. On the one hand, a household bread-maker was used. For comparison, bread was also 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^{o}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 1L of water for the bread-maker utensils). Calculations were carried out to evaluate the energy consumption associated with heating water from 15 to 55^{o}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.

Comparison and discussion of results

GHG emission values were calculated for both types of bread prepared. GHG emissions associated to 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 calculations carried out previously by researchers 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 Figure 2).

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 was accountable 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 to 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).

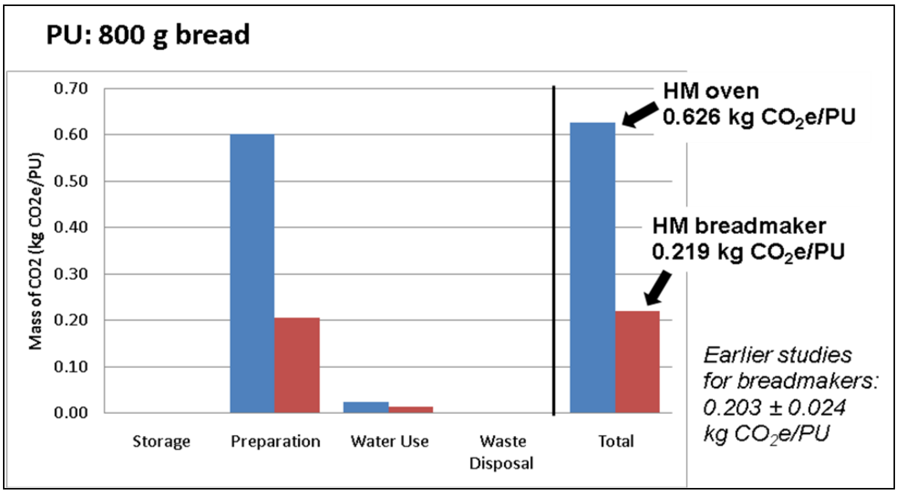

Figure 2: Bread: Importance of process steps for overall GHG emissions (blue: hand made bread, red: bread made in bread-maker)

GHG emissions associated with the preparation of home made apple juice

Home made apple juice

The only ingredients for the home made apple juice were apples. The functional unit was defined as 1L 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.

Discussion of results

GHG emissions associated to the preparation of 1L of home made apple juice were found to be approximately 234g CO_2e per functional unit (see Figure 3). Unlike for the cottage pie and the apple crumble meals discussed above, the preparation of the apple juice (juicing of apples) contributes 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 to 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).

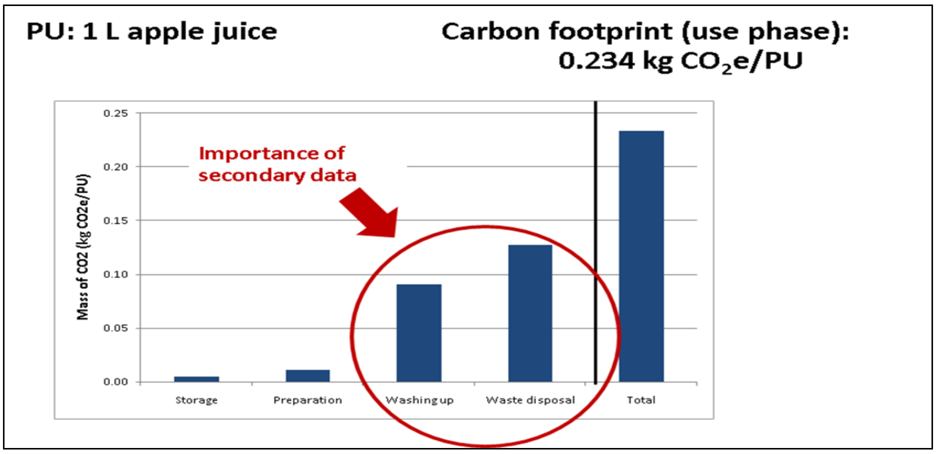

Figure 3: Apple juice: Importance of process steps for overall GHG emissions

It is important to point out that for the apple crumble and bread 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). Through cooking trials it is relatively straightforward to obtain good quality primary data for this part of the use phase. 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 data gathered for these two steps, as subjective assumptions will influence these calculations to a greater extent.

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 of preparation of the cottage pie ready meal, the energy consumption of 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.

It should be noted that although several replicates were used for each hob and each oven tested, the results only considered very few examples of each type of hob or oven. Experience shows that there can be significant differences in energy consumption between hob and oven manufacturers/models and this should be considered when using the results. The conclusions based on this limited sample of hobs and ovens will have a high degree of uncertainty.

<u>Cooking a ready prepared meal (cottage pie) in a range of domestic ovens</u>

This task aimed to measure the energy consumption of cooking the ready meal cottage pie discussed in phase 1 of this project 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, 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. For all tests a cold oven was used. 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, was used for all electric standard ovens. Five replicates were carried out in each oven.

Results and discussion

Figure 4 shows the average GHG emission values, with the variation among the replicates, on all ovens tested. The microwave ovens had by far the lowest energy consumption and hence the lowest GHG emissions per functional unit. The combination microwave and the gas ovens showed similar values for the GHG emissions per functional unit of cottage pie, with the gas oven having a slightly higher value. The convection oven had the highest associated GHG emissions with the fan-assisted oven not far behind.

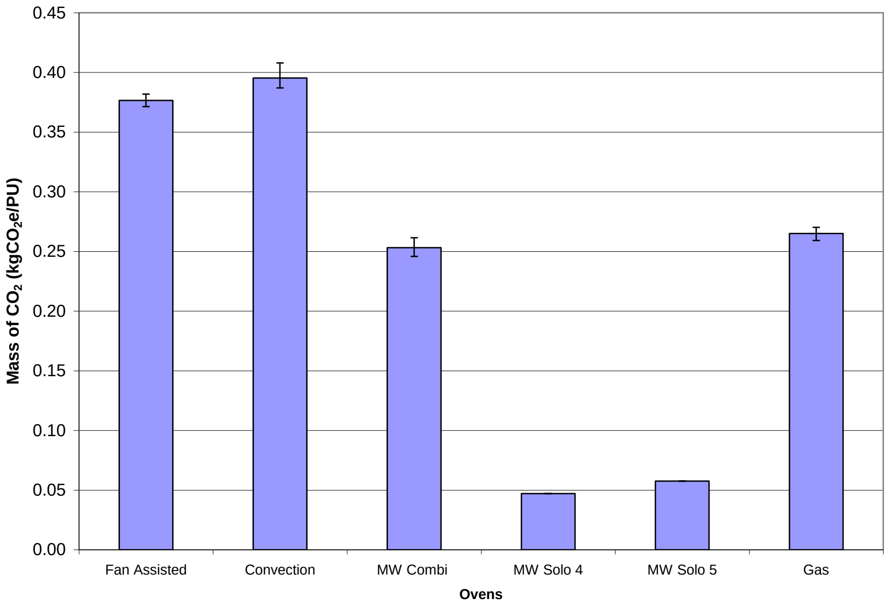

Figure 4: Calculated GHG emissions per functional unit of cottage pie

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 used had a large temperature gradient inside the cavity, varying from 170ºC at the bottom to 240ºC at the top of the cavity. For this particular oven, less time would be required to heat the product without overheating and hence less GHG emissions would have been produced. However, all the heating times used were those specified in the on-pack instructions and are likely to be those used by the consumers.

<u>Boiling vegetables using a range of domestic hobs and a microwave</u>

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 500 g 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 150 g of vegetables with 500 g of water and for the microwave 150 g of vegetables 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. This took approximately 16 minutes for the new potatoes, and 12.5 minutes for the carrots. For all tests cold hobs were used. The total energy consumption of each hob, including energy required for boiling and for cooking, was measured. At least 2 replicates were carried out on each hob.

Results and discussion

Table 2 shows the measured energy consumption and the calculated GHG emissions for boiling 150g of new potatoes and carrots. The data indicates that the gas hob has the highest energy consumption of all hobs used. However, 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 showed the lowest GHG emissions, followed by the gas hob for both types of vegetables. The highest amount of greenhouse gas 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 2: Energy consumption and GHG emissions for cooking one portion (150 g) of new potatoes or carrots in a saucepan with lid

Trials for cooking vegetables when using an electric kettle to boil water and then boil/simmer on the hob until cooked indicate that although the cooking time was decreased when using a kettle compared to using cold water for the electric hobs, there was little difference in energy consumption (Figure 5). However, in the case of the gas hob, the CO_2 emission increased when using the kettle.

Thus, the results of the tests show that in summary, microwave ovens required the lowest amount of energy consumption and hence the lowest mass of CO_2 emitted per functional unit. 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 GHG emissions than the ceramic and ring hobs.

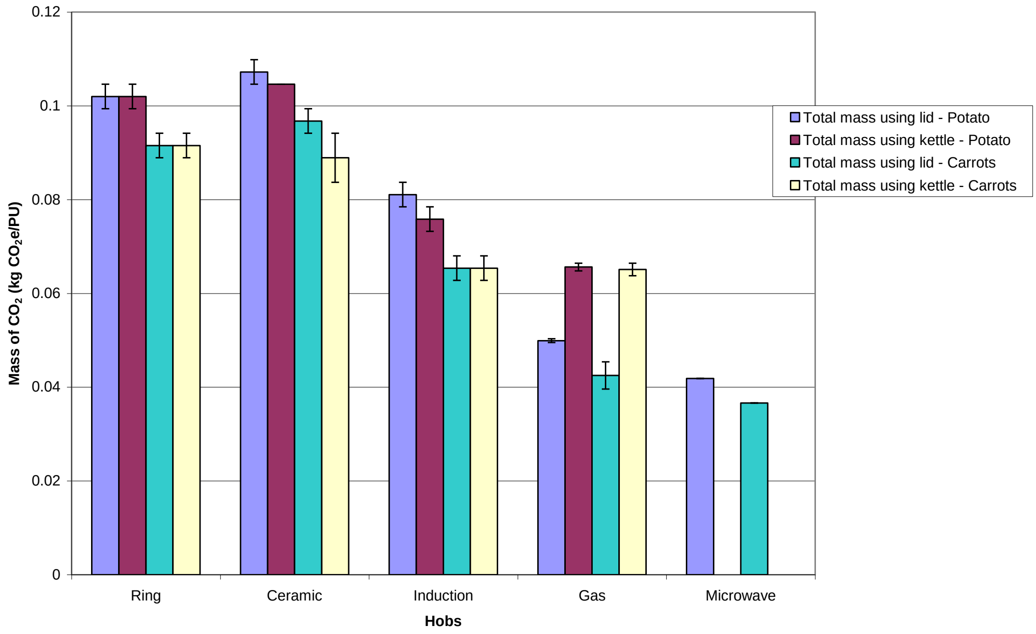

Figure 5: Difference in GHG emissions when using cold water or a kettle to cook new potatoes and carrots

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

This task aimed to show how using the same main ingredient (chicken), the associated GHG emissions of preparing a dish can vary greatly, depending on the cooking method chosen and the appliances used.

Cooking procedures

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

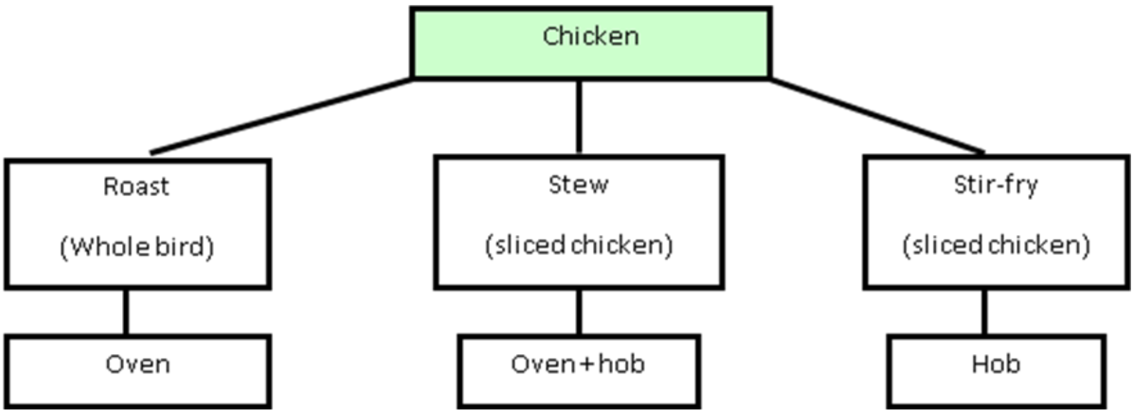

Figure 6: Cooking methods and appliances used for cooking the chicken dishes

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, 5 different models of fan assisted ovens, one natural convection oven and 8 different models of combination microwaves. The chicken had a weight range of 1.2 to 1.3 kg. They were purchased in a supermarket and left in a refrigerator overnight for temperature equalisation. The cooking time was calculated using recommendation on the chicken packaging for weight:time ratio. 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 for the combination ovens, as instructions for the auto chicken roast program were followed.

Results and discussion

Figure 7 illustrates the variation of the calculated GHG emissions for the appliances used. The gas oven had the highest average energy consumption when compared with the other ovens. Of all electric appliances, on average the combination microwaves had the lowest energy consumption followed by the natural convection and then fan-assisted ovens. When considering the amount of greenhouse gases associated with the use of each model, the gas oven had the lowest emission and the fan-assisted ovens the highest. It is important to note that there is a large variation between the ovens tested. Thus, the use of some of the combination microwaves resulted in higher GHG emissions than the use of the most energy efficient models of fan-assisted ovens.

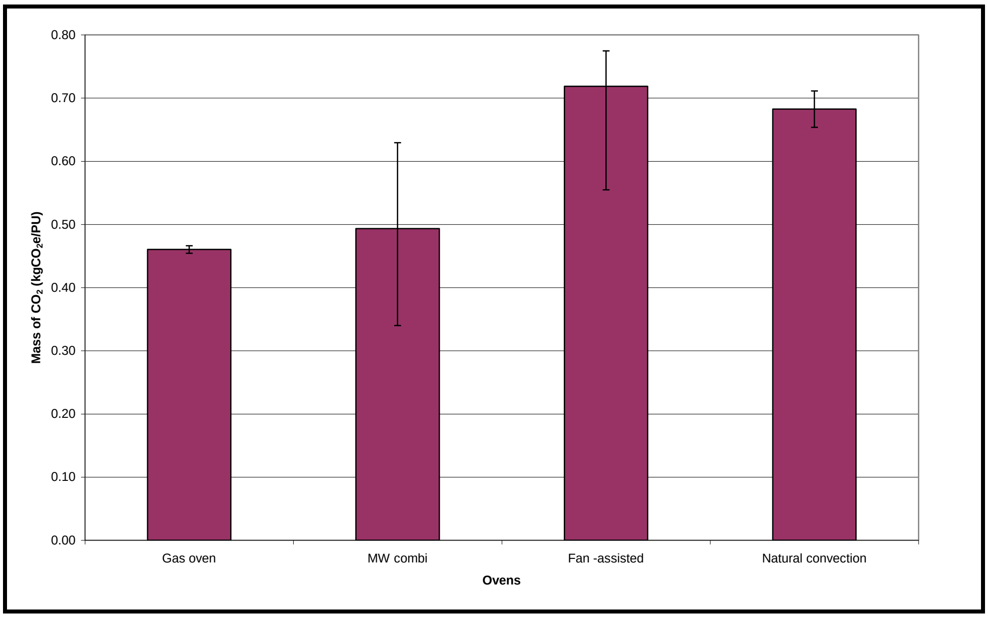

Figure 7: GHG emissions for roasting chickens using different appliances

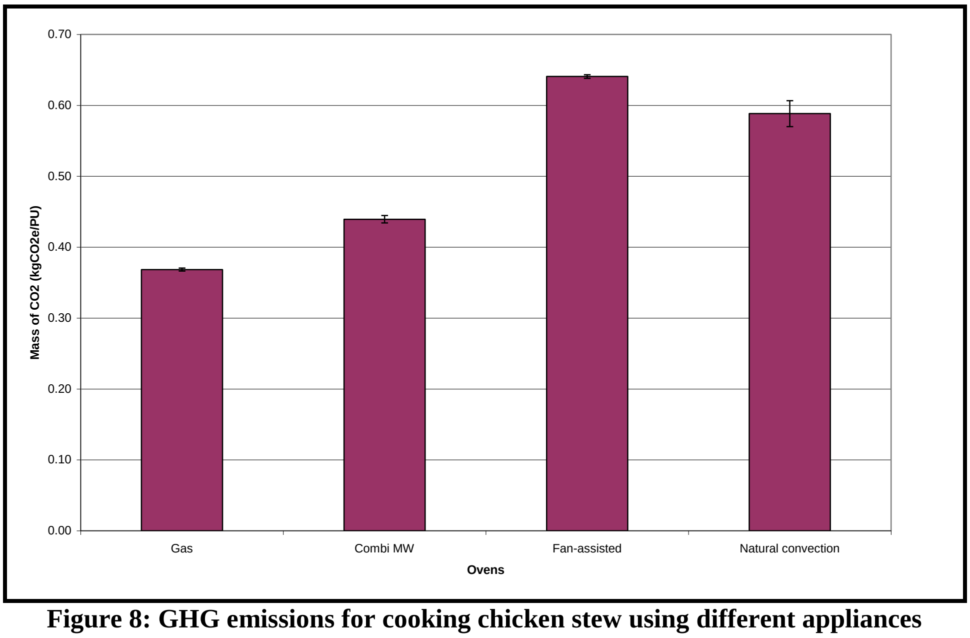

Figure 8: GHG emissions for cooking chicken stew using different appliances

Chicken stew

Vegetables and chicken pieces were fried before the stew was cooked in a gas oven, a fan assisted oven, a convectional oven or a combination microwave.

The basic recipe for the stew was found in the Sharp Combination Oven cookery book and was then adapted to cook using normal ovens.

Results and discussion
Figure 8 shows the results for the GHG emissions associated with cooking a stew with different domestic appliances. Although the gas oven had the highest energy consumption, when considering the emission factor, the GHG emissions were the lowest of all ovens. The GHG emissions for preparing a stew in a combination microwave were higher than those for the gas oven, and the conventional and fan-assisted ovens had the highest associated emissions.

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

Results and discussion
Values for the energy consumption and the CO_2 emissions obtained for cooking a stir-fry chicken dish are given in Table 3.

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 3: 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 to the use of the ceramic hob.

Conclusions

Trials for roasting chicken were carried out as close as possible to what would happen in a home situation. Overall, the results indicated that, although the gas oven had the highest average energy consumption values, when the emissions are taken into consideration it produces 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 seemed to be 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 is therefore not considered here.

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 measuring the total energy consumption for cooking a stew dish.

In the case of the chicken stir-fry the emission were lowest on 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).

The consumer

The experimental data obtained was complemented by work carried out at FPIU to gather 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 pies was observed, and 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).

A review of the literature indicated that there was no study, focused on a method to assess GHG emissions from food preparation, taking account of the interaction between the person preparing the meal and the appliance used. The objective of the FPIU study was to build on the appliance studies by FPERC, Bristol University, 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 the 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

Oven switched on for 100 minutes

Oven used for 90 minutes as left switched on for 10 minutes = 90% available

Half oven cavity used on one shelf = 50% performance

Four out of five portions of cooked food consumed = 80%

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

Observations

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 the impact on their practices. The brief was that the objective of the study was to observe how people cooked in real situations.

Table 4 shows the FPERC emissions data used, and Table 5 shows a summary of each of the cooking processes. The FPERC data was used to provide values 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. Unnecessary activity, such as having an appliance switched on for longer than needed, is considered to be wasted time. If an appliance is switched on for 100 minutes while only 90 minutes are used for cooking, this means there is 90% value added and 10% waste. If only half of the food from that cooking process was consumed, then 50% of the 90% would be value adding giving 45% value added and 55% waste overall.

	kg CO_2e/minute	FPERC reference
Gas Hob	0.0034	From FRPERC data discussed above
Electric Fan Oven	0.0084	
Gas Oven	0.0059	
Microwave	0.011775	

Table 4: Emission rates of domestic appliances

In the cooking process, the cottage pie ready meal used 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 by FPERC.

	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_2eq.	0.1768	0.0782	0.0238	0
Hob Waste CO_2eq.	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_2eq.	0.8620	0.3096	0.2592	0.2929
Oven Waste CO_2eq.	0.2147	0.0000	0.0884	0.0366
Microwave (mins)	0	0	6	1
Microwave Waste (mins)	0	0	3	0.625
MW CO_2eq.	0	0	0.07065	0.011775
MW Waste CO_2eq.	0	0	0.035325	0.007359375
Other appliances (mins)	0	3	0	1
Total kg CO_2 eq.	**1.0388**	**0.3878**	**0.35365**	**0.304675**
Waste CO_2 eq.	**0.25448**	**0.01955**	**0.123725**	**0.04396**
Value Add % (CO_2 eq.)	**75.50%**	**94.95%**	**65.01%**	**85.57%**

Table 5: Mapping summary

Focus Groups

Participant Selection
Groups were sought based on two factors, socio-economic background 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 6 - Socio economic classifications (ONS, 2008)

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 carbon could be mitigated. Group 1 covered the Over 40's non-professionals. Group 2 covered professionals for a wide age range. As seen in Figure 9, there is an opportunity for further research with the lower ages across all socio economic groups.

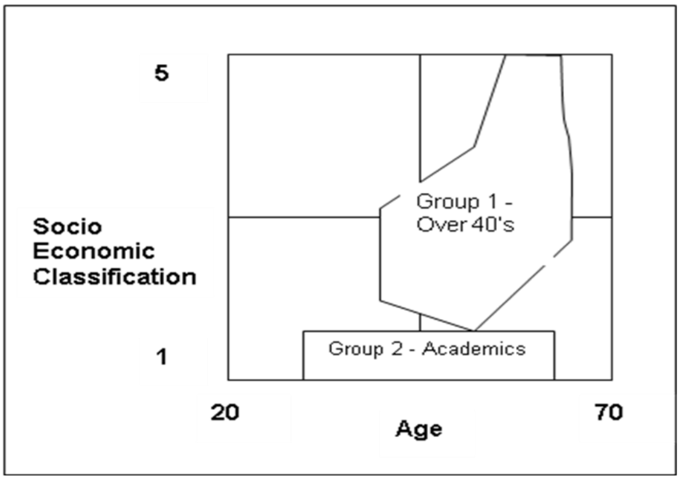

Figure 9: Focus group overview

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 7: Focus Group 1 Participants

A. Storage and Waste (20 mins)

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 sell 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 things were left in the freezer for a considerable unknown time and disposed of during these 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.

Waste disposal during cooking and unconsumed food

The product proliferation in terms of cleaning products 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.

Ingredients unused in the cooking process and cooked product reheated

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 (20 mins)

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 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 are heated (including take-aways). This is 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

From a quality and safety viewpoint all participants would switch 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 (20 mins)

How does carbon 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 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 were 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 carbon 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 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/carbon 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).

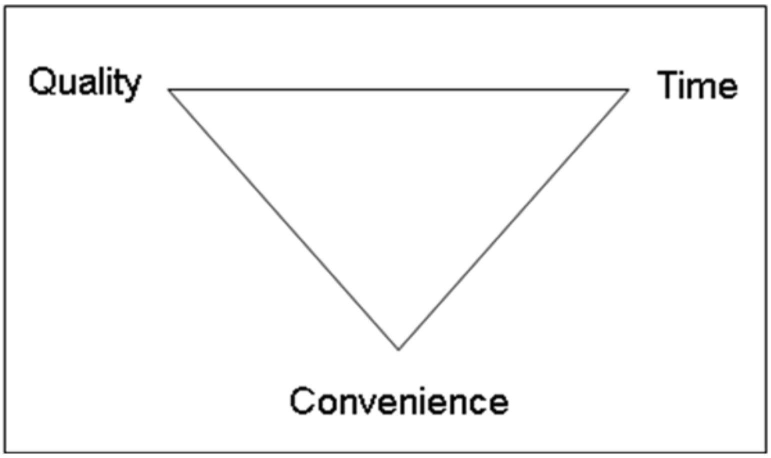

Figure 10: Observation group 1 priorities

All participants left the cookers on standby to keep their clocks running. The question asked was what % of energy this used? 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 would it help with pre-heating.

Group 2 - Academics

Focus group 2 consisted of the participants described in Table 8. This group discussed the same issues as focus group 1: storage and waste, cooking, and awareness. Results from the discussion of focus group 2, as well as results from focus group 1 are discussed 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 8: Focus group 2 participants

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 has issues concerning supermarket pack size (too big) and sell by dates. Fridge management is a vital issue, especially for vegetables, with the consensus that at least 20% of food is disposed of. In the cooking cycle, the key issue is remembering to switch appliances off. Recycling of product leaving the home was seen as essential with a high level of support.

Waste Issues	**Importance**	
	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	**Importance**	
	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	**Importance**	
	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	**Importance**	
	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

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.

Quality = 90%: At least 10% 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 is recommended to accurately define this, as it is likely to be as important if not more important than appliance choice to mitigating household energy and emissions in the cooking process. Ingredient packaging and pack size are a key driver of waste in the home.

The lifecycle GHG emissions of a RM cottage pie

This work 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". These findings have been published as a Defra publication leaflet: "PAS2050 CASE STUDY - Applying PAS2050 to a complex product: Cottage Pie Ready Meal", PB13179, Defra, 2008.

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).

The impact of all life cycle stages on the overall carbon footprint of the ready meal are shown in Figure 11. 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.

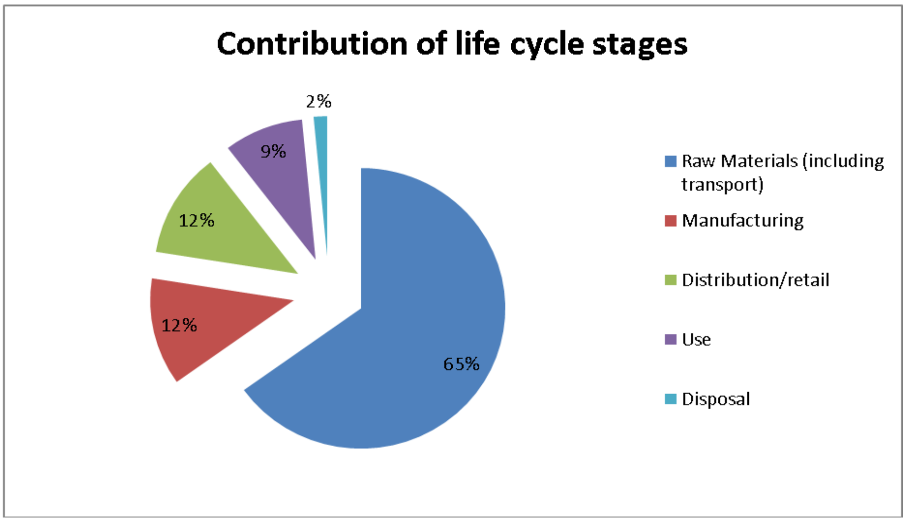

Figure 11: Impact of the life cycle stages on the carbon footprint of a cottage pie ready meal

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 11 were carried out assuming that the ready meal was heated in an electric fan oven. Figure 12 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.

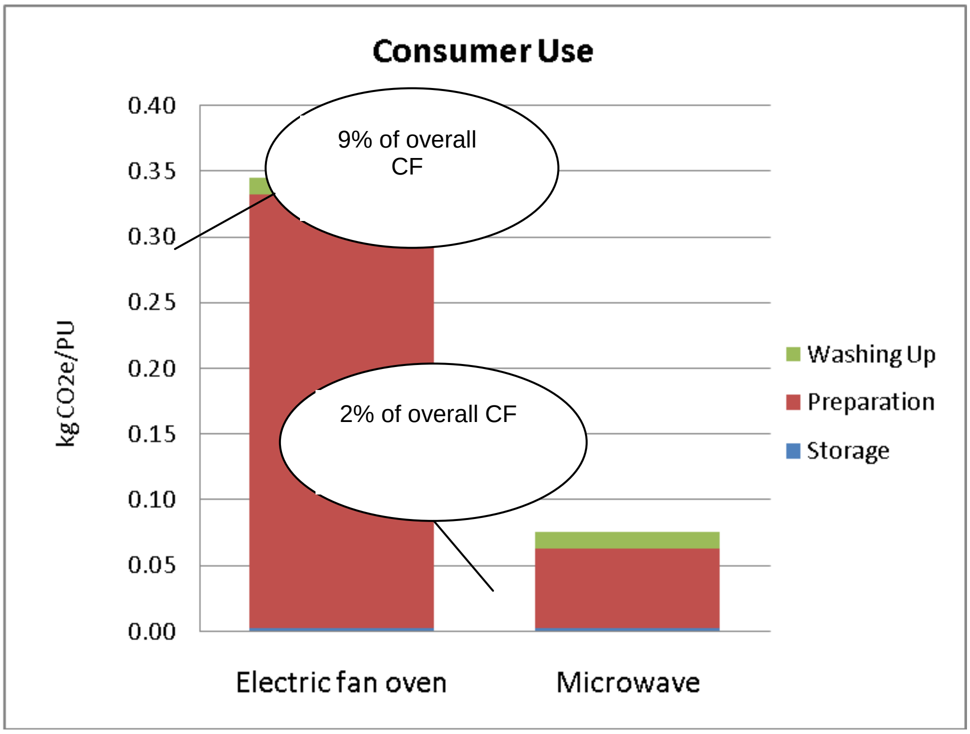

Figure 12: Impact of method of preparation on the carbon footprint of the consumer use phase

Conclusions

A literature review has shown that information focused on in-home food storage behaviour, cooking practices, and consumer waste practices and the implications of consumer behaviour for the associated GHG emissions is scarce.

This project has provided GHG emissions data of the use and disposal phases of several different food products assessed following PAS 2050. The assessment showed that for the meals studied, and if only the use and disposal phases of a meal are taken into account, a ready meal will have lower GHG emissions than an equivalent meal prepared from the ingredients. This is because a ready meal will only have to be heated up, while the preparation of a meal made from the ingredients usually includes energy and thus carbon intensive cooking, baking, etc. Future studies taking into account the whole lifecycle of the product and its ingredients should provide interesting comparisons of all aspects of the lifecycle of ready made and home made meals. Thus, data obtained from Defra projects FO 0404, FO 0405, and FO 0406/0409 could be linked up in the future, similar to the case study carried out for the lifecycle of a cottage pie ready meal.

For products such as apple crumble or bread, including a cooking or baking step, this will usually be the most carbon intensive step of the consumer use and disposal phases and good primary data should be easy to generate using cooking trials. For food products like apple juice, that are not cooked or baked, and where the preparation includes a large amount of kitchen waste, the waste disposal step is most likely to have the biggest impact on the use and disposal phase GHG emissions. Data for this step will have a much higher uncertainty, as it will have to be based to a great deal on assumptions regarding waste practices.

Research regarding the performance of different kitchen appliances for cooking and baking of various food products revealed that using a (combination) microwave for the preparation of small/medium size meals will result in lower associated GHG emissions than using conventional hobs and ovens. Gas hobs and ovens consume more energy than the equivalent electrically powered hobs and ovens to prepare the same meal, however, once the emission factors for gas and electricity are taken into account, gas hobs and ovens produce much lower GHG emissions than their electrically powered counterparts.

Finally, consumer research showed the influence of the consumer in the domestic food preparation process. The observation of food preparation and discussions in focus groups 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, contribution to the GHG emissions of food consumption, whilst internally, wasted energy of unused appliances, such as ovens being left switched on, were identified as important factors.

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References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.

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

A more comprehensive report containing the results of both phases of the project "Understanding the GHG impacts of food preparation and consumption in the home" (phase 1 - FO 0406, phase 2 - FO 0409) is being drafted and will be submitted to Defra shortly.