The role of CCS power stations in future low carbon energy systems & their interaction with the downstream CO$_2$ transportation and storage infrastructure

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Rationale

- What are the flow rates feeding into CO$_2$ T&S systems and will their variability cause issues?

- Last conference presentation last year looked at the downstream CO$_2$ T&S system constraints to flexibility: most importantly the well

- Now I will look at CO$_2$ flows feeding into T&S system from upstream system

**What I want to do:**
- Challenge the view that CCS plants will run base-load in future low carbon systems
- Raise awareness that we need to design the downstream T&S systems according to expected volatility of feed-in flows

**Why:**
- CCS research seems to be quite disconnected into the different fields or silos which are energy system modelling / CO$_2$ capture / transport /storage.
Structure of talk

1. Electricity system UCED model
2. Levels of CCS/wind capacity required to reach UK’s emission intensity targets
3. Capital and non-capital costs this implies
4. Captured CO$_2$ flows and flow variability this leads to
5. Issues associated with variable flow rates in the CO$_2$ T&S network
6. Mitigation options (& future research)
7. Key Take-home points
Electricity system UCED model

Main inputs:

- GB system
- High resolution historical wind data from 2002-2010 embedded (S. Hawkins)
- Historical demand data (matching years)
- Nuclear power generation capacity 17.1GW (BEIS 2016)
- Wind fleet: Varied: 15-45GW installed capacity
- CCS (Gas) capacity: Varied: for reaching emission intensity targets (60,100,140g/kWh)
- Additional CCGT, OCGT, DSR capacity to satisfy de-rated capacity margin

Main output:

- Electricity and CO₂ generation profiles of all individual plants
CCS/wind capacities required...

- ...for reaching emission intensities targeted by the Government

- Linear trade-off between wind and CCS capacities (approx. 1GW CCS ~ 2.6GW Wind)

- Increasing curtailment at higher levels of wind deployment is outweighed by higher capacity factors of offshore wind farms

- What capacities are realistic to expect, i.e. economically cost effective?
Cost-analysis

- Power generation mix according to **100g/kWh** emission intensity scenario
- Carbon cost at 101.1£/tCO₂ / CO₂ T&S cost 30£/tCO₂ / Gas fuel cost 21.2£/MWhth

### Annualised capital-costs [b£/yr]

- **Wind Offshore**
- **Wind Onshore**
- **OCGT**
- **CCGT**
- **CCS**
- **Nuclear**

### Yearly non capital-costs [b£/yr]

- **Wind Off. O+M+Ins.+Con.**
- **Wind On. O+M+Ins.+Con.**
- **CO₂ T&S**
- **CO₂ Emissions**
- **Gas Fuel**
- **CCGT O+M + Ins. + Con.**
- **CCS O+M + Ins. + Con.**
- **Nuclear Fuel**

**installed Wind Capacity/installed CCS capacity**
Cost-analysis

→ Costs within 7% over scenarios – but in billions!

→ The more CCS the cheaper (up to 2b£/yr)

→ Although non-capital yearly costs are higher when deploying more CCS this effect is outweighed by the lower capital cost of the smaller required power generation fleet (by capacity)
Captured CO$_2$ flows – Duration curves

- Increasing deployment of CCS in lower emission intensity scenarios leads to reduced capacity utilisation of corresponding CO$_2$ T&S system
- Time CO$_2$ T&S needs to operate at part-load increases substantially in low emission intensity scenarios

<table>
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<tr>
<th>60g/kWh</th>
<th>100g/kWh</th>
<th>140g/kWh</th>
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<td>15.0GW Wind &amp; 20.2GW CCS</td>
<td>15.0GW Wind &amp; 12.3GW CCS</td>
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Captured CO₂ flows – Variability

- Analysed variations in amount of CO₂ that is produced
- Net CO₂ flow rate variations over 6hr intervals (rolling basis over base year)

**Emission intensity scenario: 60g/kWh**
- 28% of net load changes are greater than 30% of nominal flow and 11% are greater than 50% of nominal flow (base case)

**Emission intensity scenario: 100g/kWh**
- 20% of net load changes are greater than 30% of nominal flow and 10% are greater than 50% of nominal flow (base case)
Captured CO₂ flows – Variability

- Analysed variations in amount of CO₂ that is produced

- Average CO₂ flow changes over two consecutive 6h blocks (rolling basis over base year)

  ➢ Emission intensity scenario: 60g/kWh

  • approx. 20% of average load changes are greater than 30% of nominal flow and 5% are greater than 50% of nominal flow (base case)

  ➢ Emission intensity scenario: 100g/kWh

  • 14% of average load changes are greater than 30% of nominal flow and 3% are greater than 50% of nominal flow (base case)
Issues associated with variable CO₂ flow rates

Mainly related to injection wellbores:

→ At low loads when backpressure falls off and two-phase flow occurs with subsequent JT cooling:

- Hydrate formation (JT-cooling)
- Cracking of cement and wellbore materials (JT-cooling)
- Hydrogen induced embrittlement of well material (Phase change)
- Oscillations and vibrations (exaggerated by phase change)
- Reduced lifetime due to cyclic thermal stresses (JT-cooling)

→ T&S capacity is not used as efficiently as possible: designed for maximum flow which is not often not flowing
Mitigation Options (& future research)

- **Balancing options on power plant level**
  - Solvent storage at PCC power plants
  - Liquid oxygen storage at oxy-fuel power plants
  - Hydrogen storage at pre-combustion power plants

- **Balancing options in CO2 T&S system**
  - Storage tanks
  - Interim storage in geological formation
  - Line-packing*

- **Other options/Enable wells to operate more flexibly**
  - Sophisticated well design options
  - Intelligent wells

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Key Take Home Points

1. Linear trade-off between wind/CCS capacity for emission intensity goals

2. Deploying more wind and less CCS increases costs

3. Throughout the analysed scenarios CCS powers stations operate flexibly, which will lead to variable CO\(_2\) flows feeding into T&S network

4. Downstream network needs to be designed accordingly to handle large & frequent feed-flow fluctuations
Thank you!
References