Weighing Costs and Benefits of a meshed grid in the Baltic Sea.

Anna-Kathrin Wallasch (Deutsche WindGuard)
Richard Weinhold (IKEM)
1. Methodology and Case Studies

2. Benefits: Design and Result of the Regional Market Model

3. Costs: Design and Result of the Linear Cost Model

4. Balance and Conclusion
CBA Methodology

Project assessment

Benefits
- B1 Socio-economic welfare
- B2 RES integration
- B3 CO2 variation
- B4 Losses
- Security of supply
- B5a Adequacy
- B5a System stability

Residual impacts
- B1 Environmental
- B2 Social
- B3 Other

Costs
- C1 Total project expenditures

ENTSO-E methodology 2.0

Benefits
- System Cost
- Adequacy (Electricity Prices)
- Market Model

Costs
- Cables (AC&DC)
- Offshore Nodes
- Onshore Nodes
- Linear Cost Model
Two Pre-Feasibility Analyses

Pre-Feasibility Analysis 1:
Sweden – Poland – Lithuania

Pre-Feasibility Analysis 2:
Germany – Sweden – Denmark
**Baseline Scenario**

**CS1 (SE/PO/LT) with High Offshore Wind Power**

Cost and Benefit Differences
**CS2 (DE/SE/DK) with High Offshore Wind Power**

Baseline Scenario

Cost and Benefit Differences
**Model dynELMOD:**

Linear program to determine cost-effective development pathways in the European electricity sector

**Calculation Steps**

1. **Investment**
   - Investment into Conventional and renewable generation, cross-border capacities
   - Reduced time series used

2. **Dispatch**
   - Investment result from step 1 fixed
   - Time series with 8760 hours

**Model:**
33 European countries
31 conventional or renewable generation and storage technologies
9 investment periods, five-year steps 2020 – 2050

**Outputs**
- Investment into generation capacities, storage, transmission capacities
- Generation and storage dispatch
- Emissions by fuel
- Flows, imports, exports

15 May 2018, Bremerhaven
Application in BIG Model Context
Cost benefit analysis: Focus on Baltic countries (but calculate full dispatch for all countries)

Relevant Inputs
Installed Capacities, Fuel Costs, Emission limits/prices
Scenario-specific data:
- Connections between countries
- Wind farm integrations

Outputs relevant for CBA
- Security of supply → hourly adequacy margin
- Electricity generation costs and prices.
  - Relevant stakeholders for welfare implications: Consumers, Producers (conventional and renewable), TSOs
- Hourly generation & storage dispatch
- Cross-border flows
- RES Integration factor (rate of curtailment)
- Generation and storage dispatch
- Emissions by country and fuel
Electricity generation capacities

- Entsoe TYNDP 2016 Market Modeling Data for 2020 and 2030 Scenario Vision 3
- **Offshore wind** capacities for the Baltic Sea region are set within consortium and differ by scenario

CO2 decarbonization target:

- 90% CO2 emission reduction until 2050

Other assumptions

- Prices for fuels etc. are based on the European Commission’s Reference Scenario 2016
- Time series: structure based on year 2013, full load hours are scaled to meet projections
Overall system cost differences in 2017 bn €

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
<th>sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS1: High wind, no integration --&gt; high integration</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.01</td>
<td>0.03</td>
<td>-0.07</td>
<td>-0.03</td>
<td>-0.02</td>
<td>-0.09</td>
</tr>
<tr>
<td>CS1: High wind, no integration --&gt; partial integration</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.01</td>
<td>0.03</td>
<td>-0.06</td>
<td>-0.01</td>
<td>-0.01</td>
<td>-0.06</td>
</tr>
<tr>
<td>CS1: Low wind, no integration --&gt; high integration</td>
<td>0.03</td>
<td>0.01</td>
<td>-0.03</td>
<td>-0.76</td>
<td>-0.36</td>
<td>0.07</td>
<td>0.05</td>
<td>-0.99</td>
</tr>
<tr>
<td>CS1: Low wind, no integration --&gt; partial integration</td>
<td>0.04</td>
<td>0.09</td>
<td>-0.07</td>
<td>-0.62</td>
<td>-0.36</td>
<td>-0.06</td>
<td>0.05</td>
<td>-0.92</td>
</tr>
</tbody>
</table>

- In the high wind scenarios, the difference is relatively small
- Cost changes occur due to reduced grid expansion need in case of higher offshore interconnection
- Mainly in Sweden, Poland, and Lithuania. Other Countries less affected
Average electricity price difference for scenario variations

**PL**

- Low wind
- High wind

**SE**

- Low wind
- High wind

**LT**

- Low wind
- High wind

15 May 2018, Bremerhaven
System Adequacy depends on:

- Unused generation and available capacity in each country
- State of network: flows and flow directions, which determines the available import capacity

- Derive System Adequacy Margin for each hour in each country

System Adequacy

- In all scenarios the system configuration is adequate
- Adequacy is similar in all scenarios
- For Lithuania the system adequacy is lower in the High Integration scenarios
Adequacy in case of line outages

Question:

Do scenarios with higher connectivity provide higher adequacy in case of a line outage?

Comparison: Hourly Adequacy with and without lines.

Lines excluded for system adequacy comparison:
- No Integration: Main Interconnectors
- Partial Integration: Lines to Central Point
- Max Integration: Lines between Wind farms
Adequacy in case of line outages – Sweden

Before

After line outage

- Adequacy is reduced as expected, but no threat to system adequacy overall
- No Integration scenario mostly affected
- Similar adequacy reduction in partial and high integration scenarios.
Adequacy in case of line outages – Poland

Before

Adequacy after line outage

- Differences between scenarios are smaller
- In case of lowest adequacy the decrease due to line outage is smallest
- Partial Integration is most resilient against the modeled line outage
Adequacy in case of line outages – Lithuania

Before

Adequacy in Lithuania in 2045

Free generation capacity plus available import capacity in MW

- CS1: High wind, partial integration
- CS1: High wind, no integration
- CS1: High wind, high integration

Hours

After Line outage

Adequacy in Lithuania in 2045

Free generation capacity plus available import capacity in MW

- CS1: High wind, partial integration
- CS1: High wind, no integration
- CS1: High wind, high integration

Hours

Difference in Adequacy

Difference in MW

- CS1: High wind, high integration
- CS1: High wind, no integration
- CS1: High wind, partial integration

Hours

Adequacy after line outage

- Differences relative to total generation capacity largest in Lithuania
- High integration scenario is most robust against line outage
  - Especially in case of already low adequacy
Overall system cost differences

<table>
<thead>
<tr>
<th>Scenario</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
<th>sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS2: High wind, no integration --&gt; high integration</td>
<td>-1.91</td>
<td>-0.52</td>
<td>-1.35</td>
<td>0.54</td>
<td>1.09</td>
<td>0.41</td>
<td>-1.76</td>
</tr>
<tr>
<td>CS2: High wind, no integration --&gt; partial integration</td>
<td>-1.92</td>
<td>-0.52</td>
<td>-1.35</td>
<td>0.52</td>
<td>1.05</td>
<td>0.38</td>
<td>-1.83</td>
</tr>
<tr>
<td>CS2: Low wind, no integration --&gt; high integration</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>CS2: Low wind, no integration --&gt; partial integration</td>
<td>0.01</td>
<td>-0.04</td>
<td>-0.02</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Cost decreases also here mostly in grid expansion.
Mainly in the scenario-relevant countries Germany, Sweden, and Denmark
Conclusions

Conclusions Benefits Part

- Expectation previous to model runs: Small overall system cost differences between levels of integration in the baltic sea region

- Results: Depending on Wind installation, the need for grid expansion can be reduced by increased offshore integration across countries

- Increased integration also helps to improve system reliability

Next:

- Combination of Benefits results with the Costs part in the following presentation
• Linear Cost Model (incl. expected future trends)
• Sensitivity Analysis
• All results discounted to 2017 with an interest rate of 4%

Evaluated as most suitable cost data sets
Cable Cost
(Cable + Installation)
• length- and power dependent cost
• length-dependent cost

Onshore Node Cost
(Converter/Transformer + Installation)
• power-dependent cost
• fixed cost

Offshore Node Cost
(Converter/Transformer + Platform + Installation)
• power-dependent cost
• fixed cost

CS1 (SE/PO/LT)

High Offshore Wind power

<table>
<thead>
<tr>
<th></th>
<th>HVAC Offshore Nodes</th>
<th>HVAC Onshore Nodes</th>
<th>HVAC Cables</th>
<th>HVDC Offshore Nodes</th>
<th>HVDC Onshore Nodes</th>
<th>HVDC Cables</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS1_1a Zero Integration</td>
<td>0.93 0.02 1.30</td>
<td>0.63 0.45 1.56</td>
<td>0.45 0.29 1.05</td>
<td>0.93 0.40 1.98</td>
<td>0.53 1.30 1.98</td>
<td></td>
</tr>
<tr>
<td>CS1_2a Partial Integration</td>
<td>0.93 0.02 1.30</td>
<td>0.70 0.29 1.05</td>
<td>0.93 0.40 1.98</td>
<td>0.53 1.30 1.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CS1_3a Max Integration</td>
<td>0.93 0.40 1.98</td>
<td>0.53 1.30 1.98</td>
<td>1.98 0.53 1.30</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HVDC Breakers included!

-0.66 bn€ 0.24 bn€
CS2 (DE/SE/DK)

High Offshore Wind Power

Cost Results

<table>
<thead>
<tr>
<th></th>
<th>HVAC Offshore Nodes</th>
<th>HVAC Onshore Nodes</th>
<th>HVAC Cables</th>
<th>HVDC Offshore Nodes</th>
<th>HVDC Onshore Nodes</th>
<th>HVDC Cables</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS2_1a Zero Integration</td>
<td>0.22</td>
<td>0.34</td>
<td>0.34</td>
<td>0.00</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>CS2_2a Partial Integration</td>
<td>0.94</td>
<td>0.44</td>
<td>0.82</td>
<td>0.01</td>
<td>0.31</td>
<td>0.31</td>
</tr>
<tr>
<td>CS2_3a Max Integration</td>
<td>0.00</td>
<td>0.56</td>
<td>0.56</td>
<td>0.27</td>
<td>0.16</td>
<td>0.16</td>
</tr>
</tbody>
</table>

0.46 bn€ | 0.04 bn€
Sensitivity Analysis

Exemplary Analysis for CS1_2a (Part. Integ., High OWP)

15 May 2018, Bremerhaven
Net Present Value Difference compared to Base Case

CS1 (SE/PO/LT)

High Offshore Wind power

HVDC Breakers included

<table>
<thead>
<tr>
<th>Year</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS1_1a Zero Integration</td>
<td>-1.5</td>
<td>-0.5</td>
<td>-0.5</td>
<td>-0.5</td>
<td>-0.5</td>
<td>-0.5</td>
</tr>
<tr>
<td>Partial Integration</td>
<td>-0.63</td>
<td>-0.45</td>
<td>-0.45</td>
<td>-0.45</td>
<td>-0.45</td>
<td>-0.45</td>
</tr>
<tr>
<td>Max Integration</td>
<td>1.56</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
<td>1.05</td>
</tr>
</tbody>
</table>

| CS1_2a Zero Integration | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 | 0.93 |
| Partial Integration | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| Max Integration | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 | 1.30 |

| CS1_3a Zero Integration | -0.66 bn € |
| Partial Integration | 0.24 bn € |
| Max Integration | 0.40 bn € |

Electricity System Cost in Europe
CS2: High wind, no integration --> CS2: High wind, partial integration

Approach
**CS1 (SE/PO/LT)**

**High Offshore Wind Power**

<table>
<thead>
<tr>
<th>Net Present Value Difference compared to base case (bn €)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.66</td>
</tr>
</tbody>
</table>

Partial Integration: 0.15
Max Integration: -0.2

15 May 2018, Bremerhaven
CS2 (DE/SE/DK)

High Offshore Wind Power

Net Present Value Difference compared to base case (bn €)

<table>
<thead>
<tr>
<th></th>
<th>Partial Integration</th>
<th>Max Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Present Value Difference</td>
<td>1,37</td>
<td>1,72</td>
</tr>
</tbody>
</table>

15 May 2018, Bremerhaven
• The main benefit brings the interconnection, which is already part of the base case (zero integration)

• No general trend related to the evaluation of partial and maximum integration scenarios could be identified

• The cost structure is case specific
  • Cost reduction potential is higher when hub connections are also part of the zero integration case
  • Reduction of AC components could be positive but is often compensated by additional DC offshore node cost

• Benefits are almost equal for partial and max integration scenarios, costs can vary significantly
For further information:

Mail: info@baltic-integrid.eu
Web: www.baltic-integrid.eu

**Baltic InteGrid represented by the Lead Partner:**

**Institute for Climate Protection, Energy and Mobility (IKEM)**

Magazinstraße 15–16, 10179 Berlin, Germany
Phone: +49 (0) 30 408187015
Mail: info@ikem.de
Web: www.ikem-online.de

The content of the presentation reflects the author’s/partner’s views and the EU Commission and the MA/JS are not liable for any use that may be made of the information contained therein. All images are copyrighted and property of their respective owners.