Impacts of Wind Energy Production on the European Electricity Grid using Elmod

A Nodal Pricing Approach with Particular Reference to Implementing Offshore Wind Capacities in Germany

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The Economics of Energy Markets
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Agenda

1. Introduction
2. Elmod: Model and Data
4. Results
5. Conclusion and Further Research
Introduction / Problem

Current Situation in North West Europe:

• increasing decentralized generation capacities (mainly wind)
• spare cross border capacities, as the European grid is not designed for extensive cross border flows
→ increasing congestion within the grid

Problem 1:
Impact of German North Sea Wind Power Feed-in on the Benelux Electricity Grid

Problem 2:
Impact of local but variable energy sources (wind and water) on the North West European grid

Estimation tool: Elmod using a nodal pricing approach
Due to political support installed wind capacities in Germany will further increase, especially large scale offshore wind parks are planned in the near future.

Source: DEWI, 2006
Wind capacities are mainly located along the coast line.

Offshore capacities in will increase the feed in structure.

Source: Riso, 2006
Agenda

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Elmod Overview

Model:

Considered countries:
Austria, Benelux, Denmark (West), France, Germany, Switzerland

nodes: 1270
whereof 363 have generation capacities

lines: 1844
whereof: 626 380kV
1113 220kV
105 150kV

Source: own presentation
Elmod
Load Flow Model

Assumptions

1. Disregard reactive power flows
2. Small voltage angles
3. Standardization of node voltages to respective voltage level

Power flow $P$ on line $i$ from node $j$ to node $k$

$B_i$ \quad Susceptance of line $i$

$Q_{jk}$ \quad Phase angle of voltages $U_j$ and $U_k$

\[ P_{jk} = B_i \cdot \Theta_{jk} \]

Losses $L$ on line $i$ from node $j$ to node $k$

$R$ \quad Active resistance of the line

\[ L_{jk} = R_i P_{jk}^2 \]
Nodal Pricing
Welfare Economic Approach

Price

Demand curve $p_n(d)$

$P_n^{cong}$

Consumer surplus

$P_n^{opt}$

Producer surplus

$D_n^{cong}$ $D_n^{opt}$

merit order

$C_n(d)$

Demand; Supply

Social welfare

Marginal costs of total production

Loss of social welfare

In the case of congestion the nodal price deviates from the optimum

Source: own presentation
Model
Formal Implementation

Welfare-maximization

\[ W = \sum_{n} \left( \int_{0}^{d_n^*} p(d_n) dd_n - \int_{0}^{g_n^*} c(g_n) dg_n \right) \]

Constraints

**Power flow limit** on the lines

\[ |P_l| \leq P_{l}^{\text{max}} \]

**Conservation of energy**

\[ \sum_{n} g_n = \sum_{n} d_n + L \]

Limited **generation capacity** of power plants

\[ g_n^t \leq g_{n}^{t,\text{max}} \]
### Data Generation

#### Generation capacity per type of power plant:

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Total capacity [GW]</th>
<th>Fuel</th>
<th>Total Capacity [GW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear energy</td>
<td>57.4</td>
<td>Natural gas</td>
<td>25.5</td>
</tr>
<tr>
<td>Lignite</td>
<td>22.3</td>
<td>Oil</td>
<td>22.4</td>
</tr>
<tr>
<td>Coal</td>
<td>89.6</td>
<td>Hydroelectric (Water)</td>
<td>29.6</td>
</tr>
<tr>
<td>CCGT</td>
<td>10.9</td>
<td>Pumped-storage</td>
<td>12.1</td>
</tr>
<tr>
<td>Wind</td>
<td>21.8</td>
<td>Total</td>
<td>291.4</td>
</tr>
</tbody>
</table>

#### Marginal costs of generation per type of power plant:

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Marginal costs [€/MWh]</th>
<th>Fuel</th>
<th>Marginal costs [€/MWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear energy</td>
<td>10.00</td>
<td>Natural gas</td>
<td>40.00</td>
</tr>
<tr>
<td>Lignite</td>
<td>15.00</td>
<td>Oil</td>
<td>50.00</td>
</tr>
<tr>
<td>Coal</td>
<td>18.00</td>
<td>Hydroelectric (Water)</td>
<td>0.00</td>
</tr>
<tr>
<td>CCGT</td>
<td>30.00</td>
<td>Pumped-storage</td>
<td>28.00</td>
</tr>
<tr>
<td>Wind</td>
<td>4.05</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data
Market, Demand

**Market:**
- no strategic players
- perfect market bidding (marginal cost, no market power)
- independent ISO

**Node demand:**
- each node has a reference demand based on the GDP of the region
- reference prices are based on the spot prices on the national energy exchange
- a general demand elasticity of -0.25 is assumed
- scenarios for off peak, average and peak load have been analyzed

**Wind input:**
- Given as external parameter, no stochastic simulation

The Model is solved in GAMS as Nonlinear Optimization Problem using CONOPT.
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Impact of German North Sea Wind Power Feed-in on the Benelux Electricity Grid

2 scenarios are simulated:

1. Situation today
2. Situation in 2015 without additional grid measurements

Several cases are analyzed:

- Low, average and high load
- Low and high wind input

Main findings:

- The current situation yields relatively low impact on the Benelux
- Future situation will show significant congestion between Germany and the Netherlands
Results 1 – Impact of Wind Power on Benelux Grid
Average Demand Case

Source: own calculation
Results 1 – Impact of Wind Power on Benelux Grid

Peak Demand Case

Source: own calculation
Results 1 – Impact of Increased Wind Power on Benelux
Average Demand Case / High Wind Input

Prices
[€/MWh]
- < 15
- < 20
- < 25
- < 30
- > 30

extended/upgraded lines

Situation 2005

Source: own calculation
Problem 2

Impact of local but variable energy sources (wind and water) on the North West European grid

Current grid situation analyzed

Several cases are analyzed:
- Low and high wind input
- Low and high water availability
- Average load level

Main findings:
- Although overall parameters are comparable for high wind input and high water availability respectively, local prices differ significantly
## Results 2 – Wind/Water Swing

<table>
<thead>
<tr>
<th>Hydroelectric feed-in</th>
<th>Low</th>
<th>High</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wind power feed-in</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Welfare [Mio €]</td>
<td>17.99</td>
<td>18.36</td>
<td>18.35</td>
<td>18.70</td>
</tr>
<tr>
<td>Demand [GWh]</td>
<td>188.9</td>
<td>192.4</td>
<td>193.0</td>
<td>197.9</td>
</tr>
<tr>
<td>Production [GWh]</td>
<td>190.5</td>
<td>195.0</td>
<td>195.3</td>
<td>200.7</td>
</tr>
<tr>
<td>Losses [GWh]</td>
<td>1.63</td>
<td>2.54</td>
<td>2.19</td>
<td>2.81</td>
</tr>
<tr>
<td>Average costs of production [€/MWh]</td>
<td>13.93</td>
<td>12.25</td>
<td>12.30</td>
<td>10.85</td>
</tr>
</tbody>
</table>

Source: own calculation
Results 2 – Wind/Water Swing
Nodal Prices with different feed-in scenarios

FR  BNL  North  South

France  Denmark – Germany – Switzerland – Austria

Source: own calculation
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Conclusions

German wind power extension ⇒ congestion impact on Benelux must be taken into account

planned grid extensions and own wind capacities ⇒ partly compensate external congestion problems

regionally differentiated view is necessary own measurements need to take external conditions/impacts into account

benefits of inexpensive, geographically limited energy sources remain mainly local
Further Research

Wind Energy in Europe:

• NW-Europe is only one part of the European grid; including of Spain (large amounts of wind capacity) and Italy (high import rate) necessary

→ extension of the model to cover the UCTE-grid from Portugal to Poland

Alternative Feed in Mechanisms:

• Construction of an HVDC-grid in the North Sea connecting several wind farms and allowing for optional feed in locations (e.g. UK, Netherlands, Germany and Denmark)
Thank you very much for your attention!

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Literature

DENA (2005): Summary of the Essential Results, Planning of the Grid Integration of Wind Energy in Germany Onshore and Offshore up to the Year 2020 (dena Grid study). Deutsche Energie-Agentur.


