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Designing cost-efficient, flexible, energy solutions for a decarbonized GB power system

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The transformation of the current energy system from carbon-intensive to deeply decarbonized means variable renewable energy (VRE) will become the main supplier of energy. The sharp fall in VRE cost makes it competitive compared with conventional generation (with a suitable carbon price). This is a sign that our power system is moving towards a VRE-dominant system. The variability and intermittency of VRE will inevitably lead to a demand for flexible power sources to mitigate the energy demand gap (flexibility gap). To design future power systems with a cost-efficient solution for the flexibility gap, assessing the performance of energy storage, thermal generation and interconnectors under a power system model with precise VRE output variances and mechanisms will be a necessity for future power system planners.

Our research builds a mechanism to solve this optimization by translating the project cost of an energy storage operator into the storage cost of energy in the unit-commitment process. We model the current Great Britain power system (the Now scenario) and the case when all projected VRE capacity is delivered (the Future scenario). We divide the system cost into the cost of providing energy from VRE (defined as energy cost) and the cost of providing energy flexibility from energy storage, thermal generation and interconnectors (defined as flexibility cost) to show the significance of energy flexibility.

Our research shows that in the GB power system, with all projected energy storage, VRE generation and interconnection capacity, the energy cost only accounts for 18.5% of the system cost when the gas price is 40 pounds per MWh and the carbon price is 60 pounds per ton CO_2, while the annual VRE generation is 212 TWh and the annual electricity demand is 233 TWh. The curtailed energy, mostly the excess VRE

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generation, will be higher than 100 TWh, with more than 50 TWh of electricity still coming from thermal generation (CCGT, OCGT or biomass).

By comparing the scenarios with current energy storage capacity, projected energy storage capacity, and our recommended storage portfolio, we found that energy storage is the most cost-efficient energy flexibility provider. 25 GW of energy storage capacity will enable the system cost to stays at a level of £56.68 per MWh, close to our modelling result of the current system's cost of £55.78 per MWh.

Our research finds that in the future scenario, increasing VRE capacity will reduce the carbon intensity but increase the system cost if no energy storage is added. Interconnectors will help reduce the system cost by exporting excessive VRE generation but can't provide cost-efficient energy flexibility. The thermal generation will have to shut down and start up frequently when VRE penetration is high, and the start-up cost will be material. In the future scenario, increasing energy storage capacity will avoid both the start-up and fuel costs of thermal generators and reduce the system cost. By changing the share and level of the energy storage portfolio, we find that mechanical (pumped-hydro and compressed air) energy storage performs better when providing cheap energy flexibility because it is the most suitable for frequent charge and discharge among all energy storage technologies.

Because of the stubborn thermal generation, the carbon intensity will be 65.9 g/kWh in the future scenario. using our suggested 25GW storage portfolio will help the system reach a carbon intensity of 61.1 g/kWh, which is still higher than the UK's carbon ambition of 50g/kWh. This means that keeping thermal generation online and economic dispatch will prevent the power system from reaching its emission target. To reach the 50g/kWh emission target,1.6 times as much as the projected VRE capacity is needed for the GB power system.

The main conclusion of this research is that a VRE-dominant power system's cost will rely on the cost of mitigating the flexibility gap caused by VRE rather than the cost of installing VRE generation capacity itself. System planners should plan energy storage together with VRE capacity to achieve further carbon reduction and avoid system cost increases.

Mechanical energy storage (pumped hydro and compressed air storage) was found to be more cost effective than batteries when mitigating the short term flexibility demand, i.e. when charging and discharging mutiliple times day. It will be expensive to replace the thermal generation which migitigates the longer term flexibility gap (i.e. seasonal) with energy storage.