Large Scale Electricity Storage

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I will draw on a Royal Society study of large-scale electricity storage that I am leading

- **Focus on Great Britain in the net zero era** - numbers and details are location dependent; methods and many conclusions are universal
- **Assume very high levels of wind and solar**
- **Won’t discuss ‘Grid Services’** - storage that can respond rapidly to regulate voltage and frequency: does not need much energy, negligible impact on other needs for storage

- All energy systems need storage to buffer mismatches in supply and demand. For UK electricity buffering is mainly provided by gas – average of 18 TWh in store in 2019
- Gas is being phased down, while mismatches will increase as electricity demand and the roles of wind and solar increase

Will ask:

In 2050 *could* the UK be powered at an affordable cost largely by wind and solar, supported by storage, without or with baseload?

or

Would it be cheaper to use gas + CCS* to provide the flexibility needed to match volatile wind and solar? *Low, but not zero carbon - fugitive CO2 and upstream methane leakage

The other two possible large-scale low carbon sources have a degree of flexibility, but

- Nuclear – limited by cost and perceptions; very expensive to operate flexibly
- Bio Energy with Carbon Capture and Storage – limited to some 50 TWh/year in GB by lack of resource; in principle carbon negative – should run it flat out

*The more energy wind + solar provide, the less storage and other sources have to supply - **but** they have to meet the full demand for power when sun not shining and wind not blowing → **low load factor, high cost***

Inputs to Answering Question 1

- **Hour-by-hour model of demand** – 2050 level very uncertain, no good models of profile publicly available: used model kindly provided by AFRY- 570 TWh/year

- **Hour-by-hour model of wind and solar generation**, based on real weather data over a very long period.

  Used 37 years of data (1980-2016)

  Met office says this does not provide full sample of rare weather events → *add contingency*

  - also against (uncertain) impact of climate change

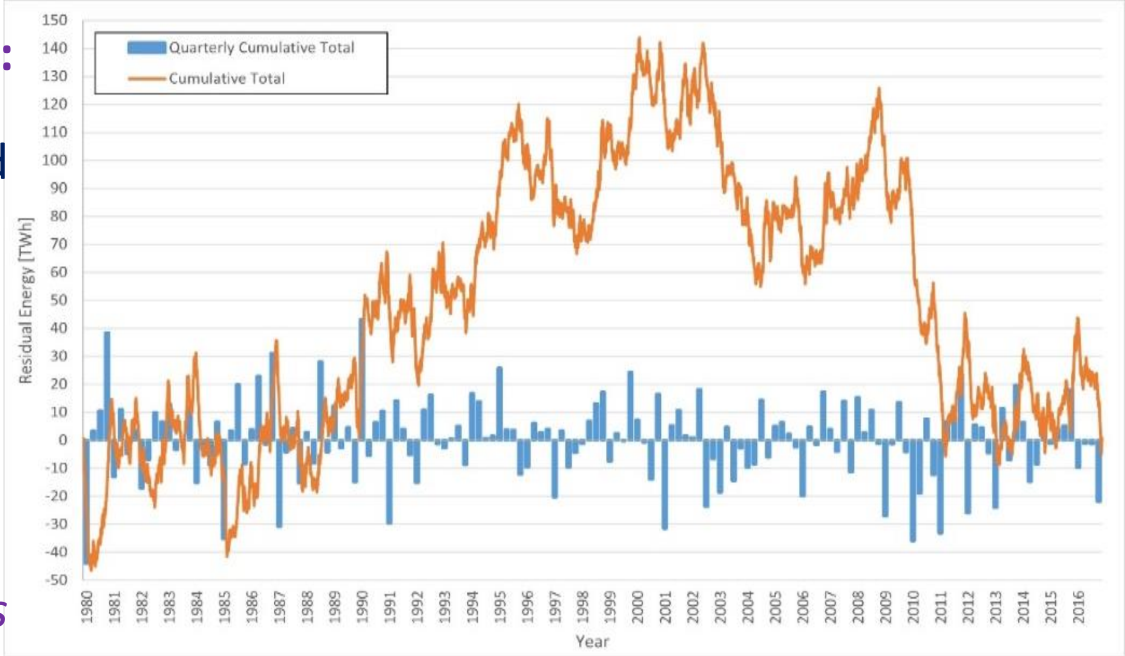
Assume wind: 70/30 off/onshore + mix 80 wind/20 solar – maximises amount that can be used directly

With this mix and supply scaled to average 570 TWh/year:

- **If** storage was 100% efficient ***and*** all surpluses could be stored → could meet demand with 190 TWh store

  With 41% efficiency (power ↔ hydrogen) need to increase Supply (to > 703 TWh) so ∑surpluses > ∑deficits/0.41

- With above wind/solar mix, the average differences of surpluses and deficits in each quarter are small compared to **volatility** which **is the issue** - ***not*** *inter-seasonal differences*



1980 2016

Inputs to Answering Question 2

- **Prospects for/possible costs of**:
  - **Hydrogen* –** best option for large-scale long-term storage *provided* suitable sites for storage in salt caverns are available: they are in the UK (otherwise Ammonia). Conversion: 4-stroke engines or fuel cells

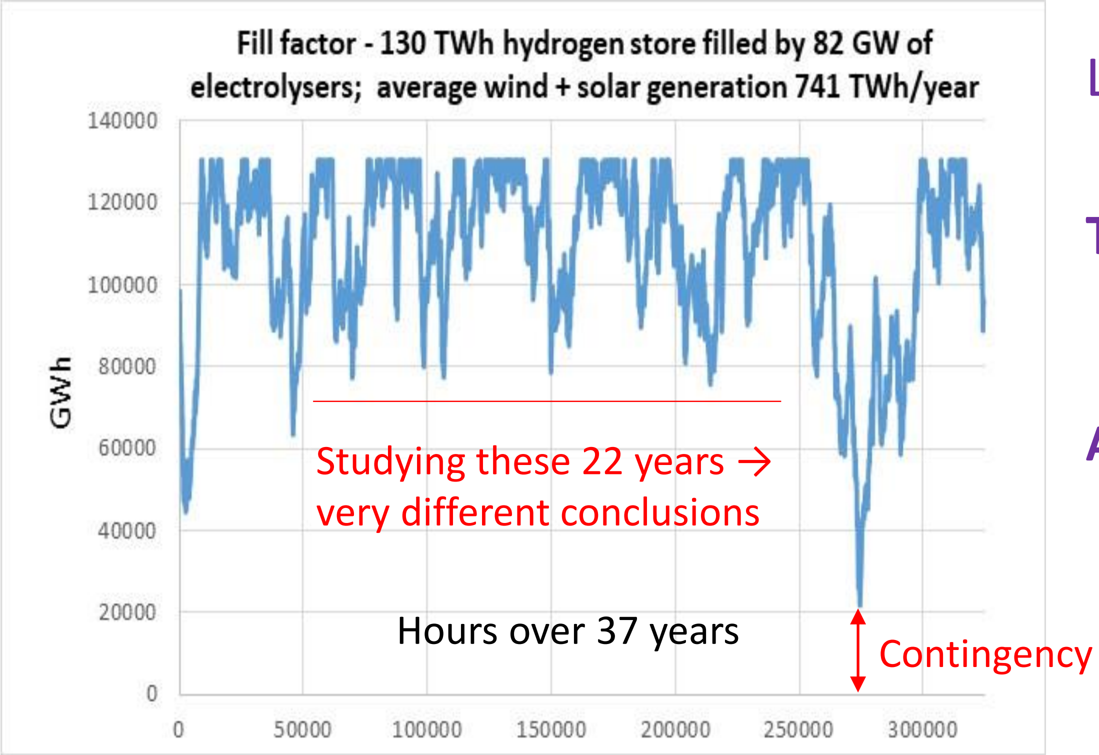
    Hydrogen is backstop – able to provide full range of power when sun not shining, wind not blowing, other stores empty
  - Non-Chemical & Thermal Storage **– A**diabatic **C**ompressed **A**ir **E**nergy **S**torage*, Thermal (pumped and sensible heat), Thermo-chemical, **L**iquid **A**ir **E**nergy **S**torage, Pumped hydro
  - Synthetic Fuels
  - Batteries (**lithium ion***, Flow,…) & Novel Chemical Storage (iron)

* Costings based on analysis of 2050 projections of costs for hydrogen, ACAES (as an example: in practice could/will have a range of technologies) and Li-ion batteries, without assuming major developments (e.g. of reversible solid oxide fuel cells/electrolysers)

Interconnectors will help managing the system **but** it would not be prudent to rely on them - there are occasional pan-European wind droughts lasting up to two weeks

Solar & Wind + Hydrogen Storage Only

With 570 TWh/year demand need ≥ 703 TWh/year renewable generation: 703 TWh/year→ Store > 236 TWh, 169 GW electrolysers. **Look at average wind + solar generation of 741 TWh/year (1.3 x demand)**:



Fill factor - 130 TWh hydrogen store filled by 82 GW of electrolysers; average wind + solar generation 741 TWh/year

Studying these 22 years → very different conclusions

Hours over 37 years

Contingency

Large store charged slowly ↔ Smaller store charged rapidly

limits: 170 TWh, 60 GW 92 TWh, 182 GW

Trade off that minimises cost:

109 TWh/year store (without contingency) + 82 GW electrolysers

Add 20% contingency (anticipated in min. cost) → **130 TWh**

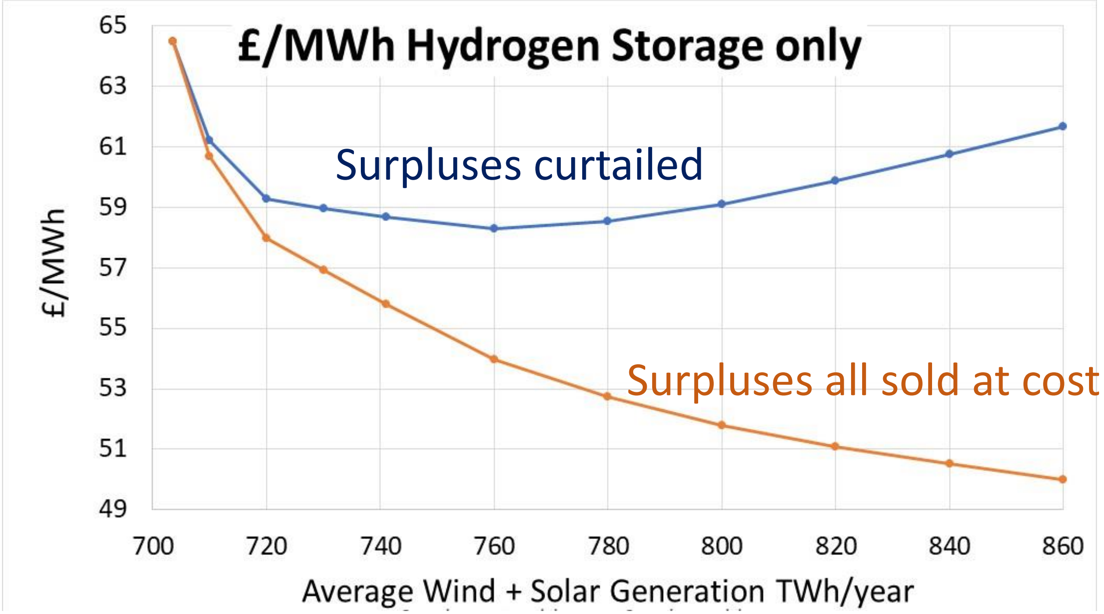
Average cost of power = [annual cost of wind & solar* + ∑(annualised cost of stores)]/570

With other stores: is additional cost offset by fall in size/cost of H2 store?

* use (for 2050) BEIS's low [high] 2040 cost estimate (£35 [45]/MWh for chosen mix)

Average cost of power – wind & solar + hydrogen store only

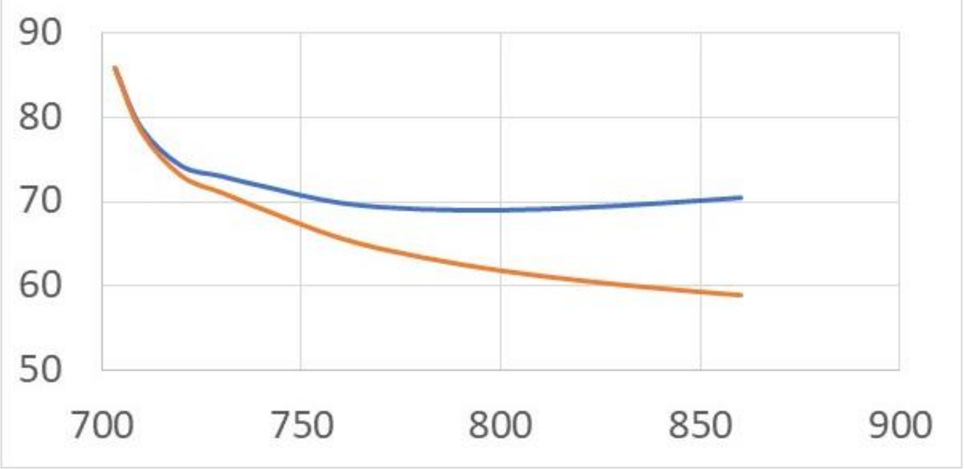
- 5% discount rate:



Cost of energy into grid, before transmission charges and losses, with energy into store @ £35/MWh

Sensitivities

- 20% → 40% contingency in store size → + £0.9/MWh
- Energy into store @ £45/MWh + £13/MWh
- 5% →10% Discount rate + £6/MWh @ 760 TWh/year
- Storage costs doubled:



With 440/700 TWh demand find similar costs (to ~ 1%) at same % above threshold for storage to work

What happens with several types of store and with baseload (nuclear)?

Would gas + CCS be a cheaper way to provided flexibility that complements wind and solar?

Other stores

- **Grid services**

  If provided by 15GW of 1 hour batteries add ~ £1/MWh to average cost of power

- **ACAES + Hydrogen**

  Adding ACAES to hydrogen probably - *very sensitive to assumptions* - lowers the average cost of power

  A small amount given priority in storing surpluses filling deficits* can deliver a lot of energy → big impact on the system, if not on the cost **note need of merit order; has not attracted much attention*

Example with av. wind + solar 741 TWh/year:

ACAES			Hydrogen			Av. £/MWh → grid
TWh	TWh/year delivered	Compressor GW	Vol (with 20%) TWh	Electrolyser GW	TWh/year delivered	
0	-	-	130	82	85	58.68
0.2	8.4	4.8	113	79	85 – 8.4	57.64
O.6	21	9.8	92	74	85 -21	58.28
For given ACAES size, cost minimum is very flat*						
0.6	17	6.5	96	69	85 -17	58.44

Difference = 8% of storage cost

**Scope for optimising for buildability, operability and reliability without compromising cost*

Baseload

Assume Nuclear

With BEIS's medium nuclear cost prediction (£78/MWh) + default storage assumption:

hydrogen storage alone (→ £58/MWh with 741 TWh/year wind + solar))

slightly cheaper than

50 TWh nuclear (→ need less wind and solar*) + hydrogen storage

But costs of both very uncertain: not possible to use costs to rule nuclear in or out

*easier to reach required level of wind and solar by 2050

- cost minimum with 50 [200] TWh/year at nuclear at around 690 [500] TWh/year wind + solar

Gas + CCS

Compare extremes: all flexibility needed to match volatile wind and solar provided by

Gas + CCS **OR** Storage

BEIS's Gas + CCS projection with 100% load factor and gas @ £22/MWh_{LHV} (recently much higher) is £80/MWh (includes £8 CO_2 cost @ £190/t)

Much lower load factor but cost mainly variable + cheap wind & solar → find £75+/MWh

– storage with default costs is cheaper

But price of gas may fall as it is phased out. Mix of gas + CCS and storage could be best option

Conclusions

- Could power GB with wind + solar + hydrogen storage

  at cost below that paid recently, and CFDs for biomass and nuclear

  but *much higher than in last decade*
- Focus on hydrogen alone *as an existence theorem* **NOT** as ‘the’ solution:

  likely to need a mix of stores (hydrogen + others: ACAES just one example), with perhaps some nuclear, some gas + CCS,…

Needs include

- Scenarios that take account of geography (location of demand, supply, storage), cost of enlarging & strengthening the grid, other uses for hydrogen;… + buildability, operability, reliability
- Range of models of demand profile + if possible longer sequence of weather data
- More thought on scheduling + *markets the could deliver the coordination that will be needed*
- Better understanding of underground storage potential (Hydrogen, ACAES, …)
- Drive down costs – roll out + demonstrate at scale

[RS study covers: large range of technologies, demand management, storage of heat, the grid with high levels of renewables and large new distributed uses (heat pumps, charging EVs – which can also act as stores,…]

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