A guide to future electrical energy demand requirements in the UK

1 Introduction

This note is to investigate what effect the necessary rapid decarbonisation of some aspects of the way we live might have on electrical energy demand.

It consists of five sections:-

1. This introduction.
2. Total energy consumption for 2018 is analysed to identify energy used for private car transport and domestic cooking and heating.
3. The characteristics of electrical energy generation are set out in more detail, based upon data for 2018.
4. Data from the first two sections are used to calculate the impact of replacing fossil fuels for private car transport and domestic cooking and heating with electrical energy.
5. Conclusions.

It focuses upon the impact of eliminating the current use of fossil fuels for private car transport and domestic heating, and replacing them with electrical energy. There are clearly many ways in which this could be achieved, including:-

- Improve public transport and thus reduce reliance on private cars.
- Encourage lifestyle change, such that travel is not considered so essential.
- Invest in an electric car charging infrastructure, and encourage electric car use, when other methods of transport are inconvenient or unavailable.
- Invest in renewable hydrogen vehicle research.
- Make homes more energy efficient.
- Invest in carbon capture and storage (CCS) where it is feasible.
- Use of biogas (obtained from plant material) to replace fossil gas.
- Use of renewable energy produced hydrogen to replace fossil gas for heating.
- Encourage use of air (and ground) source heat pumps for domestic heating and hot water or possibly hybrid heat pump/gas boiler systems.
- District heating.

What will actually happen in the future is likely to be a combination of all these things, as well as many others, some of which might not even be being considered at present.

This is a highly complex and speculative subject, and this note is therefore necessarily a little simplistic. It is based on the theoretical assumption that electrical energy is used to power private cars and domestic heating based on 2018 figures. This is clearly impossible, but it gives an idea of the scale of the challenges involved in decarbonisation on this scale, and an indication of what sort of advice should be given to individuals and policymakers regarding the impact of decarbonisation upon electricity demand.

As only a high-level comparison is being performed, it will be assumed that total energy demand and all other aspects of the energy system remain unchanged.

2 The current situation: analysis of current energy consumption[1]

Figure 1 shows the total UK final energy consumption by fuel type. It is obvious that decarbonising the economy will be a huge undertaking. A key point to note is the total electricity consumption of 25,765 ktoe[2]. This current consumption will provide the baseline against which future increases in electrical consumption will be compared.

Figure 1
2018 Final energy consumption, by fuel (thousand tonnes of oil equivalent)

		%
Natural gas	43,787	30
Electricity	25,765	18
Petroleum	63,588	45
Other	9,575	7
Total	142,724	100

Figure 2 shows how this energy is split between users. Not surprisingly, transport is very significant, 40% of the total.

Figure 2
2018 Final energy consumption, by user (thousand tonnes of oil equivalent)

		%
Industry	22,716	16
Transport	56,954	40
Domestic	41,249	29
Other final users	21,805	15
Total	142,724	100

Figure 3 shows how domestic energy use, from Figure 2, is split by fuel type. Note that almost two thirds of energy is supplied by gas, and that the total fossil fuel consumption (to be replaced by electrical energy in section three) is 29,846 ktoe (355 + 26584 + 2477 + 430 ktoe)

Figure 3
2018 Domestic final energy consumption, by fuel (thousand tonnes of oil equivalent)

		%
Coal	355	1
Gas	26,584	64
Electricity	9,034	22
Bioenergy	2,369	6
Oil	2,477	6
Other	430	1
Total	41,249	100

[1] Figures 1,2,3 and 4 are created from "Digest of UK Energy Statistics, 2019", Figure 1.1.5, Energy consumption by final user, BEIS

[2] Tonne of oil equivalent (toe) is a common unit of energy measurement which enables different fuels to be directly compared and aggregated. One tonne of oil equivalent is set equal to 41.868 Giga Joules (GJ) or 11,630 kilo Watt hours (kWh). Quantities in this report are generally quoted in thousand tonnes of oil equivalent (ktoe).

Figures 1, 2 and 3 are for final energy consumption; that is to say the energy used by the consumer. This is as opposed to primary energy, which is the energy of the fuel, taking account of thermal losses in transforming the original source fuel to useful energy, plus the energy embedded by the production of the fuel, and transmission and distribution losses. It is a convention that, for electrical energy produced by renewable sources, final and primary figures are equal, apart from transmission and distribution losses.

Figure 4 shows the split by fuel type for transport energy from Figure 2. However, this table gives the primary energy requirement. For petrol and diesel vehicles, primary energy is 8% higher than final energy[3]. Nearly fifty percent of total transport energy is used as petrol or diesel by passenger vehicles. These include buses and coaches, but as they comprise only 0.5% of the passenger vehicle fleet, they have been ignored for the purposes of this note. The total fossil fuel consumption (to be replaced by electrical energy in section three) is therefore 25,550 ktoe.

This produces 25,550/1.08 = 23,660 ktoe of final energy.

Figure 4
2018 Transport energy consumption by type of transport and fuel
(thousand tonnes of oil equivalent)

		%
Rail - elect	408	1
Rail - petroleum	662	1
Rail - coal	11	0
Rail - total	1,081	
Road-pass-elect	21	0
Road-pass-petroleum*	25,550	45
Road-pass-bio*	638	1
Road-freight-petroleum*	13,423	24
Road-freight-bio*	335	1
Road - total	39,957	
Water - petroleum	962	2
Air - petroleum	13,571	24
Total	56,954	100

* These figures are not available for 2018. They are obtained by splitting the Road total in the same proportions as in 2016.

3 The current situation: characteristics of electricity production

Figure 5 gives the split of fuels used to produce electricity in the UK during 2018. Low emission sources now make up over half of the total, and this proportion is increasing as new offshore wind arrays are being constructed.

Figure 5[4]
2018 Electricity production

	%
Renewables	33.0
Gas	39.5
Coal	5.1
Nuclear	19.5
Other	2.9

[3] Table 1.07, "Energy Consumption in the UK, 2018 update", BEIS
[4] Chart 5.6, "Digest of UK Energy Statistics 2019", BEIS

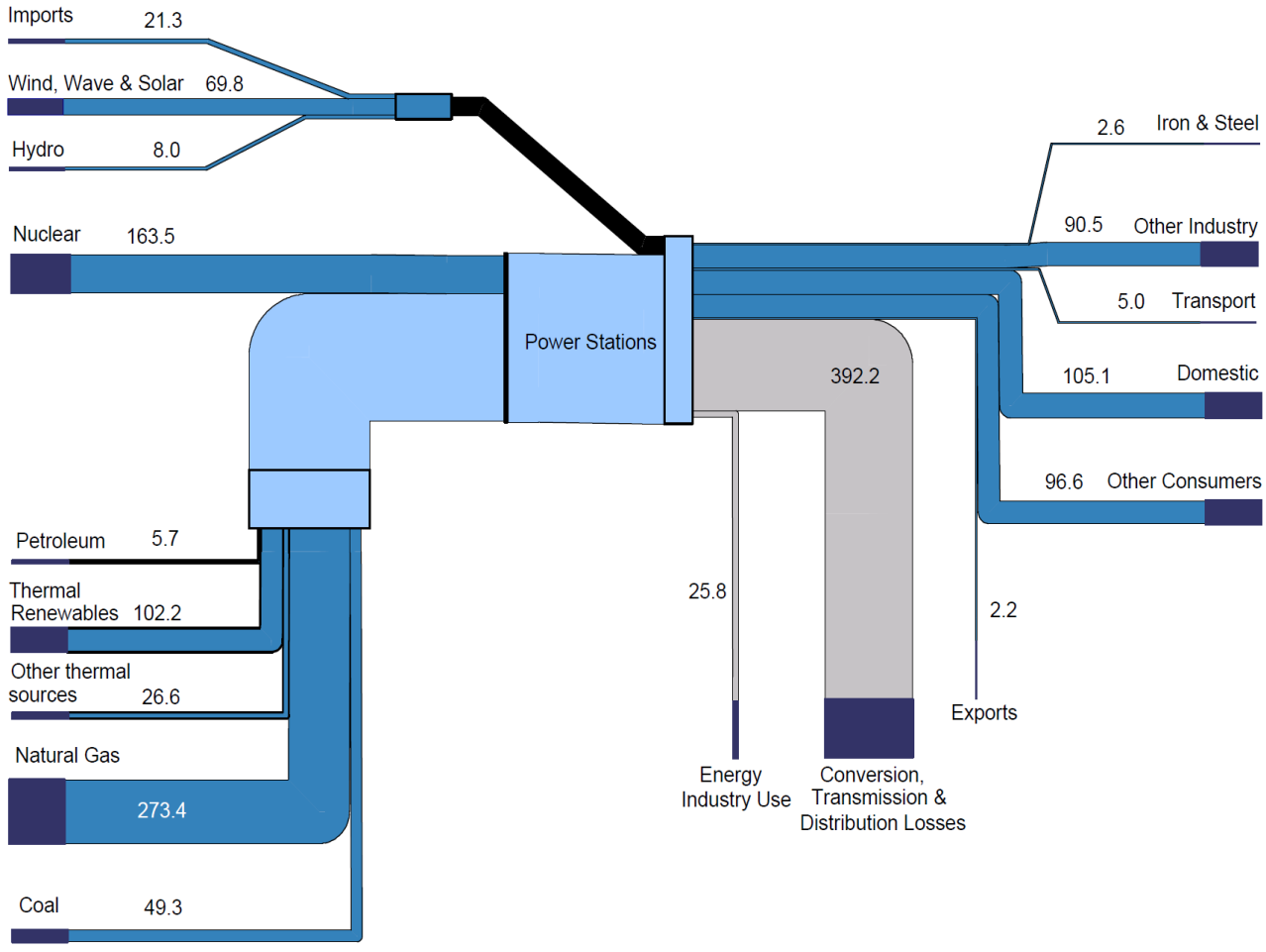
Figure 6 gives the thermal efficiencies[6] of the major thermal plants that are used to produce electricity. With the addition of transmission and distribution losses these figures help explain the large differences between primary and final energy figures.

Figure 6[5]
2018 Plant thermal efficiency

	%
Combined cycle gas turbine stations	48.9
Coal fired stations	34.1
Nuclear stations	39.8

Figure 7[7] sets out the primary sources of fuel, on the left, to produce electricity for the UK in 2018. This total is 719 Twh, or some 61,800 ktoe. On the right are the users, whose consumption is 302 Twh, or some 26,000 ktoe. From this an approximate overall Final/Primary efficiency can be calculated. The figure is approximately 302/719, so of the order of 42%.

Figure 7 Electricity flow chart 2018 (TWh)



[5] Table 5.10, "Digest of UK Energy Statistics 2019", BEIS

[6] The thermal efficiency of a power station is defined by BEIS as the efficiency with which heat energy contained in fuel is converted into electrical energy. It is calculated for fossil fuel burning stations by expressing electricity generated as a percentage of the total energy content of the fuel consumed (based on average gross calorific values). For nuclear stations it is calculated using the quantity of heat released as a result of fission of the nuclear fuel inside the reactor.

[7] " Digest of UK Energy Statistics 2019", BEIS

4 The future: decarbonising domestic heating and passenger cars

Let us assume that all domestic heating and all petroleum passenger cars are powered by electricity "instantly", using 2018 data from the previous two sections. The data is used, with no projection of expected changes in overall consumption in future years, as this would add further uncertainties. An idea of the scale of the task will therefore be gained, but based on current total consumption levels.

Firstly, domestic heating:-

- The total final energy to be replaced is, at most, the total from Figure 3, above, (41,249 ktoe) less that supplied by electricity (9,034 ktoe) and bioenergy (2,369 ktoe), giving **29,846 ktoe**.
- Assume that all this (predominantly gas heating) is replaced by air source heat pumps (though of course there are many other systems that may be used, including increased energy efficiency). These are considered to be some two to three times as efficient, in terms of energy use, as gas heating[8][9]. Taking this to be a conservative figure of two, then **15,000 ktoe of final** electrical energy would be required.
- So, in this theoretical scenario an increase in **final** electrical energy production of 15,000/25,765, or **58%**, would be required.

Secondly, private cars:-

- From the text beside Figure 4, the total final energy to be replaced is **23,660 ktoe**.
- It is generally considered that electric cars are four to five times as efficient as petrol cars[10], meaning that they require 20 – 25% of the primary fuel compared to petrol ones. Taking this to be a conservative figure of four, then **5,900 ktoe of final** electrical energy would be required.
- So, in this theoretical scenario an increase in **final** electrical energy production of 5,900/25,765, or **23%**, would be required.

Figure 8 shows the final energy consumption resulting from the above. It can be seen that, because of the increased efficiency of electric cars and the assumed air source heat pump heating system the total energy required is substantially reduced, from 142,724 to 109,004, so by 23%. The natural gas requirement is reduced by some 60%, and total petroleum usage is reduced by some 44%. However the rise in electricity demand is 81%.

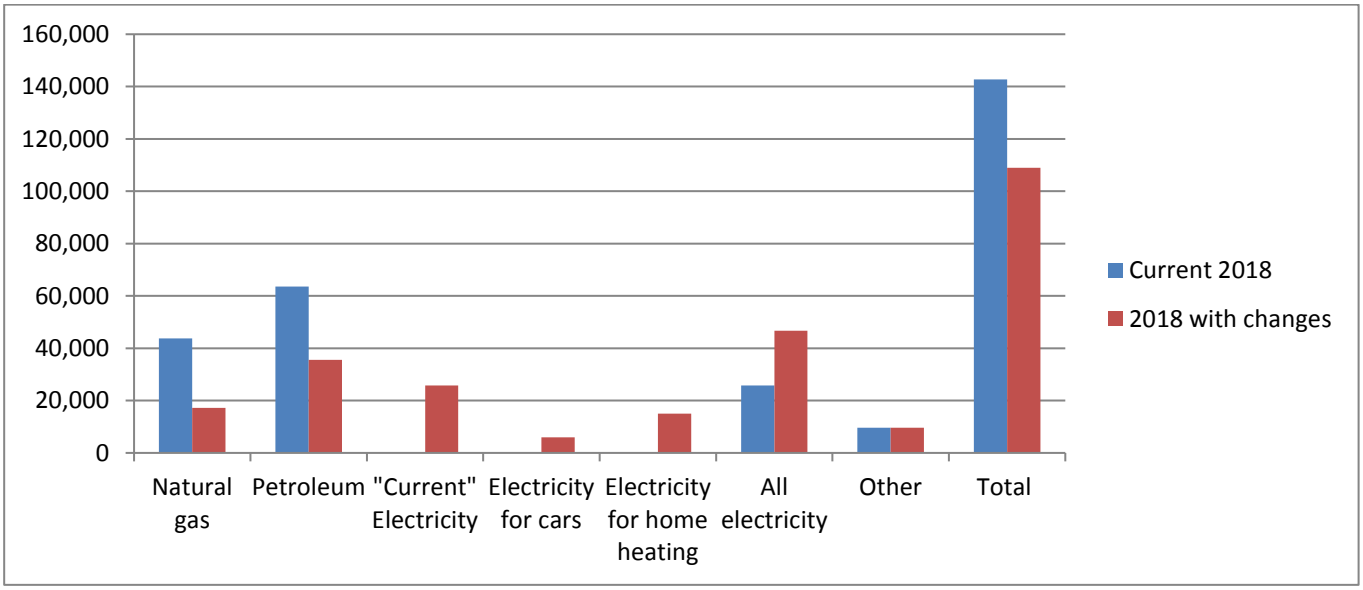
Figure 8
2018 Final energy consumption, by fuel.
Cars and home heating electrified
(thousand tonnes of oil equivalent)

		%
Natural gas	17,203	16
"Current" Electricity	25,765	
Electricity for cars	5,900	
Electricity for home heating	15,000	
All electricity	46,665	43
Petroleum	35,561	33
Other	9,575	9
Total	109,004	100

[8] www.renewableenergyhub.co.uk/main/heat-pumps-information/benefits-of-heat-pumps/
[9] www.evergreenenergy.co.uk/heat-pumps/how-efficient-are-heat-pumps/
[10] www.lightsonsolar.com/emissions-and-efficiency-in-electric-cars-versus-gasoline-cars/

Figure 9, below, demonstrates the two scenarios in graphical form.

Figure 9 Final energy consumption, by fuel - "current" 2018, and with assumed changes (in ktcoe)



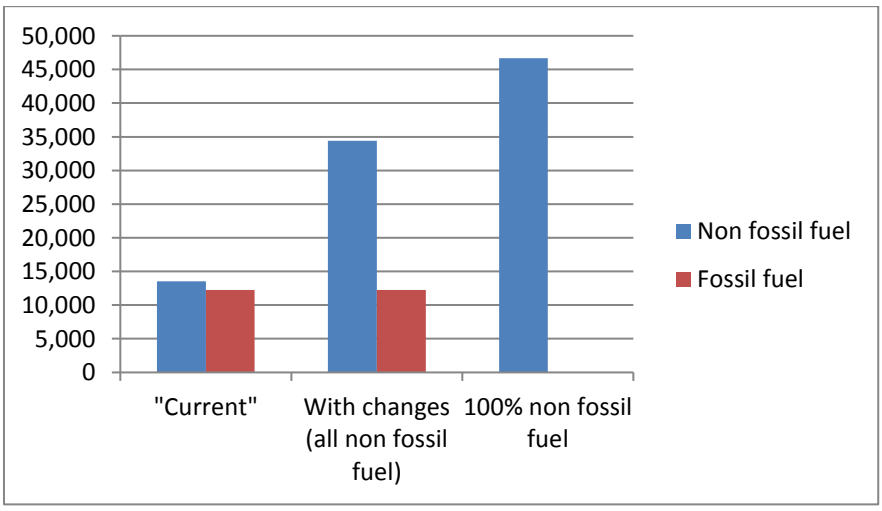
From Figure 5, it can be seen that in 2018 52.5% of electricity was produced from low carbon sources (nuclear and renewables), so some **13,525 ktoe**. If all current electricity demand (25,765 ktoe) were to be produced by low carbon sources, then an additional **12,250 ktoe (a 90% increase** [12,250/13,525]) must be produced in this way.

If the whole requirement from the decarbonisation of domestic heating systems (**15,000 ktoe**) and passenger cars (**5,900 ktoe**) were produced by low carbon sources also, then production from such sources must increase by an additional **154%** [(15,000 + 5,900)/13,525].

Therefore if all the current electricity demand, as well as the requirements for domestic heating and cooking, and passenger cars, then an increase of **244%** (90 + 154%) would be required.

This is illustrated in Figure 10, below.

Figure 10 Electricity production sources (in ktcoe)



For the purposes of this note, no account has been taken in any way of the various measures that would need to be taken to mitigate the intermittency effects of the major renewable energy systems; nor have the embedded energy impacts of replacing fossil fuel cars by electric ones. In reality it is likely that cars would not be replaced significantly before the end of their "natural" lives.

5 Conclusions

If, using the latest UK energy consumption figures, all domestic heating was to use air source heat pumps, with no improvement on insulation and the like, final electrical energy production would need to increase by 58%.

Should all current private cars be powered by electricity, then final electrical energy production would need to increase by 23%.

If all current electricity demand were to be met by low carbon sources, then there would need to be an increase in energy from such sources of some 90%. If, in addition, the requirement calculated above, for heating and cars, were to be produced by low carbon sources, then a total increase of some 244% on the current figure would be required.

Clearly such "instant" changes are impossible, and the required changes will, in reality, take many years, during which time it is hoped many of the actions mentioned at the start of this note would have been enacted to enable this low carbon transition. However the figures do give an idea of the scale of the challenge, and emphasise the significant extent to which additional low carbon energy sources must be developed in the UK to enable such a transition. A major overhaul of and investment in the electricity generation and distribution systems will be required, at a significant cost.

Brian Shorter, November 2019