Whole-system approach to assessing the value of flexible technologies in supporting cost effective integration of renewables

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Energy Modelling Activities at Imperial

- **Whole electricity System Model**
  - D. Pudjianto, P Djapic

- **Option value of flexibility under uncertainty**
  - R Vinter, I. Konstantelos, S Tindemans, P Falugi

- **Decentralised, Price based Control and Investment Model**
  - D Papadaskalopoulos, Y Ye, Y Fan

- **Advanced Stochastic Unit Commitment Model**
  - F Teng, M Aunedi

- **Combined Gas, Electricity and Hydrogen Model**
  - M Qadrdan, H Ameli, M Aunedi, R Moreno

- **Integrated Heat and Electricity Model**
  - R Sansom, P Postantzis

- **Hydrogen & Carbon Capture and Storage Model**
  - S Samsatli, N Shah, A Hawkes

- **Market Design and Business Models**
  - R Moreno, R Green, D Newbery
2020: 25% of energy demand to be supplied by renewable generation

2030: Decarbonising electricity system.... ....while

2030+: Electrifying heat and transport sectors... in order to reduce CO2 emissions by 80% by 2050
**2020**: Wind generation will displace energy produced by conventional plant but its ability to displace capacity will be limited: more than 35% of conventional generation operating at less than 10% load factor

**2030+**: Electrification of segments of transport and heat sectors: increase in peak demand disproportionately higher than increase in energy

<table>
<thead>
<tr>
<th>Year</th>
<th>Utilisation</th>
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<tbody>
<tr>
<td>2010</td>
<td>55%</td>
</tr>
<tr>
<td>2020</td>
<td>35%</td>
</tr>
<tr>
<td>2030+</td>
<td>&lt;25%</td>
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</table>
Balancing challenge and need for flexibility

Great business opportunity for flexible generation, storage, demand side response, interconnection

Surplus of energy for >15% of time

Value of flexibility frequently higher than value of energy
System integration challenge

Volume of the market for flexible balancing technologies >£60b

“Understanding balancing challenge”, Imperial College, 2012
Whole System Approach to Valuing Flexible Options - Time and Location effects

**Whole-system modelling critical for capturing Time and Location interactions**

- **Demand-Side Response**
- **Flexible Generation**
- **Network**
- **Storage**

**Increasing asset utilisation and efficiency of system balancing**

(1) Do we understand the competitiveness and synergies between alternative flexible technologies?

(2) Is the market design efficient?
Value of **Energy Storage** across time in renewable scenario

**Cost of storage £/kw**

<table>
<thead>
<tr>
<th>2015</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>1110</td>
<td>750</td>
<td>410</td>
</tr>
</tbody>
</table>

**Annual savings (£bn/year)**

- **Installed storage capacity (GW)**
  - **OPEX**
  - **G CAPEX**
  - **T CAPEX**
  - **IC CAPEX**
  - **D CAPEX**
  - **Total**

Storage design parameters

How big the energy tank should be?

How important is storage efficiency?

What is the signal from market to energy storage scientists?

Loss of revenue of CfD / ROC recovered through the market – negative prices.
Operating patterns and technology degradation

Distributed

Bulk
Quantifying the value of storage: Stochastic or Deterministic?
Investment in generation flexibility?

System value of enhanced flexibility of CCGTs will be significant.

How about the value to investors?
Energy: From the Grid to Consumers
Flexibility: From Consumers to the Grid

Separated G&T&D? Business model?

Value today: £3
Value in 2030: >£80
Electrifying transport sector: value of smart charging

- Additional cost to supply EV demand (€/EV/year)
- Carbon emissions from supplying EVs (gCO₂/km)

- OPEX
- Generation CAPEX
- Transmission CAPEX
- Distribution CAPEX

Countries: DE-DK, Spain, Italy, UK-RI
Reduced system inertia – opportunity for fast responsive technologies

Stochastic Unit Commitment with inertia and frequency regulation endogenously modelled
Can smart refrigerators displace power stations?

...but the beer is getting warm!

fridges are supporting the system
Conflicts between load following and congestion management.

Modelling of price based response of Demand Side

Using demand side response to provide **local** network management services **or** balancing services at a **national** level

**Whole-system or network centric approach?**
Example of Flexible generation: competition with other technologies

For low cost of generation flexibility (GL), build ~16-18 GW for high interconnection levels, ~28-36 GW for low interconnection levels.

For high cost of flexibility (GH), build ~10 GW.

Note: most flexible generators installed in SE&W region.
Complexity of distributed energy storage and demand response: Split benefits

Can the market facilitate this?

DSR and storage - industry business model?
Integrated heat and electricity model
Combined Heat and Electricity Network

**Options:** enhancing flexibility of gas network (linepack), more flexible CCGTs, electricity storage, Demand side response, Power-to-Gas . .
Hydrogen Supply Chain model

Spatial element: Great Britain represented by $34 \times 10^8 \times 10^8$ km$^2$ square cells

Temporal dynamic model with 4 to 6-hr periods in a day
Dealing with uncertainty in future development: Option value flexibility

Significant value in investing in flexibility to deal with uncertainty

North Sea Grid: strategic versus incremental: savings €25bn and €75bn

Member State-centric or EU wide approach?

1. Energy sufficiency?
2. RES deployment?
3. Adequacy?
4. Balancing?
Member state-centric or EU-wide capacity adequacy market?

Can you really trust ...... when it comes to security?

Savings more than €7bn per annum

EU Wide approach can save 100-160 GW of plant!
Should the capacity of the interconnector be allocated for Energy or Reserve?

Flexibility cannot be traded cross-border!

Integration of balancing market

Variable wind

Increased need for reserve

Mid merit CCGT

Base

Pump Storage
Stochastic Optimisation:
coordinating allocation of interconnection
capacity between energy and reserve

It is efficient to constrain energy flow in order to facilitate
cross-border access to flexibility
EU RES deployment

EU wide or member state centric approach?

Should the Physics be respected?

North is Windy & South is Sunny...

Wind resource

Solar resource
EU wide renewables deployment savings of 146 GW of PV & Wind => savings between €16.5 – 30bn per year

Coordinated RES deployment needs stronger interconnection
Impact of distributed generation on distribution network reinforcement

LV, MV, HV – Low, Medium, High Voltage; V and I – Voltage and Thermal Constraints UG – Underground cables; OH – Overhead lines
Benefits of EU wide market integration (versus member state centric approach)

<table>
<thead>
<tr>
<th>Area of Market Integration</th>
<th>Savings in €bn/annum</th>
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<tbody>
<tr>
<td>Integrated EU <em>Energy</em> Market</td>
<td>9 - 34</td>
</tr>
<tr>
<td>Integrated EU <em>Capacity</em> Market</td>
<td>7 - 10</td>
</tr>
<tr>
<td>Integrated EU <em>Balancing</em> Market</td>
<td>2.5 - 5</td>
</tr>
<tr>
<td>Integrated EU <em>Renewable Policy</em></td>
<td>15.5 - 30</td>
</tr>
<tr>
<td>Integrated <em>North Sea Grid</em></td>
<td>3.5 – 9.5</td>
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