European Electricity Grid Infrastructure Expansion in a 2050 Context

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Introduction

Starting out from European scenarios (of EMF28 – Energy Modelling Forum) on national level for generation capacity we address the two questions:

a) What is the cost minimal extension of the transmission infrastructure?

b) Are the extension plans of the scenarios different in their timing and regional character?

c) What is the sensitivity for more costly cross-border lines?
1) Allocate national capacities on nodal level

2) Model line sharp network investment

3) Timing and regional characteristics of network investment

4) Sensitivities on line expansion costs to analyze regional character of scenarios

→ Implementation of national scenarios to nodal resolution and optimize network investment

→ Insights of model results and sensitivities to higher cross-border costs
Agenda

1. Introduction
2. Generation Scenarios for Europe
3. ELMOD Model Application: Transmission Investments
4. Transmission Costs and Investment
5. Conclusion
## Long-Term EMF28 Scenarios for Europe 2050

### Technology dimension

<table>
<thead>
<tr>
<th></th>
<th>Default w CCS</th>
<th>Default w/o CCS</th>
<th>Pessimistic</th>
<th>Optimistic</th>
<th>Green</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCS</td>
<td>on</td>
<td>off</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear energy</td>
<td>ref</td>
<td>ref</td>
<td>low</td>
<td>ref</td>
<td>low</td>
</tr>
<tr>
<td>Energy efficiency</td>
<td>ref</td>
<td>ref</td>
<td>ref</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>Renewable energies</td>
<td>ref</td>
<td>ref</td>
<td>ref</td>
<td>ref</td>
<td></td>
</tr>
</tbody>
</table>

### Policy dimension for the EU

<table>
<thead>
<tr>
<th>Policy dimension</th>
<th>Policy dimension for the Rest of the World (ROW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No policy baseline (no policy, also without the 2020 target)</td>
<td>no policy</td>
</tr>
<tr>
<td>Reference: including the 2020 targets and 40% GHG reduction by 2050</td>
<td>&quot;moderate policy&quot; scenario ModPol; no emission trading across macroregions (but trade within macroregions e.g. within EU)</td>
</tr>
<tr>
<td>Mitigation1: 80% GHG reduction by 2050 (with Cap&amp;Trade within the EU)</td>
<td>&quot;moderate policy&quot; scenario ModPol; no emission trading across macroregions (but trade within macroregions e.g. within EU)</td>
</tr>
<tr>
<td>Mitigation2: 80% GHG reduction by 2050 (with Cap&amp;Trade within the EU)</td>
<td>IMAGE2.9 scenario; full emission trading for ROW, but no emission trading between ROW and EU. Regional relative contributions to mitigation based on the Mitigation 1 scenario</td>
</tr>
<tr>
<td>Mitigation3: global 480ppm target with full Cap&amp;Trade</td>
<td>IMAGE2.9 scenario; emission trading is allowed between all regions</td>
</tr>
</tbody>
</table>

### Additional options for models that go for the policy dimension

- Scenario package for the models that go for the technology dimension (11)
- Scenario package for the models that go for the policy dimension (7 altogether)
- Included in both scenario packages

### Additional optional scenarios for models that go for the policy dimension
Technology Specific Generation Capacity for Europe

Primes (EMF28) results in a European context – main aspects:

- CO₂ reduction target
- Nuclear power versus carbon capture and storage (CCS)
- CCTS as an option?
- Renewable generation technologies (wind & solar)
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ELMOD Application: Expansion Pathways for the European Transmission Network

Pan-European Transmission Investment for the EMF28 Scenarios

• Question: How do the different EMF28 scenarios in their choice of technology and national allocation effect the demand on infrastructure investments?

• Bottom up DC Load Flow model based on ELMOD (3,523 nodes and 5,145 lines plus DC overlay grid)

• Endogenous determination of grid investments needs up to 2050 in 10-year steps. The optimization minimizes the cost of the expansion as well as system operation.

• Model runs for the EMF28-Scenarios
  **EU1** (40% GHG reduction until 2050),
  **EU6** (80% GHG reduction until 2050)
  **EU10** (green, 80% GHG reduction until 2050)

• Additional case for each scenario: doubling of costs for cross border lines
„Optimal“ Transmission Investments

• „Optimal“ infrastructure investment = least cost system operation (nodal system)

• No integrated optimization of generation & grid: Transmission follows generation scenarios

• Higher costs / distance of transmission investment reduce the „optimal“ amount of infrastructure

Source: Kirschen, Strbac (2004), p.241
Iterative Solving of Mixed Integer Linear Problem (MILP)

1. Lumpy investment in lines:
   - Voltage upgrade
   - Additional circuits
   - DC lines

2. Relation between physical line characteristics and DC load flow parameters:

   $\rightarrow$ Calculations are repeated with updated line characteristics after expansion until they converge
Investment in AC and DC lines until 2050

- Investments in transmission lines increase with stronger emission targets
- EU6 and EU10 are similar in the volume (km and €) of investments
- Regional focus shifts with more CCS (EU6) or renewables (EU10)
Aggregated Figures for Investments until 2050

Total investment costs for transmission capacity in Europe:

- Large investments in 2020 for all scenarios
- In EU6 and EU10 investments increase in 2040/50 after stagnation in 2030

<table>
<thead>
<tr>
<th></th>
<th>in mn €</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU1</td>
<td></td>
<td>17,025</td>
<td>2,002</td>
<td>4,318</td>
<td>7,250</td>
<td>30,595</td>
</tr>
<tr>
<td>EU6</td>
<td></td>
<td>18,864</td>
<td>4,318</td>
<td>18,670</td>
<td>15,067</td>
<td>56,919</td>
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<tr>
<td>EU10</td>
<td></td>
<td>15,971</td>
<td>5,955</td>
<td>10,447</td>
<td>24,460</td>
<td>56,834</td>
</tr>
</tbody>
</table>
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Aggregated Figures for Investments until 2050

Assumption of higher transaction costs for cross-border lines in a Regional case has different impact on scenarios:

- Decrease in network investments in all scenarios (mainly DC lines)
- Overall investments are least affected in the EU10 scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Case</th>
<th>DC</th>
<th>AC National</th>
<th>AC Cross-Border</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>EU1</td>
<td>European</td>
<td>4.174</td>
<td>19.194</td>
<td>4.611</td>
<td>27.978</td>
</tr>
<tr>
<td></td>
<td>Regional</td>
<td>3.243</td>
<td>18.860</td>
<td>4.207</td>
<td>26.310</td>
</tr>
<tr>
<td>EU6</td>
<td>European</td>
<td>5.346</td>
<td>39.905</td>
<td>7.173</td>
<td>52.424</td>
</tr>
<tr>
<td></td>
<td>Regional</td>
<td>3.194</td>
<td>36.132</td>
<td>6.808</td>
<td>46.135</td>
</tr>
<tr>
<td>EU10</td>
<td>European</td>
<td>7.057</td>
<td>39.799</td>
<td>4.138</td>
<td>50.993</td>
</tr>
<tr>
<td></td>
<td>Regional</td>
<td>4.654</td>
<td>40.967</td>
<td>4.088</td>
<td>49.709</td>
</tr>
</tbody>
</table>
Aggregated Figures for Investments until 2050

Assumption of higher transaction costs for cross-border lines in a Regional case has different impact on scenarios:

- Decrease in network investments in all scenarios (mainly DC lines)
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![Change in Line Extension](image)
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Conclusion

Starting out from national generation scenarios for generation capacity we address the two questions:

a) What is the cost minimal extension of the transmission infrastructure?

- Investments include DC offshore connectors in the North and Baltic Sea but no onshore overlay network
- Network investments increase with higher GHG reduction target but are similar for EU6 (80% & CCS/Nuclear) and EU10 (80% & RES)
- Timing and regional focus varies between CCS (EU6) and renewable scenario (EU10)
- Impact of regional correlation of wind/pv availability not considered!

b) Are the scenarios dependent on cross-border network extensions?

- Higher investment costs reduce extension of DC interconnectors
- In the high renewable scenario (EU10) shift to national and only small overall decrease
Thank You for Your Attention!

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