Towards a zero Emission European power system

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Analysis using the EMPIRE power market model

- Minimize transition cost to a low carbon European power system
Assumptions

European demand for electricity [TWh/an]

- European demand for electricity is projected to increase from approximately 3000 TWh/annum in 2010 to about 4000 TWh/annum in 2050.

- The graph illustrates the expected growth in demand, with a notable dip around 2020, followed by a steady rise towards 2050.

- The data is based on the EU reference scenario 2016 and IEA Energy Technology Perspective 2016.
90% emission reduction

Baseline scenario: CCS available as a commercial technology

Alternative scenario NoCCS: same as baseline but no carbon capture and storage available
Baseline scenario: 90% emission reduction

<table>
<thead>
<tr>
<th></th>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Solar</td>
<td>536 (29%)</td>
<td>665 (17%)</td>
</tr>
<tr>
<td>Wind onshore</td>
<td>698 (38%)</td>
<td>1314 (34%)</td>
</tr>
<tr>
<td>Wind offshore</td>
<td>149 (8%)</td>
<td>492 (13%)</td>
</tr>
<tr>
<td>Gas CCS</td>
<td>81 (4%)</td>
<td>436 (11%)</td>
</tr>
<tr>
<td>Coal CCS</td>
<td>6 (0%)</td>
<td>33 (1%)</td>
</tr>
<tr>
<td>Fossil unabated</td>
<td>215 (12%)</td>
<td>350 (9%)</td>
</tr>
<tr>
<td>Others (Hydro, Geo, etc.)</td>
<td>164 (9%)</td>
<td>577 (15%)</td>
</tr>
</tbody>
</table>
**NoCCS scenario:**
90% emission reduction

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Solar</td>
<td>690 (33%)</td>
<td>788 (20%)</td>
</tr>
<tr>
<td>Wind onshore</td>
<td>751 (36%)</td>
<td>1381 (36%)</td>
</tr>
<tr>
<td>Wind offshore</td>
<td>222 (11%)</td>
<td>730 (19%)</td>
</tr>
<tr>
<td>Coal (unabated)</td>
<td>43 (2%)</td>
<td>11 (0%)</td>
</tr>
<tr>
<td>Natural gas (unabated)</td>
<td>190 (9%)</td>
<td>393 (10%)</td>
</tr>
<tr>
<td>Others</td>
<td>173 (8%)</td>
<td>580 (15%)</td>
</tr>
</tbody>
</table>
Baseline country results 2050

Capacity

Generation

- Solar PV
- Wind offshore
- Wind onshore
- Hydro RoR
- Hydro regulated
- Geo
- Wave
- Nuclear
- Bio cofiring CCS
- Bio/Bio cofiring
- Oil
- Gas CCS
- CCGT
- OCGT
- Coal CCS
- Coal
- Lignite CCS
- Lignite
Transmission

Baseline cross-boarder expansion: increases by 701% from 2010 to 2050

NoCCS Capacity increases by 811% from 2010 to 2050
Alternatives to transmission

**FIRST CONCLUSION:**
- There is a high need for flexibility in the future system
- In the studies I have shown, transmission investment seems to be an important part of the solution.

**NEW DRIVERS:**
- Demand side flexibility
- The merger of the power system and ICT

How will this affect the transition to a near zero emission power system?
# Energy balances in TWh

## Norway in 2050

<table>
<thead>
<tr>
<th>Type</th>
<th>Baseline</th>
<th>NoCCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>152</td>
<td>152</td>
</tr>
<tr>
<td>Generation</td>
<td>266</td>
<td>459</td>
</tr>
<tr>
<td>Hydro regulated</td>
<td>120</td>
<td>121</td>
</tr>
<tr>
<td>Hydrorun-of-river</td>
<td>30</td>
<td>28</td>
</tr>
<tr>
<td>Wind onshore</td>
<td>51</td>
<td>50</td>
</tr>
<tr>
<td>Wind offshore</td>
<td>65</td>
<td>258</td>
</tr>
<tr>
<td>Export</td>
<td>128</td>
<td>320</td>
</tr>
<tr>
<td>Import</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Net export</td>
<td>112</td>
<td>304</td>
</tr>
</tbody>
</table>

**Capacity:**
- **Baseline 2050:** 28 GW
- **No CCS 2050:** 62 GW
Northwest Europe winter week 2050 (Baseline)

Northwest Europe (without Norway)

Wind
Solar
Net Load

Hydro
Net Export

Operation [GW]

Operation [GW]
Northwest Europe winter week 2050 (Baseline)

Low wind in NW Europe → High hydropower production and export from Norway
Northwest Europe winter week 2050 (Baseline)

As the wind picks up hydro production is reduced.
Northwest Europe winter week 2050 (Baseline)

Northwest Europe (without Norway)

New period with low wind production → hydro ramps up

Wind
Solar
Net Load

Norway

Hydro
Net Export

CenSES
Centre for Sustainable Energy Studies
During summer hydro production has a characteristic valley shape mid-day. Typically with steep ramps on each side.

Norway
Northwest Europe winter week 2050 (Baseline)

Northwest Europe (without Norway)

Operation [GW]

Wind
Solar
Net Load

Natural gas generation, Northwest Europe

Operation [GW]

Gas
Gas w/ccs

CenSES Centre for Sustainable Energy Studies
Northwest Europe winter week 2050 (Baseline)

Northwest Europe (without Norway)

Operation [GW]

Wind
Solar
Net Load

Natural gas generation, Northwest Europe

Natural gas – fill in the gaps from low wind production

Gas
Gas w/ccs
## Northwest Europe (without Norway) 2050

<table>
<thead>
<tr>
<th>Type</th>
<th>Baseline</th>
<th>NoCCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>2124</td>
<td>2124</td>
</tr>
<tr>
<td>Generation</td>
<td>1972</td>
<td>1836</td>
</tr>
<tr>
<td>Wind onshore</td>
<td>738</td>
<td>713</td>
</tr>
<tr>
<td>Wind offshore</td>
<td>427</td>
<td>470</td>
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<tr>
<td>Solar PV</td>
<td>112</td>
<td>218</td>
</tr>
<tr>
<td>Gas</td>
<td>235</td>
<td>252</td>
</tr>
<tr>
<td>Gas w/CCS</td>
<td>279</td>
<td>-</td>
</tr>
<tr>
<td>Others</td>
<td>181</td>
<td>184</td>
</tr>
</tbody>
</table>

Energy balances in TWh

- Capacity to NO: 28 GW
- Capacity to NO: 62 GW
Key findings

- **Natural gas** still remain in the mix to provide flexibility
  - with CCS twice as much as without

- **Onshore wind** become the most significant low carbon technology
  - 1/3 of the mix in Europe
  - more than twice the share of solar PV and offshore wind combined

- **Transmission** is the favored flexibility measure

- **Hydropower** a unique resource.
Key findings

- **Policy needed**
  - Cooperate to avoid suboptimal local investments
    - Examples: CCS, offshore wind, infrastructure
  - Share risk, cost and benefits
  - Market design and mechanisms will be a key factor
  - Long-term policy and cooperation needed