The road to 2050: The need for flexibility in a high renewables world

Ana Barillas
Aurora Energy Research
Climate change is becoming a legislative priority in Europe

Supporting net-zero target
Policy position
In law
Rejecting net-zero in law
To reach net zero by 2050, the GB power market will have to transform completely: power generation up 60%; CO₂ emissions down 100%

**Generation mix in GB, TWh**

- 2020: 332 TWh
- 2030: 349 TWh
- 2040: 428 TWh
- 2050: 520 TWh

**Carbon intensity, gCO₂/kWh**

- 2020: 520 gCO₂/kWh
- 2030: 428 gCO₂/kWh
- 2040: 48 gCO₂/kWh
- 2050: 5 gCO₂/kWh

Diagram Legend:
- Yellow: Dispatchable
- Gray: Net Import
- Blue: Hydro and Other Renewables
- Red: Solar
- Green: Wind
- Blue: Nuclear
A high-renewables system increases the need for flexibility and reliability, and creates opportunities for storage.
Demand-supply matching: as we approach 2050, storage becomes necessary for the proper utilisation of renewables.

**Illustrative power demand in two typical weeks, GW**

**2030**

Sustained residual demand requires flexible generation

**2050**

Residual demand can be met by supply-demand matching through storage

- Residual demand
- Solar
- Wind
- Gas with CCS
- Nuclear
- Total Demand
Demand-supply matching: the shape of residual demand determines the size and type of storage opportunities.

Illustrative weekly residual demand profile, GW

- **Positive Residual Demand**
  $(\text{Renewables} + \text{Nuclear} < \text{Demand})$

- **Negative Residual Demand**
  $(\text{Renewables} + \text{Nuclear} > \text{Demand})$
Illustrative weekly residual demand profile, GW

- Storage absorbs excess renewables (negative residual demand)
- Storage dispatches when residual demand is positive
- Daily storage opportunity

Demand-supply matching: daily storage can be used to move power from when it is generated to when it is needed.
Demand-supply matching: excess renewable generation needs to be stored for longer periods of time

Illustrative weekly residual demand profile, GW

Excess renewable generation can't be used to meet daily fluctuations in residual demand

Residual Demand • Volume for Storage • Curtailment
Demand-supply matching: the need for daily storage increases over time, but it is capped by the amount of positive residual demand.

Maximum daily storage volume
GWh

<table>
<thead>
<tr>
<th>Year</th>
<th>Required Daily Storage Volume (GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>107</td>
</tr>
<tr>
<td>2030</td>
<td>146</td>
</tr>
<tr>
<td>2040</td>
<td>246</td>
</tr>
<tr>
<td>2050</td>
<td>216</td>
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Maximum daily storage capacity
GW

- 11 GW
- 19 GW
- 24 GW
- 30 GW
Demand-supply matching: absorbing all excess renewable generation by 2050 would require large volumes of long-duration storage

Use case for inter-seasonal storage, TWh

<table>
<thead>
<tr>
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<th>Curtailment (?)</th>
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Demand-supply matching: by 2050 the opportunity lies in converting excess renewables to non-electrical energy for use in other sectors

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With the availability of inter-seasonal storage, excess renewable generation could be fully used to meet residual demand.

Excess renewable generation exceeds unmet residual demand.

Excess renewable generation could be utilised to produce hydrogen for use in industry, transport and heat.
A high-renewables system increases the need for flexibility and reliability, and creates opportunities for storage.
Ramping: quick fluctuations in demand and supply require generation that can ramp quickly to meet residual demand.

**Demand and supply on one day in Winter 2040**

GW/HH

- **5.4 GW increase in demand in a single 30-minute period**
- **2.3 GW decrease in generation in a single 30-minute period**
- **7.7 GW of 30-minute ramping required**
Ramping: the need for fast-ramping generation increases as supply volatility increases

**High ramping requirements**
GW/half hour

- **2020**: Maximum high ramping requirement - 5.4, Average high ramping requirement - 1.0
- **2030**: Maximum high ramping requirement - 6.3, Average high ramping requirement - 1.1
- **2040**: Maximum high ramping requirement - 7.7, Average high ramping requirement - 1.3
- **2050**: Maximum high ramping requirement - 8.5, Average high ramping requirement - 1.7

By 2050, the system will need around 8.5 GWs that can respond in under 30 minutes.
A high-renewables system increases the need for flexibility and reliability, and creates opportunities for storage.

**Characteristics of renewables**
- Unpredictable
- Variable
- Undispatchable

**Near-term system requirements**
- **Flexibility**
  - Supply-demand matching
  - Ramping
  - Reliability

**2050 system requirements**

- CO₂
Reliability: wind load factors can vary significantly from expected values.

Load factor probability distribution, 2050

- 2 weeks per year have a load factor below 20%
- Average load factor is close to 40%
Reliability: Maintaining system reliability in a high-renewables world requires large amounts of dispatchable, long-duration generation.

Incremental TWh required to meet one week of low wind

<table>
<thead>
<tr>
<th>Year</th>
<th>Average wind week</th>
<th>Low wind week</th>
<th>Requirement met in part by CCGTs and peaking capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>2.8</td>
<td>1.9</td>
<td>0.9</td>
</tr>
<tr>
<td>2030</td>
<td>3.8</td>
<td>5.6</td>
<td>1.8</td>
</tr>
<tr>
<td>2040</td>
<td>5.3</td>
<td>11.4</td>
<td>2.4</td>
</tr>
<tr>
<td>2050</td>
<td>7.8</td>
<td>11.4</td>
<td>3.6</td>
</tr>
</tbody>
</table>

| | Equivalent to around 21 GW of dispatchable, zero emissions generation |

**Average wind week** | **Low wind week** | **Generation required from dispatchable generation**
The system’s requirement for quick-response, long-duration generation increases as renewable penetration increases.

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<td><strong>Max carbon intensity:</strong> 133g CO₂/kWh</td>
<td><strong>Max carbon intensity:</strong> 0g CO₂/kWh</td>
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### Capacity requirement

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<th>Duration</th>
<th>Response Time</th>
<th>Capacity requirement (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>Fast</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Slow</td>
<td>Daily storage: 11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Weekly back-up: 5</td>
</tr>
</tbody>
</table>

Notes: Inter-seasonal storage/sector coupling based on full amount of curtailed renewables following use of daily storage. GWh estimate converted to GW based on 100% LF for three months of the year.
The complexity of meeting such requirements increases with zero emission targets and excess renewable generation.

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<td>2020</td>
<td>133g CO₂/kWh</td>
<td>Pumped hydro</td>
</tr>
<tr>
<td>2050</td>
<td>0g CO₂/kWh</td>
<td>Liquid air energy storage, Molten salt, Compressed air storage, Gravitational storage</td>
</tr>
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Notes: (1) Inter-seasonal storage/sector coupling based on full amount of curtailed renewables following use of daily storage. GWh estimate converted to GW based on 100% LF for three months of the year.
A robust policy framework structured around system requirements would help drive the needed investment in flexibility.

### Net zero challenges

- Scale of investment
- Need for R&D
- Inadequate policy framework

### Policy principles

- Price the externalities
- Define the system needs
- Let the market decide