When the Wind Blows Over Europe - Technical and Economic Aspects

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Chair of Energy Economics and Public Sector Management
Agenda

1. Introduction
2. Overview
3. Wind Integration in Europe
4. Zooming in on Germany
5. Conclusion
Main Messages

- Even though wind „technology“ seems to reach saturation, wind energy is on a secular growth path, using a variety of instruments

- Relieving congestion at the „old suspects“ bottlenecks would favour the integration of wind energy in Europe

- The Amendment of the Law on Renewable Energies as well as network unbundling in Germany will further facilitate the integration of wind energy

- Bringing large quantities of offshore wind from the North Sea to the customers requires new approaches, e.g. underground HVDC cables
The Origin: Sustainability: Targets set by the 2007 European Summit („Europe in its 20s“)

205 means: … by 2020:

• **20% share of renewables in primary energy consumption** (and 10% biofuels)

• **20% increase of energy efficiency**

• **20% reduction of CO₂ (compared to 1990): -50-80% by 2050**
  - Current mindset: 450 ppm CO₂e, ~ 400 ppm CO₂

Everybody agrees, but nobody knows how to do it …
… except for Karsten Neuhoff (2007) …

→ Decarbonisation needs renewables
... and the German Ministry for Environment (BMU) – Reference Scenario for Wind Electricity (2007)

Targets for Germany:
- 18% renewables in TPEC
- 30% wind in electricity (2030)

Source: BMU, 2008
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Global Wind Capacity Installed

As of end 2006

Total : 74.221 Megawatt
New in 2006 : 15.197 Megawatt

Source: GWEC
Global Wind Capacity Distribution

As of end 2006

Total: 74.221 MW
2006: 15.197 MW

Source: GWEC
Wind Turbine Expansion Coming to an End …

Current standards:

- Capacity: 1.5 – 2.5 MW – 5-6 MW (Prototype)
- Rotor: 70 – 93 m – 126 m (Prototype)
- Height: up to 110 m (steel) / to 140 m (hybrid) / tp 160 m (lattice tower)
- Expected standard 2008: 3 MW / 100 m

<table>
<thead>
<tr>
<th>Year</th>
<th>Power</th>
<th>Rotor</th>
<th>Electricity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>30 kW</td>
<td>15 m</td>
<td>35.000 kWh</td>
</tr>
<tr>
<td>1985</td>
<td>80 kW</td>
<td>20 m</td>
<td>95.000 kWh</td>
</tr>
<tr>
<td>1990</td>
<td>250 kW</td>
<td>30 m</td>
<td>400.000 kWh</td>
</tr>
<tr>
<td>1995</td>
<td>600 kW</td>
<td>46 m</td>
<td>1.250.000 kWh</td>
</tr>
<tr>
<td>2000</td>
<td>1.500 kW</td>
<td>70 m</td>
<td>3.500.000 kWh</td>
</tr>
<tr>
<td>2005</td>
<td>5.000 kW</td>
<td>115 m</td>
<td>ca. 17.000.000 kWh</td>
</tr>
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</table>

Source: BWE
... but Offshore Wind Turbines Have yet to Prove their Viability

<table>
<thead>
<tr>
<th>Enercon E-126</th>
<th>Repower 5M</th>
<th>Multibrid M5000</th>
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<tbody>
<tr>
<td><strong>Power</strong></td>
<td>6 MW</td>
<td>5 MW</td>
</tr>
<tr>
<td><strong>Height</strong></td>
<td>135 m</td>
<td>120 m</td>
</tr>
<tr>
<td><strong>Rotor diameter</strong></td>
<td>127 m</td>
<td>126 m</td>
</tr>
<tr>
<td><strong>Locations</strong></td>
<td>3 plants</td>
<td>10 plants</td>
</tr>
</tbody>
</table>
Offshore Wind Pole Grounding Technologies

- Bucket
- Gravity Grounding
- Monopile
- Jacket
- Tripod
- Swimming pontons (development)
Market Structures: „Healthy“ Competition Among Turbine Producers
(annually sold capacity, in MW)

+ large newcomers:
  - China
  - Poland, Ukraine, etc.

Source: ISET (2006), p. 34
The “Non-”Discussion on Instruments

• Theory:
  - Quotas and feed-in prices equivalent (full information)
  - Imperfect information: Weitzman, Montero, etc. do not provide one-size fits all results
    • Quotas preferred to generate “information”, but investment obstacle may prevent from reaching the targets
  - Parallel instruments (e.g. ETS and feed-ins) may be inefficient

• Practice: efficiency vs. effectiveness:
  - UK ROC scheme ineffective (Neuhoff and Butler, 2006)
  - German feed-in system inefficient but effective

• Works in theory and in practice: Poland

  Key: Long-term contracts with utilities are possible (12 years)
  - Feed-in quota for electricity sold by utilities required from renewables: 7% of in 2008;
  - Increase to 10,4% in 2014
  - Certificate price = 360 PZI
    ./. „black power“ tariff (i.e. yearly average, ~3 €c/kW (128 PZI) as of 07/2008)
  - Serious fine: 7 €c/kWh (248 PKZ/MWh), indexed to inflation
  - 1 certificate per kWh
  - Disadvantage: no distinction b/w renewables → only after saturation of cheapest technology (onshore wind), the second cheapest technology will be installed

→ 16 GW (onshore) wind currently planned
Existing Offshore Wind Farms in the UK

2 Rounds for Offshore Wind Sites

- Round 1
  (12/2000)

- Round 2

Source: BWEA
Offshore Wind Farms in the UK according to Status

Source: BWEA
Installed Wind Capacity in Germany

Total: 22.247 MW
2007: 1.667 MW
Source: DEWI
The “Non-”Discussion on Instruments

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  - Quotas and feed-in prices equivalent (full information)
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Assessment of Network Effects of Additional Wind
(Leuthold, Jeske, Weigt, von Hirschhausen, 2007)

• When the wind blows over Europe:
  - High installation of wind energy capacities forecasted in near to mid-term future
  - Is the European Union UCTE-grid able to deal with the changes?
  - Where are grid-bottlenecks situated?
  - How much extension is reasonable (under economic aspects)?

• Forecast studies: wind capacities planned to be installed in 2020 in UCTE Europe
  - World Energy Outlook 2006 (IEA 2006) → 114 GW*/**
  - Wind Force 12 (GWEC 2005) → 180 GW

• Instruments used to analyze the grid situation
  - Physical model of UCTE-Grid 150 – 400 kV
  - Implementation of a nodal pricing scheme indentifying efficient prices on each node in the grid reflecting demand and supply, social welfare maximized
  - Implementation of an extension algorithm
  - Model coded in GAMS

*Intersection OECD Europe + Poland/UCTE Europe/**linear interpolation. 2015 OECD Europe: 109 GW; 2030: 227 GW
ELMOD: European Electricity Model
(Leuthold, et al., 2008)

Physical model (included countries):
Portugal, Spain, France, Netherlands, Belgium, Luxembourg, Denmark, Germany, Switzerland, Austria, Italy, Poland, Hungary, Czech Republic, Slovenia and Slovakia.

Nodes: 2120 (substations)

Lines: 3143
thereof: 106 150kV
1887 220kV
1150 380kV
The Model: Welfare Maximization

Welfare maximization

\[ W = \max \left\{ \sum_n \left[ \int_0^{q_n^*} p(q_n) dq_n - \int_0^{g_n^*} c(g_n) dg_n \right] \right\} \]

Constraints

Power flow limit on the line \( i \)

\[ |P_i| \leq P_i^{\text{max}} \]

Conservation of energy

\[ \sum_n g_n = \sum_n q_n + L \]

Limited generation capacity of power plants

\[ g_{n}^{t} \leq g_{n}^{t,\text{max}} \]
Grid Upgrade: The Algorithm

How does the model upgrade the power system?

1. Welfare optimization in the first model run (iteration 0)
   - Obtaining welfare and nodal prices

2. Identification of most severe congestion
   - Highest nodal price difference over a line (between two interconnected nodes)

3. Upgrading the defined line
   - Upgrading this line by adding one circuit of the same voltage level
   - It is assumed that the maximum number of circuits per link is 4

4. Performing another model run
   - Obtaining new welfare and new prices

5. Comparing welfare difference with investment costs of line upgrade

Go back to step 2

If welfare difference is higher than investment costs, go back to step 2.
If welfare difference is lower than investment costs, stop. Prior result is solution.
Scenarios

- Wind capacities distributed based on regional studies (Haidvogel, 2002; Hodebrink et al., 2004; IDEA, 2005; PSE, 2003; Verseille, 2003; Woyte et al., 2005)

- If not available, according to
  - Metrological data (e.g. European Wind Atlas)
  - Geographical data (e.g. no turbines in Alps)
  - Existing utilization

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Installed Wind Capacities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark</td>
<td>44 GW</td>
</tr>
<tr>
<td>BAU (business-as-usual)</td>
<td>114 GW</td>
</tr>
<tr>
<td>ALT (alternative)</td>
<td>180 GW</td>
</tr>
</tbody>
</table>
Price Levels All Scenarios

Price levels with grid extensions

→ ALT prices are lowest

Source: Own illustration.
Grid Upgrades (ALT Scenario) 
Largely Correspond to the Well-known Bottlenecks

Source: Own illustration.
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Wind – Potentials and Utilization

Installed Capacity per Year / Installierte Leistung pro Jahr
( Germany / Deutschland )

Source: DEWI
Offshore Wind Farms in the German North Sea

Externe Datenquellen: Elsam A/S (Denmark)

Source: BSH
<table>
<thead>
<tr>
<th>Windpark</th>
<th>Approved Capacity [MW]</th>
<th>No. of Turbines</th>
<th>Distance to coast or island [km]</th>
<th>Depth at site [m]</th>
<th>Area [km²]</th>
<th>Status</th>
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<tbody>
<tr>
<td>Alpha Ventus (B-West)</td>
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<td>12</td>
<td>45</td>
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<td>n.a.</td>
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<td>Butendiek</td>
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<td>34</td>
<td>20</td>
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<tr>
<td>Borkum Riffgrund</td>
<td>231</td>
<td>77</td>
<td>34 / 38</td>
<td>23...29</td>
<td>35</td>
<td>approved</td>
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<tr>
<td>Borkum Riffgrund West</td>
<td>280</td>
<td>80</td>
<td>50</td>
<td>29...33</td>
<td>30</td>
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<tr>
<td>Amrumbank West</td>
<td>Max. 400</td>
<td>80</td>
<td>35 / 36</td>
<td>20...25</td>
<td>32</td>
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</tr>
<tr>
<td>Nordsee Ost</td>
<td>Max. 400</td>
<td>80</td>
<td>30</td>
<td>22</td>
<td>50</td>
<td>approved</td>
</tr>
<tr>
<td>Sandbank 24</td>
<td>Max. 400</td>
<td>80</td>
<td>90</td>
<td>30</td>
<td>59</td>
<td>approved</td>
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<td>ENOVA Offshore</td>
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<td>48</td>
<td>39</td>
<td>29...35</td>
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<td>DanTysk</td>
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<td>80</td>
<td>70</td>
<td>21...33</td>
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<tr>
<td>Nördlicher Grund</td>
<td>Max. 400</td>
<td>80</td>
<td>84</td>
<td>21...33</td>
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<tr>
<td>Global Tech I</td>
<td>Max. 400</td>
<td>80</td>
<td>93</td>
<td>39...41</td>
<td>41</td>
<td>approved</td>
</tr>
<tr>
<td>Hochsee Windpark Nordsee</td>
<td>Max. 400</td>
<td>80</td>
<td>90 / 100</td>
<td>n.a.</td>
<td>50</td>
<td>approved</td>
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<td>Godewind</td>
<td>Max. 400</td>
<td>80</td>
<td>33 / 38</td>
<td>n.a.</td>
<td>37</td>
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<td>BARD Offshore 1</td>
<td>Max. 400</td>
<td>80</td>
<td>89 / 126</td>
<td>n.a.</td>
<td>58.9</td>
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<td>Meerwind Ost/Süd</td>
<td>Max. 2 x 200</td>
<td>2 x 40</td>
<td>24</td>
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<td>40</td>
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<tr>
<td>He dreiht</td>
<td>Max. 400</td>
<td>80</td>
<td>85 / 152</td>
<td>37...43</td>
<td>40</td>
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</table>

Source: BSH
## Approved Offshore Wind Farm Grid Connections

<table>
<thead>
<tr>
<th>Cable</th>
<th>Capacity connected [MW]</th>
<th>Voltage [kV] and Current [A]</th>
<th>Length [km]</th>
<th>AC / DC</th>
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<td>WindNet</td>
<td>60</td>
<td>110 kV</td>
<td>60</td>
<td>AC</td>
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<tr>
<td>Multikabel</td>
<td>Max. 376</td>
<td>2 x 1233 A</td>
<td></td>
<td>DC</td>
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<tr>
<td>Sandbank 24</td>
<td>Max. 400</td>
<td>1333 A</td>
<td>4x20 and 125</td>
<td>DC</td>
</tr>
<tr>
<td>OTP</td>
<td>4 x 200</td>
<td>110 kV</td>
<td></td>
<td>AC</td>
</tr>
</tbody>
</table>

Source: BSH
## The Amendment of the Law on Renewable Energies (EEG, July 4, 2008)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Onshore wind</td>
<td>8 c/kWh</td>
<td>9.2 c/kWh, for at least 5 years</td>
</tr>
<tr>
<td></td>
<td>Reduction: -2%/a</td>
<td>Reduction: -1%/a (after 2010)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Re-Powering: bonus of 0.5-0.7 c/kWh</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall collar: 5.02 c/kWh</td>
</tr>
<tr>
<td>Offshore wind</td>
<td>10-12 c/kWh</td>
<td>13 c/kWh, + „sprinter bonus“ of 2 c/kWh until 2015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduction (after 2015): 5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overall collar: 3.5 c/kWh</td>
</tr>
<tr>
<td>General provisions</td>
<td></td>
<td>Bonus for „system services“ of 0.5-0.7 c/kWh</td>
</tr>
</tbody>
</table>

+ The TSO has to pay financial compensation for refused amounts of energy within the feed in management; wind turbines have priority feed in

+ TSOs are obliged to enlarge and optimize existing electricity networks to integrate wind and other renewables.

→ Broad political consensus: 432/530 supporting votes
Germany on its Way to the „German Network Corp.“

„German Network Corp.“ to be created soon

Very heterogeneous discussion on institutional design
- 100% sell-out to investor and/or fund
- Public ownership
- … or something in between

Most likely to become a „Club“ solution, with multiple ownership

New ownership and corporate governance structure may „tip“ the focus from strategic network management towards issues of (wind) generation and integration

Producers of renewables (mainly wind and solar) have declared high interest to become members of the network Club

Infrastructure Acceleration Act (2006) helps, by shifting the responsibility of „plugging in the sea“ to the network company

⇒ More favourable conditions for wind integration
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Benchmark - 2015 Dena: 750 km Overhead Cable

Wind generation capacities in 2015 grid extension proposed by Dena

Planned grid extension 2015 Dena

Source: UCTE-Map modified
Alternatiave Scenario– Underground HVDC-Cable

- Based on Jeske (2007): Alternative Grid Extension Measures Due to Additional Offshore Wind Energy in the German North Sea

- Providing direct feed-in in high demand areas via HVDC; 3 lines; 3 GW each

Source: UCTE-Map modified
HVDC – Practical Implementation

Identification of three wind farm concentration-zones (WCZ)

Building of 3 offshore converter stations close to each WCZ (3 GW each)

Low-section AC-cables connect each wind farm with an offshore converter station

Converter stations collect power and uncharge it to land stations

Feed-in-nodes (cable length):

1. Dauersberg (approx. 400 km)
2. Grafenrheinfeld (approx. 550 km)
3. Hoheneck (Stuttgart) (approx. 700 km)

Converter station at feed-in node

Converter station
Offshore wind farm
HVDC-cables 3 GW
AC-cables 200 – 500 MW

Source: BSH-map modified
HVDC/Dena – investment costs

Investment costs HVDC-Installations:
- Offshore converter station 300 Mio. € (Assumption)
- Onshore converter station 150 Mio. € (According to 3GC/3GG-Projects)
- Overhead lines approx. 200 k€/km (Rudervall et al. (2000))*
- Cables 600 k€/km (Rudervall et al. (2000)/Brakelmann (2005)/modified)
- Submarine cables 720 k€/km (cables * 1,2)

Investment costs cables approx.: 2,5 Billion €
Investment costs OH-lines approx: 1,8 Billion €
Investment costs DENA-extension: 1,14 Billion €

*Rudervall’s numbers do not comply with published investment costs of 3GC/GG projects, for those could be realized much cheaper, so calculating with Rudervall’s numbers should be a conservative approximation
HVDC Cable is Economically Feasible, and it may be the Only Politically Feasible Solution

Social welfare in the total area for each scenario

- Calculations based on forecasted wind generation capacity situation in 2015
- Fossil power plants, reference demand and –prices did not change
- Reference period 1 hour
- Strong wind
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Thank you very much for your attention!

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Chair of Energy Economics and Public Sector Management