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

Balancing:
- Storage
- Interconnector
- Time shifting
- Curtailment

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

Dispatchable generation

Merit Order Of Generators

Non-electric fuel use

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

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

Marginal Cost, £/MWh

Lost Load
Carbon Cost
Fuel Cost

Baseload
Fossil CCS
Peak CCGT
Lost Load
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

- **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)**

**Net Electricity Demand, GW**

**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

Area = Energy, $E$

Annual Peak

Power, $P$

Store ceiling

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?

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

- 1500 GWh

Lifetime Value of Storage, £bn

Store Energy Capacity, GWh
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**
- **Hydrogen for Inter-seasonal**
- **CAES for weather-related variation**
  - On time up to 2 weeks
- **Thermal Energy Storage for up to about 2 days**

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

Storage Capacity, GWh

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

CAES
Heat
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

- CCS CF, No Storage
- CCS CF, With Storage
- DECC CF, 85%
Reduction in Curtailed Low Carbon Energy at Economically Optimum Level of Energy 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 different storage methods with varying timescales, ranging from batteries up to 1 hour to hydrogen & fuels up to 2 weeks. The x-axis represents the storage energy to power ratio (GWh/GW), while the y-axis shows the added cost per unit of energy ($/kWh).