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Life cycle costs and environmental impacts of production and consumption of ready and home-made meals

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ABSTRACT

Consumption of ready-made meals is growing rapidly and yet little is known about their economic and environmental impacts. This paper focuses on the economic aspects to estimate the life cycle costs, value added and consumer costs of ready-made meals, in comparison with the equivalent meals prepared at home. Their life cycle environmental impacts are also considered. A typical roast dinner is considered, consisting of chicken, vegetables and tomato sauce. Different production and consumption choices are evaluated, including sourcing of ingredients, chilled or frozen supply chains and types of appliance used by the consumer to prepare the meal. The estimated life cycle costs of the ready-made meal range from £0.61–£0.92 per meal and for the home-made from £0.68–£1.12. The lowest life cycle costs are found for the chilled ready-made meal heated in a microwave, 11% below the costs of the best home-made option. The life cycle costs of the frozen meal are similar to the best home-made option. The chilled ready-made meal has the highest value added (£2.01) compared to the frozen (£1.22) and the home-made meal (£0.44). However, from the consumer perspective, the cheapest option is the home-made meal (£1.17) while the chilled ready-made option is most expensive (£2.61). If the meal options are compared on both the life cycle costs and environmental impacts, the home-made meal is the best option overall. These findings can be used to inform both producers and consumers on how their choices influence costs and environmental impacts of food.

1. Introduction

The convenience food sector is growing rapidly, with the global ready-made meals market predicted to grow by 17% by 2016, from $1.11 trillion in 2011 to $1.3 trillion (Key Note, 2013). The majority of the expansion is expected to occur in China, the fastest growing market for ready-made meals in the world (Key Note, 2013). At present, the USA and the UK hold the largest market share in the world, estimated at £7.2 bn (Sheely, 2008) and £2.6 bn (Mintel, 2013), respectively. By comparison, the value of the whole Western European market is equivalent to £3.9 bn (Sheely, 2008), most of which is due to the UK market, which increased by 47% on the value in 2007 (Key Note, 2013). In the UK, chilled meals hold the vast majority of the market share (84%) with the rest belonging to frozen meals (Mintel, 2013). It is expected that the UK market will grow by a further 35% by 2017, reaching an estimated value of £3.5 bn (Mintel, 2013). Currently, a third of the British adult population consumes ready-made meals once a week, while in countries such as France only 15% of adults buy prepared meals. Overall, 8.8 kg of chilled and frozen ready-made meals are consumed in the UK per capita per year (Millstone and Lang, 2008).

The market is affected by many economic factors, including inflation, unemployment and household disposable income (Key Note, 2013). These are particularly apparent during an economic crisis when salaries freeze and employment goes down, while prices of value-added foods such as ready-made meals rise, affecting both consumers and producers. For a further discussion on the topic, see Aguiar and Hurst (2005). In the UK, food prices increased sharply since the onset of the recession in 2007, with the processed food sector being one of the most affected (Downing and Harker, 2012). A survey conducted by the consumer magazine WHICH? (2013) shows that 80% of consumers are worried about food prices and 60% have changed their shopping options because of the constant rise in food prices. As expected, the most affected are the lower-income earners and households with children (Green et al., 2013). As food affordability is a key factor in food poverty (Sustain, 2013), the rise in food prices affects the welfare of the

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population (IGD, 2014). In the UK, the National Health Service (NHS) spends £6 bn a year on food-related illnesses (Scarborough et al., 2011).

Therefore, it is important to analyse the economic costs of food production and consumption, considering costs to both producers and consumers, to help identify hotspots and opportunities for improvement. This can be achieved by taking a life cycle approach and using life cycle costing as a tool to estimate the costs along whole supply chains, from production of ingredients to preparation and consumption of food. Currently, life cycle costs (LCC) of food are poorly understood with few studies available in the literature. For example, Iotti and Bonazzi (2014) considered the LCC of Italian Parma ham, demonstrating the usefulness of life cycle costing for innovation, improving business efficiency and reducing production costs. Krozer (2008) also showed how LCC can be applied to identifying innovative solutions, finding that for the short-cycle products such as food the highest cost-saving opportunities are usually in the agriculture and waste management. Furthermore, de Luca et al. (2014) combined LCC with life cycle assessment (LCA) to help identify sustainable options for a citrus production system, considering conventional, integrated and organic farming. Some other studies also highlighted the need for the integration of LCC and LCA in the food sector (Senthil et al., 2003; Kloepffer (2008); Settanni et al., 2010).

However, as far as the authors are aware, no studies have considered the life cycle costs of ready-made meals which is the focus of this paper. The aim is to estimate the LCC of different ready-made alternatives and compare them to equivalent home-made meal options. In addition to the LCC, value added and costs to the consumer are also considered. Finally, to help identify more sustainable options from both the economic and environmental perspectives, the meal options are also compared for the life cycle environmental impacts, based on the previous work by the authors (Schmidt Rivera et al., 2014).

2. Methodology

The LCC methodology applied in this work follows the approach proposed by Swarr et al. (2011) and Hunkeler et al. (2008) and is congruent with the ISO 14040/44 methodology for LCA (ISO, 2006a, 2006b). This is detailed in the following sections.

2.1. Goal and scope

The main goals of this study are:

- to estimate the LCC of a ready-made meal and compare them to the costs of an equivalent home-made meal, considering different processing, distribution and consumption alternatives;
- to analyse the influence on the LCC of factors such as ingredient sourcing and type of cooking appliances;
- to estimate the value added along the supply chain as well as the costs of the meal to the consumer; and
- to compare the life cycle costs and environmental impacts of ready- and home-made meals to help identify the best options.

As the paper builds on the previous LCA study of ready-made meals by the authors (Schmidt Rivera et al., 2014), the scope, the functional unit and the composition of the meal in both studies are the same, to enable comparisons of different options for both the economic and environmental impacts. Thus, the scope of the study is from 'cradle to grave', considering all life cycle stages from production and processing of ingredients to manufacture, distribution and consumption of the meal, including end-of-life waste management. The functional unit is defined as 'preparation and consumption of a meal for one person'. The meal chosen for consideration represents a typical roast dinner, consisting of chicken meat and three vegetables (potatoes, carrots and peas) served with tomato sauce. The meal weighs 360 g with the recipe details given in Table 1.

2.2. System definition

As outlined in Fig. 1, the life cycle of the ready-made meal involves chicken rearing and cultivation of the vegetables, their processing in a slaughterhouse and at a regional distribution centre (RDC), respectively, preparation of the meal at a factory, its subsequent transport to another RDC, retailer and finally to consumer's home where it is prepared according to manufacturer's instructions. The life cycle of the home-made meal is similar, except that the meal is fully prepared at home, starting from fresh ingredients. For further details, see Schmidt Rivera et al. (2014).

2.3. Calculation of life cycle costs and value added

Total life cycle costs are estimated from 'cradle to grave' (see Fig. 2) according to the following equation:

$$LCC_{Cradle\ to\ grave} = C_{RM} + C_{PP} + C_M + C_P + C_D + C_C + C_W \quad (1)$$

where:

$LCC_{Cradle\ to\ grave}$ total life cycle cost of ready- or home-made meals from 'cradle to grave'
C_{RM} costs of raw materials (meal ingredients)
C_{PP} costs of pre-processing of raw materials
C_M costs of meal manufacturing (ready-made meal only)
C_P costs of packaging
C_D costs of distribution
C_C costs of meal consumption (consumer transport and meal preparation)
C_W costs of post-consumer waste disposal.

In addition to the LCC, value added (VA) is also considered in this work. VA is defined as sales minus the costs of bought-in materials and services (DTI, 2007), in effect representing a profit margin. It therefore provides an insight into the value to manufacturers and to society at large, the latter through the value added tax. For these purposes, the VA of the ready-made meal is estimated from 'cradle to distribution', taking into account all the costs up to and including meal distribution to and storage at retailers (Fig. 2), before being sold to the consumer. For the home-made meal, the system boundary is the same, except that the VA relates to the ingredients, rather than the meal. Therefore, the VA is calculated as follows:

Table 1
Composition of the ready- and home-made meals as served.

Ingredients	Weight (g)	Contribution (%)
Chicken	98	27.22
Potatoes	87.5	24.31
Carrots	35	9.72
Peas	35	9.72
Tomato sauce	94.5	26.25
Tomato paste	*66.2*[a]	*70*
Onions	*28.3*	*30*
Salt	1	0.28
Vegetable oil	9	2.50
Total	**360**	**100**

[a] 43.8 g of tomato paste plus water.

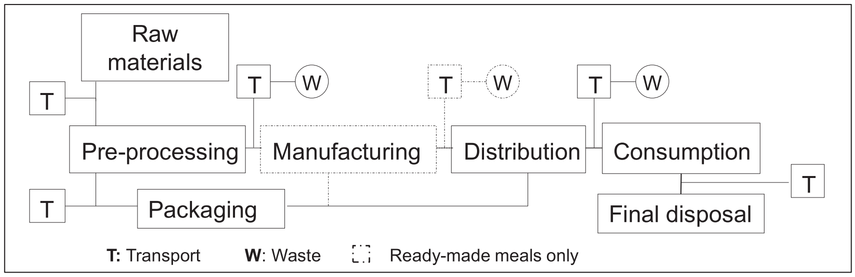

Fig. 1. The life cycle of ready- and home-made meals (adapted from Schmidt Rivera et al., 2014) [Distribution includes regional distribution centres and retailers. Consumption comprises consumer transport by car to purchase the meal, storage and preparation of the meal].

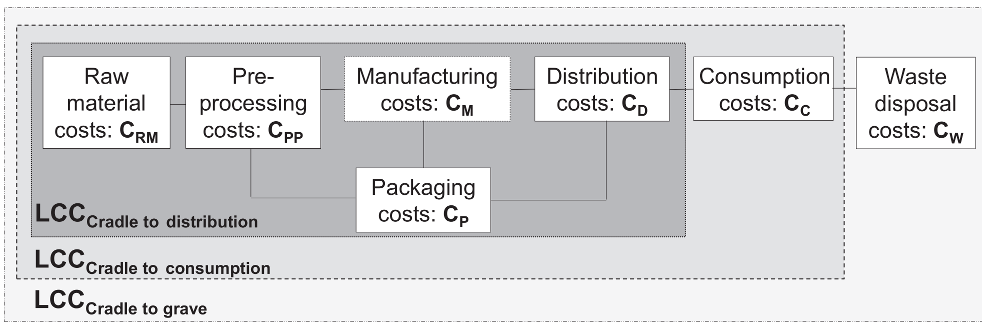

Fig. 2. Life cycle stages considered in the calculation of the total life cycle costs, value added and consumer costs [System boundaries: $LCC_{Cradle\ to\ distribution}$: used for calculation of life cycle costs from 'cradle to distribution', value added and retail price. Distribution includes regional distribution centres and retailers. $LCC_{Cradle\ to\ consumer}$: life cycle costs from 'cradle to consumption'. $LCC_{Cradle\ to\ grave}$: total life cycle costs from 'cradle to grave'].

$$VA = RP - LCC_{Cradle\ to\ distribution} \tag{2}$$

where:

VA value added from 'cradle to distribution'.
RP retail price of the meal (ready-made) or raw materials (home-made meal).
$LCC_{Cradle\ to\ distribution}$ life cycle cost from 'cradle to distribution' to the retailer.

In order to consider the consumer perspective, two types of costs are considered: total life cycle costs from 'cradle to consumer' (Fig. 2) and total consumer costs. The former, $LCC_{Cradle\ to\ consumer}$, can be estimated according to Eqn. (3):

$$LCC_{Cradle\ to\ consumer} = C_{RM} + C_{PP} + C_M + C_P + C_D + C_C \tag{3}$$

The total cost to consumer TC_c is equal to:

$$TC_C = RP + C_C \tag{4}$$

2.4. Scenarios

To examine the influence of different parameters on the LCC, several scenarios are considered for the ready- and home-made meals as summarised in Table 2. To enable comparisons of LCC with the environmental impacts, the scenarios are based on those considered in Schmidt Rivera et al. (2014).

The ready-made meal scenarios RM-1 to RM-8 assume that the ingredients are cultivated at conventional farms in the UK, except for the tomato paste, which is imported from Spain (Defra, 2013). The difference between these scenarios is that they consider either fresh or frozen ingredients, fresh or frozen meal, and meal preparation at home using a microwave or an electric oven. Furthermore, scenarios RM-9 and RM-10 examine the influence on the costs of using a gas oven instead. RM-11 to RM-12 consider respectively the effect of ingredient sourcing by substituting the British chicken with the Brazilian and Spanish tomatoes with the British for the tomato sauce. Finally, RM-13 explores the influence on the results of using some organic ingredients.

Home-made meal scenario HM-1 is similar to RM-1, assuming that all the ingredients are sourced from conventional farms and that they are cooked fresh with the chicken roasted in an electric oven and the vegetables and tomato sauce prepared on an electric hob; the tomato sauce is made from the Spanish ready-made tomato paste. HM-3 is the same as HM-1, except that the vegetables and tomato sauce are cooked in a microwave. On the other hand, HM-2 assumes the use of all-British organic ingredients, except for the onions and peas which are conventionally-grown, and preparation of tomato sauce from fresh tomatoes. The fourth, HM-4, scenario is the same as HM-1 but here the British chicken is replaced by the Brazilian. HM-5 is the same as HM-1 but it considers the implications of using gas appliances. The last two home-made options represent a variation on HM-1, with the Spanish ready-made tomato paste replaced by the tomato sauce made at home from fresh conventionally-grown tomatoes from Spain (HM-6) and the UK (HM-7).

3. Results

The results are first presented for the LCC and VA of the ready-made meal (Sections 3.1 and 3.2), followed by an equivalent analysis for the home-made meal options (Sections 3.3 and 3.4). The two types of meal are then compared in Section 3.5 for the LCC, VA, consumer costs and life cycle environmental impacts to help identify the most sustainable option.

Table 2
Scenarios for the ready- and home-made meals (adapted from Schmidt Rivera et al., 2014).

Scenario	Raw materials	Pre-processing	Manufacture and distribution	Consumption
Ready-made meals				
RM-1	British conventional chicken and vegetables; Spanish conventional tomato paste	Fresh (chilled)	Fresh (chilled)	Microwave
RM-2	As RM-1	Fresh (chilled)	Fresh (chilled)	Electric oven
RM-3	As RM-1	Fresh (chilled)	Frozen	Microwave
RM-4	As RM-1	Fresh (chilled)	Frozen	Electric oven
RM-5	As RM-1	Frozen	Fresh (chilled)	Microwave
RM-6	As RM-1	Frozen	Fresh (chilled)	Electric oven
RM-7	As RM-1	Frozen	Frozen	Microwave
RM-8	As RM-1	Frozen	Frozen	Electric oven
RM-9	As RM-1	As RM-1	As RM-1	Gas oven
RM-10	As RM-4	As RM-4	As RM-4	Gas oven
RM-11	Brazilian conventional chicken; all other ingredients as in RM-1	As RM-1	As RM-1	As RM-1
RM-12	British conventional tomato paste; all other ingredients as in RM-1	As RM-1	As RM-1	As RM-1
RM-13	British organic chicken, potatoes and carrots; British conventional tomatoes, peas and onions	As RM-1	As RM-1	As RM-1
Home-made meals				
HM-1	British conventional chicken and vegetables; Spanish conventional tomato paste	Fresh (chilled)	Fresh (chilled)	Chicken roasted in electric oven; vegetables and ready-made tomato sauce cooked on electric hob
HM-2	British organic chicken, potatoes, tomatoes and carrots; British conventional onions and peas	As HM-1	As HM-1	As HM-1 with tomato sauce made from fresh tomatoes
HM-3	As HM-1	As HM-1	As HM-1	Vegetables and ready-made tomato sauce cooked in microwave; chicken as HM-1
HM-4	As HM-1 with Brazilian chicken	As HM-1	As HM-1	As HM-1
HM-5	As HM-1	As HM-1	As HM-1	Chicken roasted in gas oven; vegetables and ready-made tomato sauce cooked on gas hob
HM-6	As HM-1 with Spanish conventional tomatoes	As HM-1	As HM-1	As HM-1 with tomato sauce made from fresh tomatoes
HM-7	As HM-1 with British conventional tomatoes	As HM-1	As HM-1	As HM-1 with tomato sauce made from fresh tomatoes

3.1. Life cycle costs of ready-made meal options

As shown in Fig. 3, the highest LCC of £0.92 is estimated for the frozen meal made from fresh or frozen ingredients and heated in the electric oven (RM-4 and RM-8). The best option is the chilled meal made from fresh ingredients and heated in the microwave (RM-1), with the total cost of £0.61, or 66% that of the frozen meal. The difference in the costs of the meals heated in the microwave

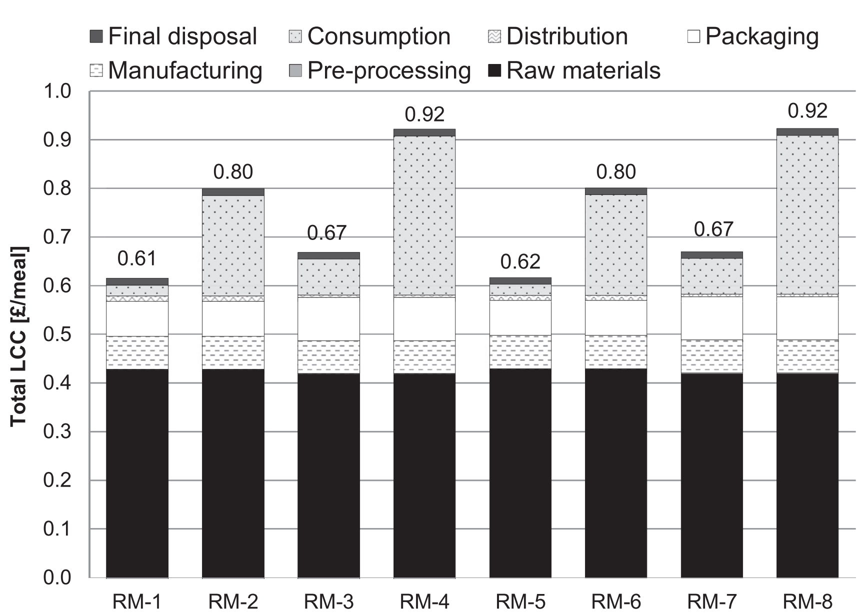

Fig. 3. Total life cycle costs ($LCC_{Cradle\ to\ grave}$) for different ready-made meal scenarios [For the description of scenarios, see Table 2].

(RM-1, RM-3, RM-5 and RM-7) is small (<9%), with the LCC ranging from £.0.61–£0.67, regardless of whether they are chilled or frozen meals. However, a much larger difference is observed between the chilled and frozen meals heated in the electric oven (15%), because the latter require longer to cook and, therefore, use more electricity.

Even greater variation is found between the meals heated in the microwave and those cooked in the electric oven, with the latter being 34% higher than the former, going up to 38% in the case of the frozen meals heated in the oven (RM-4 and RM-8). This is due to the high electricity cost, which contributes between 54% and 97% to the costs from the consumption stage, which itself is the second largest contributor to the total LCC (Fig. 3).

The greatest contributors are the raw materials, ranging from 46% for the frozen meals heated in the oven (RM-4 and RM-8) to 70% for the chilled meals heated in the microwave (RM-1 and RM-5). Chicken and tomato paste contribute collectively 70% to the costs of the raw materials and the peas add a further 12%.

The consumption stage contributes on average 19% (£0.02–£0.21/meal) to the LCC of the chilled and 23% (£0.07–£0.33) to the costs of the frozen meal options. The rest of the supply chain, from pre-processing to retailer, adds a further 21% for the chilled (~£0.15/meal) and 20% for the frozen option (~£0.16/meal).

The contribution of consumer transport to buy the meal is also significant if the microwave is used for heating the meal, constituting between 11% and 34% of the costs from the consumption stage. If the meal is heated in the electric oven, the contribution of transport is small (2%–4%). Packaging costs add between 9% and 13% to the total, with the frozen ingredients requiring more packaging than the fresh, in particular more plastic bags and cardboard boxes. Meal manufacturing contributes another 9%, while the final disposal and distribution add only 2% and 1% of the total cost, respectively.

3.1.1. Sensitivity analysis

To explore how the LCC change with different parameters, the sensitivity analysis focuses on the two life cycle stages contributing to the LCC most: the ingredients and meal consumption. The former considers different sourcing of ingredients while the latter examines the implications of using different appliances to heat the meal as discussed below.

3.1.1.1. Influence of ingredient sourcing. The following three variations on the base-case scenario RM-1 are considered with respect to the sourcing of ingredients: Brazilian instead of the British chicken (RM-11), tomato paste from British instead of Spanish tomatoes (RM-12) and some organic instead of conventionally-produced ingredients (RM-13). The results are compared in Fig. 4.

Sourcing the chicken from Brazil (RM-11) as opposed to the UK leads to a negligible (1.4%) increase in the total LCC compared to the base-case scenario (RM-1), from £0.61 to £0.62. This is despite the Brazilian chicken being £0.05 more expensive per kg (£0.87 vs £0.92; see Table 4) and the additional transportation costs – the total amount of chicken is relatively small (98 g) for this cost differential to have a greater effect.

However, using British tomato paste (RM-12) instead of the Spanish assumed in the base-case (RM-1) increases the costs more significantly, from £0.61 to £0.85. Similar to the chicken imported from Brazil, the cost of importing the paste from Spain is insignificant compared to the higher costs of production of tomato paste in the UK, because of the higher cost of tomatoes, which is the main cause for the difference in the LCC.

Finally, using organic instead of conventional ingredients increases the total LCC by a third, from £0.61 for RM-1 to £0.91 for RM-13. This is unsurprising as organic produce is more expensive (Table 4).

3.1.1.2. Influence of appliances. Three options for heating the ready-made meal are considered: microwave, gas and electric ovens. The energy consumption by these appliances for the chilled and frozen meals is summarised in Table 9.

The results in Fig. 5 suggest that using the gas (RM-9) instead of the electric oven (RM-2) to heat the chilled meal, saves 20% in total cost, reducing it from £0.80 to £0.64. This is due to two reasons: the cost of gas is much lower compared to electricity (~3 times) and the energy consumption of gas ovens is lower because of higher efficiency (Table 9). On the other hand, as also shown Fig. 5, there is little difference in costs (4%) between heating the meal in the microwave (RM-1) and gas oven (RM-9) as the higher electricity price for microwaves is countered by the much shorter time needed to heat the meal, compared to the gas oven heating.

For the frozen meals, the cost differential is greater with a saving of around 27% or £0.25 per meal if the gas oven is used instead of

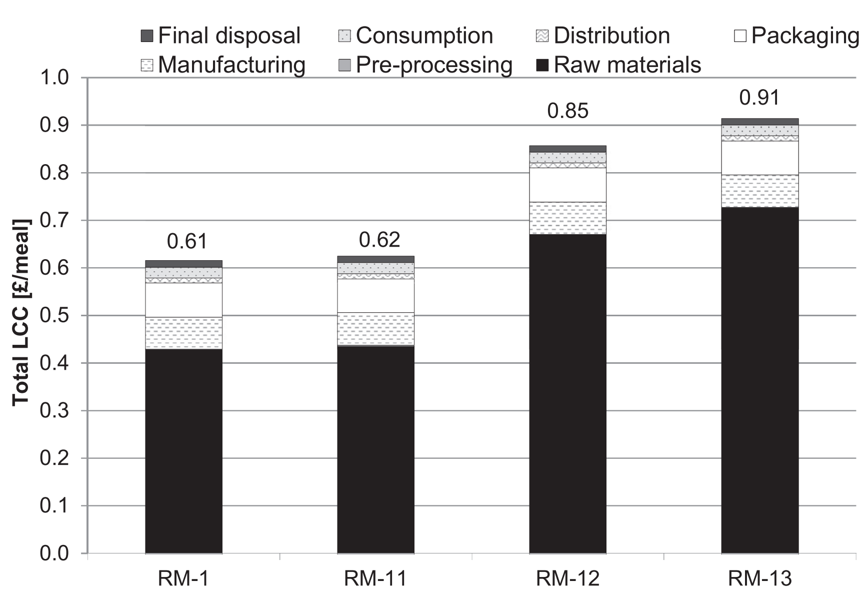

Fig. 4. Sensitivity analysis for the total life cycle costs ($LCC_{Cradle\ to\ grave}$) of the ready-made meal assuming different sourcing of ingredients.

Table 3
Life cycle inventory and costs for different ready-made meal scenarios.

	Flow or activity [unit/meal]	RM-1	RM-2	RM-3	RM-4	RM-5	RM-6	RM-7	RM-8	Cost [£/unit]	Cost data sources
Raw materials[a]	Conventional UK chicken [kg]	1.67×10^{-1}	1.67×10^{-1}	1.63×10^{-1}	1.63×10^{-1}	1.65×10^{-1}	1.65×10^{-1}	1.62×10^{-1}	1.62×10^{-1}	0.87	Defra (2013)
	Conventional UK potatoes [kg]	1.25×10^{-1}	1.25×10^{-1}	1.22×10^{-1}	1.22×10^{-1}	1.28×10^{-1}	1.28×10^{-1}	1.25×10^{-1}	1.25×10^{-1}	0.15	Defra (2013)
	Conventional UK carrots [kg]	4.98×10^{-2}	4.98×10^{-2}	4.89×10^{-2}	4.89×10^{-2}	5.11×10^{-2}	5.11×10^{-2}	5.01×10^{-2}	5.01×10^{-2}	0.41	Defra (2013)
	Conventional UK peas [kg]	4.98×10^{-2}	4.98×10^{-2}	4.89×10^{-2}	4.89×10^{-2}	5.11×10^{-2}	5.11×10^{-2}	5.01×10^{-2}	5.01×10^{-2}	1.05	Defra (2013)
	Conventional UK onions [kg]	4.03×10^{-2}	4.03×10^{-2}	3.95×10^{-2}	3.95×10^{-2}	4.13×10^{-2}	4.13×10^{-2}	4.05×10^{-2}	4.05×10^{-2}	0.43	Defra (2013)
	Spanish tomato paste[b] [kg]	5.36×10^{-2}	5.36×10^{-2}	5.26×10^{-2}	5.26×10^{-2}	5.36×10^{-2}	5.36×10^{-2}	5.26×10^{-2}	5.26×10^{-2}	3.04	Defra (2013)
	Salt [kg]	1.05×10^{-3}	1.05×10^{-3}	1.03×10^{-3}	1.03×10^{-3}	1.05×10^{-3}	1.05×10^{-3}	1.03×10^{-3}	1.03×10^{-3}	0.05	Credit Chem Group (2014)
	Vegetable oil [kg]	9.42×10^{-3}	9.42×10^{-3}	9.24×10^{-3}	9.24×10^{-3}	9.42×10^{-3}	9.42×10^{-3}	9.24×10^{-3}	9.24×10^{-3}	0.67	Index Mundi (2012)
	Road transport in the UK [km·kg]	88.3	88.3	86.6	86.6	89.4	89.4	87.6	87.6	3×10^{-5}	DECC (2014), VTT (2010)
	Road transport from Spain [km·kg]	69.7	69.7	68.3	68.3	69.7	69.7	68.3	68.3	2.5×10^{-5}	DECC (2014), VTT (2010)
Pre-processing	**Slaughterhouse**										
	Electricity [kWh]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.10	DECC (2014)
	Steam [MJ]	6.0×10^{-2}	6.0×10^{-2}	5.88×10^{-2}	5.88×10^{-2}	5.94×10^{-2}	5.94×10^{-2}	5.83×10^{-2}	5.83×10^{-2}	3.4×10^{-2}	DECC (2014)
	Water [l]	1.5	1.5	1.47	1.47	1.49	1.49	1.46	1.46	1.6×10^{-3}	United Utilities (2014)
	Chicken waste [kg]	4.53×10^{-2}	4.53×10^{-2}	4.45×10^{-2}	4.45×10^{-2}	4.49×10^{-2}	4.49×10^{-2}	4.4×10^{-2}	4.4×10^{-2}	(0.36)[c]	FAO Stat (2009)
	Cooling (meat)										
	Electricity [kWh]	7.28×10^{-6}	7.28×10^{-6}	7.14×10^{-6}	7.14×10^{-6}	2.04×10^{-4}	2.04×10^{-4}	2.00×10^{-4}	2.00×10^{-4}	0.10	DECC (2014)
	Refrigerant (ammonia) [kg]	2.25×10^{-5}	2.25×10^{-5}	2.2×10^{-5}	2.2×10^{-5}	1.05×10^{-4}	1.05×10^{-4}	1.03×10^{-4}	1.03×10^{-4}	0.34	Technicold Service Inc. (2003)
	Meat losses and waste [kg]	2.43×10^{-3}	2.43×10^{-3}	2.38×10^{-3}	2.38×10^{-3}	1.20×10^{-3}	1.20×10^{-3}	1.18×10^{-3}	1.18×10^{-3}	9.3×10^{-2}	Eunomia (2013)
	Road transport [km·kg]	1.45	1.45	1.39	1.39	1.43	1.43	1.38	1.38	3×10^{-5}	DECC (2014), VTT (2010)
	Pre-processing (vegetables)										
	Electricity [kWh]	3.71×10^{-5}	3.71×10^{-3}	3.63×10^{-3}	3.63×10^{-3}	3.74×10^{-3}	3.74×10^{-3}	3.66×10^{-3}	3.66×10^{-3}	0.10	DECC (2014)
	Water [l]	7.20×10^{-1}	7.2×10^{-1}	7.06×10^{-1}	7.06×10^{-1}	1.54	1.54	1.51	1.51	1.6×10^{-3}	United Utilities (2014)
	Steam [MJ]	6.91×10^{-4}	6.91×10^{-4}	6.77×10^{-4}	6.77×10^{-4}	9.11×10^{-4}	9.11×10^{-4}	8.93×10^{-4}	8.93×10^{-4}	0.12	Spirax Sarco Limited (2014)
	Vegetable losses and waste [kg]	3.44×10^{-2}	3.44×10^{-2}	3.37×10^{-2}	3.37×10^{-2}	4.34×10^{-2}	4.34×10^{-2}	4.26×10^{-2}	4.26×10^{-2}	9.3×10^{-2}	Eunomia (2013)
	Wastewater [l]	6.48×10^{-1}	6.48×10^{-1}	6.36×10^{-1}	6.36×10^{-1}	1.38	1.38	1.36	1.36	1.1×10^{-3}	United Utilities (2014)
	RDCm[d] (vegetables)										
	Electricity [kWh]	4.88×10^{-5}	4.88×10^{-5}	4.78×10^{-5}	4.78×10^{-5}	4.88×10^{-5}	4.88×10^{-5}	4.78×10^{-5}	4.78×10^{-5}	0.10	DECC (2014)
	Refrigerant (ammonia) [kg]	1.13×10^{-4}	1.13×10^{-4}	1.11×10^{-4}	1.11×10^{-4}	1.13×10^{-4}	1.13×10^{-4}	1.11×10^{-4}	1.11×10^{-4}	0.34	Technicold Service (2003)
	Vegetable losses and waste [kg]	6.76×10^{-4}	6.76×10^{-3}	6.63×10^{-3}	6.63×10^{-3}	3.41×10^{-3}	3.41×10^{-3}	3.35×10^{-3}	3.35×10^{-3}	9.3×10^{-2}	Eunomia (2013)
	Road transport [km·kg]	22.6	22.6	22.1	22.1	22.6	22.6	22.1	22.1	3×10^{-5}	DECC (2014), VTT (2010)
Manufacturing	Fuel oil [l]	4.13×10^{-2}	4.13×10^{-2}	4.08×10^{-2}	4.08×10^{-2}	4.13×10^{-2}	4.13×10^{-2}	4.08×10^{-2}	4.08×10^{-2}	0.53	DECC (2014)
	Electricity [kWh]	3.39×10^{-1}	3.39×10^{-1}	3.35×10^{-1}	3.35×10^{-1}	3.39×10^{-1}	3.39×10^{-1}	3.35×10^{-1}	3.35×10^{-1}	0.10	DECC (2014)
	Water [l]	4.46	4.46	4.4	4.4	4.46	4.46	4.4	4.4	1.6×10^{-3}	United Utilities (2014)
	Food waste [kg]	6.81×10^{-3}	6.81×10^{-3}	6.59×10^{-3}	6.59×10^{-3}	6.81×10^{-3}	6.81×10^{-3}	6.59×10^{-3}	6.59×10^{-3}	9.3×10^{-2}	Eunomia (2013)
	Packaging waste	8.51×10^{-8}	8.51×10^{-8}	8.4×10^{-8}	8.4×10^{-8}	8.51×10^{-8}	8.51×10^{-8}	8.4×10^{-8}	8.4×10^{-8}	9.3×10^{-2}	Eunomia (2013)
	Wastewater [l]	4.01	4.01	3.96	3.96	4.01	4.01	3.96	3.96	1.1×10^{-3}	United Utilities (2014)
	Road transport [km·kg]	37.5	3.75	37	37	37.5	37.5	37	37	3×10^{-5}	DECC (2014), VTT (2010)
Packaging[e]	Low density polyethylene [kg]	1.01×10^{-2}	1.01×10^{-2}	1.08×10^{-2}	1.08×10^{-2}	1.01×10^{-2}	1.01×10^{-2}	1.08×10^{-2}	1.08×10^{-2}	1.57	Plastic Informat (2014a)
	Polyethylene [kg]	1.04×10^{-2}	1.04×10^{-2}	1.4×10^{-2}	1.4×10^{-2}	1.04×10^{-2}	1.04×10^{-2}	1.4×10^{-2}	1.4×10^{-2}	1.37	Plastic Informat (2014b)
	Polyethylene terephthalate [kg]	2.6×10^{-2}	2.6×10^{-2}	3.5×10^{-2}	3.5×10^{-2}	2.6×10^{-2}	2.6×10^{-2}	3.5×10^{-2}	3.5×10^{-2}	1.37	Plastic Informat (2014b)
	Polypropylene [kg]	1.17×10^{-4}	1.17×10^{-4}	4.41×10^{-8}	4.41×10^{-8}	1.17×10^{-4}	1.17×10^{-4}	4.41×10^{-8}	4.41×10^{-8}	1.69	Plastic Informat (2014c)
	Cardboard [kg]	1.56×10^{-2}	1.56×10^{-2}	2.23×10^{-2}	2.23×10^{-2}	1.56×10^{-2}	1.56×10^{-2}	2.23×10^{-2}	2.23×10^{-2}	0.14	LetsRecycle (2014)
	Steel [kg]	6.34×10^{-3}	6.34×10^{-3}	6.22×10^{-3}	6.22×10^{-3}	6.34×10^{-3}	6.34×10^{-3}	6.22×10^{-3}	6.22×10^{-3}	0.22	Grupo Lyrsa (2014)
	Wood [kg]	1.18×10^{-5}	1.18×10^{-5}	1.16×10^{-5}	1.16×10^{-5}	1.18×10^{-5}	1.18×10^{-5}	1.16×10^{-5}	1.16×10^{-5}	0.25	Index Mundi (2012)
	Road transport [km·kg]	8.12	8.12	8.83	8.83	8.12	8.12	8.83	8.83	3×10^{-5}	DECC (2014), VTT (2010)
Distribution	**RDCp[f]**										
	Electricity [kWh]	4.72×10^{-5}	4.72×10^{-5}	6.16×10^{-4}	6.16×10^{-4}	4.72×10^{-5}	4.72×10^{-5}	6.16×10^{-4}	6.16×10^{-4}	0.10	DECC (2014)
	Refrigerant (ammonia) [kg]	1.84×10^{-4}	1.84×10^{-4}	3.18×10^{-4}	3.18×10^{-4}	1.84×10^{-4}	1.84×10^{-4}	3.18×10^{-4}	3.18×10^{-4}	0.34	Technicold Services (2003)
	Product losses [kg]	6.63×10^{-3}	6.63×10^{-3}	3.28×10^{-3}	3.28×10^{-3}	6.63×10^{-3}	6.63×10^{-3}	3.28×10^{-3}	3.28×10^{-3}	9.3×10^{-2}	Eunomia (2013)
	Packaging waste [kg]	1.27×10^{-2}	1.27×10^{-2}	1.24×10^{-2}	1.24×10^{-2}	1.27×10^{-2}	1.27×10^{-2}	1.24×10^{-2}	1.24×10^{-2}	9.3×10^{-2}	Eunomia (2013)
	Road transport [km·kg]	36.7	36.7	36.4	36.4	36.7	36.7	36.4	36.4	3×10^{-5}	DECC (2014), VTT (2010)

(*continued on next page*)

Table 3 (*continued*)

	Flow or activity [unit/meal]	RM-1	RM-2	RM-3	RM-4	RM-5	RM-6	RM-7	RM-8	Cost [£/unit]	Cost data sources
	Retail										
	Electricity [kWh] 5.28×10^{-2}	5.28×10^{-2}	1.37×10^{-2}	1.37×10^{-2}	5.28×10^{-2}	5.28×10^{-2}	1.37×10^{-2}	1.37×10^{-2}	0.10	DECC (2014)	
	Refrigerant (R134a) [kg]	1.51×10^{-4}	1.51×10^{-4}	4.78×10^{-5}	4.78×10^{-5}	1.51×10^{-4}	1.51×10^{-4}	4.78×10^{-5}	4.78×10^{-5}	12.8	Stoody Industrial and Welding Supply (2006)
Product losses [kg]	7.2×10^{-3}	7.2×10^{-3}	3.6×10^{-3}	3.6×10^{-3}	7.2×10^{-3}	7.2×10^{-3}	3.6×10^{-3}	3.6×10^{-3}	9.3×10^{-2}	Eunomia (2013)	
Consumption	Electricity (storage) [kWh]	2×10^{-3}	2×10^{-3}	1.8×10^{-2}	1.80×10^{-2}	2×10^{-3}	2×10^{-3}	1.8×10^{-2}	1.8×10^{-2}	0.16	DECC (2014)
	Electricity (cooking) [kWh]	0.08	1.27	0.39	2.03	0.08	0.39	0.39	2.03	0.16	DECC (2014)
	Water [l]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.6×10^{-3}	United Utilities (2014)
	Wastewater [l]	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1.3×10^{-3}	United Utilities (2014)
	Road transport[g] [l]	0.59	0.59	0.59	0.59	0.59	0.59	0.59	0.59	1.32	DECC (2014)
Waste disposal	Food waste [kg]	8.64×10^{-2}	8.64×10^{-2}	8.64×10^{-2}	8.64×10^{-2}	8.64×10^{-2}	8.64×10^{-2}	8.64×10^{-2}	8.64×10^{-2}	9.3×10^{-2}	Eunomia (2013)
	Plastic packaging [kg]	4.5×10^{-2}	4.5×10^{-2}	4.5×10^{-2}	4.5×10^{-2}	4.5×10^{-2}	4.5×10^{-2}	4.5×10^{-2}	4.5×10^{-2}	9.3×10^{-2}	Eunomia (2013)
	Cardboard [kg]	1.5×10^{-2}	1.5×10^{-2}	1.5×10^{-2}	1.5×10^{-2}	1.5×10^{-2}	1.5×10^{-2}	1.5×10^{-2}	1.5×10^{-2}	9.3×10^{-2}	Eunomia (2013)
	Road transport [km·kg]	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3.66	3×10^{-5}	DECC (2014), VTT (2010)

[a] Note that the amount of raw materials is different here from the amount of ingredients in the meal as served (Table 1) as the data here include the loses along the supply chain.
[b] For the breakdown of production costs, see Table 5.
[c] Revenue from the sales of chicken waste to the rendering industry.
[d] Regional distribution centre for raw materials.
[e] Currency exchange rates: €1 = £0.819; US$ = £0.607; 1INR (Indian Rupee) = £0.01 (XE, 31 Jan 2014).
[f] Regional distribution centre for products (meals).
[g] Average fuel consumption based on the average car size selected using data for the best-selling cars in the UK in 2013 (Car Buyer, 2014; Lee Boyce, 2013; Matt Bird, 2013) and the average distance is 7.5 km (Pretty et al., 2005). The fuel price as of May 2014. The cost of transport (see Table 6) is allocated to the meal based on the average composition of the shopping basket (ONS, 2013). The ready-made meal constitutes 1% of the shopping basket by *weight x value* so that 1% of the cost of shopping is allocated to the ready-made meal.

the electric (RM-4 vs RM-10). Conversely, there is little difference in the costs if the frozen meal is heated using the gas oven (RM-10) or the microwave (RM-3).

3.2. Value added of ready-made meal options

Two options are considered here as an illustration of the VA along the supply chain: the chilled (RM-1) and the equivalent frozen ready-made meal (RM-3). The results, estimated using Eqn. (2) and given in Fig. 6, indicate that the VA for the chilled meal (RM-1) varies from £0.86 to £2.74 with an average value of £2.01. This variation is due to the different prices of the meals sold by different retailers, also shown in Fig. 6 (based on the values given in Table 7), together with the life cycle costs up to and including the distribution to retailer. As can be seen, for the most expensive meal, the VA represents 83% of the retail price and for the cheapest it represents 60%.

For the frozen meal (RM-3), the VA is lower, ranging from £0.77–£2.07. The average VA is equivalent to £1.22, representing 68% of the average retail price. Thus, these results suggest that the chilled ready-made meal adds a greater value to the supply chain than the frozen option. This is despite the fact that the production costs of chilled and frozen meals are the same (£0.58) – the slightly higher energy costs from freezing are countered by lower wastage along the supply chain (Schmidt Rivera et al., 2014). Nevertheless, as consumers generally prefer fresh to frozen meals, retailers can demand higher prices (30% on average), thus inflating the VA. However, it is unclear if and how the VA benefits are shared along the supply chain.

3.3. Life cycle costs of home-made meal options

As indicated in Fig. 7, the lowest LCC of £0.68 are found for the meal prepared from conventionally-cultivated ingredients and ready-made tomato paste with the chicken roasted in the electric oven and the vegetables and tomato sauce cooked in a microwave (HM-3). The next best option at £0.75 is HM-1, which is similar to HM-3 except that the vegetables and the tomato sauce are cooked on an electric hob. This means that cooking a part of the meal in a microwave saves the consumer 7 pence or 10% per meal.

The meal with the organic ingredients and home-made tomato sauce (HM-2) has the highest LCC, estimated at £1.12, or 50% higher than the base case option (HM-1). This is due to the higher costs of the raw materials: £0.88 for HM-2 compared to £0.37 for HM-1.

Finally, using chicken imported from Brazil instead of the British chicken has a similarly negligible effect on the LCC as for the ready-made meal, increasing the total cost compared to HM-1 by 1% to £0.76.

Like the ready-made meal, the main cost hotspots for the home-made options are the raw materials and the consumption stage (Fig. 7). The former contributes on average 51% to the total LCC and the latter 22%. The only exception is HM-2, where the raw materials account for 79% of the costs and the consumption stage for 18%, because of the organic ingredients which have higher costs. Similar to the ready-made meal, the highest contributors are the chicken and tomatoes, contributing collectively between 50% and 70%.

In the consumption stage, the main contributor is the energy consumption, which accounts for 84–90% of the costs from this stage, with the water used for cooking and washing up adding 6–10% and the transport to purchase the ingredients the remaining 4–6%.

The costs of packaging contribute on average 18% to the total, which is higher than for the ready-made meal (9–13%). However, in the case of the organic meal (HM-2), the packing adds only 1% to the LCC. The reasons for this are two-fold: higher costs of organic

Table 4
Life cycle inventory and costs for different home-made meal scenarios.

	Flow or activity [unit/meal]	HM-1	HM-2	HM-3	HM-4	Cost [£/unit]	Cost data sources
Raw materials[a]	Conventional UK chicken [kg]	1.51×10^{-1}	–	1.51×10^{-1}	–	0.87	Defra (2013)
	Organic UK chicken [kg]	–	1.51×10^{-1}	–	–	0.96	Defra (2013)
	Brazilian chicken [kg]	–	–	–	1.51×10^{-1}	0.92	FAO Stat (2009)
	Conventional potatoes [kg]	1.1×10^{-1}	–	1.1×10^{-1}	1.1×10^{-1}	0.15	Defra (2013)
	Organic potatoes [kg]	–	0.11	–	–	0.82	Defra (2013)
	Conventional UK carrots [kg]	4.42×10^{-2}	–	4.42×10^{-2}	4.42×10^{-2}	0.41	Defra (2013)
	Organic carrots [kg]	–	4.42×10^{-2}	–	–	1.01	Defra (2013)
	Conventional UK peas [kg]	4.42×10^{-2}	–	4.42×10^{-2}	4.42×10^{-2}	1.05	Defra (2013)
	Organic peas [kg]	–	4.42×10^{-2}	–	–	4.02	Defra (2013)
	Conventional UK onions [kg]	3.61×10^{-2}	–	3.61×10^{-2}	3.61×10^{-2}	0.43	Defra (2013)
	Organic onions [kg]	–	3.61×10^{-2}	–	–	1.03	Defra (2013)
	Spanish tomato paste[b] [kg]	4.38×10^{-2}	0.17	4.38×10^{-2}	4.38×10^{-2}	3.04	Defra (2013)
	Conventional UK tomatoes [kg]	1.67×10^{-1}	–	–	–	1.17	Defra (2013)
	Organic UK tomatoes [kg]	–	1.67×10^{-1}	–	–	2.31	Defra (2013)
	Salt [kg]	1×10^{-3}	1×10^{-3}	1×10^{-3}	1×10^{-3}	0.05	Credit Chem Group (2014)
	Vegetable oil [kg]	9×10^{-3}	9×10^{-3}	9×10^{-3}	9×10^{-3}	0.67	Index Mundi (2012)
	Road transport in the UK [km·kg]	79.3	113	79.3	79.3	3×10^{-5}	DECC (2014), VTT (2010)
	Road transport from Spain [km·kg]	56.9	–	56.9	56.9	2.5×10^{-5}	DECC (2014), VTT (2010)
	Road transport in Brazil [km·kg]	–	–	–	60.5	5.5×10^{-3}	VTT (2010), Global Petrol Prices (2014)
	Transoceanic transport from Brazil to the UK [km·kg]	–	–	–	1.51×10^{-1}	5×10^{-7}	VTT (2010), Global Petrol Prices (2014); Baumel et al. (2008)
Pre-processing	**Slaughterhouse**						
	Electricity [kWh]	0.03	0.03	0.03	0.03	0.10	DECC (2014)
	Steam [MJ]	5.44×10^{-2}	5.44×10^{-2}	5.44×10^{-2}	5.44×10^{-2}	3.4×10^{-2}	DECC (2014)
	Water [l]	1.36	1.36	1.36	1.36	1.6×10^{-3}	United Utilities (2014)
	Chicken waste [kg]	4.11×10^{-2}	4.11×10^{-2}	4.11×10^{-2}	4.11×10^{-2}	(0.36)[c]	FAO Stat (2009)
	Cooling (meat)						
	Electricity [MJ]	6.61×10^{-6}	6.61×10^{-6}	6.61×10^{-6}	6.61×10^{-6}	0.10	DECC (2014)
	Refrigerant (ammonia) [kg]	2.04×10^{-5}	2.04×10^{-5}	2.04×10^{-5}	2.04×10^{-5}	0.34	Technicold Services (2003)
	Meat losses [kg]	2.2×10^{-3}	2.2×10^{-3}	2.2×10^{-3}	2.2×10^{-3}	9.3×10^{-2}	Eunomia (2013)
	Road transport [km·kg]	1.19	1.19	1.19	1.19	3×10^{-5}	DECC (2014), VTT (2010)
	RDCm[d] (vegetables)						
	Electricity [MJ]	1.83×10^{-4}	3.13×10^{-4}	1.83×10^{-4}	1.83×10^{-4}	0.10	DECC (2014)
	Refrigerant (ammonia) [kg]	1.18×10^{-4}	2.02×10^{-4}	1.18×10^{-4}	1.18×10^{-4}	0.34	Technicold Services (2003)
	Vegetable losses and waste [kg]	4.7×10^{-3}	8.05×10^{-3}	4.7×10^{-3}	4.7×10^{-3}	9.3×10^{-2}	Eunomia (2013)
	Transport [km·kg]	5.42	15.9	5.42	5.42	3×10^{-5}	DECC (2014), VTT (2010)
Packaging[e]	Cardboard [kg]	1.81×10^{-3}	–	1.81×10^{-3}	1.81×10^{-3}	0.14	LetsRecycle (2014)
	Low density polyethylene [kg]	1.0×10^{-2}	1.0×10^{-2}	1.0×10^{-2}	1.0×10^{-2}	1.57	Plastic Informat (2014a)
	Polypropylene [kg]	1.27×10^{-7}	7.04×10^{-8}	1.27×10^{-7}	1.27×10^{-7}	1.69	Plastic Informat (2014c)
	Wood [kg]	2.55×10^{-6}	–	2.55×10^{-6}	2.55×10^{-6}	0.25	Index Mundi (2012)
	Tin [kg]	7.74×10^{-3}	–	7.74×10^{-3}	7.74×10^{-3}	20.5	LME (2014)
	Road transport [km·kg]	1.96	1.0	1.96	1.96	3×10^{-5}	DECC (2014), VTT (2010)
Distribution	**Retail (vegetables)**						
	Electricity [kWh]	1.66×10^{-3}	2.83×10^{-3}	1.66×10^{-3}	1.66×10^{-3}	0.10	DECC (2014)
	Natural gas [MJ]	7.48×10^{-3}	1.28×10^{-2}	7.48×10^{-3}	7.48×10^{-3}	8.1×10^{-3}	DECC (2014)
	Product losses [kg]	1.15×10^{-2}	1.98×10^{-2}	1.15×10^{-2}	1.15×10^{-2}	9.3×10^{-2}	Eunomia (2013)
	Packaging waste	4.18×10^{-4}	7.17×10^{-4}	4.18×10^{-4}	4.18×10^{-4}	9.3×10^{-2}	Eunomia (2013)
	Retail (chicken)						
	Electricity [kWh]	0.02	0.02	0.02	0.02	0.10	DECC (2014)
	Natural gas [MJ]	1.23×10^{-2}	1.23×10^{-2}	1.23×10^{-2}	1.23×10^{-2}	8.1×10^{-3}	DECC (2014)
	Refrigerant (R134a) [kg]	4.0×10^{-5}	4.0×10^{-5}	4.0×10^{-5}	4.0×10^{-5}	12.8	Stoody Industrial and Welding Supply (2006)
	Product losses [kg]	2.16×10^{-3}	2.16×10^{-3}	2.16×10^{-3}	2.16×10^{-3}	9.3×10^{-2}	Eunomia (2013)
Consumption	Electricity (storage) [kWh]	1.59×10^{-3}	2.35×10^{-3}	1.59×10^{-3}	1.59×10^{-3}	0.16	DECC (2014)
	Electricity (cooking) [kWh]	1.14	1.21	0.67	1.14	0.16	DECC (2014)
	Water [l]	4.50	4.50	4.50	4.50	1.6×10^{-3}	United Utilities (2014)
	Wastewater [l]	4.05	4.05	4.05	4.05	1.3×10^{-3}	United Utilities (2014)
	Road transport[f] [l]	0.59	0.59	0.59	0.59	1.32	DECC (2014)
Waste disposal	Food waste [kg]	0.12	0.14	0.12	0.12	9.3×10^{-2}	Eunomia (2013)
	Plastic bag [kg]	0.01	0.01	0.01	0.01	9.3×10^{-2}	Eunomia (2013)
	Tin [kg]	7.74×10^{-3}	–	7.74×10^{-3}	7.74×10^{-3}	9.3×10^{-2}	Eunomia (2013)
	Road transport [km·kg]	3.51	3.86	3.51	3.51	3×10^{-5}	DECC (2014), VTT (2010)

[a] Costs refer to costs of production of raw materials. Note that the amounts of raw materials are different here from the amount of ingredients in the meal as served (Table 1) as the data here include the loses along the supply chain.
[b] For the breakdown of production costs, see Table 5.
[c] Revenue from the sales of chicken waste to the rendering industry.
[d] Regional distribution centre for raw materials.
[e] Currency exchange rates: €1 = £0.819; US$ = £0.607; 1INR (Indian Rupee) = £0.01 (XE, 31 Jan 2014).
[f] Average fuel consumption based on the average car size selected using data for the best-selling cars in the UK in 2013 (Car Buyer, 2014; Boyce, 2013; Matt Bird, 2013) and the average distance is 7.5 km (Pretty et al., 2005). The fuel price as of May 2014. The same cost of transport is assumed as for the ready-made meal (see Table 3, footnote g).

Table 5
Production costs for tomato paste.

Flow/activity [unit]	Amount	Spanish paste[a] [£/unit]	Cost data sources	UK paste [£/unit]	Cost data sources
Inputs					
Electricity [kWh]	0.10	9.2×10^{-2}	DECC (2014)	9.7×10^{-2}	DECC (2014)
Steam [kg]	2.53	2.4×10^{-2}	Spirax Sarco (2014)	2.2×10^{-2}	Spirax Sarco (2014)
Conventional tomatoes [kg]	6	0.44	Euro Stat (2014)	1.17	Defra (2013)
Water [kg]	156	1×10^{-3}	iagua (2013)	1.6×10^{-3}	United Utilities (2014)
Transport [km·kg]	1400	2.5×10^{-5}	DECC (2014), VTT (2010)	3.01×10^{-5}	DECC (2014), VTT (2010)
Outputs					
Tomato waste [kg]	0.19	3.7×10^{-2}	Ventosa and Martínez (2012)	9.3×10^{-2}	Eunomia (2013)
Wastewater [l]	137.5	1×10^{-3}	Modelo Factura (2013)	1.6×10^{-3}	United Utilities (2014)
Packaging waste from farm [kg]	4.5×10^{-11}	3.7×10^{-2}	Ventosa and Martínez (2012)	9.3×10^{-2}	Eunomia (2013)
Tomato paste [kg]	**1**	**3.04**		**7.60**	

[a] Exchange rate: €1 = £0.819 (XE, 31 Jan 2014).

ingredients and lower amount of packaging because the tomato paste is made at home, thus avoiding the packaging used for the ready-made tomato paste. The contribution of the remaining stages is small (<2%).

3.3.1. Sensitivity analysis

A similar sensitivity analysis has been carried out for the home-made meal as for the ready-made options, considering the effect on the costs of different appliances and sources of the ingredients. These results are displayed in Fig. 8.

The use of gas oven and hob (HM-5) instead of the electric alternatives (HM-1) reduces the total LCC from £0.75 to £0.44 because of the lower cost of natural gas compared to electricity (for energy costs, see Table 9).

The use of conventional British (HM-7) or Spanish tomatoes (HM-6) to make the home-made sauce reduces the overall meal costs by 17% and 51%, respectively, compared to the option with the organic ingredients (HM-2). Furthermore, replacing Spanish ready-made tomato paste (HM-1) by the sauce made at home from Spanish tomatoes (HM-6) reduces the LCC by 27%. On the other hand, using British tomatoes (HM-7) increases the costs by 24%. This is because Spanish tomatoes are cheaper than the British even when the costs of transportation from Spain are taken into account (Tables 5 and 6), owing to different cultivation conditions: British tomatoes grow indoors and are heated largely by electricity, while the Spanish are grown outdoors.

3.4. Value added of home-made meal options

For the estimation of VA, three illustrative examples of home-made meals are considered: HM-1, made from conventionally-grown ingredients, HM-2 prepared using organic raw materials and HM-7, using conventionally-grown ingredients and fresh British tomatoes for the sauce.

As can be observed in Fig. 6, the VA for HM-1 is estimated at £0.44 per meal which represents 45% of the retail price of the ingredients of £0.98 (see also Table 8). In the case of the meal prepared from the organic ingredients (HM-2), the VA is almost twice as high, totalling £0.97, or 51% of the ingredients' retail price. However, if the meal is made from conventionally-grown instead of organic ingredients and the sauce is made at home with fresh tomatoes (HM-7), the VA goes down to £0.47, equivalent to 40% of the retail price. This is close to the VA of HM-1: organic ingredients are more expensive than conventional, in particular, the cost of tomatoes is twice as high as that of the conventional (see Table 8) so that their replacement with the latter has a significant impact on the total costs and therefore on the VA.

Therefore, these results suggest that, from the supply chain perspective, the meal prepared from the organic ingredients provides a higher VA, almost double that of the meal with all conventional ingredients.

3.5. Comparison of ready- and home-made meals

This section compares various ready- and home-made options, first for the life cycle costs and then for the VA and consumer costs. The final section compares them for both the LCC and life cycle environmental impacts, using the results of the LCA study carried out previously by the authors for the same meal options (Schmidt Rivera et al., 2014).

3.5.1. Comparison of life cycle costs

Owing to space restrictions, only selective meal options are compared: ready-made meals made with conventionally-grown ingredients, both chilled (RM-1) and frozen (RM-3), and the (chilled) meal prepared using organic ingredients (RM-13). These are compared with their equivalent home-made meal alternatives using conventional (HM-1) and organic (HM-2) ingredients.

As shown in Fig. 9, the chilled ready-made meal (RM-1) has 19% lower LCC than the corresponding home-made option (HM-1): £0.61 vs £0.75. The frozen ready-made alternative (RM-3) also has lower LCC (by 11%). This is largely due to the higher costs of energy in the domestic compared to the commercial sector (see Tables 3 and 4) so that the cost of preparing the meal at home is higher than at factory.

The ready-made meal using some organic ingredients (RM-13) is also better economically than the equivalent home-made option (HM-2), with the former having the LCC of £0.91 and the latter £1.12. This is due to the higher amount of tomatoes used in the home-made meal to prepare the sauce compared to the ready-made paste (Tables 3 and 4) and also the use of conventional British tomatoes in RM-13, as opposed to organic in HM-2. However, if the tomato sauce in HM-1 is prepared from conventional Spanish tomatoes as in HM-6, the LCC go down to £0.55, which is the best overall home-made option among those considered in this work. This is 11% lower than for the chilled ready-made meal (RM-1) and 22% below the LCC of the frozen option (RM-3). This is largely due to the lower cost of fresh tomatoes used to make the sauce than the cost of the ready-made paste as well as the avoidance of the costs of its packaging.

3.5.2. Comparison of value added

As for the LCC, the VA of the chilled and frozen ready-made meals (RM-1 and RM-3) is compared to the VA of the equivalent home-made options, HM-1 and HM-2. Additionally, HM-7 is also considered to gauge the influence on the VA of ingredient sourcing (tomatoes from the UK rather than Spain).

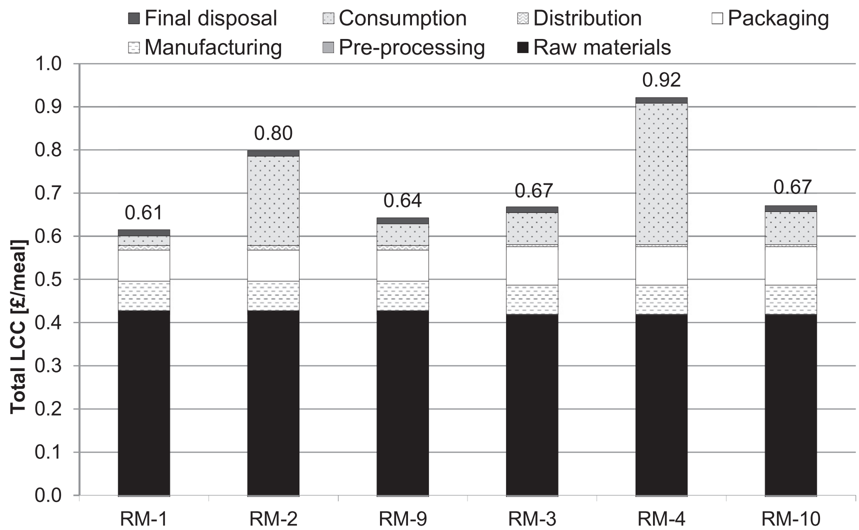

Fig. 5. Sensitivity analysis for the total life cycle costs ($LCC_{Cradle\ to\ grave}$) of the ready-made meal prepared using different appliances [RM-1: chilled ready-made meal heated in microwave; RM-2: chilled meal in electric oven; RM-9: chilled meal in gas oven; RM-3: frozen meal in microwave; RM-4: frozen meal in electric oven; RM-10: frozen meal in gas oven].

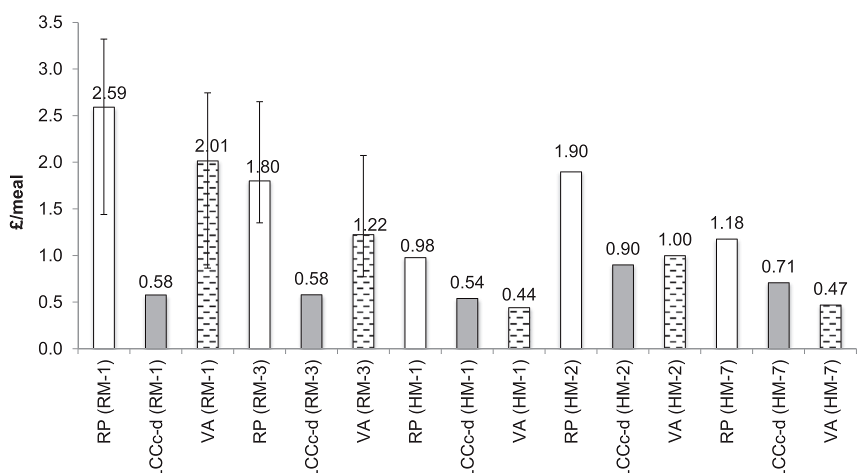

Fig. 6. Value added (VA) of ready-made and home-made meal options [RM-1 and RM-3: chilled and frozen ready-made meal, respectively. HM-1: home-made meal with conventional ingredients and pre-prepared tomato paste; HM-2: home-made meal with organic ingredients and home-made tomato sauce; HM-7: home-made meal with conventional ingredients and with tomato sauce made at home with conventional British (HM-7) tomatoes. RP: retail price. LCCc-d: life cycle costs from cradle to distribution to the retailer (LCCCradle to distribution in Eqn. (2)). Error bars for the ready-made meals represent the minimum and maximum costs related to the variation in the retail price of the meals; for details, see Table 7].

The results in Fig. 6 suggest that for the highest retail price, the VA of the chilled ready-made meal (RM-1) is around six times higher than the VA of the home-made option (HM-1). For the lowest retail price of the ready-made meal, the difference in the VA between the two meal options reduces to 50%. If the average retail price is considered, the VA of the ready-made meal is around five times the value of the home-made. In the case of the frozen ready-made meal (RM-3), its VA is almost three times that of the home-made.

Table 6
Transportation costs.

Transport type	UK	Spain	Brazil	Cost data sources
Euro 5 lorry (42 t)[a]				
Half load [£/km]	0.40	0.33	0.18	VTT (2010)
Full load [£/km]	0.49	0.40	0.22	VTT (2010)
Diesel [£/l]	1.40	1.15	0.63	DECC (2014); Global Petrol Prices (2014)
Transoceanic tanker (50,000 dwt[b]**) [£/km]**			2.5×10^{-3}	Baumel et al. (2008)
Consumer car[c]:				
Average fuel consumption [l/km]	0.08			EPA (2006); Sprit Monitor (2014); AA (2014)
Petrol [£/l]	1.32			DECC (2014)

[a] Euro 5 lorry: one of the latest in the series of standard heavy-duty vehicles as regulated by the European Commission 715/2007/EC (2007).
[b] dwt: deadweight tonnage.
[c] The average car size was selected using data for the best-selling cars in the UK in 2013 (Car Buyer, 2014; Boyce, 2013; Matt Bird, 2013).

Table 7
Retail prices for the ready-made meals.[a]

	Price [£/kg]	Price [£/meal]
Chilled meal		
Price range	4.00–9.21	1.44–3.32
Average	7.19	2.59
Frozen meal		
Price range	3.75–7.35	1.35–2.65
Average	5.01	1.80

[a] Retail prices obtained in May 2014 from the websites of the UK largest retailers: Tesco (2014), Asda (2014), Sainsbury's (2014), Iceland (2014), Morrisons (2014) and Lidl (2014).

Therefore, the actors in the supply chain benefit from the higher VA associated with the ready-made meals in comparison to the home-made, particularly for the chilled options. However, the trend is quite different when considering consumer costs, as discussed below.

3.5.3. Comparison of consumer costs

Fig. 10 compares the total consumer costs of the chilled (RM-1) and frozen (RM-3) ready-made meals with the equivalent home-made option HM-1. Three types of costs are considered: cost to the consumer to prepare the meal at home (consumption costs, C_C, as defined in Eqn. (1)), life cycle costs from 'cradle to consumer' ($LCC_{Cradle\ to\ consumer}$, Eqn. (3)) and total consumer costs (TC_C, Eqn. (4)).

The results in Fig. 10 indicate that the chilled meal has the lowest consumption costs, estimated at £0.02, while the home-made option is the most expensive at £0.2. The same trend is found for the life cycle costs from cradle to consumer, estimated at £0.6 for the chilled, £0.65 for the frozen and £0.73 for the home-made meal. However, the opposite pattern can be noticed for the total cost to the consumer, with the home-made meal being the least expensive at £1.17. The next best option is the frozen ready-made meal with an average cost of £1.87; the chilled meal costs on average £2.61. In the worst case, the chilled meal is three times more expensive for the consumer than the equivalent home-made option (£3.34 vs £1.17); in the best case, the difference is around 20% in favour of the home-made meal.

Therefore, these findings suggest that the home-made meal has lower consumer costs than the ready-made option. This, together with the perceived health benefits of home-cooked as opposed to industrially-processed food, may be important drivers for some consumers to consider home cooking. However, for others, factors such as convenience, lack of time and cooking skills may lead to choosing ready-made meals, regardless of the costs. Furthermore, some consumers may be motivated by environmental reasons when making purchasing choices. Therefore, in the next section we compare and contrast the life cycle costs with environmental impacts of ready- and home-made meals.

3.5.4. Comparison of life cycle costs and environmental impacts

As mentioned earlier, the environmental impacts of the meal options considered here have been estimated in a previous work by the authors (Schmidt Rivera et al., 2014). These results are summarised in Fig. 11, using a qualitative approach to rank different meals and identify the best option for both the LCC and environmental impacts. This so-called 'heat map' is obtained by assuming that all the criteria considered are of equal importance and then ranking them on each of the criteria. The overall ranking for each option is obtained by summing up their ranking for each criterion; the lower the total sum, the higher the ranking. The white cells in the figure indicate the lowest costs and impacts and therefore the best ranking while the black cells represent the highest values and thus the worst ranking. Note that the meal options considered in the sensitivity analysis are not included in this analysis as different sensitivity analyses have been carried out in this and the previous paper, driven by different cost and environmental hotspots, respectively.

According to the results in Fig. 11, the best option overall among the ready-made meals is RM-3 with seven out of 12 criteria, including the global warming potential (GWP), having the lowest value. However, its LCC are slightly higher than for RM-1 which is the second best option, but it has the lowest values only for three environmental criteria. The worst option is RM-8, for which seven out of 12 criteria, including the LCC and GWP, have the highest values.

For the home-made meal, the best option is HM-3 with six out of 12 criteria having the lowest values, including the LCC and GWP. The worst option is HM-2 for which the LCC and six environmental

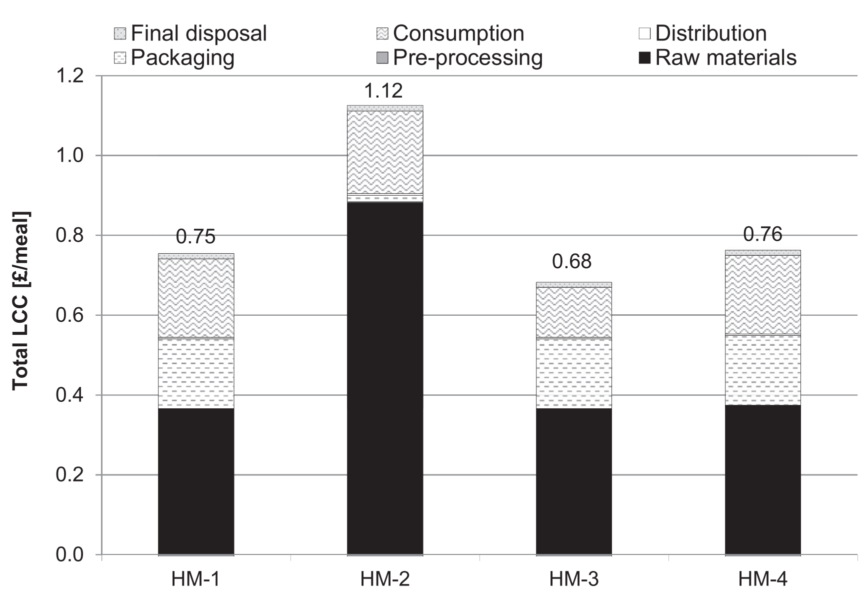

Fig. 7. Total life cycle costs ($LCC_{Cradle\ to\ grave}$) of different home-made meal options [For the description of scenarios, see Table 2.].

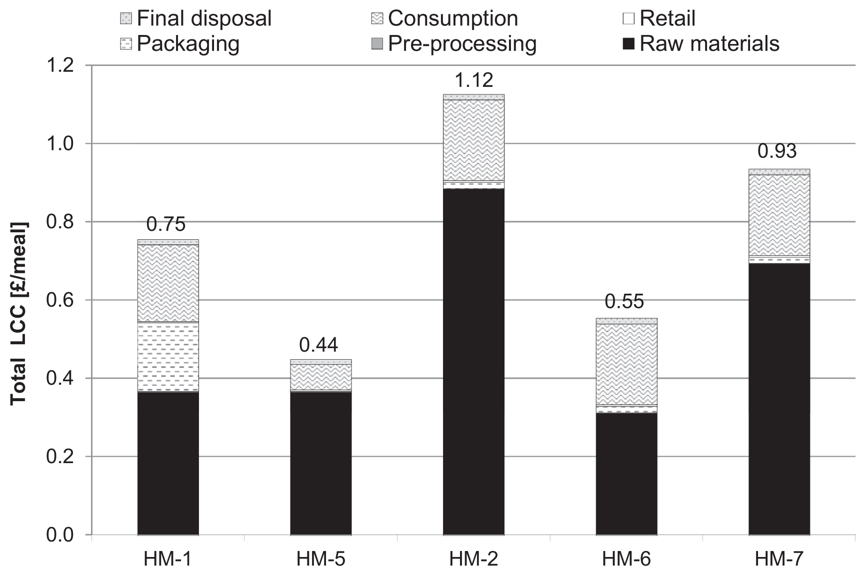

Fig. 8. Sensitivity analysis for the total life cycle costs ($LCC_{Cradle\ to\ grave}$) of the home-made meal assuming the use of different appliances and sourcing of ingredients [HM-5: as HM-1 but using gas appliances; HM-6: as HM-2 but using Spanish conventional tomatoes; HM-7: as HM-2 but using British conventional tomatoes].

Table 8
Average retail prices for the raw materials for the home-made meal.[a]

Raw materials[b]	HM-1			HM-2			HM-7		
	Weight [g/meal]	Unit cost [£/kg]	Total cost (£/meal)	Weight [g/meal]	Unit costs [£/kg]	Total cost (£/meal)	Weight [g/meal]	Unit costs [£/kg]	Total cost (£/meal)
Chicken	105.8	3.50	0.37	105.8	6.49	0.69	105.8	3.50	0.370
Potatoes	103.3	0.93	0.01	103.3	1.27	0.13	103.3	0.93	0.10
Carrots	41.3	0.94	0.04	41.3	1.32	0.05	41.3	0.94	0.04
Peas	41.3	7.48	0.31	41.3	7.48	0.31	41.3	7.48	0.31
Onions	33.4	0.86	0.03	33.4	1.41	0.05	33.4	0.86	0.03
Tomatoes	43.8	2.74	0.12	156.1	4.19	0.65	156.1	2.05	0.32
Oil	9	1.43	1.3×10^{-2}	9	1.43	1.3×10^{-2}	9	1.43	1.3×10^{-2}
Salt	1	0.61	1.0×10^{-3}	1	0.61	1×10^{-3}	1	0.61	1×10^{-3}
Total cost			**0.98**			**1.89**			**1.18**

[a] Retail prices obtained in May 2014 from the websites of the UK largest retailers: Tesco (2014), Asda (2014), Sainsbury's (2014), Iceland (2014), Morrisons (2014) and Lidl (2014).
[b] Raw ingredients, as bought by the consumer in a supermarket. Note that these amounts are different from those given in Tables 1 and 4 as the former refers to the cooked meal and the latter includes the upstream waste.

impacts, including the GWP, are the highest. HM-3 is also the best option overall, followed by HM-4 and HM-1.

Therefore, it can be argued that, on balance, the home-made meal is a more sustainable option than the ready-made. However, it should be borne in mind that this is predicated on the assumption that all the criteria are of the same importance to different stakeholders, which is unlikely. Arguably, for most, costs will be an important driver, in which case the ready-made meal RM-1 would be the best option. If, on the other hand, the GWP was of most interest, which may be the case for policy makers and environmentally-conscious consumers, then the home-made option HM-4 would be the best choice.

To take this analysis further and find out how significant the differences between the best and worst meal options may be, they are compared quantitatively in Fig. 12. These results indicate that the best (RM-3) ready-made meal option has on average 21% lower costs and environmental impacts than the worst option (RM-8), with the LCC and GWP being 28% and 34% lower, respectively. For the best home-made meal (HM-3), its LCC and impacts are on average 19% lower than for the worst option (HM-

Table 9
Energy consumption by different appliances for ready- and home-made meals.

Meal/ingredients	Microwave[a] [kWh/meal]	Electric oven[a] [kWh/meal]	Gas oven[a] [kWh/meal]
Chilled meal	0.08 (RM-1)	1.27 (RM-2)	0.83 (RM-9)
Frozen meal	0.39 (RM-3)	2.03 (RM-4)	1.33 (RM-10)
Roast chicken	–	0.51[b]	0.33 (HM-5)
Vegetables	0.08 (HM-3)	0.47[b]	0.45 (HM-5)
Tomato paste	0.09 (HM-3)	0.16[b]	0.15 (HM-5)

[a] Data for energy consumption sourced from Schmidt Rivera et al. (2014). Average energy prices in the domestic sector used: £0.16/kWh electricity and £0.05/kWh gas (DECC, 2014).
[b] All home-made meals except for HM-5.

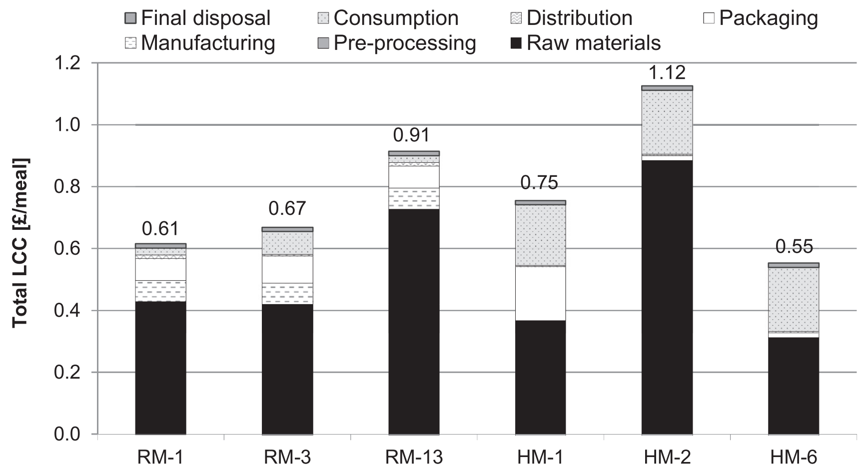

Fig. 9. Comparison of total life cycle costs ($LCC_{Cradle\ to\ grave}$) of ready- and home-made meals [For description of the meal options, see Table 2.].

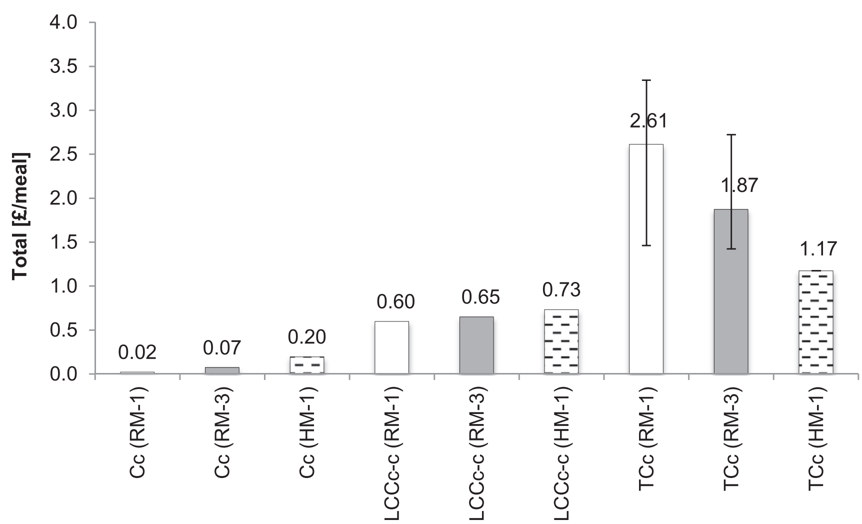

Fig. 10. Comparison of consumer costs of the ready- and home-made meals [Cc: costs of consumption (consumer transport to purchase the meal and its preparation at home); LCC_{c-c}: life cycle costs from 'cradle to consumer' as defined in Eqn. (3). TCc: total cost to consumer, as defined in Eqn. (4). For the description of the meal options, see Table 2].

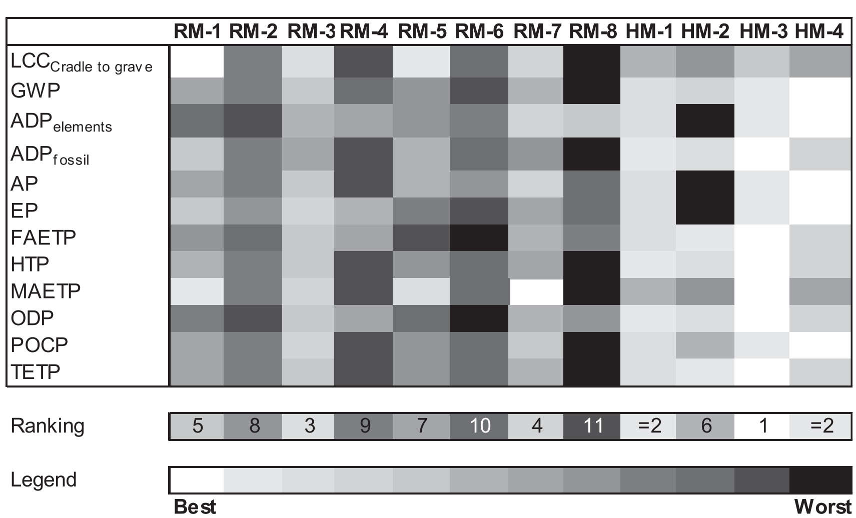

Fig. 11. Comparison of the life cycle costs and environmental impacts of the ready- and home-made meals [For the description of the meal options, see Table 2. LCC: Life cycle costs from 'cradle to grave' as defined in Eqn. (1). GWP: global warming potential (100 years); $ADP_{elements}$: abiotic depletion potential for elements; ADP fossil: abiotic depletion potential for fossil fuels; AP: acidification potential; EP: eutrophication potential; FAETP: freshwater aquatic ecotoxicity potential; HTTP: human toxicity potential; MAETP: marine aquatic ecotoxicity potential; ODP: ozone depletion potential; POCP: photochemical oxidant creation potential; TETP: terrestrial ecotoxicity potential.].

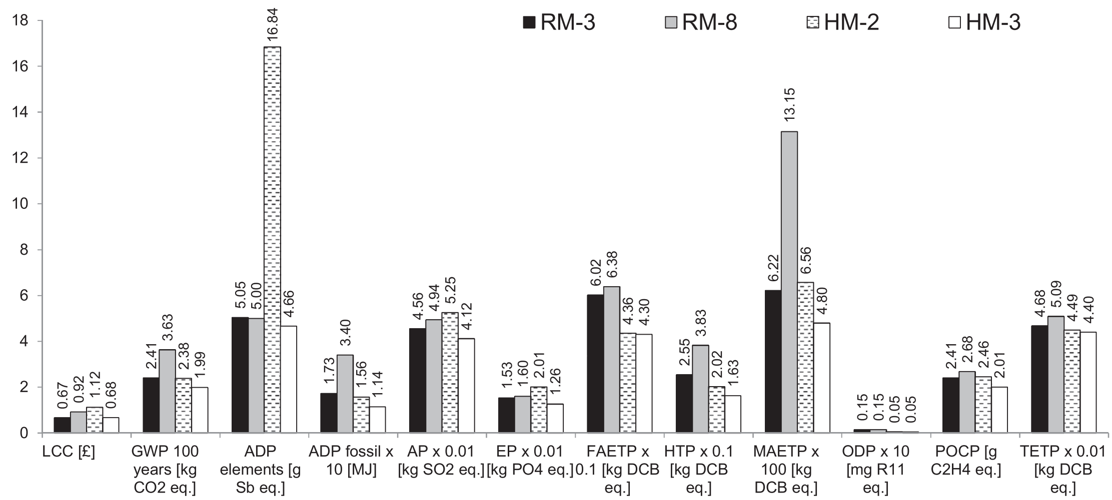

Fig. 12. Comparison of the life cycle costs and environmental impacts for the best ready- and home-made meal options [The costs and impacts expressed per meal. For the description of the meal options, see Table 2. For impacts nomenclature, see Fig. 11. Some impacts have been scaled to fit. The original values can be obtained by multiplying with the factor shown in brackets against relevant impacts. For details on the environmental impacts, see Schmidt Rivera et al., 2014.].

2), with 40% smaller LCC and 17% lower GWP. The comparison of the best home-made meal option, which is also ranked the best option overall (HM-3), with the best ready-made meal (RM-3) reveals that their LCC are quite similar, with only a 2% difference in favour of RM-3. However, the difference in the environmental impacts in favour or HM-3 is much larger, ranging from 6% for the terrestrial ecotoxicity to 200% for the ozone layer depletion potential; the GWP is 21% lower. Therefore, it could be concluded that HM-3 is the best option environmentally by a significant margin and, given a small difference in the costs with the best ready-made option RM-3 (2%), it could be considered the best option overall.

4. Conclusions

This paper has considered the life cycle costs (LCC) of ready- and home-made meals. The total LCC of the ready-made meals range from £0.61 for the chilled meal made from fresh ingredients and heated in a microwave (RM-1) to £0.92 for the frozen ready-made meal made from frozen ingredients and heated in an electric oven (RM-8). The main contributor to the LCC are the raw materials (46–70%), with chicken and tomato representing collectively 70% of the ingredients' costs. Sourcing the chicken from the UK or Brazil does not affect the total LCC but using British tomatoes or organic ingredients increases the costs between 14% and 17%. The consumption stage is the second largest contributor to the LCC (4%–36%), largely owing to the energy used to prepare the meal at home. Packaging adds a further 9%–13% to the total, with the frozen ingredients requiring more packaging than the fresh. Meal manufacturing contributes another 9% while final disposal and distribution add only 2% and 1% of the total cost, respectively.

The LCC of home-made meals range from £0.68 to £1.12 with the best option being the meal made from conventionally-grown ingredients, with the chicken baked in the electric oven and the vegetables and tomato sauce cooked in the microwave (HM-3). Similar to the ready-made options, the major cost contributors are the ingredients and meal preparation. The highest LCC is found for the meal made from organic ingredients (HM-2).

The results suggest that the chilled ready-made meal (RM-1) has 19% lower LCC than the equivalent home-made option (HM-1): £0.61 vs £0.75. The frozen ready-made alternative (RM-3) also has lower LCC than the home-made meal (by 11%). This is largely due to the higher costs of energy in the domestic compared to the commercial so that the cost of preparing the meal at home is higher than at factory.

The highest value added is found for the chilled (RM-1), followed by the frozen (RM-3) ready-made meal, followed by the home-made option made from organic ingredients (HM-2). Therefore, from the supply chain perspective, the chilled ready-made meal generates greater economic benefits to different players in the supply chain. However, from the consumer's perspective, the home-made meal (HM-1) has the lowest costs of £1.17, followed by the frozen (RM-3) ready-made meal at £1.87. By comparison, the chilled ready-made meal (RM-1) costs the consumer on average £2.61.

A comparison of the life cycle costs and environmental impacts of different ready-made meal options indicates that the best option overall is the frozen ready-made meal made from fresh ingredients and heated in a microwave (RM-3). The worst option is the frozen ready-made meal made from frozen ingredients heated in the electric oven (RM-8). However, overall, home-made meal made from conventional ingredients and cooked in the electric oven and in the microwave (HM-3) could be considered the best option overall.

These results can be used to increase both producer and consumer awareness of the economic costs and environmental impacts of convenience food, compared to home cooking. However, this study has considered only one type of meal so that further research is needed for other meal options to provide a more comprehensive understanding of the economic and environmental sustainability of ready-made meals. Furthermore, this analysis did not consider other important aspects such as health, nutritional value and convenience that also play an important role in consumer purchasing decisions. It is recommended that these issues be explored in future research.

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