The cost-effectiveness of natural gas combined cycle power plants with CO₂ capture and storage in a climate change mitigation strategy

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Background

- Target: stabilising GHG emissions at 450 ppm(v) CO₂ equivalent
- Low-carbon electricity generation portfolio’s
- What is role of NGCC-CCS in low-carbon portfolio
  - providing baseload power
  - providing backup services

Research questions

- Cost-effectiveness of NGCC-CCS
  - in baseload role compared to
    - offshore wind
    - concentrated solar power (CSP)
    - photovoltaic systems (PV)
  - as backup service compared to
    - pumped hydro storage (PHS)
    - Compressed air energy storage (CAES)
    - Li-ion battery
    - ZBrt battery (Zinc-bromine)
    - Zebra battery (Sodium-Nickel-Chloride, NaNiCl)
- What are the potential cost reductions over time due to learning?

Methodology – starting points

- Scope: costs for Europe
- Technological learning – experience curve method
  - Progress ratio (PR): fraction of original cost after each doubling of cumulative installed capacity
  - Learning rate = 1 – progress ratio.
  - Global learning
- Levelised costs of electricity including extra costs for intermittent technologies
  - Balancing
  - Transmission
  - Backup services
Levelised cost of electricity - LCOE

- Capital cost (CAPEX) and fixed operating and maintenance cost (FOM)
  - Capacity factor is crucial parameter
- Variable operating and maintenance cost (VOC)
- Fuel cost
- CO₂ emission cost
- Extra balancing and transmission costs
- CO₂ transport and storage costs

- (costs for backup services included in system cost)

Inventory of techno-economic data

- Medium values
  - Averages of the input data found in the literature.
  - Can be considered as most representative values for Europe.
- Full ranges between optimistic and pessimistic values
- Values can be lower or higher in particular regions in Europe
Medium values of techno-economic parameters and PRs

<table>
<thead>
<tr>
<th>Technology</th>
<th>Reference year</th>
<th>CAPEX (€/MW)</th>
<th>PR (GW)</th>
<th>Discount rate (%)</th>
<th>Economic lifetime (years)</th>
<th>FOM (€/MWh)</th>
<th>O&amp;M (€/MWh)</th>
<th>PR (GW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGCC</td>
<td>2011</td>
<td>1380</td>
<td>50</td>
<td>7.6</td>
<td>25</td>
<td>0</td>
<td>2.1</td>
<td>94</td>
</tr>
<tr>
<td>NGCC (part of NGCC-CCS plant)</td>
<td>2011</td>
<td>858</td>
<td>50</td>
<td>14.3</td>
<td>25</td>
<td>10</td>
<td>3.2</td>
<td>94</td>
</tr>
<tr>
<td>CO2 capture unit (CCS)</td>
<td>2011</td>
<td>1560</td>
<td>50</td>
<td>14.3</td>
<td>25</td>
<td>6</td>
<td>2.7</td>
<td>74</td>
</tr>
<tr>
<td>CO2 compression unit</td>
<td>2011</td>
<td>90</td>
<td>58</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Offshore wind</td>
<td>2011</td>
<td>1344</td>
<td>50</td>
<td>12</td>
<td>20</td>
<td>142</td>
<td>0</td>
<td>96</td>
</tr>
<tr>
<td>PV</td>
<td>2012</td>
<td>3800</td>
<td>50</td>
<td>14.3</td>
<td>25</td>
<td>25</td>
<td>0</td>
<td>110</td>
</tr>
<tr>
<td>CSP (SMS 6.9 MW, 10% storage)</td>
<td>2010</td>
<td>9862</td>
<td>50</td>
<td>12</td>
<td>20</td>
<td>24</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>PHN</td>
<td>2010</td>
<td>1707</td>
<td>50</td>
<td>7.6</td>
<td>10</td>
<td>30</td>
<td>0.6</td>
<td>100</td>
</tr>
<tr>
<td>CAES</td>
<td>2011</td>
<td>1300</td>
<td>50</td>
<td>14.3</td>
<td>20</td>
<td>21</td>
<td>6.7</td>
<td>100</td>
</tr>
<tr>
<td>Liron</td>
<td>2010</td>
<td>1635</td>
<td>50</td>
<td>10</td>
<td>15</td>
<td>19</td>
<td>2.6</td>
<td>100</td>
</tr>
<tr>
<td>ZEBRA</td>
<td>2011</td>
<td>726</td>
<td>50</td>
<td>14.3</td>
<td>15</td>
<td>10</td>
<td>0.8</td>
<td>100</td>
</tr>
<tr>
<td>ZnBr</td>
<td>2011</td>
<td>353</td>
<td>50</td>
<td>14.3</td>
<td>15</td>
<td>7</td>
<td>2.5</td>
<td>100</td>
</tr>
</tbody>
</table>

**Calculation LCOE per technology**

- Techno-economic data collection
- Inventory of progress ratios
- Inventory extra costs intermittency + decentralized
- Definition of system configurations
- Historical/CO2 emission allowance and natural gas prices
- Calculation LCOE per technology as function of cumulative capacity
- Calculation LCOE per TECHNOLOGY over time
- Calculation LCOE per SYSTEM over time
- Scenario data

**Calculation LCOE per technology as function of cumulative capacity**

**Definition of system configurations**

**Scenario data**

LCOE in 2011: ranges

- **Note:** power costs to charge storage systems are not included

- **Baseload**
- **Intermittent**
- **Backup technologies**

- **Power generation**
- **Backup technologies**

- **Gas price:** 6.7 €/GJ
- **CO2 emission price:** 13.5 €/t
- **Discount rate:** 10%
Inventory of scenarios to determine number of doublings

- Scenarios with deployment to reach climate change mitigation target.
  - 1 scenario: Energy Technology Perspectives 2012 (ETP2012).

- Focus on 3 scenarios
  - Base 450 scenario is the 450-ppm scenario (ETP scenario)
  - High renewable scenario
  - High NGCC-CCS scenario
LCOE versus cumulative capacity under medium conditions

Note: Power generation from wind offshore, and PV is not controllable, and CSP partly. In contrast, mid-merit NGCC-CCS is controllable.

Gas price is 6.7 €/GJ and CO2 price is 13.5 €/t.

Note: power costs to charge storage systems are not included

Capacity factor is set at the availability factor (see table medium values)

Natural gas price and CO2 price development

<table>
<thead>
<tr>
<th>Year</th>
<th>2011</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
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<tr>
<td>gas price *</td>
<td>€/GJ</td>
<td>6,7</td>
<td>7,5</td>
<td>7,0</td>
<td>6,5</td>
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<tr>
<td>CO2*</td>
<td>€/tCO2</td>
<td>13,5</td>
<td>33</td>
<td>70</td>
<td>107</td>
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<tr>
<td>high gas price scenario**</td>
<td>€/GJ</td>
<td>6,7</td>
<td>8,5</td>
<td>9,4</td>
<td>9,8</td>
</tr>
</tbody>
</table>

* Based on IEA – 450 scenario
** Based on IEA – current policy scenario
LCOE over time under medium conditions in the Base 450 scenario

Sensitivities of LCOEs for different variants in 2040

Taking into account backup requirements

In order include additional costs for backup requirements, we designed four stylized systems based on:

- NGCC-CCS
- IRES/NGCC
- IRES/NGCC-CCS
- IRES/energy storage

Note: All investigated scenarios have a broader portfolio of technologies than these four stylized systems. We only use these stylized systems in order to make some estimates of the backup costs.

We treat these stylized systems as isolated systems (e.g. on an island) in a world which follows the BASE 450 scenario, the HIGH-REN 450 scenario, or the HIGH-NGCC-CCS 450 scenario.
The percentage values indicate the capacity factors of the different technologies. Capacity factors (CFs) of wind and PV in the IRES/STORAGE system are lower, because part of the produced power is curtailed or used to charge power storage.

Caveats -> further research

• Techno-economic data uncertain, especially, for novel technologies like ZEBRA and Zn-Br
• Progress ratios not always available or based on short historical time series.
• No deployment projections on storage capacity in global energy scenarios
• Limited power system simulation modelling results of low carbon electricity generation portfolios with power storage
• Demand side management is not included

Conclusions – NGCC-CCS as baseload

• Less cost reductions for NGCC and NGCC-CCS plants than for the renewable energy technologies.
• Large uncertainties in the development of LCOEs of renewables.
• Cost-effectiveness compared to alternatives over time
  – depends on deployment.
  – under medium conditions:
    • cost of NGCC-CCS in same range as offshore wind and CSP
    • cost of NGCC-CCS lower than PV.
Conclusions – NGCC-CCS as backup

• Less cost reductions for NGCC-CCS plants than for storage technologies (except for PHS).

• Large uncertainties in the development of LCOEs of power storage technologies.

• Cost of NGCC-CCS as backup
  – Somewhat higher than PHS, and CAES, and Zn-Br (depending on learning)
  – Lower than Li-ion and ZEBRA.

• If cost for backup services are also taken into account NGCC-CCS is more cost-effective than a system with PHS and curtailment.