The role of hydropower in future electricity systems

Hydropower Engineering: Technologies, Projects and Future Developments

IMechE, London

3 June 2021

Mike McWilliams

mike@mcw-e.com

Understanding the role of hydropower in 2030

- What will the future power system look like?
- How will it differ from before?
- What is driving the change?
- What challenges need to be addressed?
- What key roles can hydro play?
- How can we configure hydro to suit the system?
- What changes are needed for hydro to play its role?

Future power systems look very different

- Wholesale decarbonisation of electricity is happening.
- Traditional fossil-fuelled generation is on the way out.
- New renewables predominate – led by PV and wind
- Large amounts of distributed generation
- Gas-fired generation depends on CCS – is this sustainable?
- Electrification of heating and transport, V2G and smart grid

“The times they are a-changing”

“The answer is blowin' in the wind”

What is driving the change?

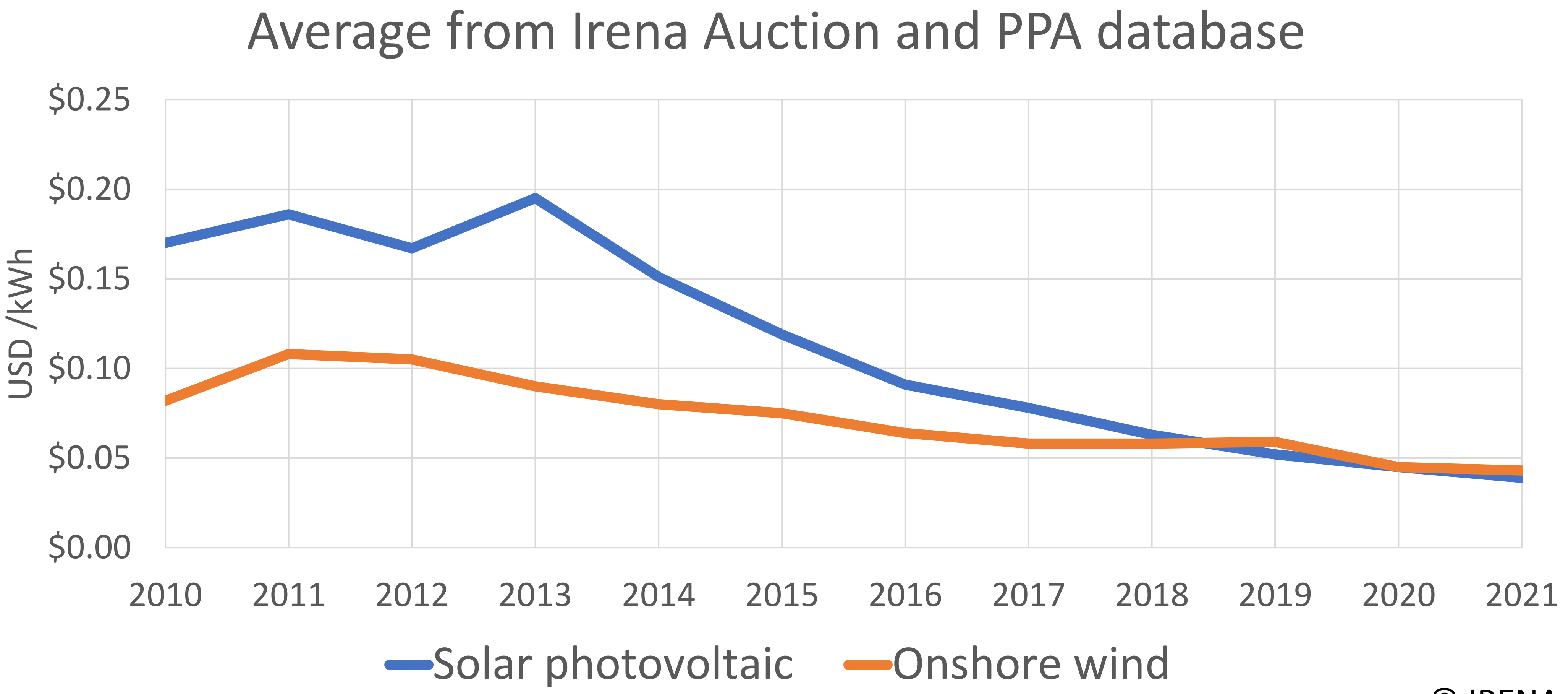
- Initially renewable energy was driven by political regulation and public sentiment.
- Commitments from 2015 Paris Agreement still drive decarbonisation – new pledges expected at COP 26.
- The cost of renewable energy falling, economics is starting to drive change.
- Fiscal penalties such as carbon border taxes will encourage decarbonisation – a likely outcome of COP 26.

The falling cost of vRE?

- In many countries variable Renewable Energy (vRE) is now the cheapest source of energy.
- Recent PV tenders in Portugal and Abu Dhabi were won with prices as low as US¢ 1.3 / kWh.
- In USA sub-US¢ 2.0 / kWh for wind is common (although this would probably be US¢ 3.0 / kWh without subsidy).
- BEIS estimates UK onshore wind and PV cost are less than CCGT*
- Few technologies can compete with these energy prices.

*Electricity Costs 2020: CCGT £53/MWh, offshore £57; onshore £46; large PV £44 – 2025 commissioning

The falling cost of vRE



How power systems differ from before?

- Traditional power systems featured relatively stable demand and predictable generation.
- Most of the generators were capable of supplying continuous base-load.
- Storage hydro could be used for peaking, and pumped storage for arbitrage.
- Storage hydro is virtually the only despatchable low carbon generation for future power systems.

Traditional generation mix

Technology	Constant	Predictable	Dispatchable	Low Carbon
Steam (coal / oil)	Yes	Yes	(Yes)	No
Open Cycle Gas Turbine	Yes	Yes	Yes	No
Combined Cycle Gas Turbine	Yes	Yes	(Yes)	No
Reciprocating (diesel / HFO)	Yes	Yes	Yes	No
Nuclear	Yes	Yes	No	Yes
Hydroelectric with storage	(Yes)	(Yes)	Yes	Yes
Hydroelectric: run-of-river	No	No	(Yes)	Yes

Future generation mix

Technology	Constant	Predictable	Dispatchable	Low Carbon
Nuclear	Yes	Yes	No	Yes
Hydroelectric with storage	(Yes)	(Yes)	Yes	Yes
Hydroelectric: run-of-river	No	No	(Yes)	Yes
Solar Photovoltaic	No	No	No	Yes
Solar Thermal	(Yes)	No	(Yes)	Yes
Wind	No	No	No	Yes
Tidal Stream	No	Yes	No	Yes
Tidal Range	No	Yes	(Yes)	Yes
Biomass / MSW	Yes	Yes	(Yes)	Yes
Geothermal	Yes	Yes	(Yes)	Yes

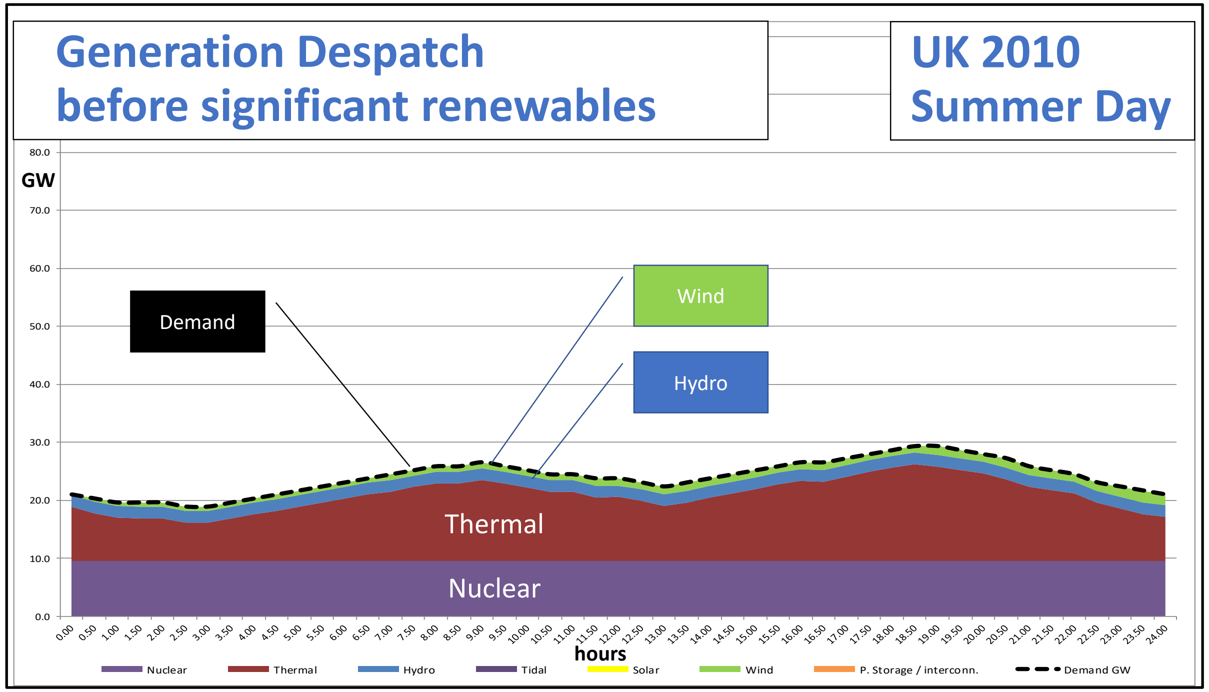
What challenges need to be addressed?

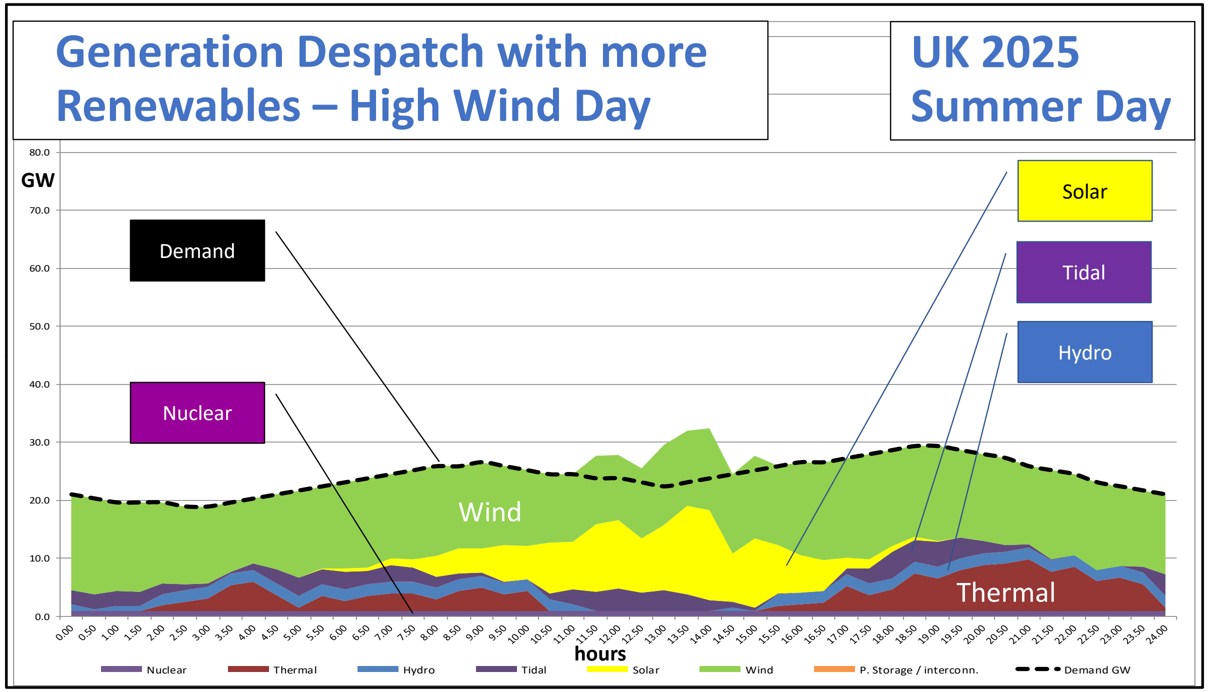
- **Dispatchability**: most renewables are not dispatchable
- **Oversupply**: due to huge capacity margins
- **Security**: to deal with *Dunkelflaute* (dark doldrums)
- **RoCoF***: inertia scarce with asynchronous generation
- **Reconstruction**: fine control of dispatchable generation
- **Grid congestion**: when the sun shines of the wind blows
- **Value of energy**: most generation has zero marginal cost

MCWe

*Rate of Change of Frequency – resisted by mechanical inertia

Dispatchability





Power systems become increasingly complex and difficult to manage. Net demand on the transmission grid varies as distributed generation fluctuates. Hydropower with storage, either diurnal or seasonal, is one of the few controllable technologies that can be ramped up and down as needed by the grid.

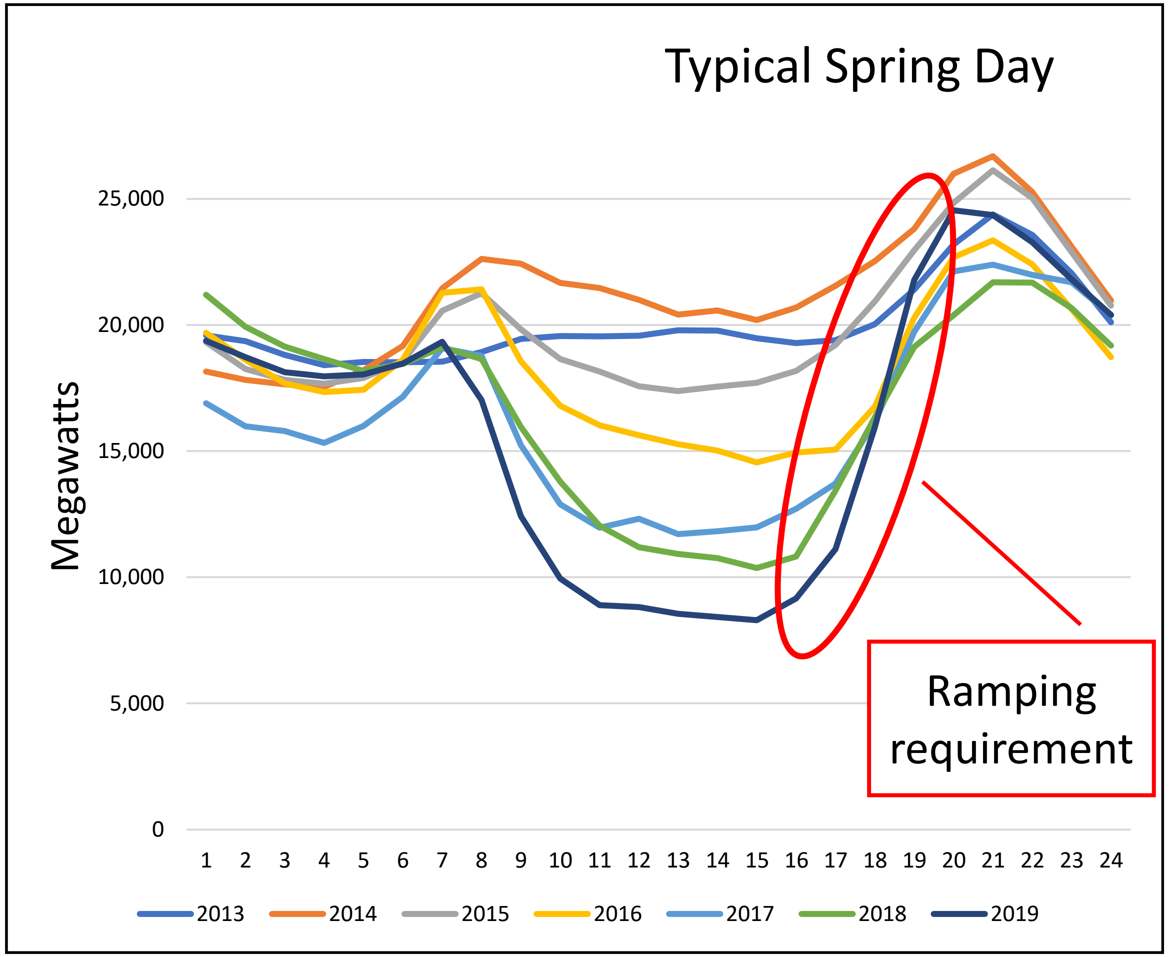
Net system demand illustrated by CAISO

In 2013 CAISO* created the duck curve, expecting transmission system demand to drop by 40% in 2020 on a sunny spring day due to distributed solar PV generation.

This reduction arrived four years earlier than expected (and not because of Covid).

The duck is getting fatter more quickly than expected: by 2019 mid-day demand was already reduced by 57%.

By Spring 2019 maximum required ramp rates had reached over 15 GW in 3 hours



*CAISO is the California Independent System Operator

Source: data from IEA / CAISO

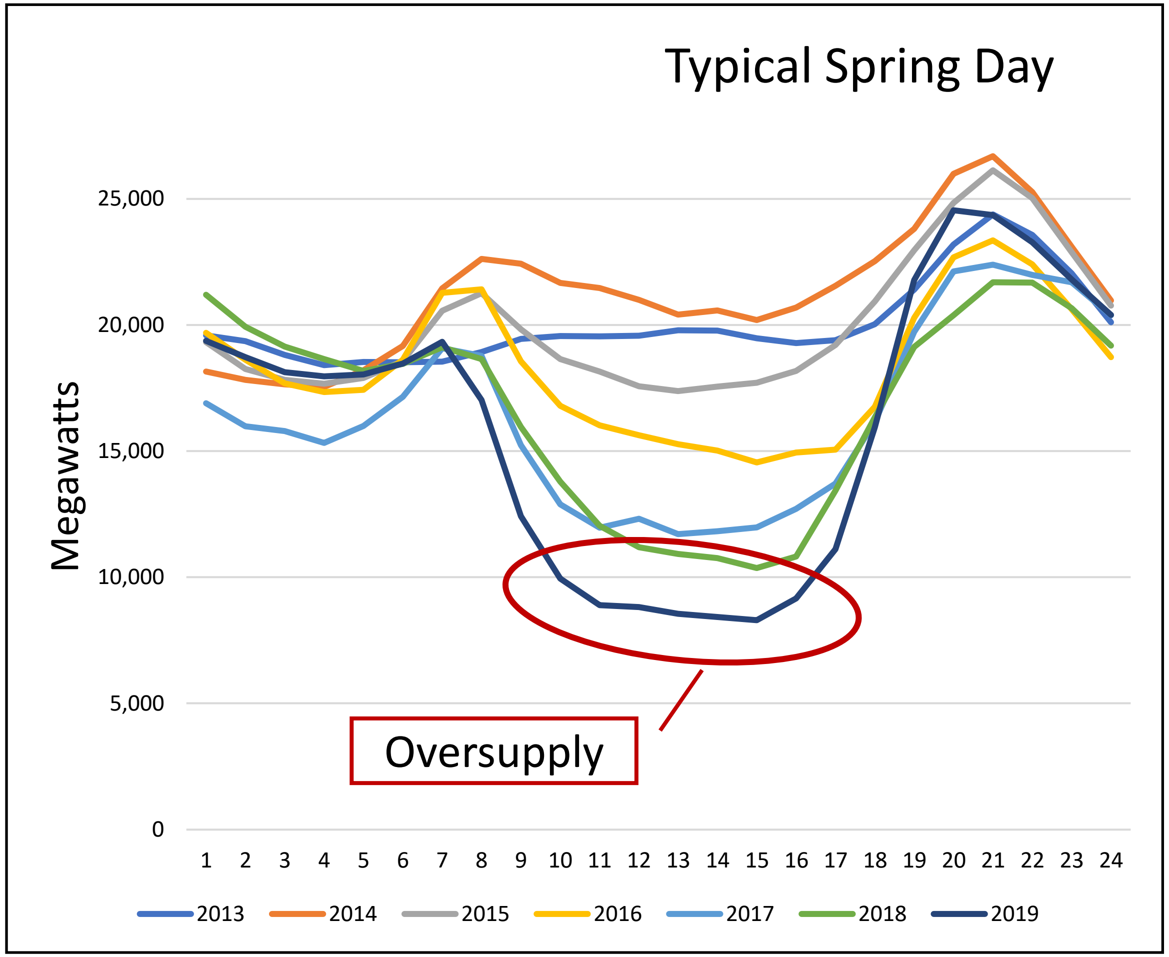
Oversupply

Oversupply is inevitable.

E.g. UK plant factors of PV (11%) and wind (27% onshore, 40% offshore) are much lower than the capacity factor of the grid (82%)*

If the bulk of energy comes from PV and wind, a huge capacity margin is needed, even if all the energy can be used.

Illustrated again by CAISO:



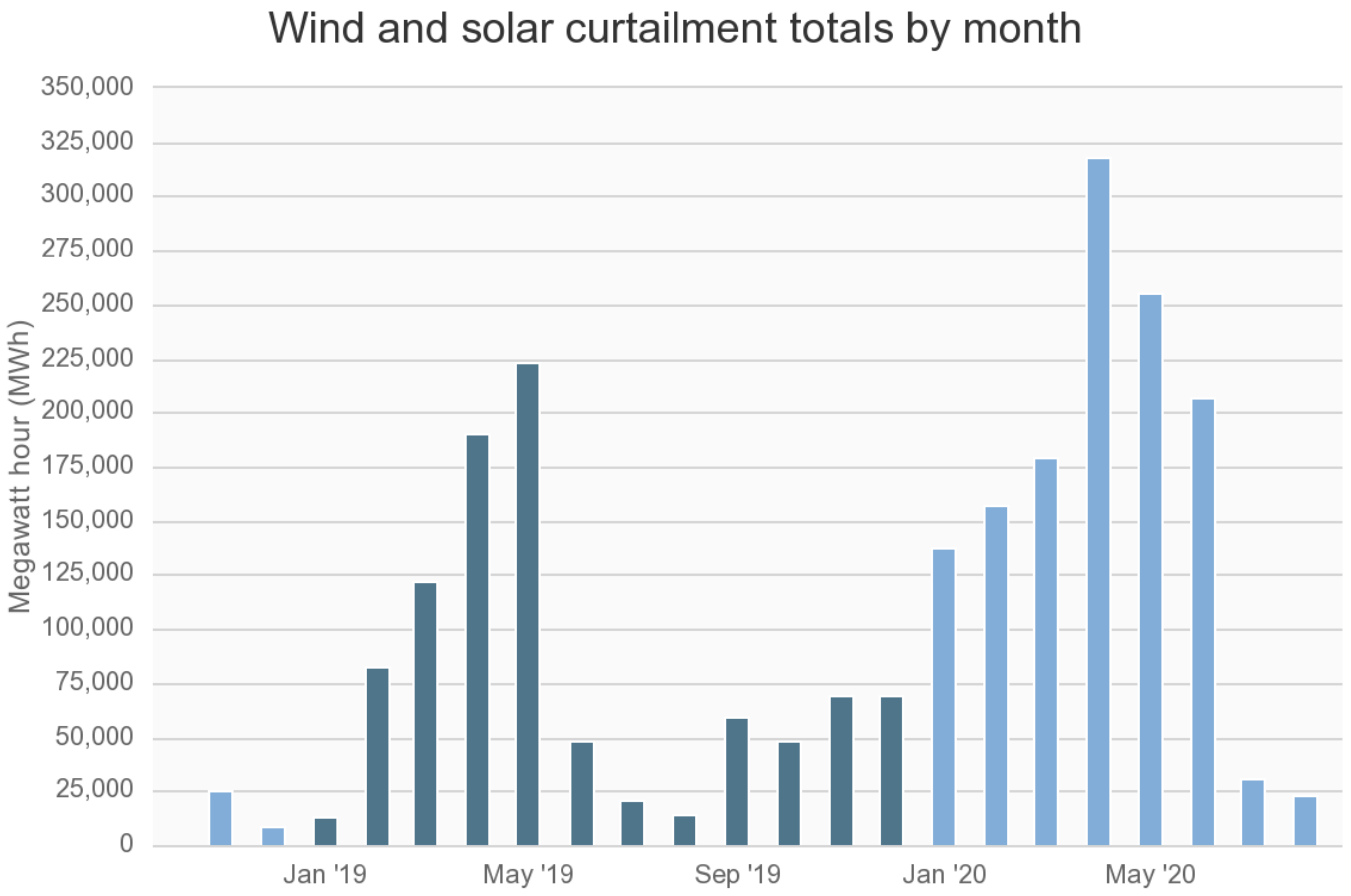
* Figures from DUKES 2020

Source: data from IEA / CAISO

Curtailment of vRE is common…

On CAISO's system curtailment of renewable energy sources due to over-supply is common, especially in the spring months.

UK is already curtailing vRE – 3.8 TWh (6%) of wind output was curtailed in 2019. In 2020 it doubled at a cost over £250 m. It will grow dramatically if significantly more storage is not introduced.



Source: CAISO

MCWe

Security

PV will not be available on winter evenings or at night; wind can drop to less than 5% of installed capacity

Dunkelflaute (the dark doldrums) can persist for days on end, and affect large areas of UK and continental Europe.

Interconnection with Europe can reduce average costs, but can't be relied on for security.

UK's hydro reservoirs hold 100s of GWh of energy when full – many times more than its 30 GWh of pumped storage. These reservoirs can contribute to energy security if the mode of operation is changed, especially if capacity is expanded.

Run-of-river hydros with diurnal pondage can contribute to security.

Rate of Change of Frequency (RoCoF)

When a loss of supply causes a power imbalance, frequency will start to drop from 50Hz (or 60Hz). If it falls too quickly, the power grid will trip.

Initial drop is resisted by mechanical inertia of synchronised generators: for the frequency to drop, the rotating equipment must slow down.

Traditionally inertia was provided by thermal and nuclear plant. Most of this will disappear from the system.

Virtual inertia – injection of active power in < 1 second, typically from batteries, – can help, but is not a substitute.

Hydropower turbine-generators can play a big role in providing inertia and system stability.

Reconstruction

When the grid fails, it needs to be re-built carefully, balancing supply with the demand as it is progressively re-introduced to the system.

This requires:

- Blackstart capability (self-start without external power supply)
- Controllable and dispatchable generation

Hydropower can provide both of these, and can be the most useful tool for reconstruction of the grid after failure.

Grid congestion

- Renewable energy resources are often clustered, and are often remote from demand centres.
- Low plant factors of many renewables mean it is often not commercially viable to provide transmission capacity to cope with peak generation. Hence transmission over-loading can result in curtailment of renewable generation.
- Conjunctive operation of hydro with renewables helps alleviate congestion
- Pumped storage works even better – absorbing excess energy for later generation.

Is Energy a suitable basis to pay for electricity?

- Thermal based systems: energy cost = fuel + O&M
- Future Wholesale

  Most low-carbon generation has zero (wind, hydro, PV, marine) or negative (nuclear) short run marginal cost; payment isn't needed to produce energy
- Future Retail

  Increasingly consumers install behind-the-meter generation (usually PV) to minimise electricity imports, but still need the grid as back-up.
  Grid operating costs are rising, and cannot be covered by energy sales.
- Energy seems a poor basis to pay for electricity in future

How will the market change?

- Retail

  How will we pay for the grid fairly as behind-the-meter generation proliferates? We will probably move towards the modern telecoms model, where you pay for a grid connection and receive a bundle of energy units.

- Wholesale

  With increasingly complex systems, ESO* needs to specify characteristics of all grid infrastructure (including generation) and control operation; paying for the facility rather than production seems more appropriate.

- One thing is certain: the market will be different

*Electricity System Operator

What key roles can hydro play?

Activity	Service	Hydro	PSH
Balancing	• Day ahead scheduling • Load following / dispatch • Automatic frequency response • Fast ramping • Arbitrage (intra-day storage) • Bulk energy storage (multi-day) • Footroom (load turn-up)	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓ ✓ ✓
Rate of change of frequency	• Inertia	✓	✓
Voltage management	• Reactive power control (location specific)	✓	✓
Transmission management	• Constraint alleviation (location specific)	✓	✓
Reconstruction	• Blackstart • Fine variable control	✓ ✓	✓ ✓

Pumped storage and some hydro can provide many of these services at zero load, hence without displacing vRE

MCWe

Configuring hydro to suit the system

New hydro should be configured to suit the system in 10-years' time and beyond; existing hydro can also be re-purposed.

- Fast and flexible response is needed - fast start-up and fast ramping.
- Plant should be robust to frequent set-point changes.
- Capacity is becoming more important than energy.
- Storage will be important – seasonal if possible; otherwise diurnal.
- Ability to provide services at zero load in order not to displace other renewables – e.g. synchronous condenser operation.
- Re-regulating dams may be needed to minimise downstream impacts
- Optimal use of sites implies multi-purpose use.

Optimising for energy can waste the resource

- A hydro site is a unique national asset
- Optimising for energy cost will usually produce a high load-factor, low capacity run-of-river scheme
- Sites should be optimised for maximum power system benefit, taking into account environmental and social impacts/benefits and multi-purpose potential
- National economic benefit (socio-economic, GVA, external costs/benefits) should be taken into account.

Providing grid support adds cost

- Storage requires a dam.
- Fast ramping requires enhanced surge facilities and possibly thicker penstocks or pressure relief valves.
- Synchronous condenser (for inertia) needs blow-down, or Pelton instead of Francis turbine.
- Peaking requires additional capacity.
- Blackstart requires a generator.

All of these add to cost and must be compensated.

History	The future
System planning only for power and energy	System planning for all services and attributes needed by the system
Hydro optimised for energy and revenue	Hydro optimised for system and national benefit
IPP projects on first-come-first served	System planning defines project sequence
Little value given to storage	Energy (water) storage has great value
Oversupply does not exist	Oversupply is a problem: footroom and load turn-up are needed – major role for pumped storage
Hydro in competition with other generation	Hydro complements other generation – more vRE means greater need for hydro and pumped storage
Hydro prioritised in multi-purpose projects (as primary source of revenue)	Multi-purpose project components prioritised for national benefit
Energy has a real cost (fuel) and value	Energy has no marginal cost and no intrinsic value: prices positive when shortfall, negative when surplus

McWILLIAMS *energy*

Q & A

Mike McWilliams

mike@mcw-e.com

www.mcw-e.com

Cebr

Full report

February 20, 2021

The Great Texas Blackout is a warning; we must be prepared for a Dunkelflaute in the UK

At the time of writing some four million Texans are reportedly without power in freezing conditions. Winter storm Uri and a loop in the jet-stream bringing the polar vortex south, have led to record-breaking low temperatures across parts of the southern US. Rising electricity demand coupled with failure of power stations means that the grid operator, the perhaps ironically named Electric Reliability Council of Texas (ERCOT), is unable to balance demand and supply. **They have so far avoided complete grid failure through a system of rolling blackouts, but this is cold comfort for those freezing in the dark. For those of us observing their difficult situation from afar this begs the question, could we be next?**

- Macro-economic study of Swansea Bay Tidal Lagoon (SBTL) for Tidal Lagoon Power in 2014 (in public domain, and used in Hendry Report).

- Substantial economic development benefit of the project – contributing to the Welsh economy £316 million during construction and £76 million pa (in 2014 prices) during operation, in addition to the energy production.

- Value of macro-economic benefits as great as the energy.

See full report