Domestic Food and Sustainable Design: A Study of University Student Cooking and its Impacts

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ABSTRACT
In four university student kitchens over twenty-one days, we captured participants' food preparation activity, quantified the greenhouse gas emissions and direct energy connected to the food and cooking, and talked to participants about their food practices. Grounded in this uniquely detailed micro-account, our findings inform sustainable design for cooking and eating at home and quantify the potential impacts. We outline the relation of the impacts to our participants' approaches to everyday food preparation, the organisation of their time, and the role of social meals. Our technique allows evaluation of opportunities for sustainable intervention design: at the appliance, in the digitally-mediated organisation of meals and inventory management, and more broadly in reflecting upon and reshaping diet.

Author Keywords
sustainability; food; practices; everyday life; energy; greenhouse gas

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: Miscellaneous

INTRODUCTION
In the UK, food production, distribution and consumption accounts for 27% of total direct greenhouse gas (GHG) emissions. It has been posited that changing from an 'average' diet to a plant-based one, could save as much as 22%. This is about 40 Mt CO_2e per year [5]. Food practices are an important potential design space for HCI. There is a growing interest in ecological sustainability in HCI, and formative studies have shed light on implications for the design of e.g. sustainable domestic energy [10, 30, 35] and water [35]. Quite recently, considerations of sustainability have turned to food in designs for alternative systems of food production and consumption [11, 12, 13].

Furthering such work, this paper applies an empirical lens to uncover the impacts that arise from food preparation at home. We analyse the cooking practices and foods observable at the cooker (i.e. "stove" or "range"), and explore the precise relationship of the food's embodied GHG arising from production/distribution (indirect emissions), with those arising from the energy required to cook it (direct emissions).

Our study took place over three weeks, with full-time UK students living in shared university accommodation. Students are a very specific yet significant demographic where design interventions might have impact: there are 6 million full-time students in UK (7% of the population)[1] and approximately 47 million (15%) in the US.[2]

Domestic student life is also a potentially fruitful domain for intervention. Student accommodation is a type of high-density housing which is often set up with communal areas, lending itself particularly well to opportunities for sustainable design. Students ostensibly have more spare time and flexible schedules, as they are less likely to be constrained by responsibilities for dependents, or by full-time employment. Moreover, many young students have recently moved away from a guardian's home and have newfound responsibilities in procuring and preparing food for themselves; they are at a specific point of "transition in practice" [32, ch. 1] where interventions and shifts might be more easily trialled and adopted to shape their competencies and ways of doing things, for later life. Finally, student accommodation is often institutionally administered, and cooperation with the university can be a basis for scalable change.

In this paper we contribute a unique fine-grained account of food preparation at the cooker in shared student residences, the energy taken to cook each food type, its GHG impact, and what it means and how it fits with the lives of our participants. Then, we discuss and evaluate (in terms of potential impact) a range of design interventions that might be applied to reduce the impact of these food practices.

RELATED WORK
Food sustainability is an increasingly important topic in HCI. Recent work has begun to address the importance of lower-impact food choice. Using food miles as a proxy for carbon impact, Kalnikaite et al. explore 'nudging in situ' with an augmented supermarket trolley [20]. There are also calls to broaden the scope and tackle areas beyond the consumer; Choi and Blevis offer a framework for disciplinary and user

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[1] Universities UK (UUK), report "The future size and shape of the higher education sector in the UK: demographic projections", 2008.
[2] Estimated from Degree enrolment statistics 2006-9, National Centre for Education Statistics, US Dept. for Education.

engagement in sustainable food cultures in urban environments [11].

Other food-related HCI research has largely sought to augment meal planning and cooking, with goals such as promoting nutrition [1, 9], organisation [18] and sociality [26, 29]. Augmented kitchens have been enhanced with projected displays to increase the cook's efficiency, as exemplified by Bonanni et al.'s 'CounterIntelligence' [6]. Kirman et al. propose aversive feedback to stimulate more frugal energy, gas and water use in the kitchen [21]. Although not yet in terms of sustainability, Grimes and Harper suggest an orthogonal departure from efficiency and planning, to explore 'Celebratory Technology' [17] which unobtrusively promotes ways in which human-food interaction is enjoyed, perhaps as gifts, for strengthening family ties, or relaxation.

Food and cooking have been widely studied outside HCI in domains such as anthropology [24], which considers food systems, food insecurity, how food brings about social change, and the influence of specific commodities. Francis' qualitative study of thirty English domestic cooks tackles the concern that increased use of pre-prepared foods is deskilling cooks and adversely effecting health [31]. She found no simple, clear-cut relationship between skills and domestic cooking practices, noting their highly individual nature despite an intricate and shared 'domestic cooking culture'. Caraher et al. use national survey data to explore the relationship between cooking skills and food choice, emphasising a general lack of specific cooking techniques and confidence to cook certain foods [7]. Also using surveys, Marquis analyses factors affecting student diet in residence halls in Montreal (Canada), finding that convenience was the most important food motivation, followed by price, pleasure, health and concern about weight [23]. Mooney and Walbourn observe that male and female college students avoid different foods citing different reasons [25]. de Leon's ethnographic work provides insight into how cooks use time and the significance of organising workspaces such as cupboards and fridges as a memory aid [14]. Wagner et al. conduct formative studies to uncover key aspects of cooking competence, and prototype sensors to measure these techniques for an 'Ambient Kitchen' [36].

The direct energy impact of cooking has been considered in isolation. Oberascher et al. measure the energy efficiency of boiling water, potatoes and eggs, and brewing coffee [27] to develop energy saving recommendations. Similarly, Oliveria et al. gave twenty UK undergraduates a fixed task (cooking instant noodles), and recorded a variation of up to three times the electrical energy due to differences in participants' cooking technique [28]. Stimulating reduction of energy in cooking has also been investigated. In a controlled study of digital energy-consumption indicators at the cooker, Wood and Newborough found that savings in cooking energy of between 10–20% were possible [39]. They stress the importance of providing regular feedback, and highlight the role of cooking technique.

The indirect energy impact of food on emissions has also been a subject of extensive study outside HCI [8, 33, 37]: Weber and Matthews highlight how food choice is more impactful to reduce indirect emissions than food-miles [37]; whereas Carlsson-Kanyama et al. highlight how diet change can lower food indirect emissions by up to 30% [8].

We aim to quantify and understand the twin impacts of energy use and embodied GHG due to food preparation, as *currently practiced* in shared student kitchens. We derive insights and implications for design from in-depth analyses, where we apply state-of-the-art life-cycle analyses (LCAs) in real kitchens and align the resulting fine-grained accounts of GHG emissions with qualitative insights into the motivations and meanings behind the practices we observe.

METHODS AND PARTICIPANTS

Our study was conducted in four student residences over 21 days on campus. Each residence contains a shared kitchen and individual study-bedrooms. There were 31 participants: 7 in one residence, and 8 in each of the other three. Where necessary we denote the residences as Blue, Green and Yellow, and Red. Participants are assigned pseudonyms to preserve their anonymity. In general, students are randomly assigned to residences in their first year of study. In later years, they may nominate individuals to share with. Red and Yellow were first-year flats, Green had a mix of first and third-year students, and Blue a mix of second and third-years.

To capture what is cooked, the use of the cooker and its energy and indirect impact unobtrusively, required a mix of four methods of enquiry.

Firstly, we use a motion-triggered wildlife trail camera mounted above the cooker, looking down at the hobs (or "burners")—we came to know this camera as 'the hobcam'. An example of the hobcam's field-of-view can be seen in Figure 1. It is intentionally positioned to avoid capturing the identity of the individual doing the cooking. The hobcam takes a photo whenever motion is detected. It contains an infrared light source and thus can capture images even in low light conditions. Each image is automatically watermarked with a timestamp.

To complement the photographic record, we logged real-time electric energy readings (every 6 s) for each flat using OWL smart meters. We recorded the energy used at every mains socket throughout the flats using Plugwise units in the shared kitchens and bedrooms of consenting participants (22 of the 31 participants).

We calculate the energy consumption for each meal by finding the start and end times of each 'cooking session' using the watermarked timestamps in the first and last hobcam images in the session. The hobcam ignores motion for 30 seconds after each photo is triggered to keep the number of photos manageable and allow the onboard storage to last for the duration of the deployment. Fortunately, the fine grained (six-secondly) energy data allows us to finely adjust the end time of our cooking sessions. It is possible for the hobcam to miss the occasional actions within this 30-second window, but it still yields good coverage of the foods cooked and cooking methods used. A cooking session may include multiple dishes or meals, where prepared concurrently, and our findings include these unless stated otherwise.

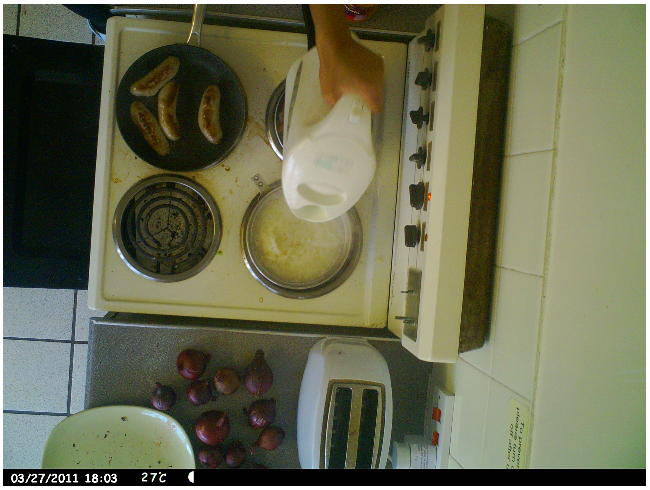

Figure 1. The Hobcam captures the hobs, the cooker dials, the grill and oven doors, and a small part of the work surface beside the cooker. All of the cookers, except the one in Blue, are the same model, and they all consist of two small and two large electric hobs at the front and rear of the cooker top, a grill below the hobs and an oven below the grill.

The amount of energy used in cooking the dishes observed is the area under the curve after subtracting both the total metered socket-level energy used during the session and a *baseline* for the whole flat (to account for any unmonitored devices). The baseline is the average whole-flat power consumption after the socket level total is subtracted in the 30-minute periods immediately before and after a cooking session.

For each cooking session we hand-annotated the number of dishes, cooker components used, the foods observed and the quantities in each dish. After Williamson et al. [38], who validated digital photography as a method for estimating portion sizes, we developed a set of ground rules for estimating food quantity by weighing portions of common food items, and cross-checking with weights reported on supermarket packaging. For hobs, we annotated the cooking method (frying, heating or boiling) and the use of lids on saucepans. Finally, for events involving boiling, we annotated the type of food boiled and the method used to bring water to the boil (kettle or hob), if apparent. It was possible to observe when cooker dials changed position but not the exact dial setting from the hobcam photos.

We then calculate direct emissions due to cooking, and indirect emissions resulting from the food supply chain. The direct emissions are computed using the DEFRA 2010 conversion factor, adjusted to include Scope 3 emissions: 0.60 kg CO_2e/kWh. Indirect emissions are calculated using our annotated food weights and the conversion factors for categories of supermarket foods detailed in a report[3] for Booths supermarket by Small World Consulting Ltd. (SWC) [4, fig. 17]. Our results are then inspected by SWC, and refined as necessary. The figures we used were the best estimates available for our region in the UK, and incorporate state-of-the-art LCAs and peer-reviewed studies, most notably those of Cranfield University and DEFRA [4].[4]

Finally, to uncover the place of food and meal preparation in the lives of our participants we conducted end-of-study interviews (11 in total—3 from 3 domiciles and 2 from the other; 7 female, 4 male). Part of each interview focused around their food-related activity: what they prefer to eat, how often they cook, and how else they may prepare or acquire their meals (take-aways, visiting friends nearby). Interviews were transcribed and then independently coded by two authors, from which themes were drawn to contribute to our findings. While participants were aware of the hobcam and that energy consumption was being monitored as part of the study, we purposefully did not ask them about awareness of energy or sustainability.

Limitations

Direct emissions arising from electricity use can vary significantly between countries, as this depends on the mix and GHG externality of energy sources contributing to the national grid. Similarly, the embodied GHG emissions for food vary with source and supply chain, and for some countries it is possible to source products locally that have to be imported in others. For our geographic region, the embodied figures we used [4] may be slightly below average, as Booths supermarket is a regional retailer that makes a documented effort to source local and UK produce, and avoid air freight and hothouse-grown products where feasible.

We acknowledge our methodology uses one of numerous potential lenses through which we could explore domestic meal preparation and as a result our GHG emissions analysis is bounded by its field-of-view. This does not include shopping or meals and snacks that are not prepared using the cooker. What this study provides is a micro-account of the practices that take place around the cooker, as an interesting and important nexus of technology, social and food interactions.

Some of our findings rely upon the embodied GHG we attributed to the foods we observed, so it is important to underscore why we feel our attributions are credible. If there is inaccuracy due to poor weight estimation, or improper GHG attribution for a specific food, this will not significantly impact our major GHG-related findings, derived from hundreds of cooking sessions. Moreover, as Berners-Lee observes, as long as the error is not deeply systematic, estimates that are limited in their accuracy can allow us to start making meaningful comparisons between *relative* GHG intensities [3, p. 5].

[3]Our carbon estimates were from the 2010 Booths report, which was the latest available during our analysis and writeup. This is no longer available online, so we cite instead the updated 2012 edition.

[4]Due to well-known inaccuracies of input-output LCA (IOLCA) for farming, SWC uses unit process LCA up to the farm gate and adds direct emissions due to transport (based on air/road freight routes to distribution centres and stores); and then an IOLCA estimate to account for everything else (e.g. supply chain of fuels, embodied GHG of vehicles, and office supplies used by Booths).

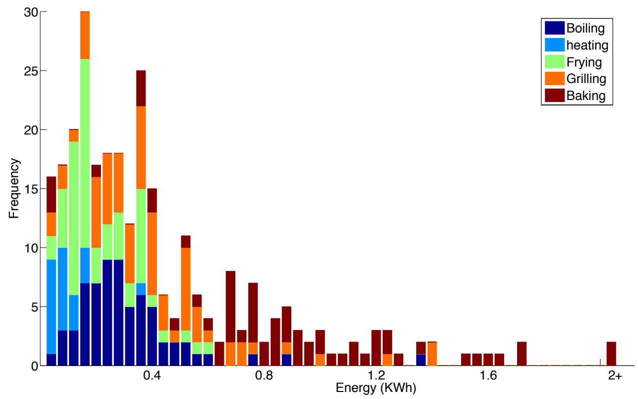

Figure 2. Energy and cooking method (286 single dish meals).

FINDINGS

During the 21 days we recorded 11,577 hobcam images, which represent 523 meals over 458 cooking sessions. Cooking these meals resulted in 324.8 kWh of electricity consumption (194.5 kg CO_2e). Table 1 contains summary statistics for the four residences. The energy used by the cooker is strikingly similar for three of the residences, but the embodied emissions are more variable. In particular, Green have significantly higher embodied emissions as they cook the most meat, including over double the amount of beef. In the rest of this section, however, we treat the sample as a whole and explore the main findings that emerged from our quantitative and qualitative analyses.

Direct and embodied emissions

Direct emissions strongly influenced by method and technique

The direct energy of a dish is a function of the cooking time and method used, which relates to the type of ingredients being cooked. It is evident from Figure 2 that dishes prepared using the oven and grill are more energy intensive than those using the hobs. In general, more elaborate dishes, in terms of the number of cooker elements used for preparation, are also more energy intensive.

We observed differences in the amount of energy required to cook the same meal, illustrating the effect of variations in technique. In the 13 instances where a single serving of pasta was cooked on its own, 0.2–0.4 kWh was normally required, but in 3 cases up to 0.75 kWh was used. In all but the highest, the water for the pasta was pre-boiled using the kettle. In the highest case, one of the participants in Red cooked spaghetti for 20 minutes, added more, topped up the water from the kettle, and cooked for a further 20 minutes. The dish was attended to regularly by its cook.

The choice of cooking method used to prepare foods can also have a large influence on the direct energy required. This is particularly evident for sausages in our data: there is over 0.5 kg CO_2e variation in the direct energy used to prepare similar quantities of sausages. On average, fried sausages take 1.2 kWh/kg (12 sessions), whereas grilled sausages take 6.7 kWh/kg (7 sessions), the latter more energy intensive by a factor of 5.6.

Perhaps related in part to a lack of 'pot watching', we found large variability in the length of pre– and post-heating, especially for the oven. 3 of the 11 cooking sessions that consumed over 2 kWh in Figure 2 consisted of pre-heat times *from* 30 *to* 50 minutes, and in some rarer cases, post-heat times of up to 15 minutes.

Continually reproduced foods and embodied emissions

We observed sharp differences in the GHG impact across the various foods consumed in our study, indicating that the make-up of individual diets (i.e. type and quantity of foods consumed) has a large part to play in the overall GHG footprint. Figure 3 illustrates the distribution of embodied emissions across the foods consumed by our participants. Pasta and bread, although frequent, are low impact by themselves. When combined with jarred sauces or cheese however, that impact soars. Chicken is consumed very frequently and so accounts for a large proportion of the meat-based emissions. Beef (steak, mince beef and burgers) occurs in few meals (just 4%) but accounts for 16% of the embodied emissions.

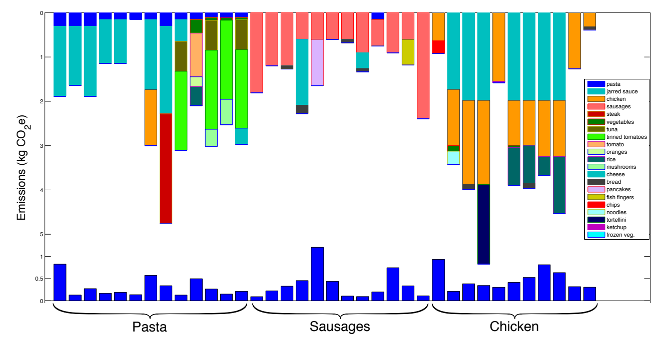

Figure 4. Direct (bottom) and indirect energy (top) for 36 common dishes with identifiable ingredients taken from 406 sessions where a single meal was being prepared in isolation (grouped by type). Embodied emissions are further broken down by ingredient.

The relative impact of various foods is even more evident in Figure 4 which focuses on the impact of a selection of complete meals. Chips (and potatoes more generally) are one of the exceptions: a low-impact food that incurs more carbon to cook than that embodied in the food. Preparation of potatoes involved high-intensity cooker components for lengthy periods.

Although we could not identify participants from the photos, it was clear from the make-up of meals and technique used to prepare them that **many dishes were frequently repeated by individuals throughout the study**. Drilling down to the ingredients that we annotated (Figure 3), what emerges overall is a repetitious diet consisting of both low and high-impact ingredients, commonly used for meals that our participants describe as 'convenient'. Large quantities of pasta, chicken, often with jars of preprepared sauces, rice, bacon, sausages, grilled cheese, usually on toasted bread, chips ("fries") and pizza, account for 54% of the total food quantity (by weight) and 56% (by frequency). Similarly, *over half* of the total embodied emissions of the foods consumed by our participants comes from this quite narrow range.

Statistic	Red	Yellow	Blue	Green
Cooker energy / direct emissions (kWh / kg CO_2e)	75.3 / 45.1	74.3 / 44.5	99.2 / 59.4	76.0 / 45.5
Other cooking appliances' energy (kWh)	6.0	14.8	19.7	17.3
Fridges and freezers' energy (kWh)	55.6	43.1	39.4	53.3
Total time using the cooker	43h 35m	53h 51m	56h 19m[‡]	46h 46m
No. meals / Non-overlapping meals	123 / 109	146 / 114	122 / 100	132 / 84
Mean time / energy (kWh) per meal	14m 17s / 0.41	16m 0s / 0.37	20m 44s / 0.61	13m 26s / 0.36
Estimated mean meal weight (kg)[†]	0.32	0.24	0.35	0.30
Food embodied emissions (kg CO_2e)	164.9	136.1	157.5	246.1
Direct / Indirect (kg CO_2e) per meal	0.25 / 0.90	0.22 / 0.67	0.36 / 0.97	0.22 / 1.18

Table 1. Energy, meals and emissions, by domicile. One of the fridges in Blue appears to have under-reported. [†]Estimated from the 406 meals prepared on their own. [‡]The figure for Blue includes 5.3 hours (8.9 kWh) when the oven was left on overnight.

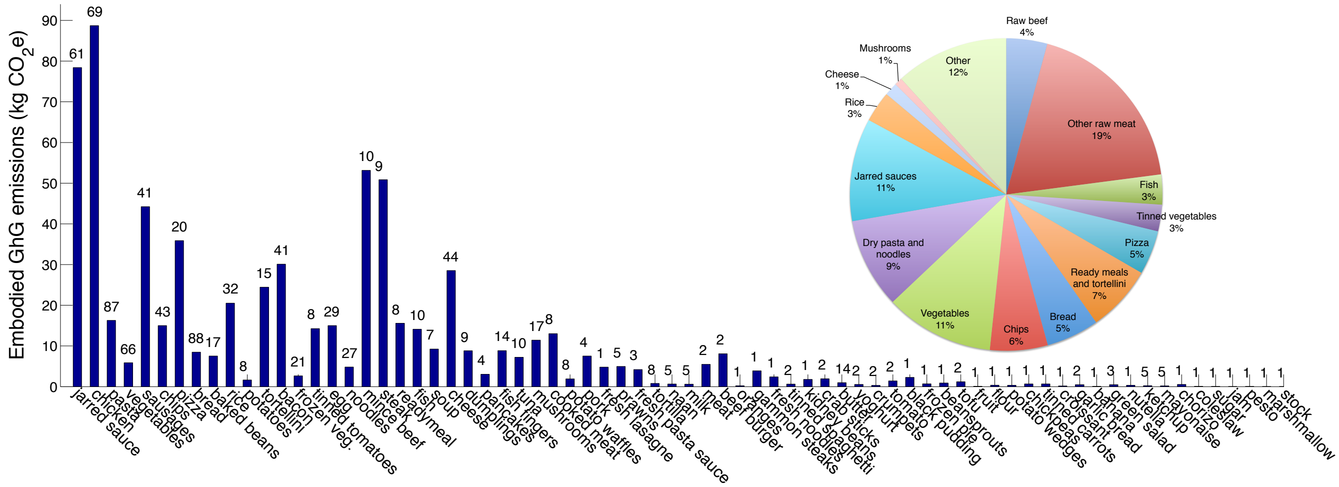

Figure 3. The food types observed ordered left-to-right by total weight. The Y-axis represents indirect emissions. The figures on top of the bars are the total number of dishes that these ingredients appeared in. The pie chart shows the percentage weight by food type.

Embodied emissions nearly four times direct

Overall, the significance of the embodied emissions *relative to* direct emissions should not be underestimated: the embodied emissions of the meals prepared by our participants i.e. getting the food to the shop-counter (701 kg CO_2e) *exceeded* those from the energy used to cook it (308.2 kWh resulting in 184.6 kg CO_2e) by a factor of 3.8.

Practical, everyday food

Our participants consistently characterised the types of meals they ate as 'simple' or 'student' food. By this, they meant that dishes require little time and effort to prepare, and that they fit well with their existing capabilities and know-how. Donna's meals consist of "*simple stuff like cauliflower cheese and pasta bakes, all those kind of really easy things*". Aaron talks about "*typical student food . . . like Super Noodles, pasta, and like pies*". Even Ian, who indicates that he dedicates more time to food preparation than most, describes his meals as "*all simple things, it's sort of sauces like curries, uh you know, that sort of food.*" An appreciation for quick and easy meals can also be seen in the quantitative data: half of all dishes took under 15 minutes of cooker time; 68.8% of the dishes were prepared on a single cooker component; and only 7% used more than two.

Flexibility and defaulting to "whatever is in the cupboard"

It was common for our participants to talk of the food available in a somewhat detached way, as if the food they have in the flat is not something they have strict control over. Miranda explains that when she cooks with friends, they "work through" the student's cooking guide and make "*um, risottos, stuff, pasta and sauce whatever, um shepherd's pie . . . whatever, whatever ingredients we have*". Leah explains that she simply eats "*whatever I've got in, whatever is in the cupboard*".

Fresh ingredients were seen as problematic and there was a general reluctance to purchase short-life foods because they were likely to be wasted. Wendy explains: "*I like vegetables and salads and stuff like that but when I buy it it just all goes off. . .*" Callum is an exception insofar as he purchases fresh ingredients regardless: he "*tend[s] to eat a lot of stuff out of the fridge [because] when I go to the supermarket I might buy too much like fresh stuff and then I feel I have to eat it before it goes out of date*".

So, what we see for our participants are somewhat pragmatically chosen meals, influenced in general by a low-level of concern with forward planning (outside of fixed timetables).

Cooking takes a back seat
Food was regularly seen, to varying degrees depending on the participants' situation and level of interest, as a functional and expedient chore. Three of our participants do not like to cook: Wendy laughs at the idea and Miranda states "*I don't like to cook for myself because it's just a lot of effort*." Three more participants do not mind cooking but do not particularly enjoy it.

Food consumption was often influenced by other aspects of participants' lives. Aaron, who says he enjoys cooking and sometimes builds it as a feature into his daily activities, admits "*cos I've been really busy I've been eating less cos like I've just not had the time to*." Donna recalls how after forgetting to eat lunch "*we didn't eat until really late, like half tenish, was supper-slash-lunch because we hadn't really had a proper lunch*." In Miranda's case, study can entirely supplant eating 'properly', "*I'm sat in the library all day with my biscuits I tend to just flurf on them and then I won't eat, proper, meals, I suppose*". Thus food itself could, at times, hold very low priority in the lives of our participants.

Dynamic timetables result in a 24-hour kitchen
The distribution of cooking times against time of day is shown in Figure 5. There is a semblance of pronounced mealtimes, but meals can occur at any hour of the day. This is partly by necessity, as students work around externally set timetables and deadlines, paid work and often hectic social lives.

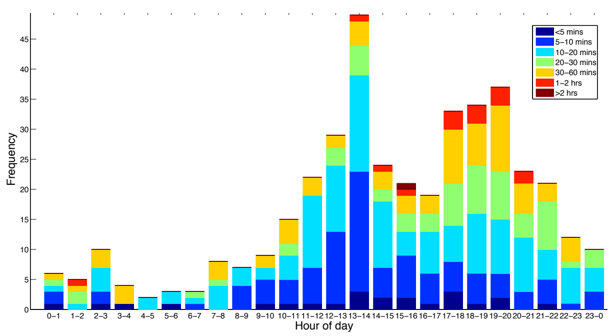

Figure 5. Distribution of the time-of-day of preparation, taken from the 406 cases where only single meals were being prepared, binned by hour of the day. A session is placed in a bin if its start time falls within that bin. Bars are coloured according to the length of the cooking session. Note that the evening meals are under-represented overall as a higher percentage of these involved multiple meals in a single session.

There is some correlation of the foods consumed to meal times, but again this is weak. Fast meals (<5 mins), especially common at lunchtime, are baked beans, egg, soup, tinned spaghetti, although we do see the same meals recurring in the evenings. Reheated 'leftovers' with rice and naan bread also appear for lunch. Longer (10 minute) meals don't seem to vary with time of day, and commonly involve pasta, bread, bacon and sausages. In fact, pasta appears throughout the 24 hour day.

Planning is within the realm of possibility
Our participants sometimes cooked dishes that contained more than one portion, to save some to eat later. Polly is an active sportsperson and cooks large amounts of "*really quick carbs . . . that's gonna fill me up for training*" early in the morning for use later that day. Ian reports on his diet saying, "*I'll go to cash and carry and I've got a lot of - I'll buy a lot of meat in bulk and break it down. So, it'll be sausages and bacon. . . . Meat and sauce or pasta, yeah typically*." While for the most part flexibility prevails over forward planning and regularity of meals, for these two participants, at least, meal-related planning is possible.

'Proper' meals and cooking as recreation
Over half of our participants spoke about preparing meals that were more "proper" than usual. These involved extra time, effort or skill to prepare and sometimes required forward planning. For two participants, these were distinguishable as meals that required cooking. Donna will "*usually do a better kind of lunch like cooking something. [Otherwise] I'll have that for supper and I might just get a sandwich or something... for lunch*". Sometimes there were weekly routine meals: on Sundays, Wendy will "*have probably a proper dinner so . . . if I make spaghetti bolognese or something*." Otherwise she has "*pasta and sauce [. . .] pretty much every night*". They could also be more occasional: for Ian, fajitas and homemade pizza are regarded as "*something easy*," but sometimes he'll share a "*proper*" meal with his girlfriend, "*something nice*".

When asked if they liked to cook, five participants claimed they did and even relished branching out from the mundane. Donna mentions "*[cooking] a couple of times for people just because I really really like to*." Whereas, Aaron seemed to enjoy experimenting with food, and sharing it with others: "*Sometimes I offered to cook pasta for people and stuff cos like I'd done something a bit diff-, weird, weird with it, so I was 'ooo try this, it's nice'*". Cooking for some is even something to look forward to. Aaron, on how cake baking is a motivational warm-up task, and reward for studying, recounts "*'I'm going to the library' and I'll be in there for quite a while and when I get back it'll be like 'yay cake!'*".

Bulk cooking and social meals
We see signs in our data that cooking together (i.e. in bulk) can be less impactful than cooking a single meal for oneself. From the 286 meals involving only a single cooker component (shown in Figure 6), we see the energy required per kg of food *decreases* as the quantity of food *increases*. This suggests that sharing meals and cooking extra portions for consumption later could help reduce the direct emissions of meal preparation, if it replaces other individual meals and does not lead to increased waste. We found that participants mostly cooked a single dish at a time, generally a single serving for themselves—and in only 11% of the observed sessions were people cooking together at the same time. We did see sessions where multiple people cooked the same dish, or where one person cooked as others observed, but this was rare.

Social meals are enjoyable, often spontaneous, rarely planned
When we asked our participants if they cooked with others, we got a wide range of responses, even from the same participant. Jess may be pressed into making food for flatmates: "*like if I'm making a fish-finger sandwich or something people will ask like, 'Can you make me one too?' So I'll make*

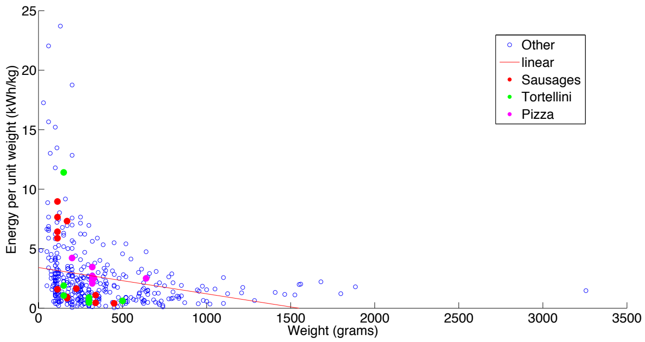

Figure 6. A comparison of the amount of energy per unit weight required to cook different amounts of food. Foods featured are colour-coded where we were able to measure it alone in a cooking session, e.g. sausages (red), tortellini (green) and pizza (magenta).

a couple..." Henry sometimes offers meals to his flatmates if they are nearby: "*occasionally if I'm cooking like a curry I might say 'Jeff do you want a curry?' and he'll be like 'ok'*." Leah notes that some of her flatmates "*cook for each other [because] they like the same things*."

Sometimes individual food preparation did overlap, leading to spontaneous social meals. "*I'll cook at the same time [...] by coincidence and we'll have a chat...*" (Polly). In Yellow, the evening meal tended to be more regular: "*Yeah most of us always eat dinner around 5, 6 and we'll eat in the kitchen. Even if we don't plan it we'll find that we're all in the kitchen at the same time eating*" (Wendy). Henry recounts a similar situation in Green. Flatmates in Red take it further; they sometimes spontaneously decide to cook and eat the same food together. Aaron recounts, "*but we don't like plan it, it just happens, so like, we don't tie each other down*".

The social aspect of cooking and dining together was often linked to enjoyment. Miranda would rather expend effort cooking for others than cook just for herself: "*I don't like to cook for myself because it's just a lot of effort. So I'll quite often cook for people, maybe once or twice a week...*" Henry sometimes cooks elaborate meals because "*it means I get to spend more time in the kitchen [...] and there's people around and it's quite good*". Donna recalls how she and her flatmates used to share meals as a form of entertainment: "*We had a sort of Come Dine with Me type thing. [...] one person would cook for whoever was available to come. And there'd usually be like 10 or 11 or 12 of us [...] So we'd take it in turns. [...], that was really good.*"

But, any advanced planning to share (days, or even hours before mealtime) became prohibitively difficult, because of food preferences, and more often because of tight schedules, or a reticence to commit. "*We did go through a period of every Wednesday, three or four of us cooking together but that stopped. Cos it was all [...] like one person would go out or one person would not want what we wanted so we didn't bother any more*" (Wendy). Donna mentions that she and Polly intend to have a shared meal, "*like we keep saying we're going to cook together but something always gets in the way*," and Leah maintained that she often ate by herself because her meals are "*at quite strange times*".

IMPLICATIONS FOR DESIGN

When proposing cooking practices as a design space for sustainability, the question of goals arises. Previous research which could help define them has tended to be piecemeal. In particular, analyses of the various stages of production and distribution of foods have highlighted the unsustainable impacts of meat and diary produce [5, 8], which might be considered as a "food choice" at the supermarket, whilst other research has focused on cooking as a contributor to the significant proportion of energy consumed in the home [39]. These are potentially competing definitions of sustainability. By studying both, as they come together during the process of cooking, we can explore and emphasise interconnections and relative priorities. As such, our findings echo, but also bring together previous findings, to elaborate the nature of GHG impacts in meal preparation and how they are sustained in everyday routines.

Like Marquis [23], we find that convenience is important to these students when it comes to cooking, but here we show that in practice this really does equate to short (most cooking sessions take less than 20 minutes) and simple cooking (most meals are prepared using a single cooker element). Importantly for questions of sustainability, this is commonly achieved through combining pre-prepared sauces with meat or pasta. It is already widely acknowledged that meat is a GHG-intensive food (e.g. [5]) but in practice we observe that it is frequently combined with another GHG-intensive food, jarred sauce. This "marriage of convenience" accounts for much of the indirect GHG emissions in the study. Otherwise, combinations with bread are popular. Again, these are often relatively high-impact but easy and quick meals such as cheese on toast or a sausage sandwich. On the one hand, the prevalence of these quick, simple meals may help to reduce cooking energy, compared to alternatives which require longer cooking or multiple elements. But on the other hand, the frequency of cooking around lunchtime, and evidence from the interviews, suggests that participants feel able to cook something both at lunch and in the evening. Moreover, as we have seen with pasta, even simple meals can be cooked with such a variability in cooking energy that a difference between cooks, if consistent over the course of a year (or a life), could begin to look significant.

Taken as a whole, our findings show that the embodied GHG impacts of meals are generally much greater than those generated by cooking them. This concurs with national estimates for the UK, but the precise contribution of cooking energy within the overall food footprint is higher in the current study (21.6% compared to 17% which includes all food-related home energy (calculated from Garnett [16])). So by looking at the actual foods that are cooked by a given group, we get slightly different (and presumably more accurate) figures. In this particular context, at least, this encourages us not to neglect cooking energy when addressing sustainability through meal preparation. However, as our findings make clear, it would also be a mistake to limit the scope of sustainable cooking to cooking energy alone. So when designing digital interactive technologies, we can consider a range of approaches to support change and reduce impacts. Drawing on our own ideas, and those of others, we use our findings to indicate the scope and proportion of impacts that could be addressed by each broad approach in this context.

Modify the appliance

Long pre– and post-heating accounted for nearly 2% of cooking energy, and could be avoided with more insistent reminders when ovens or grills are brought up to temperature, and automatic shutoff if left on for hours. Such features are already common in higher-end appliances. One might also make the direct resource impacts of everyday cooking more visible by incorporating an eco-feedback display [15, 35, 39]. A simple example is a "smart cooker" that provides running totals: the current cooking session's elapsed time, direct energy, its carbon equivalent, and per-element contribution. This would have the goal of helping the eco-conscious cook identify lower-impact elements (grill vs hob), and ways of cooking (flash-fry or sauté); and expose unnecessarily long cooking sessions. Feedback displays might affect all direct energy–consuming cooking activity (21.6% of the total GHG).

It might be possible to save 10-20% of this [39] (i.e. about 2-4% reduction of total cooking-related GHG in our study), but there is open debate about whether people routinely act as rational resource managers [35]; certainly, we observed that other aspects of everyday life took priority, and there was no evidence of concern about efficient cooking. A more effective solution (easily applied in institutional settings like ours) might be to simply replace high-energy cooking appliances (ovens and grills) with smaller, more efficient alternatives (toaster ovens or combi-ovens).

Support communal organisation

Our participants cooked just for themselves nearly 90% of the time, which accounted for 65% of the cooking energy (14% of total GHG). And yet, all of them enjoyed cooking and eating with others, and many did so when it could be negotiated around other aspects of everyday life. The sociality of cooking is clearly valued [26, 29] and an important aspect of sustainability. To explicitly support group coordination (and encourage more efficient bulk cooking), we might design mobile apps or social networking add-ons which raise awareness of other people's meal times, and allow individuals to "join" immediately proximate or ongoing events (supporting the spontaneity and flexibility our participants seemed to value). Individuals who live alone or regularly cook alone might be invited to participate in recurring "meal-sharing" schemes with those living nearby. We might then also think about how the attractiveness of more social meals, especially with less known companions, can be promoted and designed for—what Hupfeld and Rodden refer to as 'design for conviviality' [19].

Cooking as a group requires having enough food to prepare. And even when cooking for just themselves, participants often struggled with whatever happened to be in the cupboard, or in the shops on campus. Mobile apps for meal sharing and group cooking might include collective inventory management, resulting in better identification of opportunities for spontaneous, shared meals (e.g. "I have the vegetables, you bring the pasta"). Finally, existing communal housing matchmaking services might weight preferences for food and mealtimes—the flatmates we observed varied in these, and as a result, often did not share meals.

Change the food habitually eaten

Since the embodied emissions of food (about 80% of our study's total) far outweigh the emissions arising from direct energy, we suggest that for many scenarios HCI might prioritise approaches that help change the foods that are cooked. User technologies that harness and present information may help, but this means going beyond existing web tools for computing carbon externality based on manual entry. More automated solutions may see better take-up and engagement. For example, OCR might be used to analyse photos of supermarket receipts, or image processing might be applied to photos to identify foods and their volumes [22].

Rather than apply such eco-feedback at the level of individual items or shopping trips (there is evidence that this does not work so well [20]), we would rather advocate longer-term (monthly or seasonal) breakdowns, to help people recognise the most impactful foods and meals which feature as a regular part of their diet. Jarred sauce, sausages, bacon, chicken and cheese accounted for about 40% of the embodied emissions (or 32% of the total GHG) in our study. Foods containing beef, while only 4% by volume were 16% by externality. Favourite meals which happen to be high-impact, might not be eliminated altogether, but rather enshrined as celebratory [17] "proper meals" for enjoyment on special occasions or as a treat. Some of our participants engaged with online recipe resources, and as a result tried new things. An interactive cooking guide might take into account the results of an impact report, and suggest lower-impact ingredients and meals. Popular alternatives and recipes might be then incorporated into the sharing tools mentioned above, or shared in a collective sustainable recipe book [29].

DISCUSSION

Food procurement, preparation and consumption, like other fundamental components of everyday life, are products of systems of provision (technologies and infrastructures), competencies, meanings, expectations, and the social arrangement of our time [32, 34]. But in knitting together many of these components, cooking practices will likely prove to be an important focus of change towards more sustainable food.

We certainly recognise that designing interventions in this context is not easy. Changes at one point in the system shape the possibilities for change elsewhere. For example, smaller and more efficient ovens might restrict opportunities for bulk cooking; more sustainable recipes might require longer and more complex uses of the cooker. The effectiveness of any single intervention depends on a number of conditions that might not always be met (interested, motivated, flexible cooks, for example). And we should be especially cautious given the nature of the change our findings imply: a move away from foods which are evidently popular, convenient, normal and culturally significant (pre-prepared sauces,

Approach	Intervention	Rationale from findings	Indication of impacts targetted, from findings (ratio of total)
Modify the appliance	Audible reminders, auto shut-off	There was long pre- and post-heating of cooking elements.	<2% cooking energy (0.4%)
	Sensor-enhanced auto-cook function	Even amongst comparable dishes, there was a high variance in cooking durations and energy.	11% of cooking energy (2.4%)
	Replace/remove the most energy-intensive cooking technologies; for example swap the large ovens and grills with small toaster ovens.	Certain elements are particularly intensive, requiring a lot more energy to cook a similar amount of food.	Cooking energy due to ovens and grills was 16.9% (3.7%)
	In-cooker energy feedback display (elapsed time, running totals, per-element, historical)	The cooking length and method used to prepare foods influences the energy required, yet there was no evidence of participant awareness of energy required for cooking.	Potentially all cooking energy (21.6%)
Support communal purchasing and cooking	Social networking portals and apps to raise awareness of other people's shopping times and mealtimes, supporting coordination of shared meals in advance and in-the-moment joins	89% of cooking sessions contained a single cook, usually preparing one portion. When participants cooked in bulk for themselves or a group, it took less energy per unit weight. Participants enjoyed the social aspects of eating together and occasionally planned social 'proper' meals. But, ability to cook in bulk and share were strongly affected by limits on what was in the cupboard; by academic and employment timetables; and by a desire to be flexible or spontaneous.	All single-cook cooking energy. (14.1%)
	Digital assistants to support food shopping and cooking for a group. Putting together a collective "what's in our cupboards" for a group.		
	Enable housing allocations based on preferences for types of food and meal times.	Despite the good potential for sustainable sharing of meals in these flats of eight, participants who lived together would most often eat different things, at different times.	
Change the food habitually eaten	Detect and log what food is purchased or prepared. Generate periodic reports on greenhouse impacts. Provide tailored advice on alternatives.	No evidence of participant awareness of food's embodied greenhouse gas impacts; diet has large influence on overall GhG externality; embodied emissions greater than direct by factor of 3.8. Certain habitual foods (jarred sauce, chicken, sausages, bacon, and cheese) had a disproportionately high embodied emissions (40%). Certain less frequent foods (steak and mince beef) had extremely high embodied emissions (14.8%).	Embodied emissions of high-impact foods was 54.8% (43%)
	Sustainable recipe books, online resources, and recipe generation	Diet has large influence on overall GhG externality; repetition of narrow range of meals; more engagement with food during 'proper' meals. Discovery and awareness of alternatives (through friends or online resources) can promote changes in diet and method of food preparation. Some people showed a willingness to experiment with new recipes and foods.	Potentially all embodied emissions (78.4%)

Table 2. Summary of interventions. We describe (rightmost column) the portion of direct energy or embodied emissions which might be affected, as seen in the findings from our study. Note that we provide this as an indication of the scope of an intervention; the reduction that an intervention achieves will be less, and depends on its design, and the cooking practices in a given domain.

meats, and cheese). But it is important to remember that these observed cooking practices have not always been like this. They are dynamic. We must think about how technologies have a role in reshaping broader systems, and where purely technological solutions are not merited [2].

CONCLUSION

We have evaluated the potential of design interventions to improve the sustainability of cooking. These include interactions with cooking appliances, digital meal sharing apps and group inventory management, and interactive technologies such as eco-feedback that might promote awareness of and change towards alternative meals. Our study traces the largest GHG impacts to the presence and importance of wider social systems within which cooking takes place: systems of provision, the organisation of everyday life and the meaning of meals. HCI and the interactive systems it could design to support more sustainable cooking can and should be conceived within this broader context if they are to interact meaningfully with always-evolving cooking practices.

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