Future North Sea Infrastructure
Enabling the change

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TenneT / TUDelft
The European energy transition

Ambitious goals

• EU ambition: 80-95% CO$_2$ reduction in 2050 compared with 1990 levels
• Large volumes of RES needed:
  • 2000 GW of sun PV required to cover 50% of the electricity demand (TU Delft)
  • 600 GW offshore & onshore wind power required to cover 50% of the electricity demand (EWEA)
• Cooperation Member States is essential to reach the European energy goals
• Member states should agree upon targets/goals
TenneT

- Europe’s first cross-border grid operator for electricity
- 22,000 km high-voltage lines
- 41 million end-users, ~3000 employees
- HQ Arnhem (NL), Bayreuth (GER)
- 99,99% security of supply
- EUR 15.4 bn assets
- EUR 22 bn investments: 8-10 bn offshore (NL + GER, 10 years)
### TenneT offshore by 2023

**Germany**

- Fifteen grid connections for offshore wind farms
- Twelve DC connections, three AC connections
- 4,300 MW at present
- 9,832 MW by 2023 (7,132 MW by 2019)
- NordLink: 1,400 MW (2020)

**Netherlands**

- Five grid connections for offshore wind farms
- Only AC connections
- 3,500 MW by 2023
- NorNed (2008): 700 MW
- BritNed (2010): 1,000 MW
- COBRA cable (2019): 700 MW

By 2023 TenneT will have realized 17.1 GW of offshore connection capacity (13.3 GW for offshore wind energy, 3.8 GW for interconnection): 13,000 km cable.
# TenneT offshore Germany

<table>
<thead>
<tr>
<th>Project</th>
<th>Capacity (MW)</th>
<th>Commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operational</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>alphaventus</td>
<td>62</td>
<td>2009</td>
</tr>
<tr>
<td>BorWin1</td>
<td>400</td>
<td>2010</td>
</tr>
<tr>
<td>BorWin2</td>
<td>800</td>
<td>2015</td>
</tr>
<tr>
<td>DolWin1</td>
<td>800</td>
<td>2015</td>
</tr>
<tr>
<td>HelWin1</td>
<td>576</td>
<td>2015</td>
</tr>
<tr>
<td>HelWin2</td>
<td>690</td>
<td>2015</td>
</tr>
<tr>
<td>Riffgat</td>
<td>113</td>
<td>2014</td>
</tr>
<tr>
<td>SylWin1</td>
<td>864</td>
<td>2015</td>
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<tr>
<td><strong>Under construction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BorWin3</td>
<td>900</td>
<td>2019</td>
</tr>
<tr>
<td>DolWin2</td>
<td>916</td>
<td>2016</td>
</tr>
<tr>
<td>DolWin3</td>
<td>900</td>
<td>2018</td>
</tr>
<tr>
<td>Nordergründe</td>
<td>111</td>
<td>2016</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>7,132</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Planned</strong></td>
<td></td>
<td></td>
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<tr>
<td>DolWin6</td>
<td>900</td>
<td>2021</td>
</tr>
<tr>
<td>DolWin5</td>
<td>900</td>
<td>2022</td>
</tr>
<tr>
<td>BorWin5</td>
<td>900</td>
<td>2023</td>
</tr>
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</table>
**TenneT offshore Netherlands**

- Five wind areas of 700 MW
- Lowest possible LCOE
- Planning of the ‘Energy Agreement’
- Future proof
- Minimal habitat disturbance
- Innovative

<table>
<thead>
<tr>
<th>Year</th>
<th>Capacity</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>700 MW</td>
<td>Borssele</td>
</tr>
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<td>2016</td>
<td>700 MW</td>
<td>Borssele</td>
</tr>
<tr>
<td>2017</td>
<td>700 MW</td>
<td>Hollandse Kust (zuid)</td>
</tr>
<tr>
<td>2018</td>
<td>700 MW</td>
<td>Hollandse Kust (zuid)</td>
</tr>
<tr>
<td>2019</td>
<td>700 MW</td>
<td>Hollandse Kust (noord)</td>
</tr>
</tbody>
</table>

Current Offshore Wind Farms (partly under construction)

Appointed Wind Farm Areas

Potential Wind Farm Areas
TenneT subsea interconnectors

- Price conversion: high-low price areas
- Security of supply
- Social welfare
- Market coupling
- Efficient use and exchange of renewable energy production

<table>
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<th>Year</th>
<th>Project</th>
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<tbody>
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<td>2008</td>
<td>NorNed</td>
</tr>
<tr>
<td>2011</td>
<td>BritNed</td>
</tr>
<tr>
<td>2019</td>
<td>COBRAcable</td>
</tr>
<tr>
<td>2020</td>
<td>NordLink</td>
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</tbody>
</table>
NordLink

- TenneT (25%), KfW (25%), Statnett (50%)
- First direct connection between German and Norwegian electricity markets
- 623-km-long HVDC cable link, capacity of 1,400 MW, ready by 2020
- Connecting Norwegian hydropower to German wind and solar energy; natural storage of wind energy
• TenneT (50%), Energinet.dk (50%)
• First direct connection between the Dutch and Danish electricity markets
• 325-km-long HVDC cable link, capacity of 700 MW, operational ready by 2019
• Multi terminal ready: prepared to connect wind farms
• Connecting Danish wind power to Dutch/European wind and solar energy
• Security of supply
The challenge

- Sun will be the winner
- But, also wind needed
- Wind energy on land
- Wind energy near shore
- Wind energy far shore
  - Construction (expensive)
  - Maintenance (expensive)
  - Infrastructure (expensive)

Challenge
- How to get cost level down? (below Borssele)
Complementary cycles

Sun PV and wind energy are complementary during the year.
Two main functions

1. Connection of countries: price convergence
2. Transmission of offshore wind energy

No consumption at sea

Impact of failures differs

- Cost of onshore failure 200 x cost of electricity not delivered
- Cost of offshore failure 1 x cost of electricity not delivered
Solution: the Wind Connector

The ‘wind-connector’: wind infrastructure and interconnector combined in one function
Solution: hub and spoke concept

Hub and spoke delivers

Scale
A large scale European roll-out for offshore wind delivers a significant contribution to cost reduction.

Location
When far shore becomes necessary, shallow waters with great wind conditions contribute to cost reduction.

Wind connector
The wind connector combines large scale wind farms with powerful interconnectors for higher system efficiency.

Hub function/ island
By connecting the interconnectors on the island, a hub can be build that facilitates optimal energy transmission and a further European Market integration.
Solution: location

When far shore becomes necessary to realize the required scale

Shallow waters
Water depth has a significant impact on the development for offshore wind. A development in shallow waters contributes significantly to cost reduction.

Wind conditions
Wind conditions get better further at sea, which partially compensates the increase in cost for distance.

Central location
For a European coordinated roll-out, a central location is important.
Solution: location

When far shore becomes necessary to realize the required scale
Solution: scale

Small scale

Far shore: 135%
classic DC e-infra

+ 1 GW DC infra
+ distance to shore

AC solution closer to shore: 100%

Large scale

Far shore
International cooperation - island concept

- 15%: economies of scale e-infra:
  - island
  - new 2GW infrastructure
  - no steel structures/jackets

- 10%: strong, stable wind

- 10%: shallow water

- 5%: Volume $\rightarrow$ Economies of scale wind Industry (20% increase)

- 5%: interconnection (20% allocation)
Combining wind with interconnectors
The modular island: facts & figures

- Possibly three islands: 6 km\(^2\) each, 200 mln m\(^3\) sand
- €1.5 bn (rock and sand only, no infra/facilities)
- Possible connections to existing pipeline infrastructure
- Facilitates approx. 30 GW of wind farms per island
- 15 Converter stations (2 GW each) on the island
- Total: 70 GW, 7,000 turbines (10 MW)
- On the Dogger Bank: 11,400 km\(^2\)
- Hard substrate: 4.4 km\(^2\) (0.02% of total Dogger Bank surface)
Step 1

Explore & develop ‘near shore’ wind

- Individual projects by North Sea countries
- Relatively short term goals
- NL: 3.500 MW (additional) in 2023
- TenneT offshore grid developer & operator
- Separate interconnectors
- Onshore wind
Step 2

IJmuiden Ver

• Develop grid concept for IJmuiden Ver
• Development of currently appointed areas (Boven de Wadden and Hollandse Kust) possible with standardized TenneT 700 MW concept)
• First tender 2020
• In operation from approx. 2024
Step 3

Connect to infra UK

- Connect IJmuiden Ver to UK energy area (e.g. East Anglia)
- Investigate island solutions
- Cooperation with UK
- Connect to existing oil and gas infrastructure
- Approx. 2025 – 2030
- Timing possibly simultaneously to step 2
Step 4

Large scale, far shore

• Facilitates required economies of scale
• Optimal wind conditions
• Shallow waters
• Central position North Sea countries
• Interconnection hub: Wind Connectors
• Development up to 2050
The modular island

The big step: hub and spoke model
Ecological quick scan flora & fauna

In close consultation with environmental organisations

- Dogger Bank = Natura2000 area
- Additionally: the impact on other species using the Dogger Bank area
- First exploratory study of environmental impacts show:
  - Bio diversity: introduction of hard substrate marks a change to the area, however a limited change increasing biodiversity and biomass
  - Fish and sea mammals: mitigation measures or innovations limiting under water noise during construction are necessary, during operation mainly positive impact of offshore wind expected
  - Birds: impact depends on the way birds use the area, more research is needed for several bird species.
What’s next?

• Current autonomous offshore developments by the North Sea countries are important to meet national targets and reach necessary cost reduction
• Invite the North Sea countries to discuss and further develop this vision to work towards a coordinated approach
• Explore possibilities IJmuiden Ver (interconnection, small island, conversion, combination with existing infrastructure)
• Explore possibilities East Anglia with British TSO
• Start talks with ‘Brussels’ to explore possibilities to make this a European project
• Invite research community and industry to come with novel ideas
TenneT is a leading European electricity transmission system operator (TSO) with its main activities in the Netherlands and Germany. With approximately 22,000 kilometres of high-voltage connections we ensure a secure supply of electricity to 41 million end-users.
The island
The European energy transition

6 June: Political declaration on energy cooperation between the North Seas Countries (EU)

Assumptions EU: regional cooperation, cost reduction offshore wind, take away barriers
# North Sea Infrastructure

## Properties

<table>
<thead>
<tr>
<th>Cooperation</th>
<th>EU coordination versus individual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economies of scale</td>
<td>large volumes reduce marginal costs</td>
</tr>
<tr>
<td>Location</td>
<td>strong winds, shallow waters</td>
</tr>
<tr>
<td>Efficiency</td>
<td>combining wind farms with interconnector-hub</td>
</tr>
<tr>
<td>Technics</td>
<td>island facilitates AC connection technology</td>
</tr>
<tr>
<td>Logistics</td>
<td>optimization by means of island</td>
</tr>
<tr>
<td>Storage/conversion</td>
<td>power 2 gas plus existing infrastructure or water bassins</td>
</tr>
<tr>
<td>Modularity</td>
<td>guaranteed continuity and stable pipeline for market, lowering financial risks</td>
</tr>
</tbody>
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