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Energy embodied in household cookery: the missing part of a sustainable food system? Part 2: A life cycle assessment of roast beef and Yorkshire pudding

Christian J. Reynolds[a,b]*

[a]*University of Sheffield, Department of Geography, Faculty of Social Sciences, Winter Street, Sheffield, S3 7ND, UK*
[b]*University of South Australia, Division of Information Technology, Engineering and the Environment, Adelaide, SA, 5001, Australia*

Abstract

This paper firstly reviews the current state of knowledge on sustainable cookery and the environmental impacts of the food consumption phase. It then uses the example of a dish of roast beef and Yorkshire pudding to explore energy use in food production and consumption. Part 1 of this paper conducts a meta-analysis of 33 roast beef and Yorkshire pudding recipes in order to create a representative recipe for analysis. Part 2 of this paper then uses life cycle assessment and energy use data is coupled with the representative recipe of roast beef and Yorkshire pudding, to calculate the embodied energy of the meal. Seven interventions are modelled to illustrate how sustainable cookery can play a role as part of a sustainable food system. Interventions show that sustainable cookery has the potential to reduce cookery related energy use by 18%, and integrating sustainable cookery within a sustainable food system has the potential to reduce the total energy use by 55%. Finally, the paper discusses the issue of how the adoption of the sustainable cookery agenda may help or hinder attempts to shift consumers towards sustainable diets.

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Keywords: Energy demand and resource use in food consumption; life cycle assessment; cooking; home-made meals; Environmental impacts; LCA; food; meal; food energy and water nexus; energy and resource use in food consumption

* Corresponding author. Tel.: +44-7448-934888.
E-mail address: c.reynolds@sheffield.ac.uk

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1. Introduction

Part 1 of this paper provided a general introduction into energy use in household cookery and provided method to calculate a representative recipe that would describe the current cooking methods, and portion and ingredient norms. This representative recipe can then be couple with life cycle analysis tools to show the environmental impacts of the recipe (food and cooking method)

In this paper (part 2), I couple life cycle assessment data with the recipe of roast beef and Yorkshire pudding to explore the energy use in food production and consumption. In part 1, I conducted a meta-analysis of roast beef and Yorkshire pudding recipes to create a representative recipe. To illustrate how sustainable cookery can play a role as part of a sustainable food system, in this paper (part 2), I model how seven possible interventions impact on energy use within the context of this recipe. Interventions include different cooking methods, ingredient change, and increasing appliance efficiency.

2. Methods

2.1. Life cycle assessment

Embodied energy use data for ingredients was sourced from the Williams, Audsley and Sandars 2006 report [23]. This provided the primary energy used (MJ) for UK conventional and organic production of bread wheat, beef, eggs, milk, and oilseed rape. A processing/conversion rate of 40% was used to convert the oilseed rape to oil [30]. Embodied energy use data for ingredients was also sourced from the 2013 report by May, Adams, and Plackett [13] to provide comparison of primary energy use compared with energy use of ingredients across the full supply chain (primary production, processing, transport, packaging and storage/retail). The energy factors of beef were used as a proxy for dripping as both ingredients come from the same production process.

Household product level (avoidable) food waste data for each ingredient was sourced from a 2014 WRAP report [16]. Energy consumption data for UK domestic appliances (ovens and stove tops) was sourced from Wood and Newborough [24], Ovens were assumed to have been preheated for 20 minutes to come up to cooking temperature [25]. As no recipe specified refrigeration or storage prior to cooking, this set of energy use assumptions were not included in this assessment. The functional unit for the assessment was firstly "per portion of roast beef and Yorkshire pudding". However, as cooking times (and thus energy consumption) vary by weight of joint, 8 portions (the median number of portions per recipe) was selected as the representative functional unit of this analysis.

2.2. Scenario analysis

In addition to calculating the energy required to produce and cook a typical (median) roast beef and Yorkshire pudding, seven additional scenarios are investigated. In all scenarios the ingredient energy use data is sourced from the Williams, Audsley and Sandars 2006 report [23]. The assumptions and data sources are outlined below.

1. *Low heat cooking method*: As discussed in the results, a subset of the recipes featured searing the joint of beef in a pan and then transferring the beef to a low oven (55-60C) until the internal core temperature of the joint was between 55-60C – i.e.240 minutes. The Yorkshire puddings are then cooked in a hot oven (220C). The energy use for the low oven method is sourced from Wood and Newborough [24], with 1.2kWh rather than the 2kWh of a hot oven. The searing is assumed to use an electric stove/hotplate (0.6kWh) [24].
2. *Sous vide cooking method*: For this paper the sous vide method can be understood to be the placing the joint of beef in a vacuumed plastic pouch/bag and submerging this in a heated water bath for several hours until the internal core temperature of the joint was between 55-60C – i.e.500 minutes [26]. After this time, the joint is then unwrapped and placed in a hot skillet (0.6kWh) to sear the joint's surface [24]. The Yorkshire puddings are then cooked in a hot oven (2kWh). This water bath is heated by a sous vide appliance (such as an immersion circulator). Energy consumption data for sous vide appliances was sourced from an internet test website that has

tested the power use of 13 sous vide appliances. The average of the heat up phase/first hour (0.427kWh) and cook phase (0.254kWh) were used as proxies for average sous vide device energy consumption [27].

3. *Reduced portion size of beef*: Halve the size of the portion of beef (125g). All other assumptions remain the same as for typical cooking.
4. *10% energy efficiency increase of oven*: increase energy use efficiency by 10%, this would equate to a reduction to 1.8kWh energy usage oven. All other assumptions remain the same as for typical cooking
5. *Organic ingredients*: use the embodied energy use values for organic production found in the Williams, Audsley and Sandars 2006 report [23]. All other assumptions remain the same as for typical cooking
6. *Sous vide cooking method with organic ingredients*: use the assumptions from scenarios 2 and 5.
7. *Sous vide cooking method with organic ingredients and reduced portion size of beef*: use the assumptions from scenarios 2, 3 and 5.

3. Results

Table 1 outlines the median recipe for 8 portions of roast beef (2kg), and Yorkshire puddings (~670g) as calculated in part 1 of this paper. Beef contributes the largest amount of embodied energy: 55MJ, using primary production energy data from Williams, Audsley and Sandars, or 68mj using LCA energy data from May, Adams, and Plackett. Using either data set, beef was 72% of the total energy use footprint. Oven use is the second largest contributor using 15.3MJ, or 20%(a) or 16%(b) of total energy foot print). The additional scenarios are compared to the "hot oven method" in Figure 1.

Table 1 – Median recipe for 8 portions (2kg) of roast beef,
with Yorkshire puddings (~670g) as calculated by recipe meta-analysis (see part 1 of this article)

	Typical steps in recipe
1.	Pre heat oven 20 minutes
2.	Roast beef (2kg) in oven for 75 minutes
3.	Make batter. (combined Egg (200 g), Flour (225g), Milk (347ml), Water (118ml), and Oil (30ml))
4.	Oil/dripping (57ml) in Yorkshire puddings pan to heat 5 minutes
5.	Cook Yorkshire puddings 20 minutes

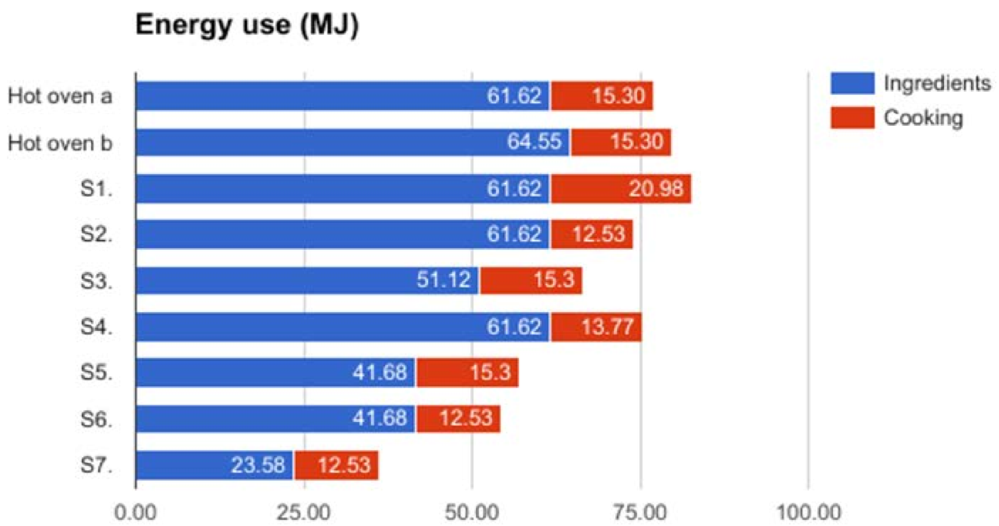

Fig. 1. Energy used for ingredients and for cooking (MJ) in the traditional "hot oven" method (a) Williams, Audsley and Sandars (2006) and b) May, Adams, and Plackett (2013)) with median timings, and in the 7 scenarios.

The low heat cooking method (scenario 1) increased energy use by 1.58kW due to the longer oven running times and the fact that the oven still had to run hot to cook the Yorkshire puddings. The sous vide cooking method (scenario 2) decreased energy use by 0.77kW. Halving of the beef portion to 125g (scenario 3) decreased energy use by 2.92kW. A 10% increase in oven energy efficiency (scenario 4) reduced energy use by 0.43kW. Switching to organic ingredients (scenario 5) decreased energy use by 5.54kW. Using the sous vide cooking method with organic ingredients (scenario 6) decreased energy use by 6.31kW. Using the sous vide cooking method with organic ingredients and halving of the beef portion to 125g (scenario 7) was the most effective reduction decreasing energy use by over half of the energy footprint (11.33kW). A comprehensive breakdown of energy use for each scenario can be found in Table 2.

Table 2 – Energy use breakdown (MJ) of producing and cooking a median weighted 8 portion roast beef and Yorkshire pudding using the traditional "hot oven" method, and scenarios 1-7, all with median timings.

	Hot oven a Williams, Audsley and Sandars (2006)	Hot oven b May, Adams, and Plackett (2013)	Scenario 1. Low heat cooking method	Scenario 2. Sous vide cooking method	Scenario 3. Reduced portion size of beef (125g)	Scenario 4. 10% energy efficiency increase of Oven	Scenario 5. Organic ingredients	Scenario 6. Sous vide cooking method with organic ingredients	Scenario 7. Sous vide cooking method with organic ingredients and reduced portion size of beef
Ingredients									
Beef	55.40	68.80	55.40	55.40	27.70	55.40	36.20	36.20	18.10
Dripping	1.57	1.95	1.57	1.57	1.57	1.57	1.03	1.03	1.03
Egg	2.82	5.84	2.82	2.82	2.82	2.82	3.22	3.22	3.22
Flour	0.55	0.81	0.55	0.55	0.55	0.55	0.39	0.39	0.39
Milk	0.87	1.80	0.87	0.87	0.87	0.87	0.54	0.54	0.54
Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Oil	0.40	0.65	0.40	0.40	0.40	0.40	0.30	0.30	0.30
Cooking									
Frying pan	0.00	0.00	0.70	0.70	0.00	0.00	0.00	0.70	0.70
Sous vide	0.00	0.00	0.00	7.03	0.00	0.00	0.00	7.03	7.03
Oven	15.30	15.30	20.28	4.80	15.30	13.77	15.30	4.80	4.80
Total energy used (MJ)	76.92	95.15	82.60	74.15	49.22	75.39	56.98	54.21	36.11

4. Discussion

This paper has calculated the energy used in producing and cooking a median weighted 8 portion roast beef and Yorkshire pudding meal, and compared the median hot oven recipe to seven energy usage change scenarios including different cooking methods (scenarios 1, 2,6 and 7), ingredient change (scenarios 3,5,6, and 7), and increasing appliance efficiency (scenario 4).

It was found that the single most effective method of energy reduction came from halving the portion size of beef from 250g to 125g. As the portion weight of 125g of beef was found within the recipe sample, this can be assumed to be a feasible reduction in the amount of beef cooked for each portion. It should be noted that this weight of beef is still above the recommended 70g daily allowance of meat by Public Health England [14]. The generation of leftovers could be an explanation for the large portions of beef, with the introductions of many sampled recipes mentioning leftovers as a reason to cook roast beef and Yorkshire pudding. If Public Health England's recommendation of 70g a day is taken as a maximum serving size, the halving of portion size from 250g to 125g of beef reduces the amount of leftovers, but still provides capacity for them (i.e. a 2kg joint for 8 becomes a 1kg joint for 8). An advantage to reducing leftovers is that this also reduces the possibility of avoidable food waste. In 2014, 8% of beef purchased by UK households became food waste, with 54% of household avoidable beef waste due to the cooking, serving or preparing of too much food, or the beef (leftovers) not being used in time [16]. With 8 median 250g portions, this would equate to 160g of avoidable beef food waste or 4.43 MJ of embodied energy wasted (5.7% of total embodied energy in the hot oven a recipe). However, if the portion size was reduced to 125g, this would mean that 80g of beef leftovers are thrown away avoidably, or 2.21 MJ of embodied energy wasted (4.5% of total embodied energy in the scenario 3 recipe). Furthermore, leftovers require additional energy use to refrigerate and possibly re-heat for future consumption. Sonesson and Davis provide an energy use value for reheating of 1.25MJ per KG [20], this equates to 0.46MJ per portion of roast beef and Yorkshire pudding or 3.72MJ for 8 portions. If all leftovers were eaten this would be 4.6% of total energy use for hot oven a.

The median cooking time of 75 minutes for the beef is confirmed as a representative typical average cooking time by a recent survey by the British Gas Board [8]. However, the British Gas Board survey also found that oven energy usage could be much higher as those in their UK population sampled tended to overcook roast beef for an extra 41 minutes above recipe advice. This would equate to an additional 4.92MJ of energy use in the cooking phase due to over cooking.

The greatest energy reduction overall was found in scenario 7. This used the sous vide cooking method in combination with organic ingredients, and the 125g reduced portion size of beef to reduce the energy footprint of the production and cooking of the recipe by 53%. It may be difficult to introduce this scenario into UK households as there may be reluctance to 1) reduce the beef portion size, 2) switch to organic foods (for reasons of cost or ingredient accessibility [2,12]) and 3) adopt a method of cookery using a modern, unfamiliar, and inaccessible, piece of cooking equipment.

Though challenging to adopt in households, the more sustainable recipe for roast beef and Yorkshire pudding described in scenario 7 could be adopted easily by the hospitality industry (i.e. restaurants and commercial catering) as they have supply chains able to source organic ingredients, have already adopted sous vide cooking methods [3,17,22], and can present smaller portions at a higher cost due to the nature of customer expectations when eating out. In addition, there may be further energy reductions possible through cooking larger numbers of portions at the commercial level, although commercial cookery has its own unique energy requirements[1,5–7,11,15]. As previously mentioned, the cooking and consumption of food outside the home has previously been modeled in Australia to have lower energy, water, GHGE and waste footprints than household food consumption [18]. Further research and modelling is required to establish if eating outside the home in restaurants or commercial canteens is more energy efficient and sustainable on an individual food item basis. Furthermore, eating practices and social norms regarding eating at home and eating out would have to shift to allow eating outside the home to occur at such a scale in the UK. This has been occurring slowly over the last 100 years [4]. However, cultural normalization of eating outside the home is achievable, with the practice of eating out in preference of eating at home currently existing in many Asian countries. For instance, in Singapore, one in three Singaporeans eats out more than they do at home, with 60% of Singaporeans eating out at least four times a week [10,28,29].

Home delivery services such as Deliveroo and Ubereats could also be used as methods to further normalise food preparation and cooking away from home. This would allow consumers to purchase the more energy efficient food to consume at home, without the need to cook it themselves. Further research and modelling is required to assess the energy impacts of food delivery companies.

It is should also be noted that not all organic production was more energy efficient in the Williams, Audsley and Sandars data set and so the organic option does not automatically equate to lower energy. Organic eggs had higher embodied energy production footprints than their conventionally produced counterparts. In addition, the primary energy used in production of ingredients may have changed since Williams, Audsley and Sandars calculated the primary energy used in production in 2006 due to production process improvements. The Williams et al data source was selected as it had both conventional and organic production processes, and it was specifically a UK production method. This is not found in other food energy use datasets [9,13]. The May, Adams, and Plackett data was provided to compliment the Williams, Audsley and Sandars data, and include full supply chain energy use in this analysis. However, both datasets may no longer be up-to-date due to increases in energy efficieny in the food system. Further research and modelling is required with up-to-date production and cooking energy use databases to verify the results of this study.

Furthermore, the results from the low oven cooking method (scenario 1) could be lower than calculated. This is due to a lack of data availability concerning the energy use of ovens at different temperature ranges. Currently manufactures have to only report the energy (kWh) required to heat a standardised load in a cavity of a domestic electric heated oven during a cycle (see IEC 60350-1:2016 or [21]). To this author's knowledge, the Wood and Newborough oven energy use data is one of the few low temperature kWh measurements available.

A further limitation of this study is that it only accounts for energy use in the production and cooking stages of consumption, a full life cycle assessment was not carried out. This paper has also had a focus on electric cooking appliances, and did not include gas appliances as a variable. Previous studies have found that gas appliances can improve energy use in ovens by 30% [19]. Considering the similar energy use patterns between studies, similar results are likely. Further modelling could be carried out using gas hobs and ovens to prove this hypothesis.

5. Conclusion

This paper has shown that sustainable cookery has the potential to reduce cookery related energy use by 18%, and integrating sustainable cookery within a sustainable food system has the potential to reduce the total energy use by 55%. Sustainable cookery is the missing part of the sustainable food system, and more must be done to raise awareness of sustainable cooking among consumers, industry, and policy makers.

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