School of Physics
and Astronomy

Group Project

Sustainability in the Kitchen

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Abstract

The aims of this project were to research the most effective ways for the UK population to adapt everyday kitchen habits to reduce energy consumption. In particular, the preparation of tea, various cooking methods, and washing up were considered. Estimates of energy savings were presented, alongside suggestions for the best methods to implement these in the kitchen. The findings were presented in a 3-tiered system in order to provide a clear recommendation for simple, memorable habit changes that readers might be able to easily implement in their own kitchens. It was estimated that implementing even the lowest recommendations from this report would lead to an 18% decrease in UK domestic energy consumption. The work is presented in an accessible format using physics of no higher than secondary school standard.

Contents

1 Introduction

The UK Government is required by law to make the UK net-zero on emissions of greenhouse gasses by the year 2050 [1]. While this effort will require vast structural change, it will also require a great change in our consumer behaviours as citizens. Though individual action can seem overwhelming and the effects far beyond us [2], when scaled to the size of a population it can make a major difference.

This paper aims to explore one element of individual action that is common to most of us across the UK, our energy use behaviours in our kitchens. It is estimated that UK domestic energy use makes up 29% of the UK's overall energy consumption [3]. Within this it is thought that the kitchen accounts for 30% [4]. The current UK energy production breakdown is approximately 43% oil, 30% natural gas, 16% "primary electricity" (including nuclear and renewables), 10% bioenergy and waste, and 1% coal [3]. Using the respective greenhouse gas emissions per unit energy produced for this breakdown, and more importantly the breakdown of energy consumption, it is possible to calculate an estimate for the CO_2 emissions from kitchen energy use in the UK of 8.1 megatonnes per annum (detailed calculation in appendix). This number in the context of the UK Government's pledge to reach net-zero emissions by 2050 [1] shows the importance and impact of improving our behaviours in the kitchen.
There is plenty of evidence [5, 6] that targeting behaviours in the home can lead to reduced energy consumption and the overall impact this can have. This paper attempts to provide the answers to what those behavioural changes should be in the specific context of the kitchen.

1.1 Justification

Since the Industrial Revolution, the use of fossil fuels has skyrocketed. This revolution brought with it new technologies that have allowed average human lifespans to increase year-on-year. Perhaps if the population had remained at the pre-industrial figure of around one billion people, the burning of fossil fuels for warmth, electricity and transport alone might not have set us on course for 2°C global warming. According to climate experts this temperature rise would greatly increase the frequency and extremity of events such as droughts, floods and heatwaves, as well as the melting of ice caps and resultant sea level rise [7]. But hypothetical thinking is of no use here. The situation now is very different, and no practical solution lies in the past. The Earth is home to seven billion people, and an addiction to diminishing reserves of natural resources. Most of the nations on Earth rely on fossil fuels to power lightbulbs, aeroplanes and everything in between [8]. Fossil fuels for electricity generation can be roughly broken down into three categories: coal, oil and natural gas. The UK, often referred to as the birthplace of the Industrial Revolution, built much of its wealth on coal [9]. As far back as 1865, certain economists pointed out that judging by the increasing rate of consumption, British coal reserves could only power the nation for around 100 years [10]. This was not a bad estimate, as the UK went from being both self-sufficient and the largest exporter of coal in the early 20^{th} century to a net importer of coal by 2001 [11]. Judging by current growth of coal production and combustion, it is estimated that global reserves could be completely depleted by 2050. While the discovery and exploration of the country's oil and gas reserves is a much more modern affair (with peak production around the turn of the millennium), the decline of production shows no sign of bucking the trend set by coal [12].

Although generation of energy from fossil fuels has been falling for the last 20 years, the demand for energy has continued to grow, with final consumption (consumption at the point of use) growing by 1.1% from 2017-2018 [13]. To keep up with this demand, governments past and present have traded raw materials with other countries. But even if we can outsource production to try and solve the problems predicted by 19^{th} and 20^{th} century economists, the burning of fossil fuels remains unsustainable. Coal, oil and natural gas are hydrocarbons, i.e. composed primarily of hydrogen and carbon. Hydrocarbons combine with oxygen during one of two combustion processes: complete or incomplete. Complete combustion occurs where oxygen is plentiful, and produces energy, water and carbon dioxide (CO_2). Incomplete combustion, where oxygen is in short supply, produces energy, water, carbon and carbon monoxide (CO). Incomplete combustion produces less energy than complete combustion, and the products are harmful to both human health and the environment - carbon in this form is commonly called soot, and contributes to the blackening of buildings in industrial cities, respiratory problems and atmospheric warming by absorption of solar radiation. While the negative effects on human health of CO_2 are not negligible [14], it is a strong greenhouse gas, and one of the main drivers of global warming. The Earth's surface reflects around 30% of the solar radiation incident upon it, particularly longwave (infrared) radiation. Carbon dioxide and other greenhouse gases in the atmosphere absorb radiation at certain infrared wavelengths, keeping it from escaping into space. As longwave radiation provides much of the Earth's heat, its entrapment can lead to global warming if greenhouse gas concentrations are relatively high. From pre-industrial levels of around 280 parts per million (ppm), CO_2 concentrations have risen to over 400 ppm [15], and are predicted to more than triple to 1500 ppm if current rates of fossil fuel consumption continue [16].

While there are ways to capture some or all of the carbon released into the atmosphere, putting these technologies in place can reduce the efficiency of burning coal from an already pitiful 37.5% [17] by around 10% [18], which means more coal is required to produce the same amount of usable energy. Without wanting to patronise the reader, we reiterate that coal is a finite resource, meaning that carbon capture is not a solution to all our energy-generation problems. The fact remains that the burning of fossil fuels is unsustainable for two main reasons. The planet's reserves are not inexhaustible, and will not be replenished any time soon - the name *fossil* fuels gives an indication of the timescales on which they are created by the natural processing of plant and animal material. Realistically, we cannot outsource our supply to another planet. The second reason is that if 'business as usual' continues, we will see warming on such a scale that our own planet might not be able to provide all we need to survive [7]. So we turn our focus to renewable sources of energy, including wind, solar and hydroelectric power. In 2018, renewable sources accounted for 33% of electricity produced *in* the UK, yet only 11% of the electricity consumed *by* the UK, which gives us an idea of the disparity between supply and demand. In chapter 18 of "Sustainable Energy - Without the Hot Air", author

David MacKay discusses physical, social and political limitations to renewable energy production in the UK. MacKay suggests that even taking a combination of measures such as covering Wales with wind turbines would not balance the equation in the favour of supply [10].

Faced with a daunting situation, what can we do? As we know, in 2019, the UK Government committed to a legally binding target of net-zero carbon emissions by 2050, following advice from the Committee on Climate Change. However, at the time of writing, the UK Government is being sued for approving plans to build Europe's largest gas-fired power station, despite its own Planning Inspectorate advising that doing so would "undermine" this commitment [19, 20]. Amid this confusion, the question emerges in a more precise form - what can we, the majority of the population who are not policy-makers, do to reduce carbon emissions? There are a growing number of energy companies who supply customers with 100% renewable energy. However, we know that even our best attempts at powering the nation on renewables might not be enough. If this is true, one practical solution seems to come to the fore; we can reduce consumption of resources by reducing our demand for energy.

1.2 Approach

In this paper we apply the principles espoused and practised in "Sustainable Energy - Without the Hot Air" [10] to everyday behaviours in the kitchen. Taking a first principles approach, we break down various kitchen procedures into their fundamental underlying physical processes. The report is pitched at a similar level to MacKay's book, the physics itself never goes beyond an A-level standard, but it is this simplicity that is key, producing clear cut values that allow comparisons for the most energy-efficient way of doing things.

We will, unless stated otherwise, always assume the best-case scenario (i.e. the upper error bound) in our calculations. This provides consistency and a safety net in our estimations, allowing us to always discuss our recommendations in terms of the minimum benefit they will provide. The paper will compare various methods for common kitchen tasks (such as making a cup of tea) first assuming perfect efficiency across all devices, before then including estimates of inefficiencies and bringing in the other complex factors that have an effect on electricity consumption.

We approach this principally from an energy reduction standpoint. While it is good to use cost reduction as an incentive, energy use reduction and cost reduction do not always align. We prove below that boiling water for a cup of tea is most efficiently done in a kettle, but to save the most money boiling it on a gas hob would be far more effective as gas is considerably cheaper than electricity [21]. We limit our discussion to the kitchen and the major energy consumption behaviours therein. We do not explore the emissions footprint or prescribe advice on the content of the meals themselves, merely the manner of preparation.

Each chapter will approach a different kitchen behaviour and will conclude with a three-tiered behaviour change recommendation. We rank these as follows:

1. Low Hanging Fruit: the smallest changes you can make that have the largest impacts
2. Intermediate: the next steps you can take to continue to reduce energy inefficiency
3. Climate Hero: the most efficient way possible

This provides a clear, prescriptive take-away so that we all might continue to reduce our wasteful energy behaviours.

1.3 Common Units and Definitions

What follows is a brief summary of the physical units and assumptions that will appear throughout the paper and a brief discussion of their context.

- Joule - J
  - Δ The Joule is the fundamental unit of energy
- Watt - W
  - Δ The Watt is the standard measure of power, which is to say the rate of use of energy. It can be more fundamentally broken down into energy per unit time where energy is measured in Joules (J) and time in seconds (s). 1W is actually a very small amount of energy, so we will typically use kilowatts (kW) which are equivalent to 1000 W. For context your kettle, as you will see below, will have a power rating somewhere around 2 kW
- Kilowatt Hour - kWh
  - Δ The kilowatt hour is a common unit for energy as it is of an order of magnitude relevant to our everyday consumption of energy. It is the energy used by running a 1 kW appliance for 1 hour. It is simple to calculate as you only need multiply your power rating in kW by the length of time it is running in hours, so your 2 kW kettle if left on for an hour would consume 2 kWh of energy
- Specific Heat Capacity - c
  - Δ The specific heat capacity of a substance is a measure of how much energy is required to give a temperature change of 1°C in 1 kilogram of a material. Water has a specific heat capacity of 4180 Joules per degree per kilogram which is a relatively high value

All temperatures will be stated in degrees Celsius.

The paper also discusses energy on a wide range of orders of magnitude from the small amount of energy used to boil 1 cup of tea to the vast amount of energy this translates to when extrapolated to the entire UK across the course of a year. It is therefore helpful to have a good idea of the prefixes used to describe orders of magnitude. Each prefix covers an increase of 1000× larger than the previous prefix.

Prefix	**Symbol**	**Order of Magnitude**
mili	m	$\times 10^{-3}$
kilo	k	$\times 10^{3}$
mega	M	$\times 10^{6}$
giga	G	$\times 10^{9}$
tera	T	$\times 10^{12}$
peta	P	$\times 10^{15}$

2 Tea

Given that the UK population drinks around 100 million cups of tea a day [22], the humble cuppa seemed like a good place to start. We began our investigation into the country's tea-drinking habits, and the energy wastage associated with them, by making a couple of assumptions: first of all, that the vast majority of us use a kettle to boil our water, and secondly, that a similar majority boil more water than we need. It was decided that we would aim to find a figure for the amount of energy – as a percentage, both of the UK's total consumption, and of the average household energy bill – that is wasted by this overestimation. Bear in mind that many cups of tea are prepared using urns/water boilers in cafes, offices and the like, but this was not factored into our estimations due to a lack of available statistics. We suspect that these hot water reserves are less efficient than kettles as: a) they are kept running for hours and b) heat is constantly being lost through their walls and they have large surface areas. Considering only the kettle is one example of assessing the best-case scenario, which was an approach used throughout this investigation.

This optimistic outlook was used in estimating that the average person boils *two* average cups of water for *one* average cup of tea. While discussing this project with friends and family, we heard a few reasons for over-filling the kettle, ranging from unsettling visions of half-empty cups of tea to full-blown fears of suspicious debris lurking at the bottom of the kettle. To ward off these worries, many people won't think twice before putting a full kettle on to boil. Over the course of a year, this amounts to a massive waste of not only time, but energy too; the question is, how much?

In order to answer this question, we needed to find a few figures. How many cups of tea do we really drink a year? As quoted at the beginning of this chapter, we found an estimate of this online courtesy of the UK Tea & Infusions Association, but not wanting to blindly accept what others told us, we also came up with our own. We used the most up-to-date

UK population estimates by age published by the Office for National Statistics, and decided that those over the age of 15 were to be considered our average tea-drinkers. This gave 53.8 million [23]. Based on our experiences living in this country, we unanimously chose 3 as the average number of cups consumed per day. We also agreed, judging by various online articles and finding the average volume of a kitchen's supply of mugs, that 300 ml was the best choice for the volume of one cup of tea (if not perfectly accurate, this is at least of the correct order of magnitude). While statistics on water quality are published at least annually, temperature does not seem to be included in these reports. We did find one (2010) BBC news article which suggested that the average temperature of cold tap water around London is 7°C [24], so based our estimate on this. This average was rounded up to 10 degrees as often there is a backlog of warmer water in the tap, or water is left sitting in the kettle at room temperature or higher before it is reused, and again, this will give the correct order of magnitude. It is perhaps worth pointing out that we are not considering water usage or wastage in this section, purely electricity and energy.

2.1 The Kettle

When discussing "energy" and "heat", it is important to understand the concept of energy conservation - a fundamental law of physics which states that energy can never be created or destroyed. Energy exists in many forms, and can be converted between them by various processes. For example, the household kettle converts electrical energy into heat via a heating element. The element conducts electricity and is heated by conduction (heat moving through a solid). The hot element then heats the water which is in contact with it, and the rest of the water is heated by convection. The energy used to boil a mass of water can be calculated using its specific heat capacity:

$$energy = mass \times specific\ heat\ capacity \times temperature\ change\ required \tag{1}$$

$$E = mc\Delta T \tag{2}$$

The heat capacity of water is 4180 Joules per degree per kilogram, where the Joule (J) is a standard unit of energy. Our 300 ml translates to 0.3 kg of water, and since the boiling point of water is 100°C, the required temperature change is 90 degrees. This gives the energy required to bring one cup of water to the boil as 112860 J. Assuming that one cup's worth of energy is wasted every time we make a cup of tea, we multiply this number by the number of tea-drinkers, the number of days in a year, and our hypothetical 3 cups a day to estimate that 6.65 petajoules, or 6.65×10^{15} J of energy is wasted on boiling surplus water every year (this is a difficult quantity to grasp, and we'll return to it soon).

These calculations give another best-case estimate. We must account for the fact that no electrical appliance is 100% efficient, so to find a value for the average kettle efficiency we then set about making our own totally unremarkable, distinctly average cups of tea. Each of us boiled 300 millilitres of tap water in the kettles in our shared student flats, assuming they gave a representative sample of the kettles of the nation. We took note of the power rating of each kettle, which ranged from 2200 - 3000 Watts (W). One Watt is equivalent to one Joule per second; in other words, power is the amount of energy transmitted in a unit of time.

$$P = \frac{E}{t} \tag{3}$$

To find the maximum efficiency, where kettles stated a range for the power rating (eg. 2500-3000 W) the lower value was used in calculations, since assuming that the kettle is running on minimum power means that it uses less energy in the same amount of time. Our ideal theoretical energy value is bound to be less than experimental values, so finding minimum energies gives us maximum efficiency.

$$efficiency = \frac{theoretical\ value}{experimental\ value} \tag{4}$$

We measured the time taken to boil our 300 ml water and used this formula, with P being the power rating of the kettle, to calculate the energy used in boiling. Theoretically, as we found before, the energy required should be 112860 J. Dividing our experimental energy values by this number and multiplying by 100 gave 5 kettle efficiencies in the range of 59-96%. Less powerful kettles were noticed to be significantly less efficient, though our sample was not very large.

The average efficiency of the kettles in our sample was 77%. To factor this into our estimation of wastage, we must treat our calculated value of 6.65 petajoules as 77% of the true wastage, with efficiency taken into account. Therefore the total energy wasted each year by people regularly boiling 1 extra cup of water is:

$$\frac{6.65\ [petajoules]}{77} \times 100 = 8.63\ petajoules \tag{5}$$

Since this is hard to imagine physically, we compare it to the UK's annual domestic electricity consumption. The government publishes an annual Digest of UK Energy Statistics (DUKES) which, among many other things, breaks down our energy consumption into use by different sectors. In 2018, the total electricity consumption amounted to 300 terawatt hours (TWh), and domestic use accounted for 30% of this, or 90 TWh [13]. One terawatt hour is equivalent to 2.78×10^{-16} Joules. We multiply our 8.63 PJ by this number to give the same estimated wastage in the desired units as 2.40 TWh.

This means 0.8% of the total annual UK energy consumption, or 2.6% of the annual domestic consumption is *wasted* by overzealous kettle users. That is to say that the average household could save around £13 [25] a year simply by boiling just enough water to sustain their tea-drinking habits.

£13 could buy a year's supply of teabags from all major UK supermarkets!

It was noted that the efficiency increased with the volume of water being heated. This increase in efficiency doesn't outweigh the energy wastage from over-boiling, but it suggests that there is some merit to boiling more water if you are going to use it.

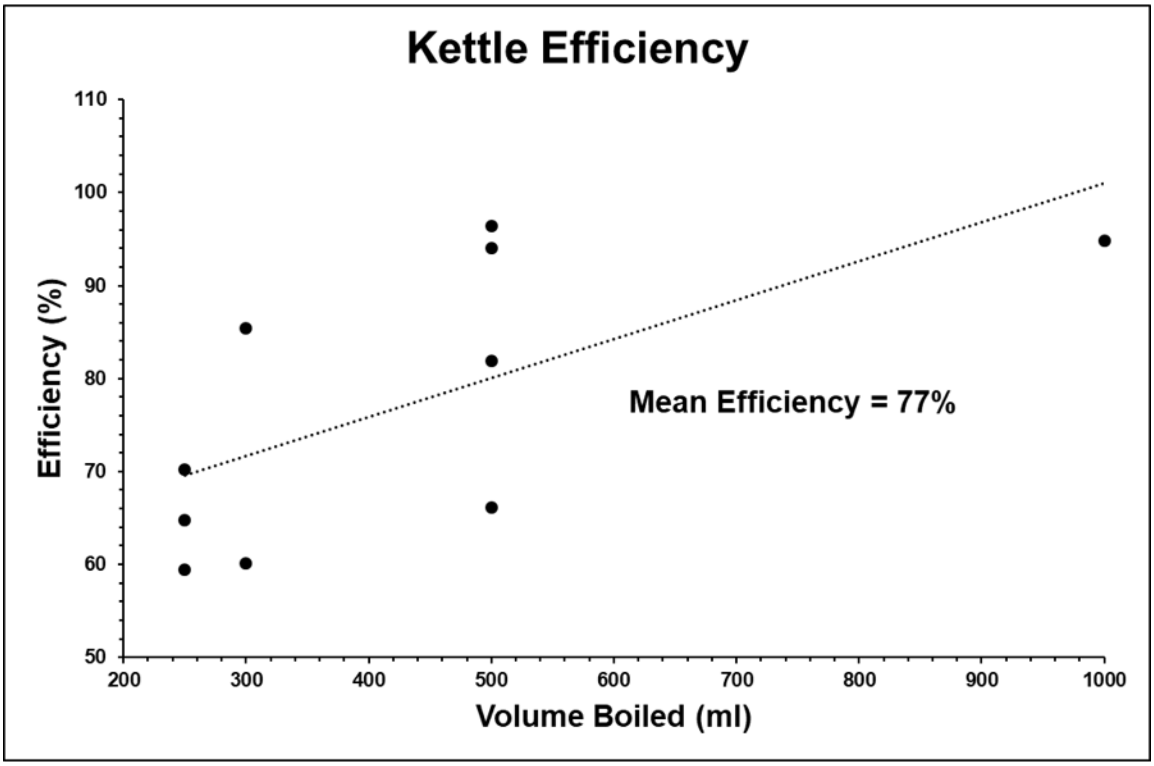

Figure 1: Kettle efficiency varies with volume

2.2 Supply and Demand

Even the “final” estimate given above is, in a way, assuming a best-case scenario. For the same reasons no kettle can be 100% efficient, neither can the National Grid. The amount of electricity consumed is significantly different to the amount supplied. In 2018, the total supply was 352 TWh [13], but only around 85% of this supply (our previous 300 TWh figure) is available. According to DUKES 2019, almost 8% of the UK’s energy supply is “lost” before it reaches the point of use, while the rest is used by the energy industry itself. If these losses confuse you, think of a long-distance runner. It would be ridiculous to expect the runner to finish a marathon in the same state they started, showing no signs of tiredness or slowing down. Just as a marathon runner does work to put 42 kilometres behind them, so too does electrical current do work to get from a power station to your home.

The electricity we use is produced at power stations, most of which are in the UK but are often located far from urban centres. Electricity leaving a power station is transported to distribution stations around the UK using very high-voltage power lines. The use of high voltages minimises losses, but doesn’t eliminate them completely. The losses are predominantly to heat: electron collisions warm up the power lines and the surrounding air, meaning there is more leakage on hot days. Since electricity at hundreds of thousands of Volts is very dangerous, it must be moved to lower-voltage lines, then transformed to 230V for safe domestic use.

At every stage of this journey, losses are incurred. This is even before we account for losses in domestic wiring, or for the fact that burning fossil fuels can produce electricity with efficiencies of as low as 25%, as mentioned in the introduction. Although most of the population has little control over *how* energy is produced, the fact that supply is driven by demand gives us at least a little say over *how much*.

Now imagine if the average person boils not just one extra cup of water, but two, three. . . even four? It doesn't take a mathematician to realise that the estimated energy wastage would (almost) double, triple or quadruple if this is in fact the case. So next time you go to boil the kettle whether you are more environmentally or economically minded, think about what you would rather be spending your annual budget on than redundant hot water, and only boil as much as you need.

1. Low Hanging Fruit: Only boil what you need. Decide which mug you want to use and fill it with as much water as you'd like tea (remember to leave room for milk). Transfer it to the kettle and pop the kettle on.

2. Intermediate: Drink your tea with friends and family! Not only will you need fewer teabags if you make a pot, your kettle will run more efficiently than if you had all made separate cups. Be wary of over-offering; if your tea-drinking companions wouldn't have made themselves the cup of tea, that defeats the point.

3. Climate Hero: Lead by example and **spread the word**! In our experience, giving those same friends and family a gentle nudge towards changing their habits is very effective. To achieve the 0.71% energy saving calculated, an estimated 54 million people need to make the change.

3 Cooking

Whether you are combining a long list of ingredients from a restaurant quality recipe or simply heating a supermarket ready-meal, cooking plays an important role in everyday food preparation. Choosing the right method when preparing a weekday meal has a massive impact on energy usage and therefore being more mindful of different processes can help save money on the monthly energy bill. Recalling that kitchen activities account for 30% of UK domestic energy use [4], this can be broken down further into energy consumed specifically for cooking ($\approx$ 17%), cooling ($\approx$ 3%) and the generation of hot air/water for cleaning ($\approx$ 80%) [26, 10, 27]. Despite a low percentage for energy consumed in cooking, it is important to review where changes in habit can be made. This report has already proved that making a small difference like boiling only a cups worth of tea can go a long way towards more sustainable living.

This section aims to consider simple cooking tasks using the most basic appliances then identifying where most energy is being consumed and where improvements can be made. The kitchen appliances under review include the stove top (commonly known as the hob in Britain), oven and the microwave oven. To be more specific, only electric ovens will be considered due to the fact UK residential ovens are generally split 70% electric and 30%

gas with an ever increasing demand for electric [28]. When it comes to hobs, both main energy supplies will be accounted for since 60% of Britain's hobs are gas and 40% are electric (ignoring magnetic induction hobs which are ever so slowly growing in popularity).

A quick calculation can be made for the total energy consumption per day and per household for the above appliances. Consider first an electric stove top where the different sized conduction rings usually range from 1 kW to 2.5 kW in power. A household using one small and one large ring for 30 minutes a day on full power will consume 1.8 kWh in energy. The average electric oven on full power comes in at around 3 kW and turned on for 30 minutes a day corresponds to 1.5 kWh per day. Finally, a standard microwave oven will usually have a power of 700-900 W clearly displayed on the front but in reality consumes a larger 1.4 kW due to inefficiencies. Using the microwave for 15 minutes a day is 0.4 kWh in energy and totalling up with the other appliances gives a **daily energy consumption of 3.7 kWh for the most basic culinary endeavours.** This is a reasonable estimate if the daily domestic energy for space heating, hot water, cooling and cooking in a household is taken to be roughly 30kWh.

3.1 Stove Top

The stove top enables heat to be applied directly to the base of pots and pans. Electric stove tops come in a variety of forms including metal resistance coils, solid conduction plates or glass-ceramic surfaces. Gas stoves on the other hand consist simply of a gas burner with functionality to adjust the rate of flow and intensity of flame. Both types of stove have their pros and cons but it is important to note that gas stoves are a lot cheaper to run whilst being less efficient than the electric kind. The aim of this study is not to persuade the average consumer into purchasing the most flashy super efficient stove top, but rather change one small habit linked with this appliance.

It is safe to say some of the most common tasks performed on a stove top involve bringing water to a boil, whether it be cooking pasta or boiling raw vegetables. From this, the act of covering a saucepan with a lid or leaving it uncovered was identified as a possible area to save energy. As previously mentioned, kettles are not 100% efficient therefore comparing different methods of boiling water and confirming a superior method is of utmost interest. It was supposed that the stove top was the most inefficient method due to heat loss from the gas burner however it would be unscientific to merely accept this as fact. Again, small scale experiments were carried out in kitchens to find the answer. Tap water measured to 300 ml was boiled inside various saucepans on gas stove tops with lids on and lids off (no boiling water was wasted in the taking of these measurements).

The efficiency of boiling water on the hob varies greatly depending on the type and size of gas burner, the pot material and diameter as well as the volume of water being boiled. Amalgamating the results, the average efficiency when bringing water to the boil in an open pan was found to be 43%, and this increased to 49% when lids were used. As noted for the kettle, the efficiency was found to increase with volume as seen in Figure 2.

Another question must be asked (and answered): how much energy could be saved if

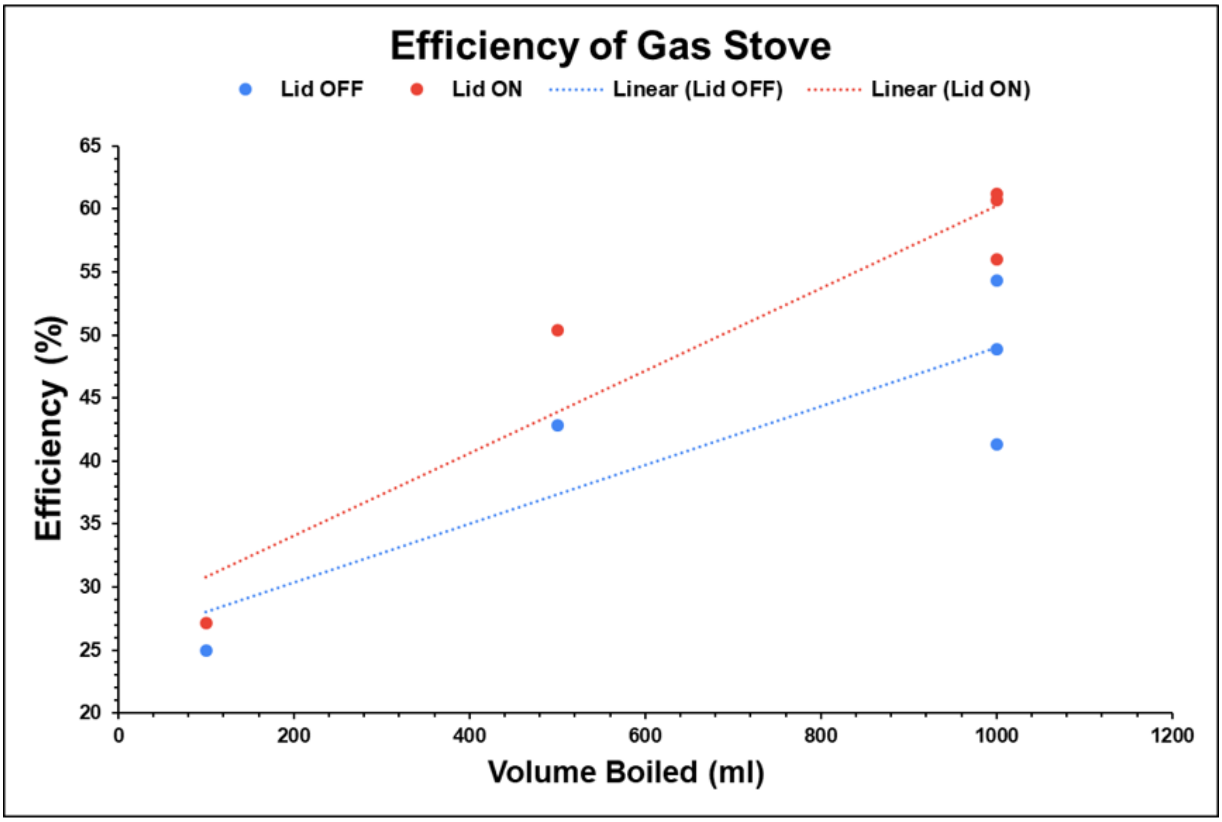

Figure 2: Efficiency varies with volume when boiling water in a pan either with or without a lid

everyone used lids when cooking on the stove top? This was estimated using similar methods as above, but is much more approximate due to the inconsistencies in cooking habits. Reliable sources for the number of pans of water boiled every day could not be obtained. There is also not an obvious and preferred method. For tea, we know that the majority of the population use a kettle. It is hard to confidently say whether or not the majority of the population use a lid when boiling water in a saucepan, whether the majority starts off with cold, warm or boiling water, or whether a considerable majority boils water on the stove at all. As mentioned above, different types of stove tops vary greatly (though unreliably) in efficiency. This calculation was based solely on gas hobs for two simple reasons: 60% of the country cooks with gas [28], and most of the kitchens used in these experiments owned gas hobs.

According to the Office for National Statistics, there were 27.8 million households in the UK in 2019 [ref]. We suppose that on average, every household boils *something* on the stove top once a day. Whether that something is pasta, soup, carrots or potatoes is relatively insignificant (discussed in section 4) therefore it is fine to assume the contents of the pan to be water.

A small pan was used to boil one litre of tap water, first without a lid, then with a lid. The same pan was used on the smallest 950 W burner at roughly the same time of day and the pan was allowed to cool to room temperature between experiments ensuring the lid was the only variable factor. The procedure was then repeated using a larger 1750 W burner. Covering the pan with a lid was found to be around 10% more efficient in both cases. Not using a lid gave an average efficiency of 51.6% whereas using lids gave 60.9%.

In the case discussed, an average of 730 kJ was used to boil one litre without a lid, and this was lowered to 620 kJ when the lid was used. If every household, when boiling their hypothetical one litre of water a day, put a lid on the pan, 1.16 PJ of energy could be saved every year. By the same process seen in sections 2.1 & 2.2, this value becomes 0.32 TWh, which is 0.1% of the total annual energy consumption (including losses in transmission) or 0.33% of the domestic total. At first, This may seem like an insignificant percentage, however the above calculations only consider bringing water to a boil and has not accounted for the longer time spent sustaining a boil/simmer for the purpose of cooking food. Far more energy will be saved by covering a pan for the entire cooking process e.g. the 7-12 minutes required for pasta. Convective heat transfer from steam to the kitchen atmosphere is significantly reduced and the vaporisation of the water is also reduced which both lead to a decrease in overall cooking time. The lid acts as a cooler with steam condensing on it's underside then dripping back into the pan. This is why the rate of water loss is slower with a lid on and as a result the lid is frequently removed when 'reducing' a sauce such as a bolognese. Removing the lid exposes the bolognese to air at a considerably lower humidity and the entire surface will evaporate into steam. Assuming a constant temperature setting on the stove top, the rate at which water escapes increases dramatically even though the boiling rate has decreased from removing the lid. The approximate energy associated with a sustained boiling/simmering process is discussed further in Section 4 but it is useful to note in the meantime that keeping a lid on throughout will save energy.

3.2 Electric Oven

Consider the act of roasting a baking tray full of vegetables (let's say carrots, potatoes and broccoli) inside a typical electric oven. To assess where most energy can be saved in this process, several questions must be asked. Is preheating the oven necessary and how much energy could be saved by skipping this step? How much energy is wasted by opening the oven door and checking up on the vegetables? Can energy be saved by switching the oven off early and relying on residual heat to finish the cooking?

It is important to first note how a standard electric oven actually works. The interior of an oven usually consists of two heating elements at the top and bottom. Electricity surges through these metal elements, which heat up in response to the electrical current supplied. The metal element is highly resistive therefore the flowing electrons collide with the metal atoms and convert their electrical energy into heat. Heat flows from the element into the oven chamber surrounding the delicious vegetables inside. The vast majority of ovens do not have a perfect seal from the outside atmosphere therefore hot air will leak into the kitchen. This may be seen as an advantage, not only because enticing smells are diffused throughout the home but because less energy needs to be used on energy draining space heaters for the kitchen if the oven is in action. The heating element cycles on and off with the help of a built in thermostat which aims to regulate and maintain the temperature selected by the user. The element will turn on whenever the oven's internal temperature falls to a certain level below the selected temperature. This is very similar to the thermostat found in most homes and when the thermostat probe senses the oven has reached the correct set temperature, it sends a signal which switches off the heating elements. This regulatory on and off cycle can be seen in Figure 3 and resembles a saw-tooth pattern which highlights the important fact that power is not being supplied to the oven heating element for the full duration of any cooking process. Instead, it periodically turns on and off.

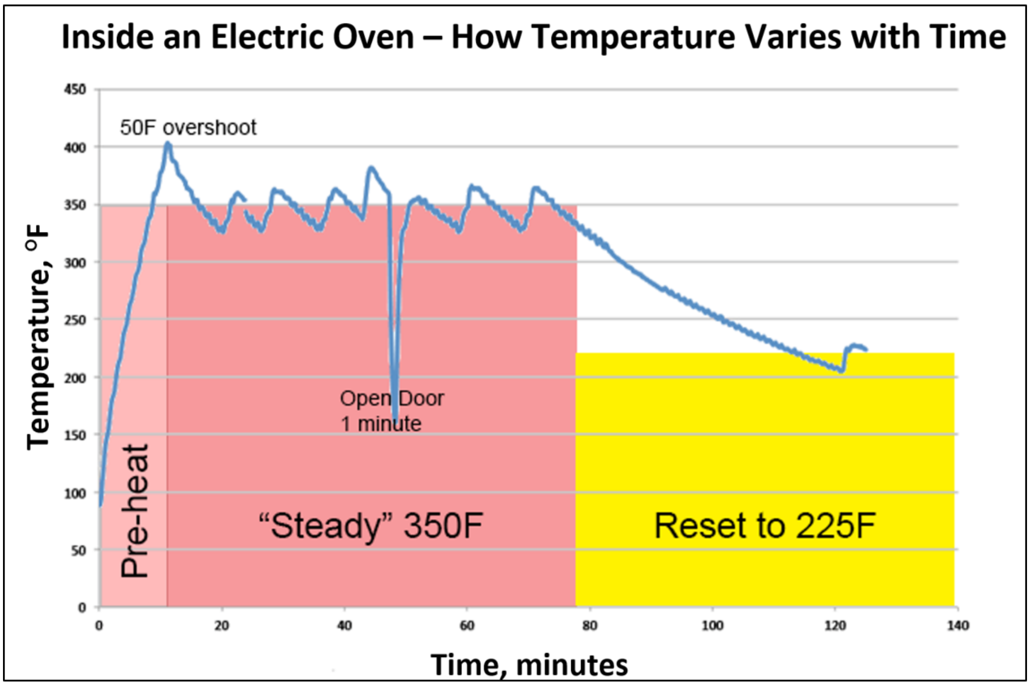

Figure 3: Temperature as a function of time inside the chamber of a JennAir conventional electric oven [29]. The thermostats regulatory cycle can be seen when kept at a constant temperature and a drop of 90° C is experienced when opening the oven door for one minute. To convert Fahrenheit to Celsius subtract 32° F and multiply by $\frac{5}{9}$.

The main user habits influencing oven energy consumption are temperature setting, duration of preheating, duration of the cooking process and the frequency of which the oven door is opened [30]. Along with many other examples, preheating the oven for the purpose of roasting vegetables can most often be skipped without any negative effect on the end result. It is worth noting that preheating an oven is a crucial step in more complex recipes such as baking a soufflè or loaf of bread but other than that, food can go into the oven at room temperature and increase with the oven. The process of preheating an oven consists of waiting 10-15 minutes for heating elements to bring a volume of room temperature air (20°C) to the user set temperature say, 200°C for roasting vegetables. To avoid some rigorous thermal conductivity equations, we will consider only the volume of air and turn a blind eye to the larger amounts of heat dissipated to surroundings or absorbed by the insulating walls. The typical thermal efficiency of an oven is relatively low at 12% due to these heat transfers [31].

The energy required to preheat the air inside a 3 kW oven can be calculated using the specific heat capacity equation used previously, $E = mc\Delta T$. Taking 60 litres as an average UK oven size gives a volume of 0.06 m^3. A value for air mass can be calculated as 0.072 kg which uses a room temperature air density of 1.2 kg/m^3. Plugging into the energy equation and using an air specific heat capacity of 1.006 Joules per degree per kilogram as well as a temperature change of 180°C results in roughly 13 kJ needed to preheat the air inside an oven. Using the power equation, this value of 13 kJ comes out as a very small fraction of the total energy supplied in preheating, 1800 kJ. This confirms the fact most heat input is absorbed by the insulating walls and dissipated to the kitchen atmosphere through the oven door. Uncovering these large oven inefficiencies reinforces that if an opportunity to skip the preheating stage is available e.g. when roasting vegetables, then why not take it and save energy. Temperature rises rapidly in the preheating phase (Figure 3) so it is reasonable to assume the food itself will closely match this rate of temperature increase.

Approximately half way through the process of roasting vegetables in an electric oven, one may decide to open the oven door and check/adjust their veg. By referring to Figure 3 once more, an internal oven temperature reduction of around 90°C over 60 seconds was observed for that particular experiment. From further research, an average temperature reduction of 20°C occurs for most door openings[32]. It goes without saying that leaving the oven door wide open for extended periods of time is not a great way to save energy. Doing this will *slowly* (internal surfaces retain heat) bring down the oven temperature to a point where the appliance is acting as a very inefficient radiator for the kitchen. Checking on food in the oven simply means more energy is required to return the oven to its set temperature. Modern electric ovens are able to retain a large amount of heat in surrounding walls and so opening the door has less of an effect. Even if the action sacrifices much less than 0.1 kWh, it adds up if repeated many times but can be prevented by keeping a clean window into the oven chamber or by waiting patiently!

How early in the cooking process can the oven be switched off to achieve perfectly roasted vegetables? The answer is in no way exact and depends heavily on the efficiency and thermal conductivity of the ovens insulating material. For the particular experiment shown in Figure 3, when the oven was switched off to reset to a lower temperature, the internal temperature appears to decrease at a rate of roughly 1°C per minute. The contents inside the oven already experience the fluctuating regulatory cycle therefore a gradual drop of around 10°C over 10 minutes should have little to no effect on the outcome of the food. This method of passive cooking [26] is a great way to save energy as power does not need to be supplied to the appliance [33] for the last 5-10 minutes of most cooking processes and approximately 0.5 kWh can be saved each day (based of the earlier energy calculations).

3.3 Microwave Oven

The microwave oven is an essential appliance in any kitchen to heat food quickly and efficiently. In the UK, 85% of homes owned a microwave in 2005 with this number slowly rising since. The common microwave oven consists of a magnetron which transfers electrical energy from a 230 V power outlet to a heated filament in order to transmit electrons in the microwave electromagnetic range. Microwaves scatter around the metal cavity and cook food by interacting with water, fat and sugar molecules then generating heat through excitations. Boiling experiments like those detailed in previous sections were carried out for the microwave, and the average efficiency was found to be 65.7%, not as efficient as the kettle. On the cooking front, however, it would appear that the microwave is the best way to go.

As an example process, let's take cooking carrots. In the microwave, adding just a couple of tablespoons of water to produce steam, this will take around 5 minutes. In a standard 800 W microwave running at 65.7% efficiency this will require 157680 J of energy. Now suppose the carrots are cooked first by boiling a litre of water in the kettle, then by boiling/simmering the carrots in that water on the hob for 5 minutes. Our experiments give an estimate of around 40000 J required for the kettle stage alone. So before simmering our water for 5 minutes using a typical hob with 40-50% an efficiency, we have used over 2.5 times the energy needed to cook the carrots through in the microwave. While we could steam our carrots on the hob too, the 20% difference in efficiency will mean the microwave takes the victory again. By another simple comparison, we can see that while electric and microwave ovens give similar results, the microwave will do so with a staggering 50% higher energy efficiency.

We accept that the Sunday roast would not be quite as enjoyable without golden potatoes or crisp Yorkshire puddings which the microwave cannot recreate, but strongly recommend that if you really want to save energy, you keep these luxuries for special occasions.

To conclude this section on cooking, let's summarise the main behaviour change recommendations.

1. Low Hanging Fruit: When bringing water to a boil on the stove top or simmering a meal, keep a lid on top!
2. Intermediate: Skip the preheating stage when possible for an electric oven and if that's not enough, switch it off 5-10 minutes early to save more energy.
3. Climate Hero: Skip the roasties and cook it all in the microwave.

4 Meal Preparation

In the last decade there has been a shift in the kitchen habits of UK dwellers. As of 2017, over one third of Brits claim to make at least one meal a day from scratch in their kitchens [34]; a number that has increased eleven percent from 2005. As a result of this trend, finding the most energy efficient and sustainable method of preparing a meal is of the utmost importance. If a way to reduce the energy used to make one meal can be found, then over the course of a year this could have a great impact on ones energy consumption.

The examples of two simple processes that will be compared when it comes to food prep are as follows;

1. Making one large batch of food, in this case, soup, (but could also be curry, pasta sauce, etc.) in advance, freezing these portions and reheating them as required.
2. Making individual portions when they are intended to be eaten on several separate occasions.

In particular the energy needed to carry out both of these procedures will be compared to determine which is more sustainable.

4.1 The Processes

It is useful to break down each method into steps in order to calculate the energy used for the method in total.

Process 1 will consist of the following steps:

1. Heat up fourteen portions of soup from room temperature to a boil.
2. Simmer the soup for one hour.
3. Cool twelve portions of soup to room temperature and store in a freezer.
4. Reheat two portions from room temperature to serving temperature.
5. Repeat step four another four times.

Process 2 will consist of the following steps:

1. Heat up two portions of soup from room temperature to a boil.
2. Simmer the soup for one hour.
3. Repeat steps one and two a further six times.

Choosing soup as the substance for these procedures was not completely arbitrary. it is a food stuff that is often made both in batches and in individual portions. On average, approximately 92% of the ingredients in soup are made up of water [35]. This is particularly useful for calculations as when equations that require a measurement of specific heat are used, the widely accepted value for the specific heat of water is a good approximation. However, choosing soup as the substance was arbitrary in the sense that the same logic and calculations can be applied to any substance that can be cooked via the same procedures, e.g. pasta sauce, curry, chili, etc.

4.2 Process 1

4.2.1 Step 1

The initial step of this process relies very much on the same physics discussed in Section 2.1. In particular, the physics of heat and specific heat capacity (2) will be used in order to calculate a value for the energy needed to bring the soup from room temperature to boiling.

Recalling that equation (2) requires the following three values in order to be computed: the mass of the system, the specific heat capacity of the substance, and the change in temperature;

It will be approximated that one portion of soup is 500 ml, which translates to 0.5 kg per portion. For this process this results in a total mass (m) of 7 kg. As mentioned before it is suitable to use the known literature value of the specific heat capacity (c) of water (4180 J °C $^{-1}$ kg^{-1}) in calculations as a good approximation. The Oxford Dictionary states that room temperature is "conventionally taken as around 20°C"[36], so this is the value that will be used in calculations. As mentioned before the boiling temperature of water is 100°C, resulting in our total change in temperature (ΔT) equalling 80°C.

Plugging those values into equation (2) results in the total energy for step one as **2340800 J**.

4.2.2 Step 2

Nearly every soup recipes calls for a stage of allowing the soup to simmer for a long period of time. For the simmering process and for the purpose of this research, it is useful to think of the simmering process in terms of the method of simmering, instead of the exact energy used. For this example it will be assumed that the soup will be simmered on an electric hob for one hour.

Electric hobs are supplied a certain amount of power. They are also supplied with a dial which determines the temperature of the stove top. Most assume that this dial is a direct correlation to the temperature of the heating element of the stove, when in actual fact it correlates to how often the heating element is supplied power. The heating element can either be on or off, meaning that if the dial is set to 2/10 then the power input to the heating element will be adjusted accordingly. For a pot of soup to be kept at a simmering temperature for 1 hour it is estimated that a setting of 3/10 will be used. This means that for every 60 seconds that the pot is simmering, the heating element of the stove will be active for approximately 18 seconds.

For a pot large enough to hold 7 litres of soup it is safe to assume that the largest heating element on a household stove would be used, which typically has a power output of 3000 W.

With a power of 3000 W and the heating element being supplied power for a total of 1080 seconds over the course of the hour, a total energy of **3240000 J** is required in order to keep our soup at a simmer. This method is used because the emphasis is not on the exact energy used, but the approximate energy used in comparison to our other method. This method allows us to compare methods without dealing with complex thermodynamics and integral calculations.

4.2.3 Step 3

For step three, once again equation (2) will be used to calculate our energy requirement. An assumption was made that once cooked, the soup will be allowed to re-cool back to room temperature (20°C) before being stored in the freezer. The UK Food Standards Agency states that the optimum temperature of a freezer is -18°C [37]. This means that for this calculation, a change in temperature (ΔT) of 38°C will be used. It is also assumed that from the initial batch of fourteen portions, two will be eaten immediately upon being cooked. Meaning that only twelve portions will be frozen, resulting in a mass (m) of 6 kg. Putting these numbers into equation (2) results in an energy of 953040 J.

However, there is an additional calculation that must be taken into account for this step. As the temperature of a freezer is -18°C and the freezing temperature of water is 0°C, the water-based soup will undergo a change of state from liquid to solid, due to freezing. This change of state requires energy. The amount of energy required to change the state of 1 kg of a material is known as the specific latent heat [38].

The relationship used to determine the heat energy required to change the state of a substance is:

$$E = ml \tag{6}$$

Where E is the heat energy, m is the mass of the substance (6 kg) and l is the specific latent heat capacity. Once again the specific latent heat of water can be used as a good approximation. As the focus will be on the freezing of the soup, the specific latent heat of fusion for water will be used: $l = 3.34 * 10^5$ J kg^{-1}.

Putting these values into equation (6) results in an energy of 2004000 J required to change the state of our soup.

This equates to a total energy of **2957040 J** required to reduce the temperature of our soup from room temperature to -18°C.

4.2.4 Steps 4 & 5

The final step of this process is to calculate the energy needed to reheat the remainder of our soup from room temperature to serving temperature, as required. Once again it is assumed that two portions of soup will be eaten at a time, and it is also assumed that before the reheating process each double portion of soup will be brought out of the freezer prior and allowed to return to room temperature (this step greatly reduces total energy, as if the work done to heat the soup from -18°C were taken into account the change of state from solid back to liquid would have to be considered). The appropriate serving temperature of a bowl of water based soup is 99°C, resulting in a change of temperature (ΔT) of 79°C. The mass (m) of the remaining soup is 6 kg.

Once again plugging these results into (2) and calculating results in an energy of **1981320 J**.

Adding together the values for energy required for each step results in a total energy required for Process 1 of **10519160 J**.

4.3 Process 2

The initial step of Process 2 is almost identical to that of Process 1. Energetically it is identical. Instead of heating up 7 kg of soup once, 1 kg of soup will be heated seven times. It can be seen from (2) that this will give the same result regardless of which method is chosen, as both share the same total mass. Once again giving a total energy for step 1 of **2340800 J**.

The same method as Step 2 of Process 1 will be used to calculate the energy required to simmer the soup. This time as 1 kg will be simmered at a time, we can assume that a smaller stove top and heating element will be used. The average power of a small to medium sized heating element is 2000 W.

Powering the stove's heating element with 2000 W for 1080 s will require 2160000 J. This will be done a further 6 times, bringing the total energy requirement for the simmering stage of Process 2 to **15120000 J**.

Adding together the values for energy required for each step results in a total energy required for Process 2 of **17460800 J**.

4.4 The Simmering Stage

Figure 4 shows the total energy of each process and how they both varies with different simmering times. Before taking simmering into account, Process 1 has additional energy from boiling, freezing and reheating that is the same regardless of simmering time, whereas Process 2 only has additional energy from initial boiling. For the two processes discussed it was found that for a simmer time of one hour, Process 1 used less energy, but it can be seen that when the simmering/cooking time is below 25 minutes (see Appendix for python script), it is in fact Process 2 that uses less energy overall. For an example like soup this value of 25 minutes may be too small a time to leave simmering, but as mentioned these process were used for their generality and these numbers can be applied to many different forms of food.

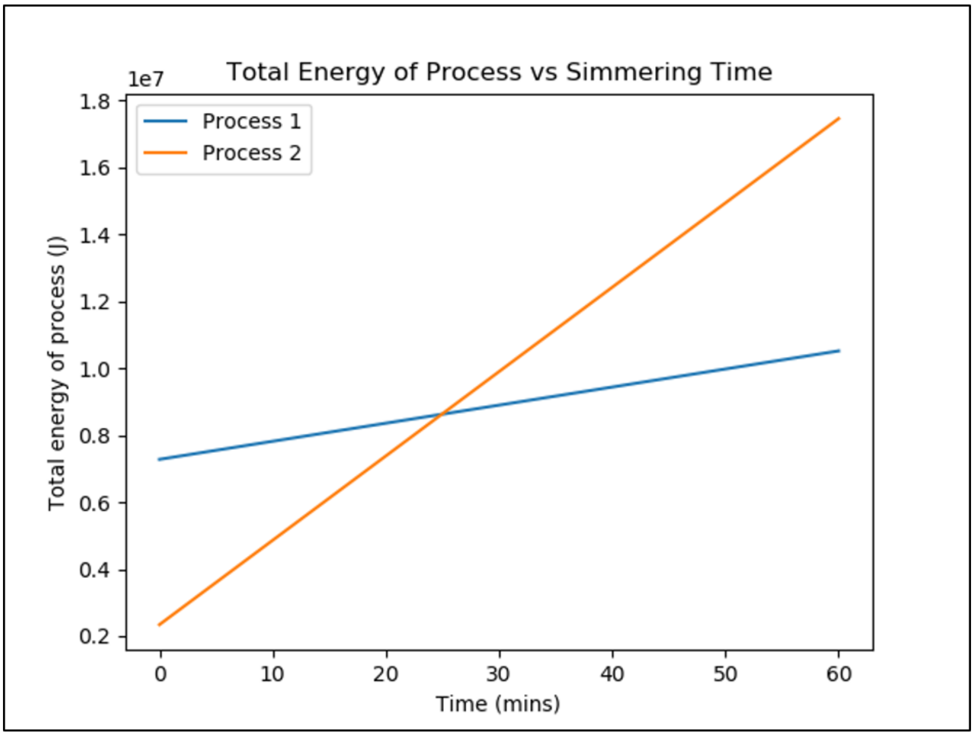

Figure 4: How total process energy varies with simmering time.

4.5 The Takeaway

Comparing the results for total energy of each process: total energy consumption of Process 1 = $1.05 * 10^7$ J vs. total energy consumption of Process 2 = $1.75 * 10^7$ J. We can see that the energy used by Process 1 is only $\approx 60\%$ of that used in Process 2, with an energy difference of $7.0 * 10^6$ J. Over the course of a week this is the equivalent of $1.0 * 10^6$ J per day, or equivalent to boiling approximately 9 cups of tea per day. If one were to complete these process once a week for a year, then the total energy savings of Process 1 compared to Process 2 would come out at $3.64 * 10^8$ J. Revisiting our number for total domestic energy consumption in the UK of 90 TWh, with 27 TWh of this being from the kitchen (30% of annual domestic consumption [4]). Meaning that the average domestic kitchen energy consumption per person can be given by the total divided by the population (approx. 66 million as of 2018 [23]), giving a value of $4.09 * 10^{-7}$ TWh per person in the UK. Converting our energy difference between the two process in the TWh gives a value of $1.01 * 10^{-7}$ TWh, approximately 25.7% of a persons annual kitchen energy consumption or 7.4% of their annual energy bill.

A 7.4% difference in energy consumption would save the average person £37 on their energy bill!

1. Low Hanging Fruit: If a food takes more than 25 minutes to cook through, then cook these food types in batches, and store them for future consumption.

2. Intermediate: Be mindful of cooking times. Try not to leave food simmering longer than needed. Get your food cooked and off the stove as quickly as possible, regard-

less of whether you are batch cooking, or not.

3. Climate Hero: If it is safe to do so, cut out any simmering stages of recipes completely, especially if this stage is for flavour and not food safety.

5 Cleaning Up the Kitchen

Everyone knows the feeling of having to bite their tongue when witnessing a ‘different’ technique in the kitchen sink. Fill the sink? Leave the tap running? Journalist Toni Hargis even suggests that a cultural divide on the subject of washing up exists [39]. This chapter is here to end the debate by assuming that the most sustainable method, while maintaining hygiene, is the right method.

Although there is a lack of financial incentive to save water compared reducing your annual energy bill, this is very important if you’re working towards a less guilty conscience. Of the Earth’s water supply, 96.5% [40] is salt water and only 1% is available for drinking. 2% of the water is frozen. Water is vital for life, and being conservative with water usage will prevent shortages leading to events like the recent drought seen in Cape Town which led authorities to warn residents of a potential “Day Zero”, when the city’s taps would stop running [41].

5.1 Washing up

Many people like to leave the tap running while doing their washing up. This not only wastes a considerable amount of water, but will add significantly to your energy usage. With an average water flow out of your tap of 8.5 litres per minute, 5 minutes of running water uses 42.5l of water. That is equivalent to roughly half a bath. The energy used to heat this amount of water to 30 degrees Celsius can simply be calculated using the equation Q = MCdT, as described in the introduction. Assuming the temperature of the coldest water coming out of your tap is about 10 degrees Celsius, we need 84,000J per litre of water to heat it. This equates to 3,570,000J per 5 minutes of running water, or 990Wh.

This is a lot of water and energy for a bit of washing up. So what if we fill the sink with water instead? It may seem quite inconvenient, as the water gets dirty quickly, but the amount of water and energy saved is undeniably significant. Assuming an average sink volume to be roughly $12,000cm^3$, this will use 12l of water. To heat this water, 1,008,000J are needed or 280Wh – under a 3rd of the energy compared to leaving the tap on. The only inconvenience might be the inability to rinse dishes, however using some cold water to rinse won’t involve increasing your energy usage. This equates to a saving of 710Wh per day, which would result in saving 250kWh per year. With a current price in the UK of 14.37p per kWh, that equates to a saving of roughly £36 per year. For quite a simple lifestyle change, this is quite a significant save in energy.

A clear threshold can be seen here, where filling a sink would not save you water or energy. If the tap only needs to be run for under 1.5 minutes, there is no need to fill your sink full of water, as the water usage would not exceed the 12l it takes to fill the sink.

Using cold water would save you the full 990Wh per day equating to £50 per year. Washing up with cold water and washing up liquid is still hygienic. The only downside is that it might take a little bit more effort to scrub food off, as it comes off more easily with hot water.

5.2 Dishwasher vs Washing up

Many people will be surprised to hear that the most convenient option is a reasonably conservative option in this case. Thanks to the increased efficiency of dishwashers over the last 10 years they aren't awful for the climate. On average, dishwashers use roughly 1800 Wh per day assuming a 1800 W dishwasher (used for 1 hour per day), and 15 l of water per cycle. Water consumption in this case is good compared to 12 l for one sink full of water (measured ourselves). Clearly more energy is used here than washing up though, even when compared to leaving the tap running. However if it is possible to use the dishwasher every other day, waiting until it is more full, the usage drops to 900 Wh per day, only just beating leaving a hot tap running. Considering its convenience, and taking into consideration the possibility of using it less than every other day, it is not a bad option. Taking the step to use your dishwasher every other day instead of every day will save you about £47 per year.

Using your dishwasher every other day instead of washing up with the hot tap running could be considered more of a reasonable and manageable lifestyle alteration. Although this will be lowering your energy bill by about £4-5 per year, this could save roughly 12500 l of water a year, or 150 baths! This won't save you significant amounts of money, but fresh water is a limited resource and good to use conservatively.
From an energy saving perspective, rinsing your dishes before putting them in the dishwasher is okay if cold water is used. But for maximum conservation of energy and water, it is often recommended to let the dishwasher do its job.

Running a hot tap quickly becomes an energy drain and uses huge amounts of water without most people even realising, as we have just got far too familiar with them running for longer than they should be. Although running it cold will save lots of energy, we must consider the conservation of water too, so that leads us to filling a sink with cold water. This isn't the most manageable lifestyle adjustment, so using a dishwasher at most every other day seems like a good compromise.

1. Low Hanging Fruit: Fill your sink with hot water instead of running your hot tap

2. Intermediate: Use a dishwasher (and only when full)

3. Climate Hero: Fill your sink with cold water

6 Conclusion

We wish for the major take away from this report to be that even very small behavioural changes in the kitchen can have considerable impacts on energy use. Our results show that if everyone made sure to only boil the amount of water they needed this would reduce UK annual domestic energy consumption by 2.6%, which equates to an 8.6% reduction in UK kitchen greenhouse gas emissions (see appendix). If every person were to cook a batch of soup that would last them a week, once a week, over the course of a year, then the energy saved would be the equivalent of boiling 9 cups of tea per day, or $\approx 7.4\%$ of a persons annual domestic consumption.

If everyone in the country were to take on even only our lowest hanging fruit recommendations then we calculate there could be an 18% reduction in UK domestic energy use.

Due to our approach, this shows the minimum reduction we could see in energy use. At every step we have assumed the higher end of efficiencies so in reality there is potentially more energy to be saved by the same recommended actions.

The recommendations we make are clear and simple, but changes of behaviour and habit are not. We hope to show that there is a large scope for energy saving in the kitchen for members of the public and by making these small changes they can help do their bit. Evidence shows that members of social circles who lead by example on such behaviours (find ref) help to normalise the behaviour within their peer groups, driving the others to adopt the behaviours as well. You can play your part by taking on the suggestions we make in this report and, just as importantly, telling your friends you are doing so.

If you take only four things away from this report we suggest you remember to:

- Boil only as much water as you need and boil it in a kettle
- When given the opportunity do meal prep cooking rather than many small meals
- Put that lid on that pot unless the recipe specifically says not to
- Do not leave the hot tap running whilst you wash up

Many of these changes can be incorporated into broader behaviour patterns, such as if you are living communally cooking together rather than separately or boiling enough water for everyone who wants a cup of tea (and no more!).

As the awareness of the importance of the climate emergency begins to percolate through society many more people will be considering what they can do in order to reduce their own impacts on the environment. The recommendations we have made here provide a clear way that almost everyone might be able to start to do just that.

7 Appendix

Here follows the full calculation of UK CO_2 emissions from energy use in the kitchen.

Using numbers from the UK government [3] the UK's domestic energy use is 29% of the total energy consumption. Energy Saving Trust numbers that show 30% of this is from the kitchen [4]. Taking a total annual UK electricity consumption value of 300 TWh [13] gives us how much electricity we use in the kitchen.

$$0.29 \times 0.3 \times 300 \text{ TWh} = 26.1 \text{ TWh} \tag{7}$$

Then we can take the recommended conversion factors for greenhouse gas emissions of electricity use of 0.309 kg CO_2 equivalent per kilowatt hour based on the breakdown of UK electricity production [42].

$$0.309 \text{ kg/kWh} \times 26.1 \text{ TWh} = 8.1 \text{ Megatonnes} \tag{8}$$

Similarly the savings in emissions from just boiling the correct amount of water as stated in the conclusion can be calculated using the same factors.

$$0.309 \text{ kg/kWh} \times 0.026 \times 0.3 \times 300 \text{ TWh} = 0.7 \text{ Megatonnes} \tag{9}$$

This is equivalent to 8.6% of the emissions from the kitchen.

7.1 Code used to generate Figure 4

```
import matplotlib
import matplotlib.pyplot as plt
import numpy as np

def energy(time, power):
    e = power * time
    return e

def main():
    p1e = []
    p2e = []
    time = []
```

```
    keytime = []
    for i in range (61):
        p1 = 7279160 + energy(i*18, 3000)
        p2 = 2340800 + (7 * energy(i*18, 2000))
        if p1 < p2:
            keytime.append(i)
        time.append(i)
        p1e.append(p1)
        p2e.append(p2)


    print(keytime[0])
    plt.plot(time, p1e, label = 'Process 1')
    plt.plot(time, p2e, label = 'Process 2')
    plt.xlabel('Time (mins)')
    plt.ylabel('Total energy of process (J)')
    plt.title('Total Energy of Process vs Simmering Time')
    plt.legend()
    plt.savefig('simmeringtimes.png')
    plt.show()


main()
```

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