Pre-feasibility study – Case study 1

Copenhagen, May 23rd
Andreas Møser, Lund University
Outline

• Approach
• Technical assumptions
• Scenario structure
• High & Low offshore wind energy development
• Various HVDC–integration levels
• Scenarios designs and roadmaps
• Scenario comparison
• Extended analysis
Pre-feasibility study – Case Study 1

Approach

• Technology assumptions

• Localizations and Design of OWE
  - Wind Turbine & foundation layouts
  - Cable layouts & Transformator stations
  - 2 visions, high and low

• Localisation and Design of offshore network
  - Onshore connection points
  - Offshore substations
  - Various levels of HVDC-integration Zero, Partial, Max

• Component list/Cost-benefit

• Grid functions and services

• Power flow and DC-protection analysis

• Input to market analysis, spatial planning, regulatory questions, etc.
Technology assumptions

<table>
<thead>
<tr>
<th>Component</th>
<th>Pre-2030</th>
<th>Post-2030</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wind turbines</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-2030:</td>
<td>8 MW</td>
<td></td>
</tr>
<tr>
<td>Post-2030:</td>
<td>12 MW</td>
<td></td>
</tr>
<tr>
<td><strong>Inter-array voltage</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre and post 2030:</td>
<td>66 kV AC</td>
<td></td>
</tr>
<tr>
<td><strong>AC transformer substations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre and post 2030:</td>
<td>600 MW</td>
<td></td>
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<tr>
<td><strong>AC export cables</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre and post 2030:</td>
<td>300 kV AC</td>
<td></td>
</tr>
<tr>
<td><strong>Converter technology</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VSC: Modular Multi level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>System: Symmetrical Monopole or Bipole</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>HVDC cable voltage</strong> (available)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-2030:</td>
<td>± 525 kV</td>
<td>2500 MW</td>
</tr>
<tr>
<td>Post-2030:</td>
<td>± 640 kV</td>
<td>3000 MW</td>
</tr>
<tr>
<td><strong>AC onshore grid</strong></td>
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<td></td>
</tr>
<tr>
<td>Pre and post 2030:</td>
<td>300-400 kV AC</td>
<td></td>
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</tbody>
</table>
Scenarios

Integration level

Zero Integration
- High OWP \rightarrow Scenario 1a \rightarrow Vision + Roadmap
- Low OWP \rightarrow Scenario 1b \rightarrow Vision + Roadmap

Partial Integration
- High OWP \rightarrow Scenario 2a \rightarrow Vision + Roadmap
- Low OWP \rightarrow Scenario 2b \rightarrow Vision + Roadmap

Max. Integration
- High OWP \rightarrow Scenario 3a \rightarrow Vision + Roadmap
- Low OWP \rightarrow Scenario 3b \rightarrow Vision + Roadmap

OWP level
High/Low OWP visions

High OWP – 2045

OWP capacity: **11.2 GW, 47 TWh/y**
Low OWP – 2045

OWP capacity: 5.7 GW, 24 TWh/y
Scenarios

Integration level

Zero Integration

Partial Integration

Max. Integration

OWP level

High OWP

Low OWP

Scenario

Scenario 1a

Scenario 1b

Scenario 2a

Scenario 2b

Scenario 3a

Scenario 3b

OWP level

Vision + Roadmap

Vision + Roadmap

Vision + Roadmap

Vision + Roadmap

Vision + Roadmap

Vision + Roadmap
Scenarios

Integration level

Onshore AC- & DC connection points
**Scenarios**

**Integration level**

- **Zero Integration**
- **Max. Integration**

**Scenario concept – Integration level**

- **Scenario 1a**
- **Scenario 1b**
- **Scenario 2a**
- **Scenario 2b**
- **Scenario 3a**
- **Scenario 3b**

- **Vision + Roadmap**
- **Onshore AC- & DC connection points**
- **Only onshore DC connection points**
Scenarios

<table>
<thead>
<tr>
<th>Integration level</th>
<th>OWP level</th>
<th>Scenario</th>
<th>OWP level</th>
<th>Scenario</th>
<th>OWP level</th>
<th>Scenario</th>
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</thead>
<tbody>
<tr>
<td>Zero Integration</td>
<td>High OWP</td>
<td>Scenario 1a</td>
<td>Low OWP</td>
<td>Scenario 1b</td>
<td>Low OWP</td>
<td>Scenario 2b</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>High OWP</td>
<td>Scenario 2a</td>
<td>Low OWP</td>
<td>Scenario 2b</td>
</tr>
<tr>
<td>Partial Integration</td>
<td>High OWP</td>
<td>Scenario 2a</td>
<td>Low OWP</td>
<td>Scenario 2b</td>
<td>Low OWP</td>
<td>Scenario 2b</td>
</tr>
<tr>
<td>Max. Integration</td>
<td>High OWP</td>
<td>Scenario 3a</td>
<td>Low OWP</td>
<td>Scenario 3b</td>
<td>Low OWP</td>
<td>Scenario 3b</td>
</tr>
</tbody>
</table>

Focus on High OWP for this presentation!
1a. High OWP, Zero integration – DC Overview

OWP capacity: 11.2 GW, 47 TWh/y

Legend
CS1
1a. Zero int. - High OWP
HV system
   1a. Onshore connection point
   1a. HVDC converters
   1a. 640kV DC lines
   1a 300kV AC lines
OWP system
   OWP-2025
   OWP-2030
   OWP-2035
   OWP-2040
   OWP-2045
General
   EEZ
   Countries

Cables viewed schematically
Scenarios

<table>
<thead>
<tr>
<th>Integration level</th>
<th>OWP level</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero Integration</td>
<td>High OWP</td>
<td>Scenario 1a</td>
</tr>
<tr>
<td></td>
<td>Low OWP</td>
<td>Scenario 1b</td>
</tr>
<tr>
<td>Partial Integration</td>
<td>High OWP</td>
<td>Scenario 2a</td>
</tr>
<tr>
<td></td>
<td>Low OWP</td>
<td>Scenario 2b</td>
</tr>
<tr>
<td>Max. Integration</td>
<td>High OWP</td>
<td>Scenario 3a</td>
</tr>
<tr>
<td></td>
<td>Low OWP</td>
<td>Scenario 3b</td>
</tr>
</tbody>
</table>

Vision + Roadmap
3a. High OWP, Max integration – DC Overview

OWP capacity: 11.2 GW, 47 TWh/y

Cables viewed schematically
Scenarios

<table>
<thead>
<tr>
<th>Integration level</th>
<th>OWP level</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zero Integration</td>
<td>High OWP</td>
<td>Scenario 1a</td>
</tr>
<tr>
<td></td>
<td>Low OWP</td>
<td>Scenario 1b</td>
</tr>
<tr>
<td>Partial Integration</td>
<td>High OWP</td>
<td>Scenario 2a</td>
</tr>
<tr>
<td></td>
<td>Low OWP</td>
<td>Scenario 2b</td>
</tr>
<tr>
<td>Max. Integration</td>
<td>High OWP</td>
<td>Scenario 3a</td>
</tr>
<tr>
<td></td>
<td>Low OWP</td>
<td>Scenario 3b</td>
</tr>
</tbody>
</table>
2a. High OWP – Part integration – Overview Grid

OWP capacity: **11.2 GW, 47 TWh/y**

Legend
- CS1
  - 2a. Part int. - High OWP
  - HV system
    - 2a. Onshore connection point
    - 2a. HVDC converters
    - 2a. 640kV DC lines
    - 2a 300kV AC lines
  - OWP system
    - OWP-2025
    - OWP-2030
    - OWP-2035
    - OWP-2040
    - OWP-2045
  - General
    - EEZ
    - Countries

Cables viewed schematically
Zero vs Partial vs Max grid integration

<table>
<thead>
<tr>
<th>Feature</th>
<th>Integration</th>
<th>Zero (1a)</th>
<th>Partial (2a)</th>
<th>Max (3a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC converter substations</td>
<td>14</td>
<td>9</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>DC cable length (km)</td>
<td>3 283</td>
<td>1 979</td>
<td>2 378</td>
<td></td>
</tr>
<tr>
<td>DC conductor volume (km*mm²)</td>
<td>3.8*10⁶</td>
<td>4.8*10⁶</td>
<td>6.4*10⁶</td>
<td></td>
</tr>
<tr>
<td>OWP on DC system (GW)</td>
<td>4.8</td>
<td>4.8</td>
<td>11.2</td>
<td></td>
</tr>
<tr>
<td>Onshore AC transformers</td>
<td>15</td>
<td>15</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>AC export cable length (km)</td>
<td>1 073</td>
<td>1 073</td>
<td>354</td>
<td></td>
</tr>
<tr>
<td>AC export cond. vol. (km*mm²)</td>
<td>1.7*10⁶</td>
<td>1.7*10⁶</td>
<td>0.6*10⁶</td>
<td></td>
</tr>
</tbody>
</table>

Linear infrastructure crossings (cables, pipelines)
High wind
Extended analysis
Integrated power trade with wind – Example 3

Intra hour power flow

Utilization rates
Conflicts with other sea users

Total length of cables passing through other uses of the sea
High wind

- Navigational routes/navigation lines
- Navy exercise areas
- Fishing areas - high exploitation
- Fishing areas - medium exploitation
- Fishing areas - low exploitation
- Nature 2000 areas

1a - high wind, zero integration
2a - high wind, partial integration
3a - high wind, max integration
For further information:

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