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

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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

Balancing:
- Storage
- Interconnector
- Time shifting
- Curtailment

∑ = net demand

Dispatchable generation

Merit Order Of Generators

Non-electric fuel use

∑ = National fuel demand

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

![Graph showing steeper load-duration curves for Year 2010 and Year 2050.](graph.png)
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

2007 2010 2015 2020 2025 2030 2035 2040 2045 2050
‘Thousand Flowers’ Low-Carbon Pathway in 2050
12 days of surplus, 10 days of deficit, 2 days surplus

2500GWh of surplus

Storage needed

1500GWh of shortfall

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\textsubscript{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 (1)

- Baseload
- Fossil CCS
- Peak CCGT
- Lost Load

Marginal Cost, £/MWh

- Lost Load
- Carbon Cost
- Fuel Cost
Marginal Costs of Generation (2)

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

Net Electricity Demand, GW

Use peak generation to avoid loss of load

Use low carbon to displace high carbon

Use baseload to displace low carbon

Lost Load (Storage Replaces Peak Generation)

Peak Plant Fossil Fuel (CCGT)

Low Carbon Fossil Fuel (CCS)

Baseload (Renewables And Nuclear)

Time (Hours)
3 Thresholds of Storage

- Perfect forecasting
- Economically optimum
- Reference levels of demand are at thresholds.
- Minimum generation to avoid more expensive generation
Store Sizing with Real Demand Data

Move the ceiling down.
Increasing power, $P = \text{peak generation saved}$
Calculate the energy capacity, $E = \text{store capacity}$
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

Store Energy Capacity, GWh

Store Power Rating, GW

Peak
Lopping.
Flexible
Demand?

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. Store Power

![Graph showing the relationship between lifetime value of storage and store power rating for different scenarios.]
Value of Storage vs. Storage Capacity

- 1500 GWh

- Lifetime Value of Storage, £bn

- Store Energy Capacity, 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
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 the relationship between store energy capacity and power rating for various applications.](image-url)
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.

Net Value of Storage, £bn

Storage Energy Capacity, GWh

- Markal 3.26
- High Renewables
- High Nuclear
- High CCS & Bio-Energy
- Low Cost
- Friends Of Earth
- CPRE
- Mark Brinkley
- National Grid
- Atkins
Optimum Storage Energy Capacity

Storage Capacity, GWh

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

CAES
Heat
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

[Bar chart showing comparison of load factors for different scenarios:
- CCS CF, No Storage
- CCS CF, With Storage
- DECC CF, 85%

Categories: Markal, High Renewable, High Nuclear, high CCS, Low Cost, FOE, CPRE, Brinkley, Nat. Grid, Atkins]
Reduction in Curtailed Low Carbon Energy at Economically Optimum Level of Energy Storage

![Bar chart showing reduction in curtailed low carbon energy with and without storage. The chart compares different scenarios including Markal, High Renewable, High Nuclear, high CCS, Low Cost, FOE, CPRE, Brinkley, Nat. Grid, and Atkins, with and without storage.]
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**

![Graph showing the cost of storage with increasing timescales]