High-temporal-resolution analysis of UK power system used to determine the optimal amount and mix of energy storage technologies [2015 Powerpoint]

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High-Temporal-Resolution Analysis of UK Power System Used to Determine the Optimal Amount and Mix of Energy Storage Technologies

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Overview of FESA, “Future Energy Scenario Analysis”

Electricity Demand
- Electric Vehicles
- Heat Pumps, Appliances etc.
- Domestic, Commercial and Industrial

Uncontrolled Generation
- Wind
- Wave
- Tidal
- Solar PV
- CHP

\[ \sum = \text{net demand} \]

Balancing:
- Storage
- Interconnector
- Time shifting
- Curtailment

Merit Order Of Generators

Dispatchable generation
\[ \sum = \text{National fuel demand} \]

Non-electric fuel use

Total UK CO₂ Emissions
The Future Need for Energy Storage:
Steeper Load-Duration Curves

[Graph showing the net demand, GW, over the hour of the year for Year 2010 and Year 2050]
DECC 2050 Calculator – (e.g. High Renewables)

Electricity generation

- Electricity imports
- Non-thermal renewable generation
- Nuclear power
- Carbon Capture Storage (CCS)
- Unabated thermal generation
- Domestic demand

TWh/year vs. Year
DECC 2050 Calculator (Higher Renewables Scenario)

Net Demand in GW

- Peak Plant (Unabated)
- Low Carbon (CCS)
- Baseload (Nuclear+Hydro)
- Curtailed Renewables

Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec
‘Thousand Flowers’ Low-Carbon Pathway in 2050
12 days of surplus, 10 days of deficit, 2 days surplus

2500GWh of surplus
1500GWh of shortfall
Storage needed

Example Weather, 23rd Feb to 18th March
Interconnectors  Surplus  Low Carbon Gen.  High Carbon Gen.
Costs of Electricity Generation

- Baseload and renewables: High capital cost but ‘free’ running costs
- Fuel costs:
  - £16/MWh\(_e\) for CCS,
  - £23/MWh\(_e\) for peak gas-fired plant
- Carbon price: £76/tonne of CO\(_2\) equivalent
  - Peak gas plant 460kg/MWh\(_e\)
  - CCS plant 50kg/MWh\(_e\)
- Value of Lost Load (DECC & Ofgem) £16,940/MWh\(_e\)!
Marginal Costs of Generation (2)

Value of lost load (VOLL) is not really helpful in determining economic optimum despatch most of the time.
3 Thresholds of Storage

- **Lost Load** (Storage Replaces Peak Generation)
- **Peak Plant Fossil Fuel (CCGT)**
- **Low Carbon Fossil Fuel (CCS)**
- **Baseload (Renewables And Nuclear)**

Use peak generation to avoid loss of load.

Use low carbon to displace high carbon.

Use baseload to displace low carbon.
3 Thresholds of Storage

- Perfect forecasting
- Economically optimum
- Reference levels of demand are at thresholds.
- Minimum generation to avoid more expensive generation

Net Electricity Demand, GW

Time (Hours)
Store Sizing with Real Demand Data

Area = Energy, E

Annual Peak

Power, P

Store ceiling

Move the ceiling down.
Increasing power, \( P \) = peak generation saved
Calculate the energy capacity, \( E \) = store capacity
Optimum Ratio of energy Capacity to Power (GWh/GW) (High Renewables Scenario)

- Large Energy Capacity
  - But Usefulness is Limited
  - By Power Rating
  - Of Store

- Large Power Rating
  - But Store Spends Too Much Time
  - Full or Empty
Optimum Ratio of energy Capacity to Power (GWh/GW)

- Inter-Seasonal Storage => Fuel Storage
- Intermediate Timescales: Daily, weekly, Monthly, Weather

- Peak
- Lopping
- Flexible
- Demand?

Store Energy Capacity, GWh

Store Power Rating, GW

Legend:
- Low Cost
- High CCS & Bioenergy
- High Nuclear
- Markal 326
- National Grid
- CPRE
- Atkins
- Mark Brinkley
- High Renewables
- Friends Of The Earth
Value of Storage vs. Storage Capacity

Store Energy Capacity, GWh

Lifetime Value Of Storage, £bn

1500 GWh

- Markal 3.26
- High Renewables
- High Nuclear
- High CCS & Bio-Energy
- Low Cost
- Friends Of Earth
- CPRE
- Mark Brinkley
- Atkins
- National Grid
Capital Costs Per Power and Energy for Energy Storage

- Sodium-Sulphur Battery
- Isentropic Heat Storage
- Compressed Air Energy Storage
- H2 Underground + Gas Turbine

Cost, £GB

Legend:
- Cost Per 100W
- Cost Per kWh
Size of Storage and Appropriate Technology by Application

- Batteries for Short-Term
- CAES for weather-related variation (On time up to 2 weeks)
- Thermal Energy Storage for up to about 2 days
- Hydrogen for Inter-seasonal

Graph showing store energy capacity (GWh) vs. store power rating (GW). Different technologies and their respective capacities and power ratings are indicated with different colors and labels.
Optimum Ratio of energy Capacity to Power (GWh/GW) (High Renewables Scenario)

Lower gradient at small storage volumes, suitable for a short-term of storage technology

Higher gradient at larger volumes, suitable for a longer-term storage technology
Optimum Solution is Multiple Stores Working Together

Peak of each curve is the economic optimum level of storage.
The diagram illustrates the optimum storage power across different scenarios:

- Markal
- High Renewable
- High Nuclear
- high CCS
- Low Cost
- FOE
- CPRE
- Brinkley
- Nat. Grid
- Atkins

The storage power is measured in GW (Gigawatts) and is color-coded as follows:

- CAES (blue)
- Heat (red)
Optimum Storage Energy Capacity

Storage Capacity, GWh

CAES
Heat

Markal
High Renewable
High Nuclear
high CCS
Low Cost
FOE
CPRE
Brinkley
Nat. Grid
Atkins
Components of Value of Energy Storage

- Markal
- High Renewable
- High Nuclear
- high CCS
- Low Cost
- FOE
- CPRE
- Brinkley
- Nat. Grid
- Atkins

- Carbon
- Fuel
- Capital
Energy Storage Cycle Time vs. Weather Predictability

Limit of accurate forecasting: 2 days

Limit of approximate forecasting: 5 days

(Mark Brinkley scenario is an outlier for several reasons)
Modest Improvement in Load Factor of CCS

Graph showing comparison between CCS CF, No Storage, CCS CF, With Storage, and DECC CF, 85% for different categories:
- Markal
- High Renewable
- High Nuclear
- high CCS
- Low Cost
- FOE
- CPRE
- Brinkley
- Nat. Grid
- Atkins

The graph indicates improvements in load factor for CCS with storage compared to those without storage and the DECC CF, 85% benchmark.
Reduction in Curtailed Low Carbon Energy at Economically Optimum Level of Energy Storage

![Graph showing reduction in curtailed low carbon energy at economically optimum level of energy storage. The graph compares the amount of curtailed energy with and without storage for various scenarios, including Markal, High Renewable, High Nuclear, high CCS, Low Cost, FOE, CPRE, Brinkley, Nat. Grid, and Atkins.](image-url)
Conclusions – Part 1

- The need for energy storage is increasing
- The optimum ratio of GWh/GW (time constant) increases exponentially with power rating
- Strong law of diminishing returns with energy capacity, GWh
- The cost-effective technologies appear to be heat/cold storage and Compressed Air (CAES)
- Storage is cost-effective for cycle times of approximately 2 to 5 days but no more:
  - Poor Economics of storage technologies
  - Inadequate long-term weather forecasts
Conclusions – Part 2

- Energy storage can substantially reduce the following parameters but it is not economically feasible to build enough storage to eliminate them:
  - Curtailed low-carbon energy
  - High carbon peaking generating plant
- Energy storage can increase the utilisation factor of fossil-fuelled plant with CCS, but it is not economically feasible to use storage to bring it up to the levels anticipated in the DECC 2050 Calculator Model
Next Steps

- Forecasting Errors – How the optimum size, despatch algorithm and value of storage change with imperfect forecasting
- Extend FESA to a European model – the optimum role of storage alongside interconnectors
- Demand response – where (in timescale) does DR finish and storage begin?
- Alternative supply scenarios – more electricity generation mixes, e.g. from ETI, Shell, UKERC
Cost of Storage with Increasing Timescales

- **Batteries**
  - Up to 1 hour
- **Above-Ground Heat or Cold (?) Storage, Or Flow Batteries**
  - Up to 12 hours
- **CAES & Pumped Hydro**
  - Up to 2 weeks
- **Hydrogen & Fuels**

The graph shows the added cost per unit of energy (\$/kWh) on the y-axis and the storage energy to power ratio (GWh/GW) on the x-axis, with different storage technologies indicated by various lines and markers.