Department
for Environment
Food & Rural Affairs

Estimating UK domestic solid fuel consumption, using Kantar data

Summary of results and discussion

Annexe A of 'Burning in UK Homes & Gardens'

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1. Introduction

The purpose of this paper is to: present the results of a quantification method conducted by Defra that takes data from a Defra-commissioned research by Kantar Public (Kantar) in 2018-19 to estimate the UK quantity of solid fuels burned domestically over that period; and to objectively compare these results with the estimates published by the Department of Business, Energy and Industrial Strategy (BEIS) in The Digest of UK Energy Statistics (DUKES) 2019[1] for residential solid fuel use in 2018. This is of interest to Defra because in order to estimate air pollution emissions from solid fuel burning, there is a need to understand the quantities of solid fuel being burnt, the burning appliances[2] used, and the amount of emissions burning different solid fuels on different appliances give rise to. This report explores the first two elements.

For domestic combustion of solid fuels, the National Atmospheric Emissions Inventory primarily uses (DUKES) that is published by the Department of Business, Energy and Industrial Strategy (BEIS) to provide estimates of the amounts of solid fuels being burned domestically each year. The DUKES figures for how much coal-based solid fuels are burned in total each year are seen as relatively robust because they are based on industry sales figures. However, estimating the quantity of wood fuel that is burned domestically is seen as particularly challenging[3], because wood may be purchased through informal means or accessed free. Therefore, household surveys of domestic burning are commonly used internationally in order to estimate the quantity of wood fuel consumed domestically.

In 2015, BEIS (the Department of Energy and Climate Change, at the time of the survey) commissioned a one-off survey on domestic combustion for the winter and summer burning seasons from autumn 2013 through 2014, which was used to produce an estimate of residential wood fuel use in the UK for 2014. The results of the survey and the tables used in the final energy calculation that produced the total domestic wood fuel consumption estimate were published by BEIS in 2016 in Energy Trends, with the title 'Summary results of the Domestic Wood Use Survey'[4]. The study that this was based on will therefore be referred to in this paper as the DWUS. The final energy calculation produced as a result provides a baseline for DUKES' annual estimate of domestic wood fuel. This baseline is updated each year with data on new indoor burning appliance installations, and a temperature-correction methodology is applied.

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[1] A more recent DUKES was published in July 2020: https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes#2020, but the reference for this report is DUKES 2019 for 2018.
[2] Burning appliances include closed stoves and open fires (see the Kantar Final Report for more details).
[3] See AQEG (2017, pp25-26): 'The Potential Air Quality Impacts from Biomass Combustion'. Available here: https://uk-air.defra.gov.uk/assets/documents/reports/cat11/1708081027_170807_AQEG_Biomass_report.pdf
[4] These are available here: https://www.gov.uk/government/publications/summary-results-of-the-domestic-wood-use-survey

It is possible that domestic combustion has risen since the DWUS, with possible consequences in terms of air pollution. Therefore, Defra commissioned research in 2018 to update and extend the understanding of domestic burning that had been developed as a result of the DWUS to include the range of solid fuels and appliances now used, both indoors and out and to enable the spatial disaggregation of data collected. This research was conducted by Kantar Public, advised by a steering group that included DWUS project expertise from BEIS. It also included representation from the Devolved Administrations and members with extensive knowledge of domestic combustion, wood fuel production and consumption, related emissions and how they are estimated in the National Atmospheric Emissions Inventory (NAEI).

The core activity survey (CAS) that Kantar conducted to gather data for the solid fuel quantification that Defra has done built on lessons from the DWUS in order to reduce some of the uncertainties in the DWUS dataset[5]. In particular, this led to shifting the focus of the survey from burning in the last year (the approach taken in the DWUS) to burning in the last week, in order to facilitate recollection and the accuracy of responses. These improvements have resulted in different questions being asked and therefore required the creation of a very different method for calculating the UK solid fuel quantity estimates from the one used in the DWUS project.

Like with the DWUS, the method that has been developed for estimation has required making a number of assumptions in order to scale up to the national level. The methods section (Section 2) and the quality assurance (QA) report in the appendices provide an overview of the approach taken to the quantification that this paper reports on. They also detail the associated assumptions made and how recommendations arising from the QA have been addressed.

This paper, therefore, presents a summary of the main results from the quantification of different solid fuels used in UK domestic settings during April 2018-March 2019, based on the data collected by Kantar through the CAS[6]. Beyond an overview of the resulting UK solid fuel estimates and the method used to produce them, it compares[7] the results with the estimates from the 2019 DUKES for 2018 since this was the latest estimate available at the time of analysis. This has been slightly revised in DUKES 2020[8].

The paper also provides a discussion of likely sources of differences between the two sets of estimates, alongside related evidence from the Kantar research.

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[5] The CAS was conducted as part of a Defra-funded research project called ‘Burning in UK Homes and Gardens’. This paper is an annexe to Kantar’s final report for this project.

[6] For further details, please see the methods section in Chapter 1 of Kantar’s final report called ‘Burning in UK Homes and Gardens’, which is available at http://randd.defra.gov.uk/, to which this paper is an Annex.

[7] A direct comparison with DUKES is not straightforward because in the case of wood the units used are different, and in the case of coal the categories are different.

[8] The revision made to domestic wood increased the total slightly by 2.2 ktoe.

2. Overview of estimation method for quantifying use of domestic solid fuel

This section outlines the processing involved in getting from the raw survey data to national estimates of solid fuel burning in an indoor environment. (A simpler method is used for outdoor burning and this is briefly mentioned). The final method chosen[9], in consultation with the steering group for the quantification, drew particularly on data from both survey questions outlined earlier: the hours a respondent said their main burning appliance was lit for the previous week (appliance running time) and the quantity of each solid fuel they estimated they had burned over the same period (by weight [kg] or bulk volume [buckets]).

The method primarily relies on the appliance running time data. The steering group advised that this was likely to be more reliable because it is easier to recall and estimate hours an appliance is lit than the weight or bulk of solid fuels used. Therefore it advised that this is the data most commonly applied in estimating emissions from domestic combustion internationally. However, the quantities data was used to attribute the hours of appliance usage to the different solid fuels burned. The method also took a 'bottom-up' approach, given the survey focus on burning in the previous week, to build up from respondent data to an annual figure for each solid fuel burned (the unweighted sample size who provided this data was 807 respondents).

Whilst the starting point for the method used for estimation is very similar for both the DWUS and the Kantar-based approach (data on the weekly hours an appliance is lit), the Kantar-based approach apportions the input fuel type to achieve a split by solid fuels based on the solid fuel use weights and volumes reported. On the other hand, because 90% of respondents to the DWUS reported burning wood logs, for the DWUS's analysis the assumption was made that the hours of burning reported were attributable to wood fuel consumption, and that therefore use of appliance running time data alone was justified.

The other major difference in the approaches taken to estimation is that the Kantar-based method apportioned solid fuel use (by appliance type) based on individual responses about household usage, and then scaled up. The DWUS drew on the seasonal hours data collected and used respondent estimates of average number of hours burned in the past winter and summer, as well as numbers of appliances reported, to provide a more top-down quantification of wood fuel usage. These differences in approach make the outputs from the two methods challenging to compare.

[9] For an outline of options considered, how the survey was designed in relation to these, and the reasons this approach was chosen, please see Appendix 7.2.

Inputs from Kantar core activity survey

Inputs	Use
Appliance type	Applying correct fuel use/hour for conversion from running time
Running time of main appliance used in previous week (hours)	Primary variable used for calculation of each fuel used
Fuels used in last 12 months and indoor/outdoor	Counting the number of fuels to split the running time by
Weight of each fuel used in previous week (kgs)	Assigning proportion of the running time to each fuel (if the respondent used multiple fuels)
Bulk volume of each fuel used in previous week, if weight not provided (10 litre buckets converted to kgs)	
Seasoning of most wood burned in the last week (if wood logs were used)	Application of Net Calorific Values (NCVs) and fuel use/hour for conversion from running times; assigning proportion of the running time to each fuel
Region	Grossing up to national figures
Urban/rural	
Smoke Control Area (SCA)[10]	

2.1 Calculation of indoor burning quantities

The indoor quantities are based on the appliance running time variable. Fundamentally the method apportions the running time between the fuels that the respondent has indicated they have used indoors, and then the running time for each fuel is converted to weight and scaled appropriately. More detailed steps are described below.

Firstly, if the respondent used more than 1 fuel indoors in the past 12 months, we assume that the running time provided needs to be split between all the indoor fuels that are stated. A respondent is assumed to use a fuel indoors for the survey week if a positive appliance running time is provided, a positive quantity or bulk estimate is provided, and they state they have used the fuel ‘indoors only’ in the past 12 months or ‘both indoors and

[10] A smoke control area is an area in the UK where residents are not permitted to emit smoke from a chimney unless they are burning an authorised fuel or using an exempted appliance. For more information, see https://www.gov.uk/smoke-control-area-rules.

outdoors' and the survey month is any of: April 2018, October 2018 to February 2019. This set of months was chosen based on the monthly totals of appliance running time – these months had substantially greater running time of indoor appliances compared to other months.

Once the number of solid fuels to apportion the total appliance running time has been determined, we use the weight and bulk estimates provided and convert these to energy use. There are several steps and assumptions to carry out these conversions. For wood logs, the bulk density conversion and the net calorific value (NCV) used is dependent on the response to the seasoning question:

Wood logs moisture content[11]

Assumed moisture content	Answer to seasoning question
10%	It was pre-dried when you bought or got it
20%	No response; Don't know; It was seasoned when you bought or got it; It was seasoned at home for between 13-18 months; It was seasoned at home for over 18 months; Other
30%	It was seasoned at home for less than 6 months; It was seasoned at home for between 6-12 months, It was unseasoned

[11] The moisture contents (MC) used here for the different options provided for the seasoning question are based on assumptions, informed by: (a) the FAO's and Forestry Commission's bulk density moisture content options; (b) Defra's policy position that dry wood has an MC of 20% or below, and wet wood has an MC above 20%; (c) Defra guidance that wood needs to be seasoned at least a year to become dry (meaning have a moisture content of 20% or less); and (d) the proportion of respondents who said they were burning wood that was completely unseasoned. When taking account of the estimates of the quantities of wood burned at these different MCs, the average MC for all wood fuel burned is approximately 21%. There was not a clear consensus amongst the steering group as to whether the assumptions made seemed sensible, with suggestions made that they were both too high and too low. It should be noted that the new solid fuels legislation requires that wet wood is dried for at least two years. This is based on advice from industry and consistent with the definition of seasoned wood used in the consultation on cleaner domestic burning in 2018. Defra guidance is being updated.

For respondents who provided volumes (in number of 10 litre buckets) of solid fuel used rather than weight (in kg), a simple conversion is used:

$$Weight\ of\ solid\ fuel = Bulk\ density\ (kg\ per\ 10\ litres) * Number\ of\ 10\ litre\ buckets\ used$$

The bulk density conversion factors used for each fuel were drawn from a literature review conducted by Wood plc for the research project. A number of the bulk density conversion factors recommended by Wood plc are based on various sources with different figures. After discussion with the steering group, it was decided to use the stacked wood bulk density conversion factors published by the UN's Food and Agriculture Organisation[12] for logs[13], taking account of the different moisture contents. This was weighted to softwood because of industry information that they largely sell softwood for wood fuel, and that hardwood that is burned is likely to come from informal sources[14]. See Appendix 7.3 for the bulk density factors used for the different fuels.

The total running time was apportioned to each fuel, based on the proportion of total energy use to which that solid fuel contributed in the week the respondent was asked to recall how long their appliance was lit. To calculate this proportion the weight in kg needs to be converted to energy used (kWh) using the following formula[15] (step 1):

$$Total\ energy\ use\ (kWh) = \sum_i \frac{Weight\ of\ fuel\ i\ burnt\ (kg)}{1000} \times NCV\ of\ fuel\ i\ \left(\frac{GJ}{t}\right) \times 277.8$$

Using this energy use estimate, we can derive a proportion of the total energy use for that respondent that is attributable to each solid fuel they used. These proportions are applied to the total running time in a later step.

The appliance running time for each respondent is then scaled up to reflect:

- Each wave of the survey measures burning activity during a week. To capture burning across the whole period the survey covered without gaps between waves,

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[12] FAO (2015) Wood Fuels Handbook.

[13] Wood plc had recommended using an average for spruce and oak for both RWE (round wood equivalent) and Fw (stacked chopped wood logs) across moisture contents (0-50%). The steering group suggested that bulk measurements using buckets required more account to be taken of the air gaps between logs, thus the team did a brief review of the literature highlighted by the steering group and adopted the FAO Fw (stacked chopped wood logs figures) based on the MCs identified earlier and a weighting of 75% of spruce and 25% for oak because of information that commercial sales of wood fuel are predominantly softwood and hardwood more likely to be accessed through the grey market or free (rather than 50% for each that Wood plc had suggested).

[14] As mentioned earlier, bought wood only forms part of what is burned in the UK. However, data on the grey and free wood market is minimal, and therefore the only information found in relation to softwood and hardwood usage for wood fuel was from the commercial sector.

[15] Note that the constant 277.8 is an approximate conversion between GJ and kWh.

each wave needs to account for between 1.5 and 3 weeks, so a simple scaling factor is used for this.

- Scaled to the household population for their combination of region, urban/rural status, and SCA status.
- A small uplift is applied to account for non-response within their combination of region, urban/rural status and SCA status – usually less than 5%.
- Running time is scaled up by 14% to account for no data gathering in March 2019 – this figure comes from the BEIS heating degree days statistics provided alongside DUKES (the survey ran from April 2018 to February 2019; to scale the usage to the period April 2018 to March 2019 we took the total heating degree days for the two periods and divided the April 2018 to March 2019 total by the April 2018 to February 2019 total).

This gives us the total running time, which is then split by fuel using the proportions determined in step 1 outlined above and in more detail in Appendix 7.1.

The running time for each fuel is then converted to weight (kg) through use of fuel use per hour for each appliance[16] and the net calorific value (NCV)[17] for each fuel (reflecting moisture content for wood fuels)[18]:

$$Weight\ of\ fuel\ (kg) = \frac{1000\ *\ appliance\ running\ time\ (h)\ *\ energy\ use\ per\ hour (kW)}{NCV\ of\ fuel\ \left(\frac{GJ}{t}\right) \times 277.8}$$

2.2 Calculation of outdoor burning quantities

The appliance running time question in the CAS only applies to indoor burning, so we are limited to the weight and bulk estimates provided by respondents. These are used to calculate a straightforward ratio of indoor to outdoor burning for each fuel; this ratio is then applied to the indoor burning estimates to come up with a simple and highly uncertain estimate of outdoor burning.

[16] See Appendix 7.5 for figures used, sources and calculations.

[17] The net calorific values used largely come from DUKES 2019 and are listed in Appendix 7.4.

[18] Note that the constant 277.8 is an approximate conversion between GJ and kWh.

3. Domestic solid fuel use estimates

3.1 Domestic consumption of wood fuel

Table 1 below provides the main results of the quantification derived from the Kantar research for UK wood fuel consumption in the period April 2018 to March 2019. This is divided into a number of sub-categories of wood fuel: wood logs (pre-dried, seasoned [air-dried] and wet [partially seasoned or unseasoned][19]), wood briquettes, wood pellets, wood chips and waste wood. The waste wood category includes both discarded wood that has been salvaged (for example, from skips) and fallen wood that has been gathered, although it is clear from a question on the sourcing of wood that some of the wood that respondents categorised as wood logs had also been collected or given[20].

Using the Kantar data and Defra quantification method, the estimate for total UK domestic wood fuel consumption in homes and gardens in 2018-19, is 2.41 megatonnes[21] (Mt), of which 1.74 Mt was burned indoors and 0.67 Mt outdoors. Indoors, the greatest quantity of wood fuel used was in the form of wood logs with a mix of moisture contents: in total, wood logs made up 1.43 Mt of wood fuel burned indoors in the UK in that 12 month period. Waste wood was the next largest of the wood categories used indoors, constituting 0.20 Mt of indoor wood consumption[22].

Outdoors, waste wood was the main type of wood fuel burned (0.60 Mt), and whilst wood logs came second, the amount of wood logs burned outdoors across the UK in that period was much smaller (0.06 Mt).

The total quantities of wood briquettes (0.04 Mt indoors and 0.01 Mt outdoors), wood pellets (0.06 Mt indoors and <0.005 Mt outdoors) and wood chips (0.01 Mt indoors and 0.01 Mt outdoors) estimated to have been burned domestically in 2018-19 were all relatively small in comparison.

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[19] The information on seasoning of wood logs came from a question asked of respondents who had burned wood the previous week about whether most of it had been bought or got pre-dried or seasoned, been seasoned by the burner (and if so for how long), or burned unseasoned. As mentioned, any quantities of wood logs seasoned for 12 months or less were treated as wet as per current Defra guidance (https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1903131256_Seasoning_Wood_Web_Feb_2019_V5.pdf) and assumed to have a moisture content of 30%. Wood logs that were seasoned for over a year, as well as any that were bought/got seasoned, were assumed to be seasoned properly and have a moisture content of 20%. Any wood logs that were bought or got pre-dried was assumed to have a moisture content of 10%.

[20] It is also possible that some of the gathered wood burned in the last week by respondents in the survey and classified by them as waste wood were logs.

[21] 1 megatonne is equivalent to 1 million tonnes; 1 tonne = 1,000 kg.

[22] It is important to note that the quantity of solid fuel burned is only one aspect of establishing pollution emissions estimates, given emission factors and the calibration of the NAEI model against measured levels of PM.

Table 1: UK domestic wood fuel consumption estimate for April 2018 to March 2019

Fuel	Seasoning	Indoor estimate (tonnes)	Outdoor estimate (tonnes)	Total (tonnes)
Wood logs	Kiln-dried (10% MC*)	258,324	10,944	269,268
Wood logs	Seasoned (20% MC*)	798,239	22,021	820,259
Wood logs	Wet (30% MC*)	372,838	24,781	397,619
Wood briquettes	Seasoned (10% MC**)	36,276	5,633	41,909
Wood pellets	Seasoned (10% MC**)	56,304	2,749	59,053
Wood chips	Seasoned (20%[23] MC**)	14,834	6,822	21,656
Waste wood	Mixed (20% MC*)	199,517	596,937	796,454
WOOD TOTAL		*1,736,331*	*669,887*	***2,406,218***

* Assumed moisture content

**Based on use of wood log net calorific values and associated moisture contents from Forest Research and/ or DUKES (see Appendix 7.4 for detail).

3.2 Domestic consumption of coal

Table 2 below provides the results for the estimation of the UK domestic consumption of coal in 2018-19, based on the Kantar data. Three sub-categories of coal-based fuels are used in the core activity survey: house coal, smokeless coal and coal briquettes[24].

[23] The NCV used for wood chips is from work by Wood plc on the Kantar hours and weight data and converting bulk densities. But please note that the bulk density conversion for wood chips recommended as a result of a literature review, was based on an average for spruce and oak wood chips from 0%-50% moisture content (MC) that can be found in the FAO (2015) Wood Fuels Handbook, and that Forest Research recommends an NCV of 12.5 that equates to 30%.

[24] There are a number of different types of coal-based solid fuel that can be classified as smokeless, including naturally-occurring anthracite and manufactured solid fuels that are often based on anthracite. Coal briquettes are a form of manufactured solid fuel, which are often smokeless, but not necessarily. Smokeless fuels are authorised fuels under the Clean Air Act 1993.

The total for UK coal consumption in that period derived from Defra's quantification approach, using net calorific values, is 0.88 megatonnes (Mt), of which 0.86 Mt was burned indoors and 0.02 Mt was burned outdoors. Smokeless coal accounted for 0.42 Mt indoors and 0.01 Mt outdoors, house coal 0.34 Mt indoors and 0.01 Mt outdoors, and coal briquettes 0.09 Mt indoors and 0.01 Mt outdoors.

Table 2: UK domestic coal-based solid fuel consumption estimate for April 2018 to March 2019

Fuel	Indoor estimate (tonnes)	Outdoor estimate (tonnes)	Total (tonnes)
Smokeless coal	417,753	6,608	424,361
Coal briquettes	90,791	6,198	96,989
House coal	350,271	7,641	357,912
COAL TOTAL	*858,816*	*20,446*	***879,262***

3.3 Domestic consumption of other 'solid fuels'

Table 3 below provides the estimates of the UK 2018-19 quantities of the other solid fuels burned domestically identified in the Kantar core activity survey: green (or garden) waste, household rubbish, charcoal and peat. These estimates are the least reliable because they are based on small sample sizes. The largest quantities burned were of green waste (0.18 Mt) and household rubbish (also 0.18 Mt), the vast majority of which was burned outside. Charcoal was also largely burned outdoors (0.13 Mt), with 0.01 Mt apparently burned indoors. The small amount of peat that was estimated to be burned was almost all burned indoors (0.01 Mt).

Table 3: UK domestic consumption estimates of other solid fuels in April 2018 to March 2019

Fuel	Indoor estimate (tonnes)	Outdoor estimate (tonnes)	Total (tonnes)
Charcoal	9,726	133,650	143,376
Green waste	3,698	181,123	184,821
Rubbish	11,158	171,180	182,337
Peat	13,038	213	13,252

4. Comparing domestic wood fuel estimates from Kantar-based and DUKES methods

This section compares the estimate of domestic wood fuel use using the quantification method described above based on the Kantar data, with the estimate for domestic wood fuel use published in DUKES (in 2019) for 2018. As mentioned, the Kantar-based wood fuel use estimates includes estimates for both indoors and outdoors burning in domestic settings, while the DUKES wood fuel estimate is founded on research that covered the winter and summer periods, starting in autumn 2013 through 2014 so that a full winter season was included. It focused solely on wood use indoors. The domestic wood fuel use estimate derived from the DWUS is updated in DUKES on an annual basis with data on new indoor burning appliance installations. A temperature-correction methodology is also applied to account for variation in temperature from the baseline year (2014).

To facilitate comparison between the Kantar-based wood fuel use estimate reported here and the DUKES residential wood use estimate, two sets of calculations have been done. The first is that the DUKES estimate, which is given in tonnes of oil equivalent has been converted to Gigajoules by multiplying by 41,868[25], and then to tonnes by dividing the Gigajoules total by the Gross Calorific Value (GCV) for domestic wood in 2018, which was 16.3[26].

The second is that the Kantar-based estimates have been re-calculated so as to show weights in tonnes that are equivalent to wood at 20% moisture content[27] as this is the underlying moisture content assumption in the DUKES wood fuel estimate[28]. This has then been multiplied by the Net Calorific Value (NCV) for wood at 20% MC of 14.7 (see appendix 7.4 for sources) as the Defra quantification approach used NCVs.

A comparison between energy values in kWh (gross) is also provided as this requires less application of assumptions (for example on moisture contents) than the conversions between energy and mass described above. The results of the conversion of all wood

[25] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/840015/DUKES_2019_MASTER_COPY.pdf

[26] From: https://www.gov.uk/government/statistics/dukes-calorific-values (Note -- these are updated every year, but the 2018 and 2019 domestic wood GCVs were the same.)

[27] What this report refers to as ‘seasoned wood’.

[28] Moisture content (MC) indicates the percentage of the mass that is due to water in comparison with its total mass. To calculate those weights that were not at 20% MC, it was necessary to convert them first to oven dried weight (0% MC) by taking off the percentage of the weight which is water and then converting the oven dried weight to 20% MC, using the following equations:

(a) *oven dry weight = initial weight – (MC of initial weight X initial weight)*
(b) *weight at 20% MC = oven dried weight X 100/80*

categories to 20% moisture content in relation to tonnes are provided in Table 4 below. Overall, this has led to a small reduction in the total figures for wood fuel consumption in comparison with Table 1 (above), which included wood of different moisture content: the quantity of wood consumed indoors decreased from 1.74 Mt (at mixed moisture content) to 1.73 Mt (at 20% moisture equivalent) and the quantity consumed outdoors fell from 0.70 Mt to 0.67 Mt. Combined, this standardisation of the moisture content means a reduction in our estimate for all wood consumed domestically in 2018-19 of <0.01 (0.0034) Mt, from 2.41 Mt to 2.40 Mt[29].

Table 4: Defra UK wood fuel estimates for 2018-19 at 20% moisture content (MC)

Solid Fuel	Indoor estimate at 20% MC (tonnes)	Outdoor estimate at 20% MC (tonnes)	Total estimate at 20% MC (tonnes)
Wood logs (pre-dried)	290,615	12,312	302,927
Wood logs (seasoned)*	798,239	22,021	820,260
Wood logs (wet)	326,233	21,683	347,917
Wood briquettes	40,811	6,337	47,148
Wood pellets	63,342	3,093	66,435
Wood chips	14,834	6,822	21,656
Waste wood	199,517	596,937	796,454
WOOD TOTAL	*1,733,590*	*669,205*	***2,402,795***

*This includes 0.07 Mt of wood burned indoors for which respondents did not know the seasoning.

Table 5 below compares this adjusted estimate for wood fuel use above, using the Kantar data and the quantification method described in this report, with the DUKES estimate for 2018. What this shows is a significant difference between the two estimates for UK annual wood fuel consumption for similar periods[30]. The DUKES estimate for 2018, when converted from tonnes of oil equivalent units to gigawatt hours is 26,063 GWh (gross) for domestic indoor wood fuel burning whereas the Kantar-based estimate is 10,886 GWh (on a gross basis) for indoor and outdoor burning. This is 58% less than the DUKES estimate.

[29] Differences due to rounding.
[30] The periods are similar, but not the same: Defra's estimate is for April 2018 to March 2019, whereas DUKES is for the 2018 calendar year. The possible implications of this are discussed later.

The difference in tonnes - 5.76 Mt (GCV) for the DUKES estimate, and 2.40 Mt (NCV) for the Kantar-based estimate – is very similar.

Table 5: Comparison between the Kantar-based and DUKES domestic wood fuel use estimates

	Kantar-based estimate	DUKES estimate (2019)
Year	2018-19	2018
Original units	kWh net	2,241 kilotonnes of oil equivalent (ktoe) gross
Converted to kWh gross	10,885,519,970 kWh (gross)**	26,062,830,000 kWh (gross)***
Converted to tonnes	2.40 Mt****	5.76 Mt*****
Assumed moisture content of tonnes	20%	20%

* In DUKES 2020, this has increased by 2.2 ktoe.
**This is equivalent to 9,817,002,672 kWh net (7,082,788,528 kWh indoors and 2,734,214,144 kWh outdoors). To convert to gross for comparison with the DUKES kWh estimate, this is divided by 14.7 NCV gross and multiplying by 16.3 GCV.
***1 ktoe = 11,630,000 kWh (DUKES 2020 standard conversion factors from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/924591/DUKES_2020_MASTER.pdf). This gives 26,062,830,000 kWh for 2,241 ktoe gross.
****Of which approximately 1.73 Mt burned indoors and 0.67 Mt outdoors as in Table 4.
*****This is based on wood burned indoors only.

4.1 Potential sources of difference between Kantar-based and DUKES domestic wood fuel use estimates

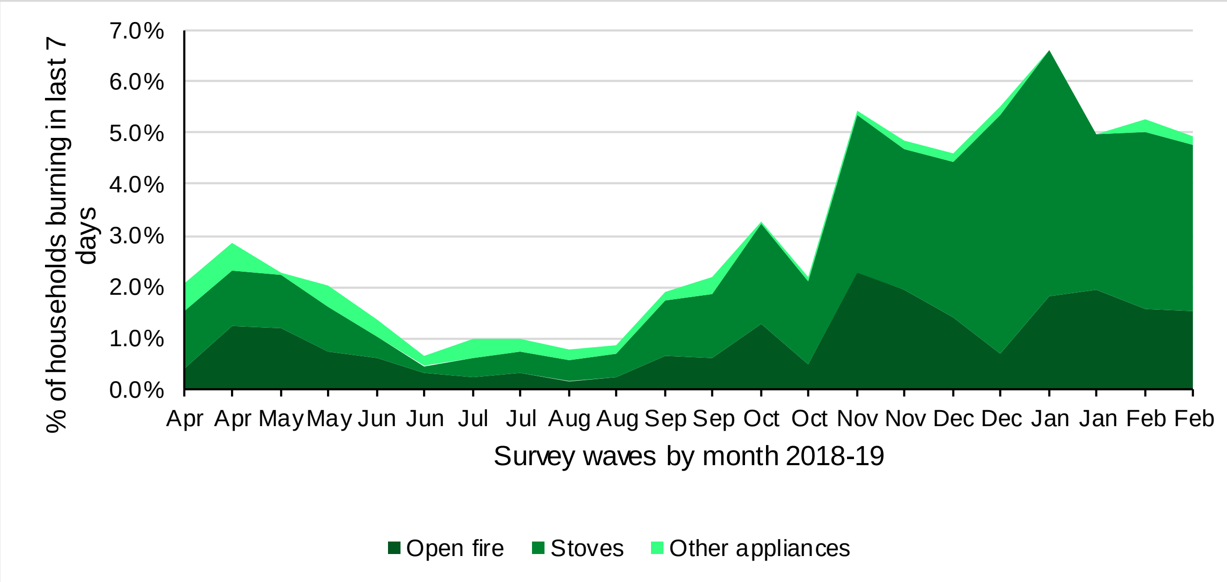
There are a number of differences between the data used, the methods adopted and the assumptions made to produce the DUKES and Kantar-based estimates that are likely to have an impact on the results and could explain the differences between the two. These are largely related to differences in the questionnaire design of the DWUS and Kantar surveys that informed the estimation methods adopted. The design of Kantar's core activity survey was based on learning from the DWUS in collaboration with BEIS.

Some of the differences identified are qualitative in nature (in the sense that it is not possible to quantify their potential impact) and a couple may narrow the gap between the estimates rather than explain the current size of the difference. These are mentioned later in this section, but we start by looking at the factors deemed most likely to explain why the Kantar-based estimate is lower than that of DUKES, based on the evidence available.

4.1.1 The proportion of UK households that burn per week

Whilst the Kantar research found that the proportion of households in the UK burning solid fuels in the year prior to being surveyed was 8.0%[31], on a weekly basis this proportion was lower, particularly in the early summer months). This is illustrated in Figure 1 below, which shows that in the summer period of later June to August 2018, the incidence of indoor burning was 1% or below. Even at the peak winter period in late December/early January, it was about 6.5%[32].

Figure 1: Incidence of indoor burning from April 2018 to Feb 2019, showing which main appliances were used



The average number of hours of appliance operation each week appear to be a little higher according to the Kantar data than the DWUS for both winter and summer[33] (see section 3.1.6 later). However, the Kantar data presented above suggests that throughout the year only a proportion of in-use appliances[34] were lit in a given week, with the

[31] This is similar to the DWUS figure of 7.5% for households that burned wood fuel, although the percentage for wood fuel users is 6.9% in the Kantar study. The questions to determine incidence were a little different: whilst the Kantar research took place in 2018-19, it asked a retrospective question about burning in the last year to determine incidence; the DWUS question which determined incidence asked about burning more generally.

[32] The question on whether someone who said they had burned in the last year had burned in the last week was asked every wave of the Kantar omnibus survey (approximately every 2 weeks over a 10.5 month period) of a different nationally-representative sample (so different respondents each time).

[33] When using the DWUS parameters for winter (21 weeks) and summer (31 weeks); the DWUS-based quantification identified only two seasons in the year.

[34] Which are nevertheless used.

percentage higher in winter than in summer. This may suggest that DWUS respondents who gave responses on weekly hours of usage in a season may have overestimated their use and/or not adequately accounted for periods when they did not use their appliance. These differences in appliance usage between the findings of the two surveys are likely to be a very significant source of difference between the wood fuel consumption estimates they have provided.

4.1.2 What is burned in the appliance when it is lit

Another potentially important reason for the difference in estimates is that the quantification method applied to the DWUS findings, which provides the baseline residential wood use estimate for the DUKES method, assumes that all of the heat output from the hours a stove is lit are due to the burning of wood. The Kantar-based method, meanwhile, apportions a proportion of the appliance running time to each of the solid fuels burned. Both the DWUS and the Kantar surveys found respondents who burned both coal and wood: 31% of DWUS indoor wood burners said they also burned some form of coal, and Kantar's CAS data suggests 25% of indoor burners had burned both wood/waste wood and coal in the week prior to being surveyed[35].

The Kantar core activity survey findings are given in Table 6 below, although it is important to note that this table is about the proportion of respondents who burned in the last week who reported burning those solid fuels and not the quantities of those solid fuels they burned (those mixing fuels may systematically burn in greater or lesser quantities than those sticking to one fuel, for example).

Table 6: Proportion of CAS respondents who burned different fuel combinations in the last week

Proportion of respondents who burned solid fuels in the previous week	Weighted %
% who burned wood fuel (including waste wood) only	58.4%
% who burned coal of any type only	12.5%
% who burned wood and coal (including other fuels)	25.0%
% who burned other combinations of fuel used[36]	4.2%

[35] In the PiT, 45% said they burned wood or a wood mix at least occasionally. However, unsurprisingly, given this, it seems the figure for the CAS in terms of burning coal and wood in the last week is lower.
[36] Wood and other fuels, coal and other fuels, and other fuels only.

It is clear therefore that some people are burning both wood and coal on their appliance, and it is likely this is often on the same fire. The exact quantities and therefore contribution this makes to the emissions from coal is a recognised challenge to quantify. However, the Kantar-based study suggests that 58% of the estimated hours of burning in the UK is attributed to wood, 41% to coal, and 1% to the other solid fuels identified (Table 7 below) with only 12.5% burning coal-based solid fuels exclusively (Table 6).

The contribution of coal to burning and the resulting emissions becomes more evident when the conversion to kWh is taken into account, because of the energy intensity of coal. Once this is taken into account, the Kantar-based quantification suggests that 52% of the estimated kWh of energy use indoors is attributable to wood and 47% to coal (see Table 7 below). It is likely therefore that the incorporation of the coal burned by those who burn both wood and coal within the Kantar-based method is a significant source of difference between the two estimates.

Table 7: UK estimates of hours of burning indoors & kWh in 2018-19 by main category of solid fuel

Solid fuel type	Number of hours of burning indoors*	Proportion of indoors hours total	kWh indoors	Proportion of indoor kWh total
Wood	656,611,381	58%	7,082,788,528	52%
Coal	468,492,827	41%	6,417,457,927	47%
Other	8,824,624	1%	119,775,944	1%
TOTAL	1,133,928,833	100%	13,620,022,399	100%

* The percentage of wood burned to coal increases if taking account of the outdoor component (approximately 60% wood to 40% coal). The Kantar survey suggested very little coal is burned outdoors.

It should be noted that the Kantar-based quantification of the UK annual total usage for coal and coal-related solid fuels, though relatively similar to coal usage in 2018 reported in DUKES 2019[37] (which is seen as relatively reliable) is 16% higher[38] (see section 3.2 below). Therefore, Defra may be overestimating the contribution of coal to the hours of burning, though probably to a small degree, and this may also contribute to the lower estimate for wood consumption produced as a result.

[37] DUKES 2020 has been published since the analysis was done, and any changes to the 2018 figures as a result of updates are not accounted for in these comparisons.
[38] This does not account for any temperature correction to align the periods of the two quantifications (see section 3.1.7).

It should also be noted that the sensitivity analysis conducted on the quantity results suggested that they were particularly sensitive to the moisture content assumptions for wood logs (see methodology section for what assumptions were used). The proportion of wood logs that were assumed to be burned wet indoors was 26%; this was based on responses from households that had mainly burned wood in the previous week that had been seasoned for a year or less; the assumption made in the estimation was that this had a moisture content of 30%. However, the proportion of wood logs that was assumed to be burned very dry because they were bought or got pre-dried was 18% and this had an assumed moisture content of 10%. Waste wood was assumed to have been seasoned and have a moisture content of 20% as there was no Kantar data on which assumptions could be made about how dry or wet it generally was when burned.

4.1.3 The proportion of wood fuel burners in the UK population

Table 1.1 that is published as Annexe B alongside this report uses data from the Kantar CAS survey, together with 2018 data on household numbers, to reproduce Table 1.1 that was published as part of the outputs from their DWUS project. This shows that 6.9% of the sample weighted to the UK population burned wood fuel in the year prior to the research being conducted (April 2018 to February 2019). The DWUS, covering autumn 2013 through '14, found that wood fuel users made up 7.5% of the sample.

Because the UK has seen a small growth in the number of households since the DWUS in absolute terms the 7.5% and 6.9% equated to a similar number of households: c. 1.9 million and 2.1 million respectively. This difference in the calculation of the total number of UK wood fuel burning households might underpin some of the difference between the Kantar-based and DUKES estimates, although not directly as neither quantification method simply grossed results by the estimated number of UK burner households. The DWUS results for all appliance usage in kWh over 2014 was grossed by multiplying by the 2014 estimate for UK household numbers divided by the number of survey respondents, whilst the Defra quantification method used the survey weighting to calculate the percentages who burned which was then applied to the UK household projection. It is therefore not clear how significant this potential source of difference may be, if at all.

4.1.4 The number of appliances used overall and within a household

In order to estimate domestic wood fuel use for DUKES each year, data on appliance installations and capacity, as well as heat days are used to adjust the baseline provided by the DWUS. The assumption made is that most new appliance sales are new installations, although there is also an assumption for replacement rates. With approximately 120,000 appliances (largely stoves) estimated to be sold each year since 2014, this has led to an increase in the DUKES estimates of the quantity of wood burned in homes in each of the subsequent years.

The Kantar data itself is not able to provide any direct evidence for or against this assumption. However, analysis of the English Housing Survey (EHS) data from 2003 to 2016 undertaken as part of the Kantar-led research project does suggest that whilst there was an uplift of 1.3 percentage points in appliance ownership of stoves and open fires within the English population over those 13 years (from 13.4% in 2003 to 14.7% in 2016), the main change has been a shift in the appliance mix from open fires to closed stoves.

Ownership is not the same as use, however. Analysis of the 2011 Energy Follow-Up Survey (EFUS) also undertaken as part of the Kantar research project indicates that a fifth of households were not using their appliance(s) in 2011 (c.9.5% used them when c.12% households were recorded in the EHS that year as owning at least one burning appliance in the same year). The figures on incidence of appliance usage from the EFUS, BEIS and Kantar are not directly comparable, because the focus and questions are a little different; however they suggest that the percentage of households using burning appliances indoors have remained relatively stable and may even have declined to a little extent since 2011.

This could be interpreted as indicating that many new stove installations are replacements for existing burning appliances that were being used, in particular open fires, rather than additional installations. Therefore, it is possible that a potential source of some of the difference in estimates between the two methods is due to the assumption that new installations represent additional appliances. However, it is also possible that many of the new installations identified through new appliance installation figures are actually new stove installations within existing burner households that are increasing the number of appliances on which they burn and are therefore indeed additional.

There is no direct evidence that is able to definitively support either position. However, the DWUS did ask about all appliances a respondent used indoors in their home, including of the same type (for example, when a household used two or more open fires). Their findings suggest that on average a household that burned wood fuel at that time used 1.05 appliances, although this did include some appliances that were not used during the period the survey covered (14% of all the appliances identified). Of those appliances that were used during the period the survey covered, 9% were second, third or fourth appliances (open fires or stoves) in the same household.

The more recent Kantar research found through the point-in-time burner survey that 10% of respondents did (at least sometimes) use another type of indoor appliance too (though the options mostly did not provide the possibility for the respondent to include an appliance of the same type). This could suggest that the average number of burning appliances being used per household is increasing, at least to a small extent, in support of the assumption that at least some of the new appliances are new installations. However, the evidence is not conclusive, and what there is appears to be more supportive of the supposition that many new installations are replacements for existing appliances that are in use with only some additional to the existing number of appliances already being used in the UK.

In terms of questions on appliance running time and the quantities of fuel used, the Kantar core activity survey (CAS) focused on the usage of the main appliance the respondent said they used in the previous week, and not on any additional appliances they may have used. Respondents were therefore not asked about the usage of such additional appliances and therefore the use of secondary burning appliances is not factored into the Kantar-based quantification of wood fuel usage.

This may be a source of some underestimation within the Kantar-based domestic wood use results from the quantification method reported here, and therefore may have contributed to the differences in estimates seen, although it is not known by how much because it would depend on how much a household used any additional appliances. Defra's assessment is that it is unlikely to be a significant source, given the data available and expert advice. The steering group suggested that secondary burning appliances were unlikely to be used frequently, which is why it was felt acceptable for the core activity survey to focus on the main appliance.

4.1.5 The UK appliance mix in use

Linked to the above, it is possible that there are underlying differences in assumptions about the UK appliance mix between DUKES and the Kantar-based quantification which have also contributed to the difference in estimates. Modern stoves tend to be more efficient and use less wood per hour than older stoves, and be much more efficient than open fires.

The percentages of appliances used (including secondary appliances) from the DWUS, which underlie the quantification that informs DUKES were 44% open fires, 52% closed stoves, and 2% all other appliances. However, as mentioned, the calculation of the DUKES wood fuel estimate also incorporates additional appliances installed since the 2014 baseline provided by the DWUS (accounting for average kW capacity). This will have changed the appliance mix that underpins the 2018 DUKES estimate and probably shifted it towards closed stoves, although it is not clear what the current mix is.

The UK appliance mix inherent in the Kantar-based estimate presented in this paper is based on the CAS data on main appliances used in the last week: 32% were open fires, 60% closed stoves (two-thirds of which were newer, modern stoves[39]), 1% biomass boilers and 7% other appliances (when excluding the 4% of respondents who did not know what the main appliance used was). However, the results of the quantification method (see Table 5.1 in Annexe B for quantities burned in two main appliance categories) suggests the proportion of the wood fuel burned in this appliance mix was a little different, with 26% of wood (including waste wood) burned on open fires, 68% in stoves, and 6% on the other appliances.

It is feasible therefore that differences in assumptions in the two methods about the UK appliance mix may be a source of difference between the two estimates. However, with

[39] Meaning these appliances were installed after 2009, and the efficiencies for stoves up to 5 years in age from the BEIS DWUS quantification were applied in the Defra quantification.

the incorporation of new installations as part of the DUKES method, it is probable there is not a large difference in the underlying appliance mix assumptions. Moreover, it is not clear whether the nature of any difference would contribute to increasing or decreasing the gap between the estimates.

4.1.6 The mean number of hours per week an appliance is lit

The estimation method based on the DWUS used the results of a question asking about average weekly appliance running time during the winter and summer respectively in the autumn 2013 to '14 period, based on 7 pre-defined options[40]. The Kantar-based estimation method uses survey data about hours of use of the main appliance in the previous week as reported by the respondents sampled in each survey wave. This was not categorised into ranges but used as given. In consultation with the Steering Group, it was felt that the latter approach was likely to elicit more accurate information because it does not ask an individual to generalise across a whole season; instead it asks about the actual hours of usage the week before they were surveyed.

Though the questions and their approach are rather different, the appliance running time data from both can be used to provide average hours of burning in a week in a particular season, which whilst not completely comparable, provide a sense of whether there are differences in hours that might help to explain the difference in estimates. The DWUS estimation result is based on survey data that suggested the peak burning season was of 21 weeks' duration over the winter, and the summer season, which had fewer average hours of burning, lasted 31 weeks of the year. The average hours of use per week per appliance according to the DWUS was 22 hours in the winter and 10 hours in the summer.

Table 8 below divides the Kantar core activity data on appliance running time into four seasons of 3 months each[41]. The average (mean) hours of use per week for the 2018-19 period was 28 hours in winter, 15 hours in spring, 9 hours in summer and 21 hours in autumn. Overall, this suggests that the average hours of burning reported in the Kantar survey are higher, not lower, than that of the DWUS and therefore appliance running time does not on its own appear to be a cause of the lower Kantar-based domestic wood fuel estimate.

However, similar to point 3.1.1 above, what this table indicates in the columns showing percentages are the average proportions of burners[42] who burned indoors the previous

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[40] The options given were: over 80 hours per week; between 41 and 80 hours per week; between 21 and 40 hours per week; between 12 and 20 hours per week; less than 12 hours per week; never; and don't know.

[41] The seasons were classified as Spring = Feb-Apr, Summer = May-Jul, Autumn = Aug-Oct, Winter = Nov-Jan. This does require using data from April 2018 with February 2019 to provide the spring data, which is also missing any data from March 2019. This means that the spring data will not be fully representative of spring 2019.

[42] Burners are those who said they had burned at home in the last year.

week during that season: 61% in the winter, 19% in the spring, 7% in the summer and 33% in the autumn. Therefore although the average hours of those who did burn in the previous week appear to be higher in the CAS, the number of those who are burning those average hours are much lower.

Table 8: Mean number of hours indoor burners burned and proportion of indoor burners that burned on that day during the last week by season (mean and % of indoor burners)

Day	**Spring**		**Summer**		**Autumn**		**Winter**	
	Mean	%	Mean	%	Mean	%	Mean	%
Monday	2.1	12%	0.9	2%	2.7	21%	3.7	42%
Tuesday	1.6	10%	0.8	2%	2.7	20%	3.7	43%
Wednesday	1.7	11%	0.8	2%	2.6	20%	3.6	41%
Thursday	1.5	10%	0.7	1%	2.7	20%	3.7	42%
Friday	1.5	9%	1.1	3%	2.8	20%	3.9	43%
Saturday	1.5	9%	1.1	3%	3.3	24%	4.5	50%
Sunday	1.7	10%	0.9	2%	3.3	23%	4.5	49%
Total	**15.1**	**19%**	**8.7**	**7%**	**20.8**	**33%**	**27.9**	**61%**

4.1.7 The period that the estimates cover

Another credible source of difference in the estimates is that the periods covered are slightly different. The DUKES estimate is for January-December 2018, whereas the Kantar-based estimate is for April 2018-March 2019. There was an unusually cold spell in March 2018 which likely impacted on appliance usage (certainly the Kantar qualitative interviews suggested as much) and may be a reason that the DUKES estimate is higher. BEIS has indicated that it did lead to quite a significant increase in the 2018 wood fuel estimate from the baseline and appliance adjustments. However, Defra is unclear how big an effect applying temperature-corrective methodology to account for this period would have on the quantity estimates produced based on the Kantar data.

4.1.8 Differences in regional indoor wood burning incidence rates

There are differences in the regional wood-burning incidence rates[43] that the two surveys provided (see Tables 1.1 in Annexe B) which might also be a source of difference in the estimates based on the two sets of data, although it is not known what the impact of this is. The estimated quantities of wood fuel burned indoors by region are available in Table 4.1 in Annexe B, but there is no equivalent for comparison in the published results of the DWUS.

5. Comparing domestic coal estimates from Kantar-based and DUKES methods

The main focus here is in the comparison of the total estimates for coal, including coal-based MSFs, given in Table 9 below. Whilst relatively similar – the Kantar-based estimate is 0.88 Mt as opposed to the DUKES estimate of 0.76 Mt – the Kantar-based estimate is 0.12 Mt more than DUKES and therefore 16% higher.

Table 9: Comparison between Defra and DUKES' coal estimates

Kantar-based estimate[44]: 2018-19 (tonnes)			**DUKES estimate[45] for 2018 (tonnes)**	
House coal	357,000		**Steam coal**	327,000
Smokeless	424,000		**Anthracite**	191,000
Briquettes	97,000		**Manufact. solid fuels**	240,000
TOTAL	***878,000***		***TOTAL***	***758,000***

The reason for the focus on comparing the total estimates for all coal-based domestic use is that the sub-categories for types of coal-based solid fuels used in the CAS are different to those in DUKES. In DUKES, there is a general category for coal that includes anthracite (a naturally-occurring smokeless coal) and steam coal as sub-categories. Steam coal

[43] The percentages of the population in a specified area estimated to burn indoors.

[44] Net calorific values for different categories of coal were used in calculating this quantity (see Appendix 7.4).

[45] This is based on actual quantities reported by the industry.

covers a variety of other types of naturally-occurring coal, including house coal – or bituminous coal as it is also called – which was one of the three sub-categories for coal in the Kantar survey. The Kantar survey did not specify anthracite. It is assumed most of those burning anthracite will have classified it as smokeless.

DUKES then has a separate category for manufactured solid fuels (MSFs), which are largely presumed to be coal-based. A lot of coal-based MSFs are smokeless, but not all. Again the Kantar study did not have a category for MSF as it was not a term that the qualitative research suggested is used by burners, but instead picked up on the usage of terms such as briquettes (or ovals or ovoids). However, as Table 9 above indicates the estimates for briquette usage is small, so it is assumed that the majority of those burning a smokeless MSF will have categorised it as smokeless. Generally what this means is that although at an overall level the Kantar-based and DUKES estimates are comparable, at sub-category level they are not (or not directly).

There is relative confidence in this overall total for coal from DUKES, given domestic coal usage is easier to assess from sales data than wood, although BEIS is collecting data to update the split between different coal-related sub-categories. There are a number of possible reasons for what may be a relatively small over-estimation arising from the Kantar-based quantification. However, it is not known which – if any – are significant:

- Individuals may have over-estimated the weight or number of buckets of coal they used in a week which impacted how the hours of usage were apportioned to different fuels in Defra's quantification.
- The aggregation approach (the same as used for all the solid fuels, including wood and waste wood) used to gross up to UK households exacerbated over-estimation at respondent level.
- The use of the NCV for manufactured solid fuel for all the smokeless solid fuel category, given anthracite (which has a different NCV) was not specified.

It is also important to note, as already mentioned, that the periods that the two estimates cover are different, and that the DUKES estimates include the period that was known in the media as the 'Beast from the East'. If temperature corrective methodology is used to allow the Kantar data to be applied to 2018, it is possible that Defra's coal consumption figure would go up further.

6. Conclusion

In summary, the quantification of UK solid fuel use in homes and gardens in 2018-19 based on the Kantar data has produced an estimate of domestic coal consumption that is a little higher than DUKES estimate for 2018, and one which is a lot lower for wood. The 0.88 Mt of coal the Defra quantification has calculated is 16% higher than the DUKES estimate for 2018, and may be an overestimate, given relative confidence in the DUKES total estimate.

The Kantar-based estimate for wood fuel consumption for domestic burning (indoors and out) for 2018-19 is 10,886 GWh (gross) (or 2.40 Mt [NCV] when converted to tonnes). This is 58% less than the DUKES estimate for 2018, which when converted from tonnes of oil equivalent units is 26,063 GWh (gross) for domestic indoor wood fuel burning (or 5.76 Mt [GCV]). There are a number of potential reasons for this difference in the estimates. However, based on the evidence available, Defra believes that the key ones are:

1) An assumption built into the baseline for the DUKES estimate, based on the DWUS, that the average weekly hours of appliance operation for winter and summer is applicable to all appliances used over the year: data from Kantar's core activity survey suggest only a proportion of burners burn at a given time of the year, even when domestic burning peaks in the mid-winter.
2) The account taken in the Defra estimate of the coal that was burned on some appliances that also burned wood in the previous week: the quantification done based on the DWUS assumed that all the hours of appliance use could be attributed to wood-burning, though the survey found that 31% of wood fuel users also used coal.
3) The fact that the 2018 DUKES estimate covered the significantly cold period called colloquially 'the Beast from the East': the CAS data on hours of burning and solid fuel used in the last week that is the basis of the Kantar-based quantification did not.
4) The annual uplift of the DUKES estimate due to appliance installation data based on the assumption that almost all are additional rather than replacement appliances: the evidence taken from the surveys on this is less clear than in other areas, but on balance it seems to point towards more appliance installations being replacements for existing burning appliances that are used than currently assumed within the DUKES estimate.

However, even with the evidence presented in this paper, it is difficult to quantify the extent the factors identified above have contributed to the difference in estimates. This is because the questions on the surveys that are the sources of the data for the quantification that inform each estimate are often very different, and the approach to quantification as a result has also been very different. Therefore both the data used and the methods of arriving at the estimates are difficult to compare. As a result, there may be other differences in the data or the quantification approaches and the assumptions that underpin them that have not been identified but have contributed to the difference in estimates that have been produced.

Overall, Defra believes the Kantar core activity data is likely to better reflect current burning activity. This is because, building on the experience of the DWUS based on advice from BEIS, the questions on appliance running time and fuel usage were focused on the previous week to aid recollection and to prevent over-generalising. The data is also more recent, with a base sample size that is larger.

However, both surveys depended on the ability and willingness of respondents to accurately report what they did. In both the DWUS and the CAS, there were differences between participant estimates based on appliance running time and those based on solid fuel weights that may reflect respondent difficulties in reporting what they did accurately. Only a study which involved weighing all the fuel burned by representative burning households at different times of the year, and which measured the moisture content of the wood burned, would provide more certainty and this would be a very challenging and expensive study to implement.

The difference in estimates may also be due to challenges in converting the survey data into estimates. Both estimation methods require making a number of assumptions, which lead to some uncertainties. The assumptions used in the quantification method reported here are outlined in the methods section (Section 2) and the appendices.

BEIS will consider the results of this quantification and the explanations of the sources of differences between the resulting estimates reported here and those of DUKES to decide what changes, if any, they will make to the next update of DUKES in 2021 (covering 2020). They will publish their response in Energy Trends. Defra and BEIS will build on this study and continue to work together to develop and improve estimations of solid fuel use in this highly uncertain sector.

DUKES is the key source of activity data in relation to domestic burning and it is used to inform the National Atmospheric Emissions Inventory (NAEI). Changes in DUKES are likely to impact the NAEI but this study does not tell us how much by (or even whether results would be higher or lower).The other key variable in calculating emissions from different sources are the emissions factors that are applied. Defra is embarking on a project to update the emissions factors used to calculate emissions from residential burning to better reflect the nature of the solid fuels and appliances used both currently and into the future, and in order to evaluate the impact of the new solid fuels legislation.

As a result of not yet knowing (a) whether the DUKES estimates will change next year in response to the results of the quantification method reported here, and if so to what extent, and (b) what changes, if any, there will be to emissions factors for domestic burning, it is also not yet known what the impact of Defra’s quantification work will be on the NAEI. It is therefore not yet clear what the implications of this work will be for estimates of emissions from the UK residential sector. However, it is clear that UK residential emissions from domestic combustion will continue to be a major contributor to the UK emissions of particulate matter.

7. Appendices

7.1 Defra UK domestic solid fuel quantification – Quality Assurance

Date: 27/10/2020

Disclaimer

In the interest of removing bias in the quality assurance process, the assurer was not given any additional documentation (for example, information on preliminary work; references for third party data used, etc.) for the analysis beyond the R script and the raw datasets required to conduct the analysis. Therefore, any concerns and recommendations raised regarding the analysis as part of the quality assurance process were based on the R script and raw datasets alone. Any work that had been undertaken prior to this analysis to obtain the most appropriate data and methodology was not considered in the quality assurance process.

Statement/Summary

The analysis is asking a straightforward question: what is the amount of solid fuel of different types that was burned in UK domestic homes and gardens in 2018-19. The analysis estimates the extent of domestic solid fuel use across the entire UK, extrapolated from responses of over 46,000 people in a professional survey (the core activity survey) conducted by a third party (Kantar). The survey asked a different representative sample every 2 weeks over the course of nearly a year whether they had burned indoors and/or outdoors in the last year, and if so whether they had burned in the last week, and if so how much of each solid fuel they had burned and how many hours their main appliance had been lit for.

The use of quality survey data is recommended for answering the analysis question because of the informal and particular nature of domestic burning habits from home to home. For example, it is difficult to obtain accurate information on the quantity of wood used for domestic burning through sales data alone due to the fact that some people use wood they have collected for free. However, there are general limitations involved with using proxy data such as surveys as evidence in analyses due to the prevalence of inaccurate or ‘Don’t know’ responses.

In regards to this analysis, particular limitations of this survey include the fact that some respondents did not know the weight of fuel burnt in kilograms, and that respondents could not be asked how long they burnt a certain weight of a particular fuel in their appliance directly[46]. As such, key information is distributed between different questions in the survey. These limitations complicate the analysis.

Multiple steps are undertaken to address these data limitations such as, formatting, standardising and scaling the data. Most of these steps are appropriate, but there are a few steps that rely on some fairly large assumptions (particularly those that gap-fill by imputing data based on similar responses in the survey) that could give inaccurate results.

The number of instances where data are imputed should be recorded for reference, and the method behind each manually created scaling factor should be double-checked to ensure that there are no unanticipated outcomes (e.g. Step 4, c)). In addition, values from third party sources are used to help standardise and scale the data. These values should be referenced and checked to ensure that they are appropriate. They should also be checked to ensure they do not have large upper and lower bounds which might cause a substantially large range of possible results in the output from this analysis. Finally, the results from this analysis should be verified against any similar analyses to ensure values are sensible.

This analysis is fit for purpose provided that:

- The methodology recommendations are addressed;
- Verification is undertaken by comparison of the results to similar analyses, for example.

Part 1: Background and Methodology (including assumptions)

Background

This analysis aims to use data from an extensive survey (n=46,729) of solid fuel domestic burning in the UK (the Core Activity Survey, conducted by Kantar for Defra from April 2018 to mid-February 2019) to calculate the UK quantities of different fuels burnt in different domestic burning appliances in order to improve domestic solid fuel burning emissions estimates for the UK.

[46] Respondents were asked two separate questions that focused on 1) how many hours their main appliance had been lit for on each of the days of the previous week, and 2) what quantity (in kg or as a bulk estimate [in buckets]) of each solid fuel they had burned in the previous week.

Methodology

Note: Assumptions are given a RAG rating for their anticipated impact on the results of the analysis. Green = no major concerns; Amber = there are shortcomings; Red = serious concerns.

Step 1: The overall weights (kg) of different fuels burnt were calculated and then multiplied by Net Calorific Values (NCV) to get the energy value for each fuel (in standardised units). This was done separately for wood and other fuels.

a) The amount of fuels burnt indoors were determined by:
    - Assigning 1 if response indicated explicit indoor burning or;
    - 1 if both indoor/outdoor indicated and month of survey is in winter (October – April) and;
    - If a valid response to the quantity burnt was given.
b) The energy value of fuels burnt indoors was calculated from the weight (kg or bulk density (BD) estimate) of fuel used given in the responses by:
    - Multiplying by the NCV specific to each fuel, where given weights (kg) of fuel used were given;
    - Multiplying by the BD-weight conversion factor, then the NCV where BD estimates of fuel used were given.

Assumptions:

i. NA responses for Smoke Control Area (SCA) are not SCAs – there may be cases where very new SCAs are missed, but this is unlikely.
ii. When unclear, burning is assumed indoors if burning is during winter months and the fuel is wood or coal.
iii. The NCV and BD conversion factors are appropriate for each fuel used.

Step 2: The number of hours of burning indicated per day in the survey were scaled to make them representative of the adult population and typical week in that year (by each: region, urban/rural classification, SCA, day of the week, and survey wave).

a) The number of hours respondents indicated burning for per day was multiplied by the:
    - Wave coefficient (number of weeks each wave represents);
    - Uplift scale (to get population-level estimates);
    - Weight (scaling factor accounting for oversampling in certain areas – theoretically 1 if representative of the population);
    - Non-response scaling factor (weight of responses who indicated any burning activity (including 'don't know' for hours) divided by the weight of responses who explicitly stated the number of hours of burning).
b) Scaled hours of burning per day were summed across rows to get a weekly value.

Assumptions:

i. Respondents' burning during the specific week asked about can be generalised over longer periods (using the wave coefficient).

ii. The uplift scaling factor is appropriate for each type of region (urban/rural; SCA/no SCA).
iii. Weights for respondents are calculated correctly using adult population estimates.
iv. Respondents who did not know how many hours they burnt for had similar patterns of burning to those that supplied answers in the same subset category (i.e. the non-response scaling factor is appropriate).

Step 3: The overall hours of appliance operation calculated in step 2 were proportionately assigned to each fuel based on the percentage energy use of each fuel (energy values were calculated in step 1).

a) For respondents that indicated only 1 fuel use (calculated in step 1), all hours were assigned to that fuel.
b) For >1 fuel:
    - For each response, the energy value of each fuel used was divided by the total energy value of all fuels used (% energy use).
    - The total number of hours of appliance operation was multiplied by the % energy use of each fuel to proportionately assign hours to different fuels.

Assumptions:

i. All hours of burning for respondents that indicated they used 1 fuel can be allocated to that fuel.
ii. The energy value of fuel burnt is proportional to hours of appliance operation using that fuel.
iii. Fuels were burnt in the main appliance of the home and not secondary appliances.

Step 4: The hours assigned in Step 3 were summed by appliance type in each category (region, source of fuel, seasoning behaviour, urban/rural classification, SCA), scaled to include the month of March, and poor/non-response in hours was accounted for.

a) Hours were summed by category (region, source of fuel, seasoning behaviour, urban/rural classification, SCA).
b) If no split by fuel was given in the response: for those non-responses, the proportion of hours a certain fuel was used was calculated using the proportion of hours that that fuel was used for across the whole dataset.
c) If the total number of hours given was different [less] than the sum of the hours of usage indicated by responses for each fuel: this proportion was taken and multiplied by the responses for each fuel (uplift).
d) To account for March, all hours (including the total) were multiplied by the March scaling factor.

Assumptions:

i. When there is no split of hours by different fuels, the number of hours that a particular fuel was burnt for are related to the proportional split between fuels as indicated by typical responses in the survey.

ii. The uplift is appropriate (i.e. the total hours indicated represents burning of other fuels not detailed in the survey, and is not due to inaccuracies in the response).
iii. The March scaling factor is representative of burning activity in that month.

Step 5: The hours were converted back to weights (kg) using a conversion factor to get: weights of different fuels burnt in different appliances in different regions over the course of ~1 year (April 2018-March 2019). Additional formatting of the dataset was undertaken to exclude unwanted columns and include other variables of interest through merging of datasets.

Assumptions:

i. The conversion factor (constant) can be applied to all fuel types equally.

Part 2: Recommendations and Questions

Recommendations – Methodology

- Each scaling factor created (as listed in the assumptions) should be double-checked for whether it is appropriate and whether it is doing what is intended. Particular regard should go into checking the Step 4 ii) assumption – that not only does it create an uplift for when total hours are more than the total of those split by fuel, but also whether there are any cases where the opposite is true.
- The number of cases where missing values are imputed based on similar responses in the survey should be recorded to make sure there are not too many instances that would lower confidence in the accuracy of the results.
- Assumptions about how the survey sample can be extrapolated to the population should be double-checked to ensure there is not too much generalisation for certain areas/time periods.
- Values taken from other analyses/sources should be double-checked to ensure that they are accurate and appropriate and references should be provided. For example, whether the NCV and BD conversion factors are applicable to the fuels indicated in the survey; are there a large range of values for a single fuel that could be used resulting in large upper/lower boundaries in the results?
- To calculate the `hours_unadj` variable in Step 2, rows of hours of burning for each day of the week in the survey are summed. These hours include -5 values (substituted in place of NAs). The inclusion of -5 values causes confusion: positive, valid hours could theoretically be summed alongside -5 values. At best, this would give negative values for the `hours_unadj` variable and could be filtered out (as is done later in Step 4). However, positive values could result in keeping some instances of an underestimated `hours_unadj` variable in further calculations. It is recommended to include some checks in the analysis to verify whether -5 appears alongside positive values in the R script to avoid underestimation in the `hours_unadj` variable (some checks have been done in the attached R script – see below).

Recommendations – R code

Note: an amended R script 'dc_v8_QA_TWP.R' has been produced which implements some of the recommendations below. The R script is broken down into steps which correspond to the steps outlined in the methodology, above.

- The script should be annotated with dates and authors (e.g. Analysis last updated on 01/01/2020 by Joe Bloggs). In addition, the time period which the data cover should be explicitly stated in the script.
- Superfluous lines of code should be removed (e.g. artefacts of previous versions of the analysis).
- The analysis should be broken down into obvious sections to aid comprehension (e.g. Step 1 etc.). Headings for each step should be created as annotations using '####' that can be navigated to quickly using the scripting tools in RStudio. For larger scripts, a single script should be created for each section with its own output that feeds into the next, etc.
- The code should be annotated fully to facilitate comprehension, especially steps in 'for loops', and new variables or columns as and when they appear (e.g. the 'zero' column; 'wavecoefficient'). Alternatively, a variable 'key' should be provided alongside the analysis. A 'key' would be especially useful in this analysis since many of the columns appear as 'q3' in the analysis and further interrogation is needed to understand what each refers to.
- New temporary variables should be created for each step in complex calculations (e.g. within the 'for loop' in Step 2).
- Create a new line for each new step in complex calculations to avoid lengthy and unreadable lines (e.g. within the 'for loop' in Step 2)
- In future analyses, new columns should be created within a dataset (or even a new data frame) when undertaking processes such as scaling instead of overwriting existing values in the dataset. This facilitates error checking and means the whole analysis does not need to be re-run if something goes wrong (e.g. within the 'for loop' in Step 4).
- Units should always be provided in annotations even if they are explicitly stated at the start of the analysis (e.g. kg).

Questions

- Are there any results from similar analyses that can be used to verify whether the results are at least in the correct range of values?
- In the survey, why weren't individuals asked to try and estimate the number of hours of burning of each fuel in each appliance type directly? If there were concerns about the accuracy of these estimations, they could have at least been used as a verification method.
- What work was done to ensure values taken from third party sources are appropriate, and can references be provided for them?

7.2 Response of quantification team

7.2.1 Methodology recommendations

a) Attribution of factors used in the quantification and keeping records of imputed cases

The QA rightly notes the need to be clear on where any factors used in the quantification approach that are drawn from external sources come from. This paper includes attribution of these sources, many of which are already used for the DUKES calculations, or are standard conversion factors. The choice of bulk density conversion units was based on a literature review that was conducted by Wood plc for the Kantar research project, with further review by the Steering Group (that is included in Appendix 7.3).

The scaling factor mentioned in Step 4ii) is accounting for a small percentage of respondents who indicated fuel use but could not provide a quantification. This can only increase the total appliance running time. Cases where this happens are not imputed directly; the valid responses for appliance running time are instead inflated to account for the quantification non-response. Overall this is less than 5% uplift in running time. It is not practical to publish the full set of non-response uplift figures because there is a different uplift for each combination of region, rural-urban classification, smoke control area status, and survey wave.

b) Appropriateness of scaling factors to UK households

The point raised in the QA to check that extrapolation to UK households is appropriate for each time period is a slight misreading of what the process is doing. The scaling is applied to the sum of all the waves with each wave being uplifted to account for several weeks of burning. We were conscious that the aim was to provide an annual total and therefore the running time is summed across all waves and then scaled up to UK household totals.

Contrary to the concern expressed in the QA about over-generalising the scaling factors, our main concern has been that our post-stratification of the data produces some strata with small sample sizes in unusual combinations of region, rural-urban classification and smoke control area status. We did not look in-depth to see if there was a more efficient stratification we could use (for example collapsing some of the categories with small sample sizes into some of the larger categories).

c) References to conversion factors and dealing with N/A values in the data set

Reference tables for NCVs and bulk density conversions are included in section 2; these were not available to the quality assurer. Error checking has been carried out to ensure that the coded N/A values were not treated as negative values in the calculation, but we *agree that the coding could filter these out at an earlier step to avoid confusion and potential for errors.*

We accept in full the recommended changes to the analysis script, and these do not impact on the final results.

In addition, it should be noted that a sensitivity analysis was conducted to explore the potential impact of a number of the key assumptions. As the final method used the appliance running times given by the respondents, these relate to indoor burning and so the sensitivity analysis is also limited to indoor burning. The analysis focused on the assumptions that were found to be most sensitive to change (other than assumptions that have a linear impact on the results). The two assumptions that had the greatest impact on the results were the choice of method to gross the sample up to the UK household total, and the moisture content assumption for wood logs.

7.2.2 Question design to facilitate the quantification approach used

This project has been advised by a Steering Group that includes experts on domestic combustion. Two approaches to quantification of domestic solid fuel use were identified with their assistance and this informed the design of the core activity survey:

1. *the appliance running time approach, which uses the hours a burning appliance is lit to calculate heat output per hour which allows for estimating the quantities of solid fuel used for that stove, where only one type of solid fuel is used*
2. *the weight-based approach, which uses estimates given by domestic solid fuel users of the quantities of solid fuels a domestic solid fuel user has burned*

The appliance-running time approach is usually seen as likely to provide more accurate results because hours of appliance usage is assumed to be easier for individuals to estimate reliably than the weight (or bulk) of different solid fuels burned. However, the appliance running time approach is not able to provide useful data on quantification where a solid fuel user is burning more than one type of solid fuel. The preliminary qualitative interviews with a diversity of domestic burners suggested that burning both wood and coal was relatively common, and this was confirmed in the surveys.

Therefore, as with the original BEIS study, it was decided to collect data for both hours of appliance usage and estimated weight of solid fuel use, but focus relevant questions on the burning a household had done in the last week rather than the last year, as it was thought this would help recall and provide more accurate estimates of both the period of appliance usage and of how much of each solid fuel was burned.

The BEIS study chose to use the appliance-running time data alone (average hours an appliance was lit in winter and in summer), as the assessment was that the household estimates for the weight of wood burned in the last year was too high. The initial Defra quantification used each set of data separately (the hours an appliance was lit and the weight of solid fuel burned) and compared results from the two approaches. Using respondent data from the last week, the weight-based approach produced lower quantities *figures than the hours, and having sense-checked them with the Steering Group, it was decided that the hours data was likely to be more reliable. However, it was also decided to use the weight data to apportion the hours of usage of the main indoor appliance by a household to the different solid fuels they said they had burned that week as otherwise it would not have been possible to attribute the resulting energy consumption calculated from appliance running times to the range of solid fuels being burned.*

The questions on the hours an appliance was lit and on the weights/bulk of the solid fuels used were asked separately because initially it was assumed that the quantification approach used would use one set of data or the other. However, given a quarter of the weighted sample burned wood and coal in the previous week, and that the qualitative interviews indicated this was probably on the same fire, it is not clear how a question that attempted to ask respondents to attribute the hours an appliance was lit to the quantity of a particular solid fuel would be feasible as it is unknown how those who burned more than one type of fuel would attribute hours to that fuel.

7.2.3 Verification of results

Defra is not aware of any survey data that is similar enough to the Kantar core activity survey to be able to verify the quantification results Defra has produced in that way. The nearest in terms of focus is the BEIS study, but as mentioned the approach that BEIS took was to ask about appliance and fuel usage over the last year, and therefore the data from the questions is very different, and the quantification approach therefore very different. The Stove Industry Alliance (SIA) ran a larger survey of burners[47] in 2018. However, the questions asked were based on the BEIS survey and therefore not comparable to the Kantar data for the same reasons as the above. Having said this, their reported results were much closer to the Kantar results[48].

As part of the Kantar research project, analysis was done by BRE of data on appliance ownership from the English Housing Survey from 2003 to 2016[49] to explore trends in ownership. However, that survey only provides information on the presence of solid fuel appliances, not their usage and so cannot be used for quantification of solid fuels burned. BRE also did some analysis on the 2011 Energy Follow-Up Survey[50], as part of this workstream, as this gives more insight into usage; however, again the nature of the reported data does not allow for any direct comparison with the Defra quantification. Another Energy Follow-Up Survey was completed recently, but the results have yet to be published. It is possible that there may be some data here that can be compared with the

[47] It is not known how representative the burners who participated were.
[48] These have not been published, but the SIA made a presentation on their analysis to Defra and to BEIS.
[49] https://www.gov.uk/government/collections/english-housing-survey
[50] https://www.gov.uk/government/statistics/energy-follow-up-survey-efus-2011

Kantar data, although again it is unlikely that there will be any that is directly comparable to the weekly data that has informed the Defra quantification.

Defra has sought out other information to sense-check the wood results, beyond the expertise on the Steering Group. This includes confidential wood industry reports on sales, and on the timber harvest and market; on-line retail consumer advice on how much wood to purchase for a winter season; and analysis of data from the black carbon network over a number of years that provides another means to monitor domestic burning[51]. The market data seems to support a figure for domestic wood fuel use that is much closer to the Defra quantification, although the degree of reported use of commercial wood fuel in domestic settings in the Defra quantification may be less than might be expected. There is a lot of uncertainty with all these data sources, however, and it is possible that some of the commercial solid wood fuel use that is attributed to domestic use is actually being used by the UK's hospitality sector (holiday lets, restaurants, pubs, hotels, campsites, etc). Depending on resourcing, this may be something that Defra will decide to explore in more depth in the future[52].

[51] Black carbon network data, used together with modelling, has broadly validated the NAEI PM2.5 estimates and mapping based on the DUKES wood use data. However, this particular analysis for Defra found that between 2009 and 2016 PM2.5 emissions from wood burning did not rise, possibly because of a shift from stoves to open fires. Defra has commissioned further analysis that will cover the period 2018-19 in order to provide another means of verification of the quantification results.

[52] Covid-19 has prevented any exploration of this possibility this year.

7.3 Bulk density conversion factors

Fuel	Bulk density conversion from volume to weight in kg (kg per 10 litre bucket)	Sources
Wood logs: 10% MC	3.28	Chopped log wood stacked (Fw) for 10% MC from Table 7 (page 7) from the FAO's (2015) Wood Fuels Handbook: https://roycestreeservice.com/wp-content/uploads/Wood-Fuels-Handbook.pdf. Assumption: 25% oak, 75% spruce based on information on commercial sales); converted to kg per 10 litre bucket.
Wood logs: 20% MC	3.49	Chopped log wood stacked (Fw) for 20% MC from Table 7 (page 7) from the FAO's (2015) Wood Fuels Handbook: https://roycestreeservice.com/wp-content/uploads/Wood-Fuels-Handbook.pdf. Assumption: 25% oak, 75% spruce based on information on commercial sales); converted to kg per 10 litre bucket.
Wood logs: 30% MC	3.90	Chopped log wood stacked (Fw) for 10% MC from Table 7 (page 7) from the FAO's (2015) Wood Fuels Handbook: https://roycestreeservice.com/wp-content/uploads/Wood-Fuels-Handbook.pdf. Assumption: 25% oak, 75% spruce based on information on commercial sales); converted to kg per 10 litre bucket.
Wood briquettes	5	Equated to wood (solid - oven dry) from Forest Research: https://www.forestresearch.gov.uk/tools-and-resources/biomass-energy-resources/reference-biomass/facts-figures/typical-calorific-values-of-fuels/ Note: the NCV used for wood briquettes assumes 10% MC.
Wood pellets	6.25	FAO (2015) Wood Fuels Handbook, Table 6 - Typical values of bulk density for selected wood fuels: https://roycestreeservice.com/wp-content/uploads/Wood-Fuels-Handbook.pdf. Forest Research (10% MC): https://www.forestresearch.gov.uk/tools-and-resources/biomass-energy-resources/reference-biomass/facts-figures/typical-calorific-values-of-fuels/

Wood chips	3.27	FAO (2015) Wood Fuels Handbook, Table 7 (average of 0% MC for spruce and 50% MC for oak): https://roycestreeservice.com/wp-content/uploads/Wood-Fuels-Handbook.pdf.
Charcoal	1.97	Environment Agency (2016) Material comparators for end-of-waste decisions, Materials for fuels: charcoal, Report – SC130040/R8: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/545578/Material_comparators_for_fuels_-_charcoal.pdf http://www.soliftec.com/fuelproperties.htm (300°C charcoal) Chapter 10 - Using charcoal (industrial grade but indicates this is often used for domestic also): http://www.fao.org/docrep/X5328E/x5328e0b.htm
Smokeless coal	8.79	Environment Agency (2016) Material comparators for end-of-waste decisions, Materials for fuels: coal, Report – SC130040/R9: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/545579/Material_comparators_for_fuels_-_coal.pdf http://www.soliftec.com/fuelproperties.htm
Coal briquettes	4.1	http://www.soliftec.com/fuelproperties.htm (soft coke hard briquettes)
House coal	7.27	ECN Phyllis2; https://www.ecn.nl/phyllis2/Biomass/View/958 Environment Agency (2016), Material comparators for end-of-waste Decisions, Materials for fuels: coal. Table 6.1: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/545579/Material_comparators_for_fuels_-_coal.pdf
Waste wood	6.93	FAO (2015) Wood Fuels Handbook, Table 7: https://roycestreeservice.com/wp-content/uploads/Wood-Fuels-Handbook.pdf. (0% MC for spruce and 50% MC for oak) Note that the NCV used for waste wood assumes 20% MC.

Green waste	2.48	WRAP data - Material bulk densities: http://www.wrap.org.uk/sites/files/wrap/Bulk%20Density%20Summary%20Report%20-%20Jan2010.pdf (Food and garden waste; Field work data: Material bulk density; Historical weighbridge data: Operational bulk density)
Rubbish	2.26	WRAP data - Material bulk densities: http://www.wrap.org.uk/sites/files/wrap/Bulk%20Density%20Summary%20Report%20-%20Jan2010.pdf (Drink cartons, mixed paper and card; Self-reported data: Material bulk density)
Peat	5.5	FAO - 9. ENERGY USE OF PEAT http://www.fao.org/docrep/x5872e/x5872e0b.htm (Sod peat, 35%M / Milled peat, 45%, Peat pellets/briquettes, 15%) Note the NCV used for peat assumes an MC of 30%

7.4 Net calorific values

Fuel	Net Calorific Value (NCV)	Source
Wood logs - 10% MC	16.86	Forest research (2013) for wood NCV (GJ/t) with 10% MC: https://www.forestresearch.gov.uk/documents/1953/FR_BEC_Calorific_value_vs_moisture_content_v20a_2013.xlsx
Wood logs - 20% MC	14.71	Forest Research (2013) for wood NCV (GJ/t) with 20% MC: https://www.forestresearch.gov.uk/documents/1953/FR_BEC_Calorific_value_vs_moisture_content_v20a_2013.xlsx Also DUKES domestic wood NCV for 2019: https://www.gov.uk/government/collections/calorific-values
Wood logs - 30% MC	12.57	Forest Research (2013) for wood NCV (GJ/t) with 30% MC: https://www.forestresearch.gov.uk/documents/1953/FR_BEC_Calorific_value_vs_moisture_content_v20a_2013.xlsx
Wood briquettes	16.85	Equated to wood NCV for 10% MC from Forest Research (2013): https://www.forestresearch.gov.uk/documents/1953/FR_BEC_Calorific_value_vs_moisture_content_v20a_2013.xlsx
Wood pellets	16.85	Equated to wood NCV for 10% MC from Forest Research (2013): https://www.forestresearch.gov.uk/documents/1953/FR_BEC_Calorific_value_vs_moisture_content_v20a_2013.xlsx
Wood chips	14.71	Equated to wood NCV for 20% from Forest Research (2013): https://www.forestresearch.gov.uk/documents/1953/FR_BEC_Calorific_value_vs_moisture_content_v20a_2013.xlsx Also DUKES domestic wood NCV for 2019: https://www.gov.uk/government/collections/calorific-values
Charcoal	14.71	Equated to wood NCV for 20% from Forest Research (2013): https://www.forestresearch.gov.uk/documents/1953/FR_BEC_Calorific_value_vs_moisture_content_v20a_2013.xlsx Also DUKES domestic wood NCV for 2019: https://www.gov.uk/government/collections/calorific-values
Smokeless coal	28.11	Equated to other manufactured solid fuels in DUKES 2019: https://www.gov.uk/government/collections/calorific-values
Coal briquettes	28.11	Equated to other manufactured solid fuels in DUKES 2019: https://www.gov.uk/government/collections/calorific-values

House coal	25.14	Equated to domestic house coal in DUKES 2019: https://www.gov.uk/government/collections/calorific-values
Waste wood	14.71	Equated to wood NCV with 20% MC from Forest Research (2013): https://www.forestresearch.gov.uk/documents/1953/FR_BEC_Calorific_value_vs_moisture_content_v20a_2013.xlsx Also DUKES domestic wood NCV for 2019: https://www.gov.uk/government/collections/calorific-values
Green waste	12.56	Equated to wood with 30% MC from Forest Research (2013): https://www.forestresearch.gov.uk/documents/1953/FR_BEC_Calorific_value_vs_moisture_content_v20a_2013.xlsx
Rubbish	6.98	Equated to municipal solid waste NCV (MC 30%) in DUKES 2019: https://www.gov.uk/government/collections/calorific-values
Peat	12.56	Equated to wood with 30% MC from Forest Research (2013): https://www.forestresearch.gov.uk/documents/1953/FR_BEC_Calorific_value_vs_moisture_content_v20a_2013.xlsx

7.5 Appliance age and property assumptions

The appliance heat outputs from the domestic wood use study (BEIS, 2016) were used in the calculations for the Kantar-based estimation, although these were put together for wood fuel burning rather than solid fuel burning more generally. This was because the steering group were not aware of any 'real world' data that might be more appropriate. This was adjusted to take account of the more limited data on appliance types and age within Kantar's core activity survey than in BEIS DWUS.

There was no breakdown of what the 'other' category (a category that included range cookers) comprised within the CAS, apart from biomass boilers. Since the percentages of biomass boiler usage was very small, this was integrated into the 'other' category for the purposes of this quantification and the typical heat output and efficiency assumptions from Table 2.6 in the summary results of the domestic wood use survey[53] were taken for pellet stove, manual boiler, automatic boiler and range cooker, and averaged to use for this 'other' category.

There was no age categorisation for open fires either and so again the typical heat output and efficiency assumption for open fires from Table 2.6 was used for this appliance category.

Respondents were asked for the age of their stove within broad time periods that equated to the closed stove efficiencies within Table 2.6 from the DWUS. In the DWUS all stoves of less than 5 years of age were assumed to be 70% efficient; given the DWUS was focused on the 2014 period and the Kantar study was conducted in 2018-19, this equates to the Kantar-based stove category of post-2009 stoves. Similarly the DWUS category of more than five years ago up to 15 years ago where stoves are assumed to have an efficiency of 65% equates to Kantar's category of 2000-2009 stoves, and the more than 15 years ago DWUS appliance age category where the stove is assumed to be 50% efficient equates to the pre-2000 stove category. For those who did not know the age of their stove, a weighted average across stove ages has been used of 65%.

These figures have been plugged directly into the code calculations in relation to each respondent, and therefore do take account of the appliance mix found in the Kantar study rather than the BEIS study, including in terms of the age of appliances. However as the average efficiency assumption of 65% for stoves of unknown age indicates, there is little difference in this aspect to the results of the DWUS.

The following table provides an overview of the age and appliance property assumptions used in this study, plus associated data.

[53] https://www.gov.uk/government/publications/summary-results-of-the-domestic-wood-use-survey

Table 10: Appliance property assumptions plus proportion of main appliances of each type

	Typical heat output (kW)	Overall efficiency assumption (%)	Solid fuel use per hour (kWh)	Proportion of main appliances used of this type**
Open fire	3	17%	17.6	32%
Closed stove	6	65%	9.2	60%
Other*	14	71%	18.5	8%

*This includes both biomass boilers (1%) and the other category (7%).

**These proportions exclude the 4% of weighted respondents who did not know.

7.6 Steering group terms of reference

Department
for Environment
Food & Rural Affairs

Domestic Combustion Research Steering Group: Terms of Reference

1. Aim of the Research

The domestic combustion research aims to capture and record attitudes and behaviours relating to domestic combustion. In particular, it seeks to collect activity data close to the point at which this takes place in order to record an accurate picture of domestic combustion activities in the UK.

The data obtained will serve to inform policy-making in this area by reducing current gaps in the evidence base and reducing the level of uncertainty relating to domestic combustion in the national emissions inventory.

2. Research Objectives

The specific research objectives are to:

2.1 Provide reliable data (at urban and rural level within each of the four nations of the UK) on the **type and quantity of material** being burnt and how this is being burnt;

2.2 Provide detailed understanding of **knowledge of and attitudes towards burning** at home;

2.3 Provide detailed understanding of the links between burning behaviours and **socio-economic factors** (e.g. fuel poverty);

2.4 Provide detailed understanding of **barriers to behavioural change** (e.g. costs, availability of alternatives, willingness/ability to switch to alternatives; awareness of issues, credibility of messages, and role of burning in the home);

2.5 Provide data on the change in burning practices over time (specifically, a comparison pre/post 2005 e.g. for those living in their own homes since that time).

3. Research Design

3.1 The research design has both qualitative and quantitative components;

3.2 Data collection is anticipated to last for one year in order to capture seasonal variations in domestic combustion behaviours;

3.3 The quantitative data is required to be robust enough to allow for breakdown by: key socio-demographic groups; region; urban/rural classification; presence/ absence of Smoke Control Areas (SCAs).

4. The Steering Group

The steering group will provide advice and governance to the project team, helping to ensure the project aims are met and the benefits of the project maximised.

The roles of the steering group are to:

- Act as a sounding board to advise on the design and delivery of the study;
- Monitor and supervise the progress of the project towards achieving its objectives, raising concerns as appropriate;
- Provide technical and professional expertise and challenge to ensure the achievement of project objectives;
- Identify areas where further technical work, advice or guidance is needed;
- Advise on policy implications and potential sensitivities around the findings;
- Advise on dissemination of the findings to maximise benefits from the research results.

5. Steering Group Meetings

- The project will run from February 2018 to March 2019.
- There will be an initial meeting at the outset of the project to finalise project design and methodology with contractors. We anticipate approximately three subsequent meetings to coincide with project delivery.
- Steering group meetings will be based in London. Where individuals are unable to attend we will arrange an alternative means of participation, such as teleconferencing.
- All discussion papers and agenda items will be available to steering group members in advance of the meetings.

6. Steering Group Membership

The steering group will be composed of representatives that can provide relevant technical, policy and industry expertise to support the successful achievement of project aims and objectives.