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A Top Down View of the Challenges of A "Net Zero" Energy Future and the Implications for Storage

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Paul Rathbone[*]

Introduction

During 2019, the UK Government committed through legislation to bring UK greenhouse gas emissions to "*net zero*" by 2050, compared with the previous target of at least 80% reduction from 1990 levels. "*Net zero*" means any emissions would be balanced by schemes to offset an equivalent amount of greenhouse gases from the atmosphere, such as planting trees or using technology like carbon capture and storage. The UK's 2050 net zero target was recommended by the Committee on Climate Change ("CCC"), the UK's independent climate advisory body.

The bulk of the UK's greenhouse gas emissions arise through the generation and/or consumption of energy. This article takes a "top down" look at what the current state of energy supply and consumption is in the UK, considers what the "net zero" commitment means in terms of changing that and looks at the implications for the storage industry in its widest sense.

There is no doubt in anyone's minds that achieving the target will be a major challenge in itself, and the changes required in both energy infrastructure and the way we run our lives will be considerable. But many people do not fully appreciate not only the scale of the challenge, but also the fact that current renewable power technology cannot provide the whole answer. Storage solutions will be crucial to delivering energy consistently and across various sectors. For instance:

- the more intermittent renewable power replaces "on demand" gas power and heating, the more energy storage will be required to deliver consistent power when intermittent sources are low;
- the whole hydrocarbon-based transportation fuel distribution network will have to be replaced by a combination of electric car rechargers and a hydrogen generation, distribution and storage network; and
- the preferred route to the UK's "net zero" position requires a large amount of CO_2 capture and sequestration which will bring a whole new storage industry into being.

Whilst this article is based on the UK, for which good data exists, other countries seeking to move to net zero will have similar challenges, albeit modified by their own circumstances.

The key sources of data include various publications by the CCC and the UK Government's publication "Digest of the United Kingdom's Energy Statistics" or "DUKES". Whilst this article focuses on the UK, practically every economy seeking to move towards net zero will have similar issues.

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Background

In considering the route to "net zero" it is helpful to look at where we are starting from. Figure 1 sets out the UK energy supply and consumption in 2019 by product.

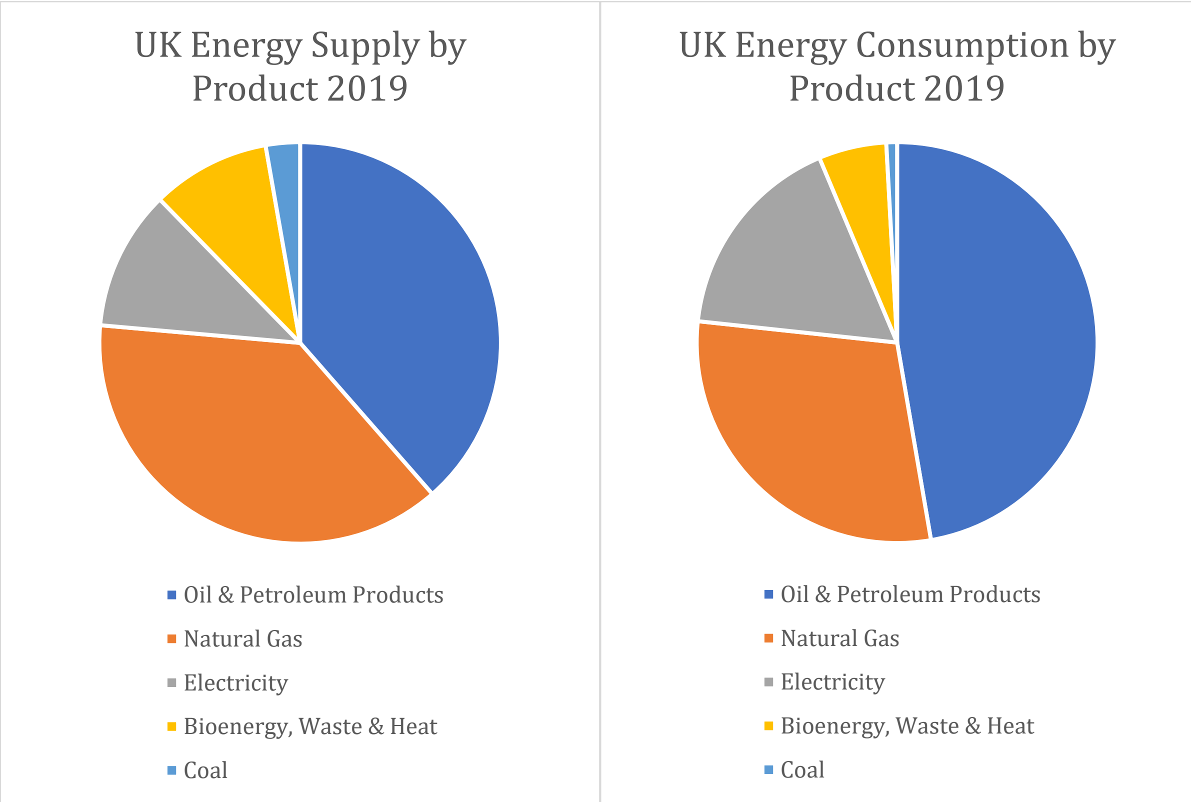

Figure 1: UK Energy Supply and Consumption by Product 2019. Source: DUKES 2019

Well over three quarters of the UK's energy supply in 2019 came from oil, gas and coal. Much of this was also consumed as such, for instance with crude oil converted into gasoline and diesel and then used to run road vehicles. Some gas and bioenergy resources were converted into electricity, but only 17% of total energy consumption was consumed in the form of electricity. There is a long way to go if the country is to be weaned off hydrocarbons.

In terms of what this means for storage, there will also be consequent big changes. Oil and gas storage and supply infrastructure (the "mid-stream") will start to become redundant, although some may still be required and others convertible as I discuss later. But other forms of energy storage will need to replace them – and quite what that is made up of will depend upon Government policy and technological developments.

Where is this energy consumed? Figure 2 shows the 2019 consumption by sector, as well as the proportion of each sector that is currently supplied by hydrocarbon fuel – oil, gas and coal.[1] It is evident from this graphic that huge changes will be needed if the net zero target is to be met.

[1] For simplicity I have excluded bioenergy, waste and heat from this number, since this is generally seen as "sustainable" even though some of it does give rise to CO2 emissions.

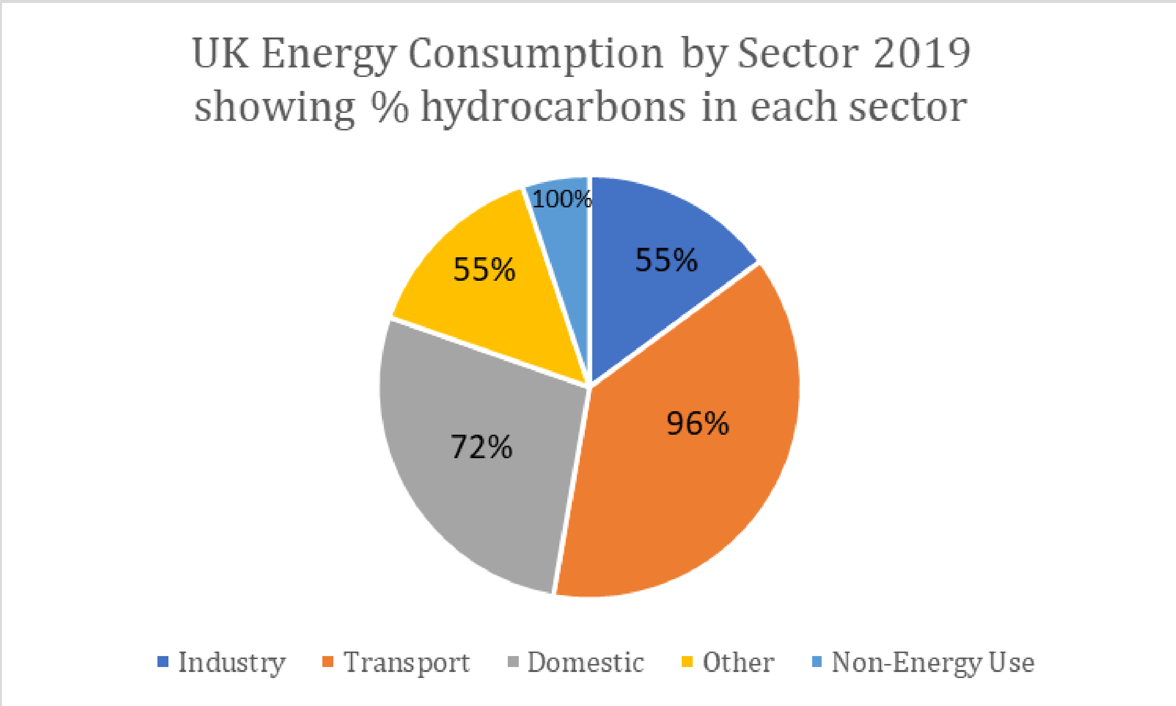

Figure 2: UK Energy Consumption by Sector 2019. Source: DUKES 2019

In broad terms, we consume a third of our energy to move around, another third at home and the remaining third at work in industry, commerce and the public sector. The category "non-energy use" is largely oil products being used to manufacture goods such as petrochemicals and plastics. I will consider each of these separately.

Transport

The transport sector is dominated by road vehicles, which in 2019 accounted for some 72% of energy consumed in transport. Air travel came next, with 24%. Rail and shipping make up the remainder, but at 4% are a tiny part of the picture.[2] Given this make up, it is not surprising that 96% of energy in the transport sector was provided by petroleum products – gasoline, diesel and jet fuel.

Finding cleaner alternatives to burning hydrocarbons for transportation will make a big difference in bringing our emissions down, both from a CO_2 control point of view but also in terms of air quality. Thus the UK Government, advised by the Committee for Climate Change, has been focussing on encouraging electric vehicles as a key policy.

- The UK Government has set a core target for at least 50%, and potentially as many as 70% of new car sales to be electric vehicles ("EVs") by 2030, and up to 40% of new van sales in England. At the same time as setting this target, it planned to end the sale of new conventional petrol and diesel cars and vans by 2040.[3]

[2] DUKES 1.1-1.3 alternative units 2019
[3] CCC Technical Report p136

- The Scottish Government has made a commitment to "phase out the need to buy" new petrol and diesel cars or vans by the earlier date of 2032.[4]
- Very recently, the UK Prime Minister has announced the end to sales of non-zero emission cars, vans and motorcycles being brought forward to 2030, although some hybrids would still be approved until 2035.[5]

So what does this mean in practice? In 2017, cars and light goods vehicles made up 75.8% of gasoline and diesel fuel consumed in the UK.[6] Thus this sub-sector alone makes up more than 20% of our total energy consumption. This is bigger in energy content than current electricity generation (which one can see from Figure 1 above is around 19% of total energy consumption). Yet the CCC estimates that replacing all of these vehicles with EVs will require only perhaps a 30% increase in current electricity generation. A lot of the reasoning behind this is conversion efficiency – some 70% of the inherent energy in gasoline is lost in the engine, so replacing internal combustion engines with electric engines makes sense as long as the electricity comes from a more efficient source.[7] But the CCC have also made some big assumptions about behaviour change (i.e. people driving less) which in my opinion will be much more difficult to legislate for.[8]

It is also helpful to consider numbers of vehicles. The current UK fleet of cars amounts to c. 33.9 million units; this has been gradually increasing between 2% and 1% per year since 2014. The current penetration of electric vehicles in this UK fleet is 0.3%, with a further 0.4%% being plug-in hybrids and 1.6% being other hybrids.[9]

In the last 5 years annual new registration were in the order of 2.5 million vehicles per year. Total electric vehicles sold in 2019 amounted to 38,000, or 1.6%. Hybrids amounted to a further 6%, but they do not qualify as electric vehicles under the Government's targets.[10] To meet the target of at least 50% of new vehicle sales being EVs by 2030, and assuming a static market in unit terms, sales of EVs will have to increase by a factor of 32x, or a cumulative annual growth rate (CAGR) of 38%. This will require a huge retooling of the automotive industry, service station infrastructure and power supply and networks, which has only just begun.

- Automobile assembly plants will need restructuring
- Engine plants will close, to be replaced by battery factories
- Service stations will need to replace refuelling facilities with power points
- Local distribution networks will need to be upgraded to meet the need to charge vehicles outside homes
- More power generation will be needed to meet demand.

Furthermore, electric cars currently have a higher up front cost than those with internal combustion engines. For instance, the retail price of a Renault Zoe, one of the most affordable EV cars on the market, is currently nearly twice the price of the Renault Clio, a

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[4] ibid
[5] https://www.gov.uk/government/news/government-takes-historic-step-towards-net-zero-with-end-of-sale-of-new-petrol-and-diesel-cars-by-2030
[6] OR&P analysis of DUKES 2019 Table C8
[7] https://fueleconomy.gov/feg/atv.shtml
[8] CCC Technical Report
[9] Department of Transport VEH0203
[10] ibid

similar sized ICE car, even after the UK Government's EV subsidy.[11] According to Bloomberg New Energy Finance ("BNEF"), the cost of the battery packs is currently around $10-12,000, which adds a lot to an "economy" model vehicle. Economies of scale and technology are steadily reducing this. BNEF believes that battery prices will fall from an average of US$156/kWh in 2019 to around US$100 in 2023, a 36% reduction.[12] The CCC has assumed that the price will be £73/kWh in 2025, close to the BNEF forecast, and that they will fall another 32% between 2025 and 2050.[13]

The up front cost differential between EVs and those that run on petrol or diesel is mitigated by lower costs to run the vehicle. Although in the UK electricity at 18.9p/kWh (2019 average UK domestic tariff) seems more expensive than petrol at an effective 12.9p/kWh (2019 average UK retail price of unleaded petrol), an electrical engine is much more efficient than an internal combustion engine ("ICE").[14] After conversion, the approximate costs of the energy going into the drive train are 21.0p/kWh for an electric motor and 43p/kWh for petrol in an ICE.[15] But a lot of the higher cost of fuel is caused by taxes – of the 43p/kWh above, some 63% is tax and duty.[16] In addition, if the increased power demand and increased demands on the network all have to be funded by the consumer, this advantage might be diminished by increased network charges and the cost of intermittency (see below). And of course the Government will be looking to replace its income from petroleum duty through other sources. Revenue from fuel duties now stands at £28 billion a year, which is 1.3% of national income.[17] Will it really be able to replace that with other taxes and not increase tax on electricity?

This leads to many profound policy questions. Beyond the target for phasing out conventional cars, vans and motorcycles, no firm policies on the restructuring of the transport system are yet in place in the UK, and there are many questions yet to be answered. For instance:

- Will the EV essentially become a "luxury" item, beyond the reach of poorer members of society?
- If so, how will the transport needs of rural communities be addressed?
- Will "smart cabs" be developed in time and could they replace the need to own a car?
- What will they cost?
- Will more investment have to be put into public transport?
- What is the future of public transport anyway post-COVID 19?
- Who will pay for the reinforcement of the electricity networks to allow EVs to be recharged every night?

Addressing these questions goes further than the scope of this paper, which simply seeks to highlight some of the challenges. But simply from a storage point of view, if the legislation

[11] https://www.renault.co.uk/vehicles.html?page=H79R, Clio MRRP £15,895, Zoe MRRP ££26,995 after £3,000 Plug-In Car Grant
[12] https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/
[13] CCC Technical Report
[14] OR&P analysis of data from DBEIS (Energy Prices Road Fuels and Other Petroleum Products and Quarterly Energy Prices)
[15] OR&P analysis assuming 10% loss for electric motor and 70% loss for ICE
[16] VAT at 20% plus fuel duty 57.95p/litre
[17] https://www.statista.com/statistics/284323/united-kingdom-hmrc-tax-receipts-fuel-duty/

stands as it is, practically all hydrocarbon fuel depots will become redundant, whilst service stations will need to restructure from providers of fuel in a quick, efficient transaction to providers of recharging facilities, with a much longer delivery time (usually c.30 minutes currently). Unless, that is, a large quantity of cars do not end up being EVs but instead use hydrogen fuel cells. I discuss this next.

The other side of road transport is freight and HGVs. Here the picture is not so clear. Short haul electric freight has been around for years, and there are some good arguments that electric trucks would be much more economic than diesel-fuelled vehicles once suitable clean power generation and recharge infrastructure investment has been made. However, focus is also being put into hydrogen as a "green" fuel. Hydrogen's energy content per kg is very high, although its energy density (energy per litre) is not as high as gasoline or diesel, and it simply produces water (as steam exhaust) when consumed in a fuel cell, so if the practical problems of storage and easy refuelling can be overcome it would make a very compelling fuel source.

The big challenges with hydrogen as a road fuel are storage and generation. Hydrogen is the smallest atom in the atomic table, and in its steady state, H_2, it is also the smallest molecule. Thus it is not easy to keep it in storage. Additionally, it is also explosive, with a much larger "combustion range" than natural gas and an invisible flame. So the increasing use of hydrogen will lead to big storage opportunities, as long as the health and safety issues that go with it can be overcome.

In terms of generation, the industry is now differentiating between "green" hydrogen, generated through electrolysis of water, and "blue" or "grey" hydrogen generated through reformation of methane. Electrolysis produces only water as a by-product, so is clean, but requires a great deal of energy. Methane reformation requires less energy, but produces CO2 as a by-product. In its base case scenario, the CCC assume that blue hydrogen will be the norm, but that this will have to be matched with carbon capture and sequestration ("CCS") to meet the net-zero target.

To summarise, in order to reach "net zero", the whole road transportation sector, making up nearly one third of the nation's total energy consumption, will have to change from hydrocarbon fuelled vehicles to either electric or hydrogen-fuelled vehicles. This will have huge storage implications. The UK has 41 coastal and 20 inland fuel storage terminals, all of which will either become redundant or need refitting to store hydrogen (probably as ammonia). The 8,000 or so filling stations around the UK will all have to be respecified to have both fast recharging and hydrogen fuelling facilities. This will require huge investment, the precise scale and scope of which won't become clear until we have better clarity on hydrogen technology and whether the hydrogen fuel cell is preferred over wholly electric vehicles in the future.

Domestic Energy

I now turn to the domestic energy sector, which as I showed above contributes another third of the UK's total energy consumption. This mainly consists of the energy we use to heat and light our homes, as well as running the various electric appliances that modern life seems to require.

In 2019, domestic energy in the UK was fuelled as follows:

2019	TWh	
Oil & Petroleum Products	31.4	6.5%
Natural Gas	309.9	64.5%
Electricity	103.8	21.6%
Bioenergy, Waste & Heat	31.6	6.6%
Coal	3.9	0.8%
	480.6	100%

Source: DUKES 2019

Electricity provides lighting, and to a much lesser extent heat and cooking fuel. But some 83% of the UK housing stock is heated by gas or oil.[18] To move the domestic third of our energy consumption towards net zero will require major changes.

Such a change is not unprecedented. If one looks at domestic energy consumption in 1970, coal, coke and breeze amounted to 43.4% of the total – now down to 0.8%. But this time the replacement covers a bigger proportion of homes over a shorter timescale.[19]

The CCC recommendation is to focus on two strategies: low carbon heat through use of heat pumps, and improving the thermal efficiency of the housing stock. Both make sense in many cases, but application of these solutions is more difficult in others. For instance, many of the average dwellings in the UK are considered "space-constrained" for the installation of low-carbon heating systems. This implies that, in accordance with CCC guidelines, a large number of UK houses "*are generally expected to be more expensive to decarbonise, as a result of the restricted number of technologies suitable for these homes and increased costs associated with some space saving technologies*".[20]

The CCC does not see the total abolition of the UK gas network as a base case. Older urban houses connected to the grid, without space for heat pumps, will be very costly to convert. However, in its "further ambitions" scenario it sees the potential for putting hydrogen into the gas mix to reduce emissions, as well as using more biomethane. This has some potential for new storage plays.

But the issue of cost is probably the biggest hurdle in reforming domestic energy use. A ground source heat pump costs between £11,000 and £15,000 (or more depending on ground conditions); to install an air source heat pump costs between £5,000 and £10,000 and comes with noise issues.

Turning to thermal efficiency, this could be a big opportunity to reduce energy consumption. In the last comprehensive English survey, carried out in 2014, some 56% of housing stock was 50 years old or more, with 20% being build prior to 1919 so now 100 years old.[21] Putting proper insulation into these old buildings could make a huge difference to efficiency. But that comes with major challenges. Putting thermal insulation on the walls of a single-skinned

[18] Analysis of DUKES 2019 data
[19] DUKES Table C1 goes back to 1970
[20] CCC Technical Report page 81
[21] EHS 2014 Housing supply report

Victorian house is a major task which will either significantly alter the outside appearance – which can bring planning problems in many neighbourhoods – or requires stripping all the plaster off the interior, with all the disruption caused by total redecoration of the building. So without financial assistance in meeting these costs there is likely to be considerable resistance from homeowners to this change.

Affordability is a key issue in pushing through change in the domestic sector. The CCC puts it well:

> *"The transition, including for workers and energy bill payers, must be fair, and perceived to be fair. Government should develop the necessary frameworks to ensure this. An early priority must be to review the plan for funding and the distribution of costs for businesses, households and the Exchequer."*[22]

Households rarely invest in long term improvements if the up front cost is significant to their annual budget, even if the economic value generated by the project is positive over time. And at present, without carbon taxes or similar disincentives to use less or cleaner power, the project may not be cost efficient. It is likely to require a mixture of public encouragement, differentiating taxes and direct subsidy to make a big difference to reforming the energy habits of the UK domestic sector.

What does this mean for storage? Certainly, heating oil storage will become largely redundant, as more and more oil fuelled homes convert to electric-powered heat exchangers. Gas storage may also be effected, but the UK doesn't have a lot of this, and the future of the gas grid is uncertain, since some or all of it may be kept running with a mixture of biogas and hydrogen. But the main growth area will be electrical storage. Whilst overall efficiency would probably suggest that larger grid-based storage is best, if investment here is not delivered in a sufficient and timely manner to prevent power failures when intermittent generation falls short, individual homes will be looking to their own storage back-up to cover those gaps, which could turn into a big opportunity for businesses able to supply and fit domestic sized batteries. I discuss the intermittency issue later.

Other Sectors

I will not cover the other sectors in as much detail. Each has its differences, but the challenges are similar.

The industry sector's energy needs currently include about 55% hydrocarbon fuels. However, this conceals big differences within the subsectors. Mineral processing, chemicals, food & beverages are large gas consumers, whilst other sectors use more electricity. Each industry will need to develop its own plan for reaching net zero, but some such as cement and petrochemicals will always produce some greenhouse gas emissions, so the CCC assumes that they will rely on carbon capture and storage to comply.[23]

The commercial sector's energy usage is divided about 43% hydrocarbons (largely gas) and 57% electricity. The hydrocarbon consumption is largely for heating buildings, and the same solutions of electric heating and better efficiency as apply to the domestic sector will operate

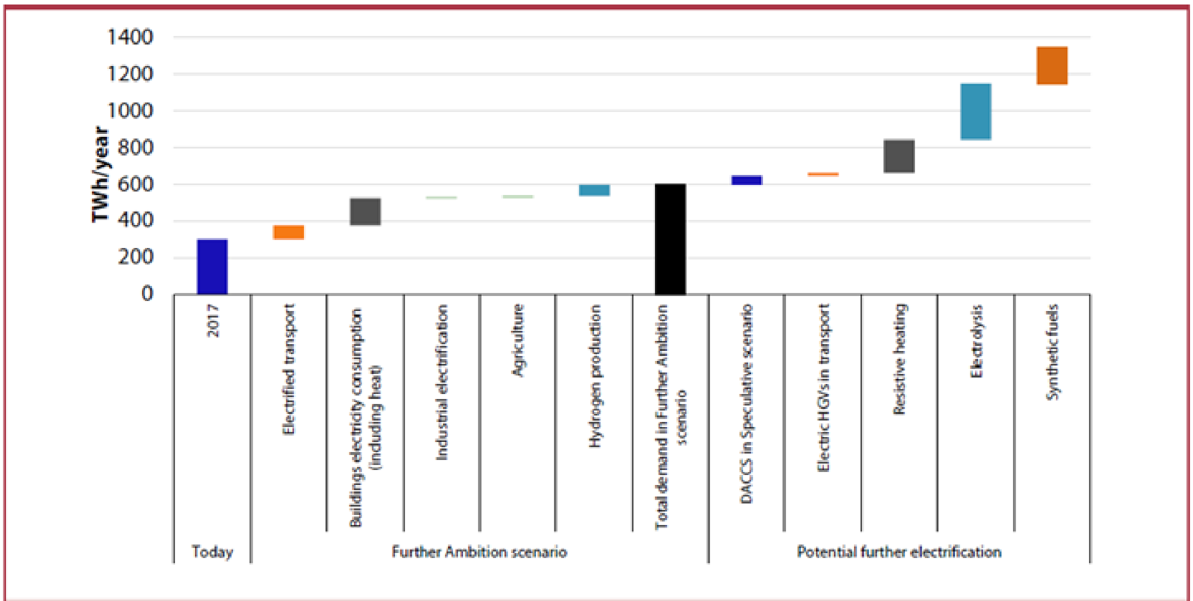
[22] CCC Main report May 2019 page 12
[23] CCC Technical Report page 105

here. Public administration on the other hand is about two thirds oil & gas. It is less clear what this involves, although it will no doubt include gas boilers and back-up diesel power in essential sites such as hospitals, as well as defence requirements.

A Matter of Supply

So I have discussed some of the issues that will need to be overcome on the demand side to move towards net zero. The other side of the equation is the supply side.

On a system level today c. 300 TWh of electricity is consumed each year in the UK. In its base case, the CCC assumes that, in order for our emissions to move to net zero, electricity consumption will have to double to c. 600 TWh by 2050. But the analysis of supply in Figure 1 above suggests that power generation would have to at least quadruple to substitute for the current hydrocarbon-based supply. Figure 3 shows how the CCC sees demand building up.



Source: CCC analysis.
Notes: Electric HGVs in transport are hydrogen fuelled vehicles switching to electricity.

Figure 3: CCC Projections of increased electricity demand to 2050. ***Source: CCC technical report page 25***

You will see that the potential demand for electricity goes up further than 600 TWh in certain scenarios. This is because, in order to restrict demand to this level and still reach net zero, the CCC have assumed that (i) there will be some 270 TWh of hydrogen-based consumption making up the difference and (ii) this hydrogen, together with back up power generation, will still use natural gas, but with CCS.[24] In addition, not shown on the chart at all, are several assumptions on further efficiencies, particularly in heating insulation discussed above. Without these key technologies, electricity demand could be much higher if we are to achieve net zero.

[24] CCC Technical Report page 19

If electric vehicles replace internal combustion engine powered vehicles, and most households are heated by electricity not gas, where will all this extra energy come from? According to the CCC to achieve this goal circa 9-12 GW of generation capacity will need to be installed each year to meet their targets.[25] The answer most people give will be "renewable power", and indeed this will contribute a good proportion of the replacement power needs. But current renewable technology cannot bridge the entire gap.

Renewables have been getting cheaper. Many argue that they are already cheaper than gas, but this comparison is difficult. Currently, gas-fuelled power generation pays very little for the CO2 it produces since carbon charges are very low. But renewable power does not have to pay any charges for intermittency – thus it can always undercut gas on a spot price basis because the marginal cost of producing wind or solar power is tint, as long as the wind is blowing or the sun has risen. This makes the current cost of both gas and renewable power lower than they should ideally be if we want to produce economic incentives to encourage low carbon but reliable power.

Intermittency is a big challenge. If all our power comes from wind and sun, what happens when the wind doesn't blow at night? The immediate answer is "storage", and certainly there is a place for this. But there are times when the wind doesn't blow hard for days on end, and when this happens in winter, so that there are fewer sunny hours in a day, this can make the variation in generation very large indeed. I demonstrate this in Figure 4 below, which shows the combined wind and solar generation by day in England through 2019.

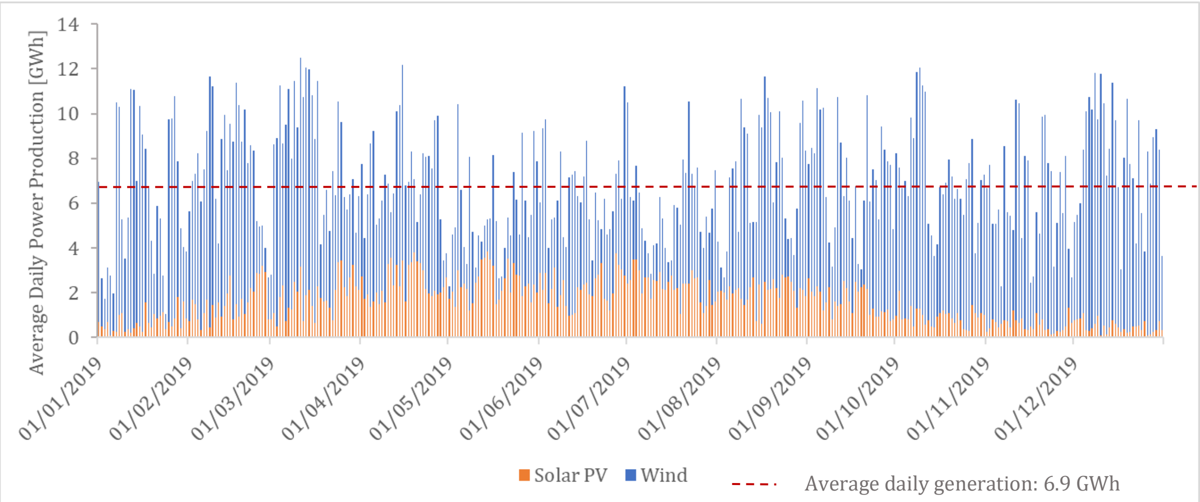


Figure 4: Daily wind and solar generation in England, 2019. ***Source: Gridwatch***

In Figure 4 it is evident that there is a huge amount of fluctuation on a daily basis in the combination of wind and solar energy generation, caused by seasonality and the weather. There are times in winter when winds are calm and there is little sun, and this can happen across the whole of Western Europe at the same time, so importing power at such times may not be possible. Therefore, the more we rely on renewable power for our energy, the more back-up we will need, either in the form of alternative generation capacity or energy storage.

To give an idea of the scale of storage required, consider the period in late February/early March, when combined wind and solar generation was below average for six days in a row.

[25] CCC Technical Report page 19

In order to bridge that gap without back-up generation would either require the installation of two and a half times the generation capacity required to meet average demand, or storage equivalent to 2.4 days total demand. To give some idea of the scale of this, if we take the CCC's base case of 600 TWh demand and assume that the gap was met by battery storage, this would mean 3.95 TWh of storage, which using the CCC's 2050 cost of battery storage might require investment of around £200 billion.[26]

The other issue with renewable energy in the UK is that there may simply not be enough of it to be self-sufficient. This was the conclusion of the late Sir David MacKay, former Chief Government Scientist, in his excellent book "Sustainable Energy – without the hot air".[27] He took a top-down view on the opportunities for every sort of renewable energy throughout the UK and came to the conclusion that, if we wanted to do without hydrocarbons, we had three choices:

- Either significantly reduce our energy consumption per head; or
- Invest in nuclear power to make up the difference; or
- Import renewable energy from other countries.

It was this analysis, among others, that led the UK Government at the time to back new nuclear power stations to replace the current fleet.

The CCC's recommendations are consistent with Sir David MacKay's conclusions, except that they don't exclude all hydrocarbons. Instead, they assume in their base case that back-up power beyond 35GW of nuclear will be provided by natural gas, some derived from bio-waste and some from traditional extraction, and look to achieve "net zero" by requiring significant investment in CCS – around 167 Mt per year by 2050.[28]

So in summary, the big storage investment opportunity, and challenge, is to develop solutions to bridge the intermittency gap, particularly the multi-day one which occurs several times a year.

Conclusion

In conclusion, in order to meet the UK Government's ambitions, there will be a need for massive investment in both renewable power and hydrogen energy systems, together with distribution and storage infrastructure for both. In addition, either CCS technology will have to be made commercially viable, or even more generation capacity and energy storage will be required. Quite how the UK Government will achieve this is unclear – my own view is that it will require a major rework of the power pricing systems to reflect both a proper price of using carbon and the cost of intermittency, together with a major rethink of how the Government's cheaper cost of capital can be utilised to keep the cost of investment efficient.

The scale of change required to meet the "net zero" target makes it difficult to summarise, and this article just touches on some of the steps needed and challenges to be faced. It is quite clear that, in order to meet these challenges, there will need to be:

[26] $3.95 \times 10^{12} \times £50/1000$
[27] *Sustainable Energy – without the hot air* by David JC MacKay, available free at withouthotair.com
[28] CCC Technical Report page 19

- Unambiguous public support;
- Changes in societal behaviour;
- Huge investment with consequent financing issues; and above all
- Clear Government policy.

We are clearly faced with the so-called Chinese curse of “living in interesting times”.