Experimental statistics on whole UK energy flow incorporating end use energy efficiency

Introduction

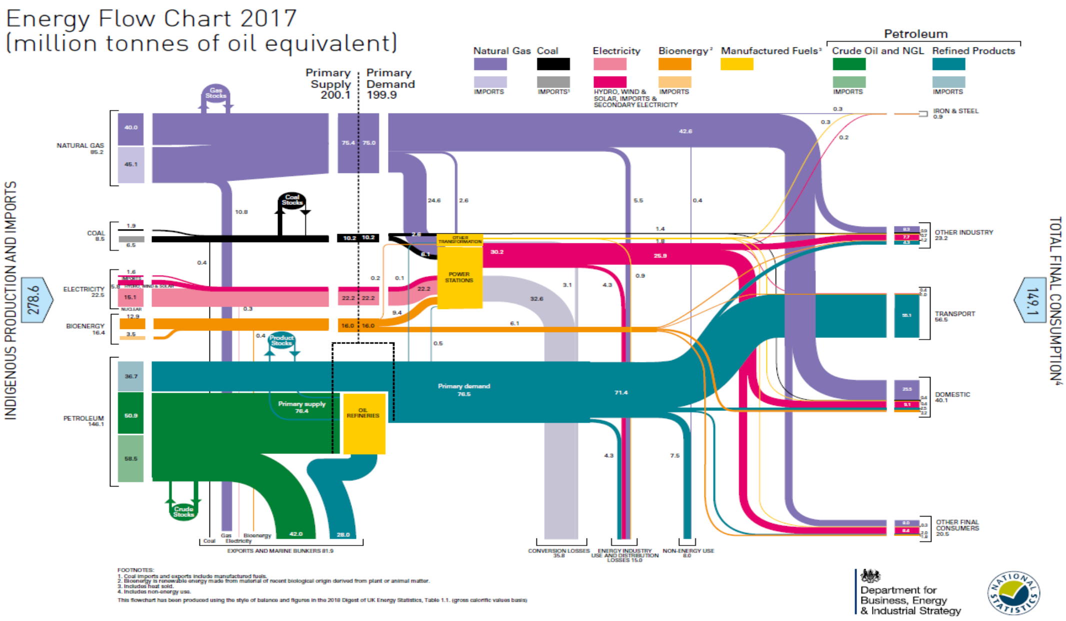
BEIS have published energy flow charts ('Sankey' diagrams) for over 40 years, most notably in the Digest of UK Energy Statistics[1] (DUKES). These provide a pictorial overview of the whole UK energy system, from supply through to consumption. The production of these charts is now common practice internationally, including [International Energy Agency](#) and [Eurostat](#).

Currently, nearly all charts in use worldwide do not take account of the energy efficiency once the energy has been delivered into consumption. A notable exception to this is the work carried out by the Lawrence Livermore National Laboratory (LLNL)[2] for the US which refocuses the flowchart to consider energy efficiency and not simply consumption. This article uses a similar methodology and assumption base to apply to the UK's domestic consumption. These are the first steps towards expanding the pictorial representation of energy efficiency in the UK, therefore feedback is welcomed.

Why are we doing this? Energy efficiency is energy saved

The existing energy flow charts published in DUKES provide information on energy supply through to energy consumption. As shown in Figure 1, supply (on the left) comes from production and imports. The supply for each fuel then flows to electricity generation, oil refineries, exports and marine bunkers, final consumption or stocks. This flow chart accounts for losses in energy transformation processes with conversion losses, 35 million tonnes of oil equivalent (mtoe), shown at the bottom of the chart.

Figure 1: UK Energy flow chart, 2017



However, with these charts only losses in energy transformations are shown. What is not shown are the losses in end use consumption, be that as lighting, heating, or transport. Energy consumption can be reduced by consuming less energy (which can be assessed

[1] www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes
[2] LLNL 2017 US Flow Chart: https://flowcharts.llnl.gov/content/assets/images/energy/us/Energy_US_2017.png
LLNL Report on Residential Energy Use: https://e-reports-ext.llnl.gov/pdf/550009.pdf

through the usual Sankey diagrams in DUKES) but it can also be reduced by using the end-use energy more efficiently. The current flow charts do not document this. To explore this idea, the concepts of "useful" and "rejected" energy are introduced, where "useful" energy services the intended purpose of an appliance and all other energy is "rejected".

Definitions: "Useful" and "Rejected" Energy

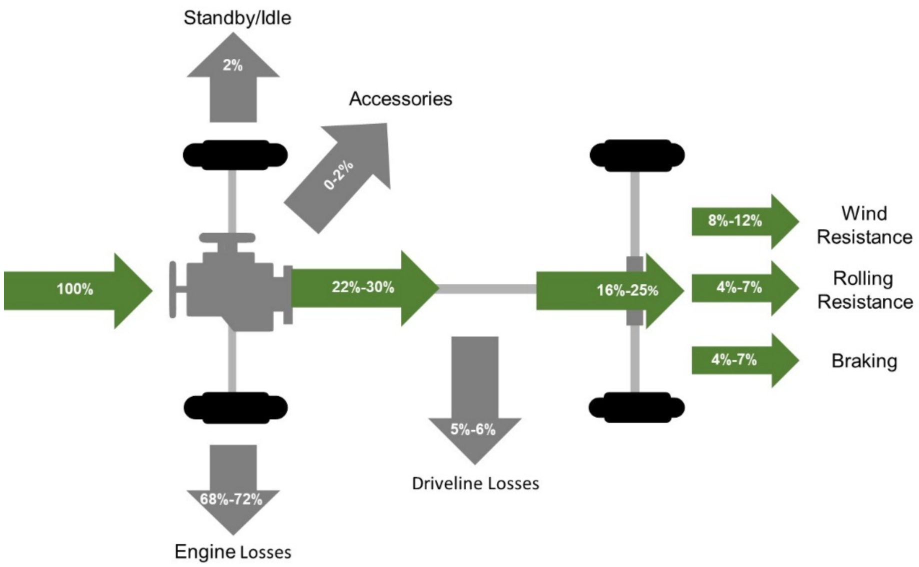
Useful energy: energy which services the intended purpose of an appliance
Rejected energy: all remaining energy which is not "useful" and does not service the intended purpose of the appliance is considered "rejected"

Limitations of the analysis:

- **Efficiencies are at appliance level** and do not account for, for example, energy loss as a result of heat loss through walls
- Heat energy is considered to be "rejected" if heating is not the intended purpose of the appliance. For example, heat from a light bulb is "rejected", despite the fact that in winter the energy would be useful heat. This analysis does not scale to this level of complexity.
- The efficiencies used in this analysis come from a variety of sources and the quality of these data will change and improve over time.

To illustrate the concept, Figure 2 shows the typical flow of energy used and lost in the process of moving a petrol-powered Internal Combustion Engine (ICE) car[3].

Figure 2: Energy losses in an internal combustion engine (ICE) car[4]



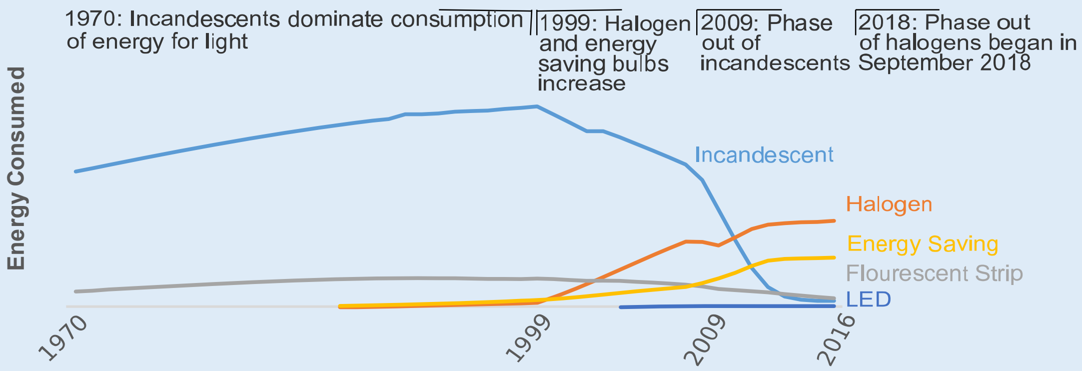
Not every unit of energy going into a car is used to move the car. For each unit of energy, (e.g. a litre of petrol/diesel), nearly two thirds are lost to engine friction, engine-pumping losses and waste heat; a sixth is lost to idling; and only one eighth is used to move the vehicle, with the remainder lost to driving friction and accessory use. Despite regular vehicle improvements most of the energy is not used for forward momentum and is 'rejected'.

[3] Efficiencies differ depending on vehicle specification. For example, diesel-powered vehicles can achieve a greater engine efficiency and air resistance is dependent on the shape of a vehicle.
[4] Figures sourced from: www.fueleconomy.gov/feg/atv.shtml. Note that this example is for illustrative purposes only and that this efficiency differs from the 21% used for petrol/DERV cars in this project's methodology.

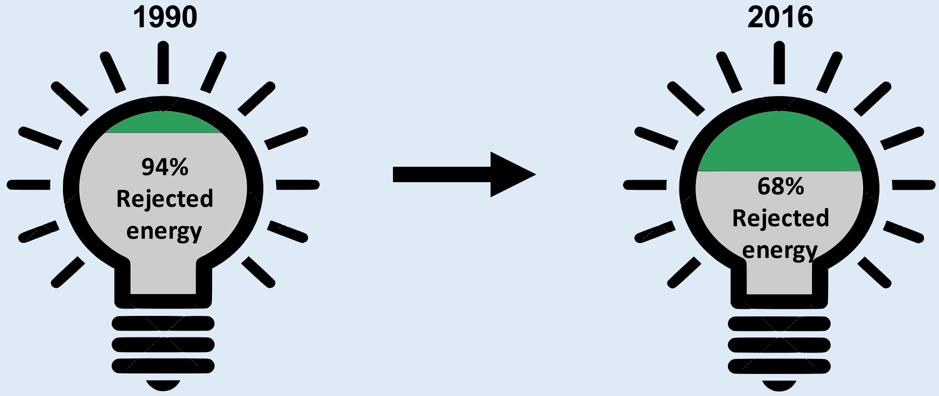
A similar situation exists for industrial and home appliances. For example, lights release heat energy as well as light energy. This heat energy is not serving the appliance's intended and primary purpose and is therefore lost, or "rejected" and only light energy is considered "useful".

Case Study: Lightbulbs

Chart B1: Evolution of energy consumed for light by bulb type



As of 1999, consumption from incandescent bulbs began to decline, displaced by halogen and energy saving bulbs. The phase out in 2009 increased the rate of decline pushing incandescent consumption towards zero in 2016. As of September 2018, halogens will be phased out and will likely be replaced by energy saving bulbs and LEDs driving down consumption and 'rejected' energy for lighting due to their higher efficiencies.



From 1990 to 2016, a change in bulb types used to light buildings and homes in the UK has resulted in a reduction in rejected energy for lighting, from 94% to 68%.

Given the potential savings through greater energy efficiency, a pictorial representation of how "useful" and "rejected" energy offers further insight into the energy consumption and can identify where the greatest potential savings can be made.

Method

The method adopted for this project uses two main pieces of data: energy consumption and appliance efficiencies. For each appliance, the consumption is multiplied by its respective efficiency to calculate "useful" energy and the remaining consumed energy is considered "rejected". The data for UK energy consumption were sourced from the 2018 DUKES and Energy Consumption in the UK (ECUK) publications, which report on 2017 figures. The data for end use energy efficiencies is collected from a range of sources which are detailed in the supporting workbook at: www.gov.uk/government/publications/energy-trends-june-2019-special-feature-article-experimental-statistics-on-whole-uk-energy-flow-incorporating-end-use-energy-efficiency, along with rationales for using these efficiencies. A range of sources have been used due to the varying levels of detail and data availability in each. All the efficiencies used for transport, and some for domestic, have been sourced from LLNL's Energy Flow Charts[5] publication for the US. For industry, the sub-sector efficiencies have been sourced from the US Office of Energy Efficiency & Renewable Energy[6]. The remaining efficiencies have been sourced through a combination of BEIS' internal assumptions and product policy data, along with desktop research for some efficiencies at lower and more detailed levels of disaggregation. These data facilitate users to gain insights on end use energy efficiencies.

The flowchart

Figure 3 presents a simplified UK energy flow chart with the inclusion of "useful" and "rejected" energy. The chart illustrates energy flows from primary fuel on the left, through energy transformations and finally to end use on the right. End use by sector is split into "useful" and "rejected" energy as can be seen on the far right. Broadly, from an input of 192[7] mtoe, the energy is split between 'useful' and 'rejected' energy approximately 39 per cent to 61 per cent.[8]

The Excel worksheets published alongside this article enable users to alter energy efficiencies and consumption to understand how the balance between "useful" and "rejected" energy can change, and the impact it has on the bigger picture. These alterations will aggregate and feed into the summary table and chart. Users may wish to put in their own efficiency factors which incorporates losses in the fabric of buildings.

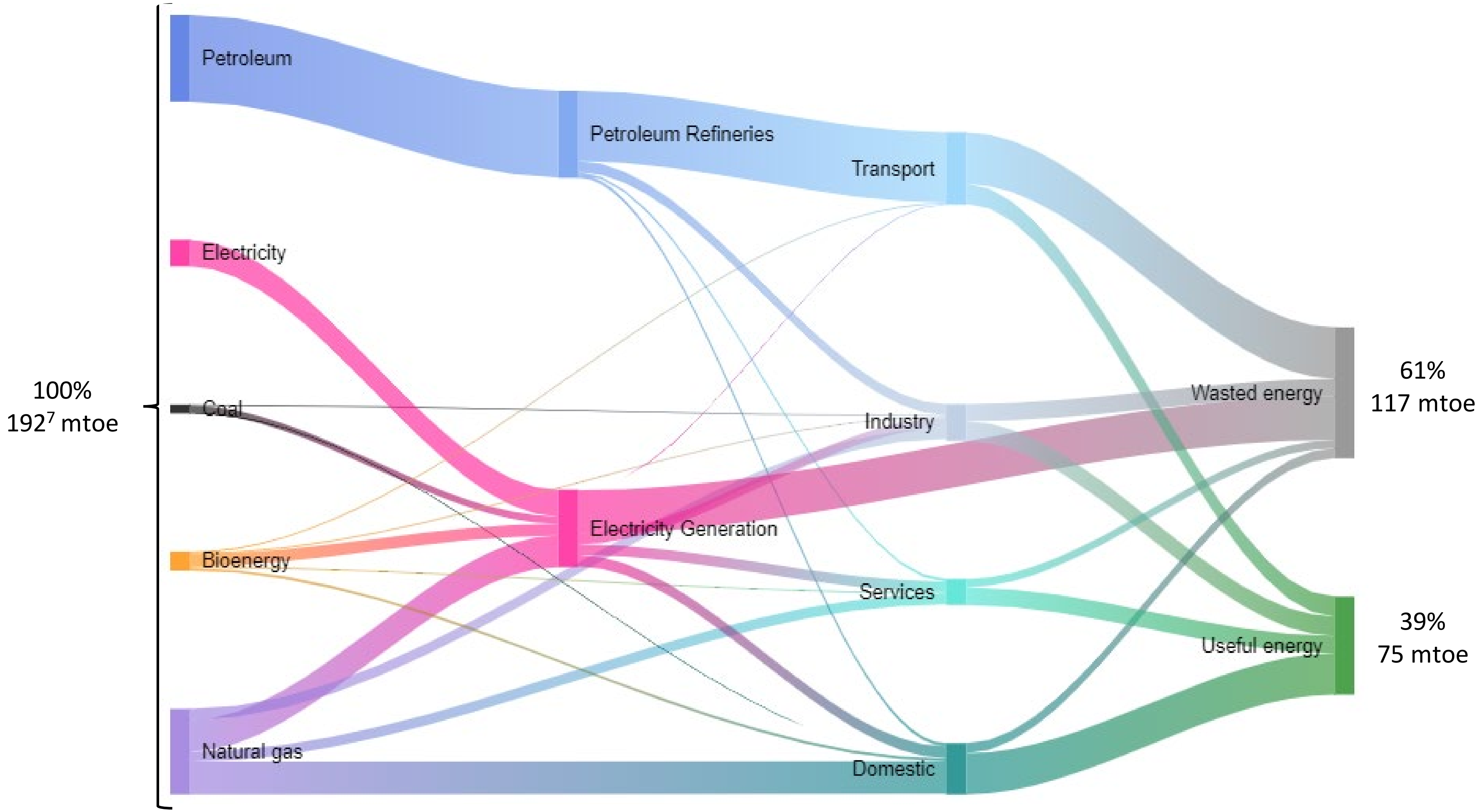
[5] Transport: https://e-reports-ext.llnl.gov/pdf/537889.pdf
Domestic: https://e-reports-ext.llnl.gov/pdf/550009.pdf

[6] www.energy.gov/eere/amo/manufacturing-energy-and-carbon-footprints-2010-mecs

[7] The input figure is sourced from the UK Energy Balance published in DUKES. Fuel consumption for non-energy purposes have been excluded from this analysis (e.g. The petro-chemical industry uses hydrocarbon fuels as feedstock for the manufacture of its products). This figure is equal to primary supply subtract non-energy use.

[8] Note that in this analysis electric boilers have an assumed efficiency of 100% compared to 84% for gas. Taking into consideration the efficiency of the electricity generation process of roughly 40%, this would then imply that gas boilers are more efficient if electricity was supplied from the grid. However, if the electricity was to be fully supplied by solar PV, this would then imply that the electric boiler is more efficient.

Figure 3: Energy flow chart with final "useful" and "rejected" end use energy

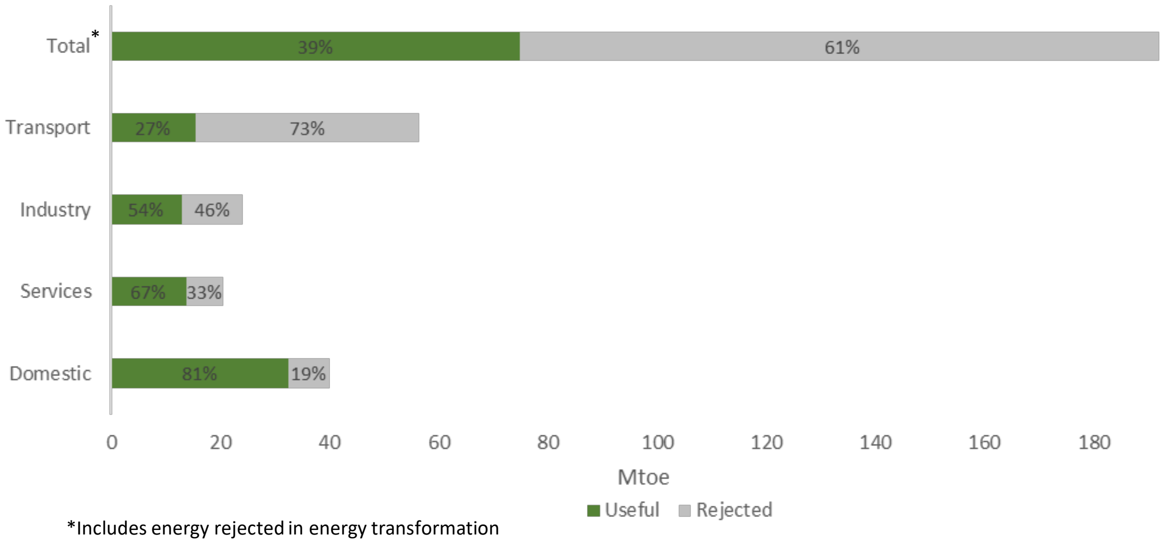


Differences in energy efficiency rates between sectors

The results show substantial variation between sectors. Based on the data assembled here, 81% of end use energy in the domestic sector is "useful" and 19% "rejected". This is followed by services, industry and transport with 68%, 53% and 27% of "useful" energy, respectively. Overall, an estimated 39% of end use energy in the UK was "useful" in 2017.

Figure 4 presents proportions of "useful" and "rejected" energy by sector as well as the energy values in million tonnes of oil equivalent (mtoe) for each sector.

Figure 4: "Useful" and "rejected" energy proportions by sector, 2017



The principal difference in efficiency between sectors is very closely related to the fuel mix entering the sector. The greatest amount of "rejected" energy is from transport, where the "rejected" energy for petrol and diesel cars alone accounts for over 20 mtoe annually. Putting this into perspective, total industrial consumption in 2017 was 24 mtoe, of which 13 mtoe was "useful".

International comparisons

Figure 5 provides a UK-US comparison at sectoral level. Note that the US domestic and transport figures use 2005 efficiency assumptions therefore a cautious approach is advised when drawing conclusions from these tables. Due to limited research in this area to date, this is the best international benchmark to compare with, but caution should be used as energy efficiency rates will have changed over time.

Figure 5: UK-US end use energy efficiency comparison

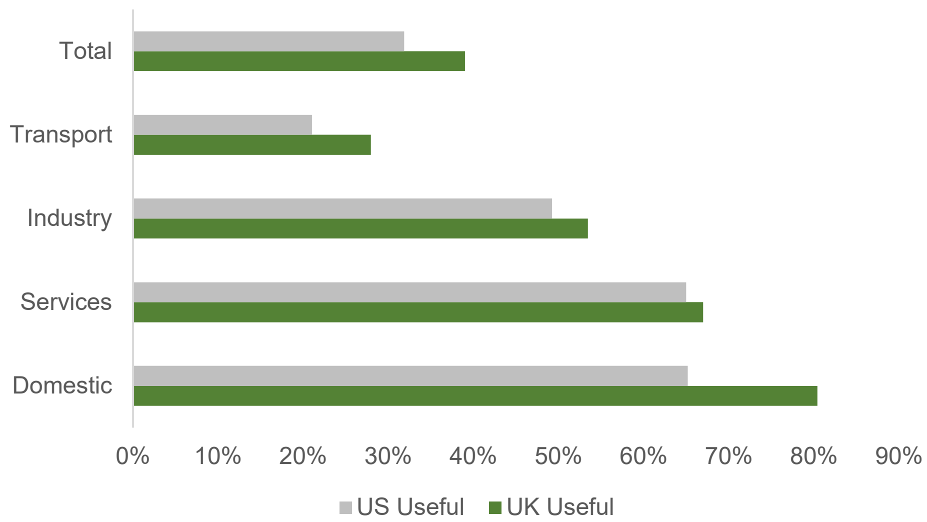


Figure 5 shows that, overall, the UK has a higher proportion of useful energy (39%) when compared with the US (32%). This can broadly be attributed to differences in the domestic and transports sectors:

- Domestic – The UK's "useful" energy proportion is 15 percentage points greater than that of the US which can largely be attributed to differences in boiler efficiency assumptions for space heating (UK – 84% and US – 77%)

- Transport – The UK has a higher proportion of energy used by air and HGV, compared to the US, which have higher efficiencies than cars and LGV. Therefore, the UK has a higher proportion of energy consumption used in higher efficient vehicles, result in an overall greater "useful" energy.

Concluding comment: these are first steps towards an energy efficiency flowchart

To date, BEIS' statistical description of energy has concentrated on supply and demand with little attention given to the efficiency of how energy is consumed. More efficient consumption requires less energy, is cheaper, and reduces greenhouse gas emissions other factors remaining equal.

However, the data presented here are very much a first step, using reliable secure consumption data put against a range of efficiencies which will change over time and will need refinement and improvement.

The data supporting this analysis has been published alongside and can be found at: www.gov.uk/government/publications/energy-trends-june-2019-special-feature-article-experimental-statistics-on-whole-uk-energy-flow-incorporating-end-use-energy-efficiency. The Excel worksheets enable users to alter energy efficiencies and consumption to understand how the balance between "useful" and "rejected" energy can change, and the impact it has on the bigger picture. These alterations will aggregate and feed into the summary table and chart.

As these are the first steps towards expanding the pictorial representation of energy efficiency in the UK, comments are welcome.

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