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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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:

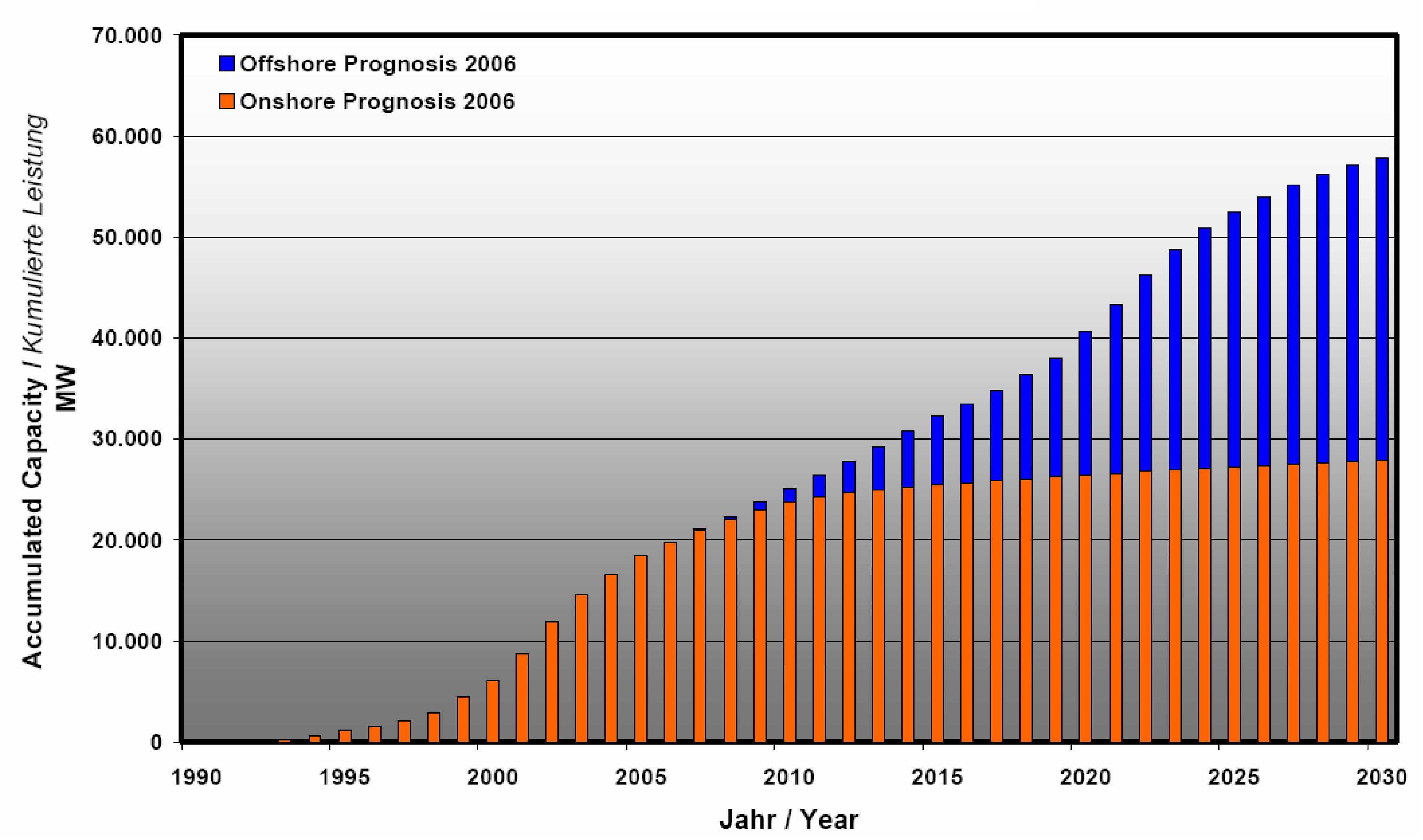
Impact of German North Sea Wind Power Feed-in on the Benelux Electricity Grid

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

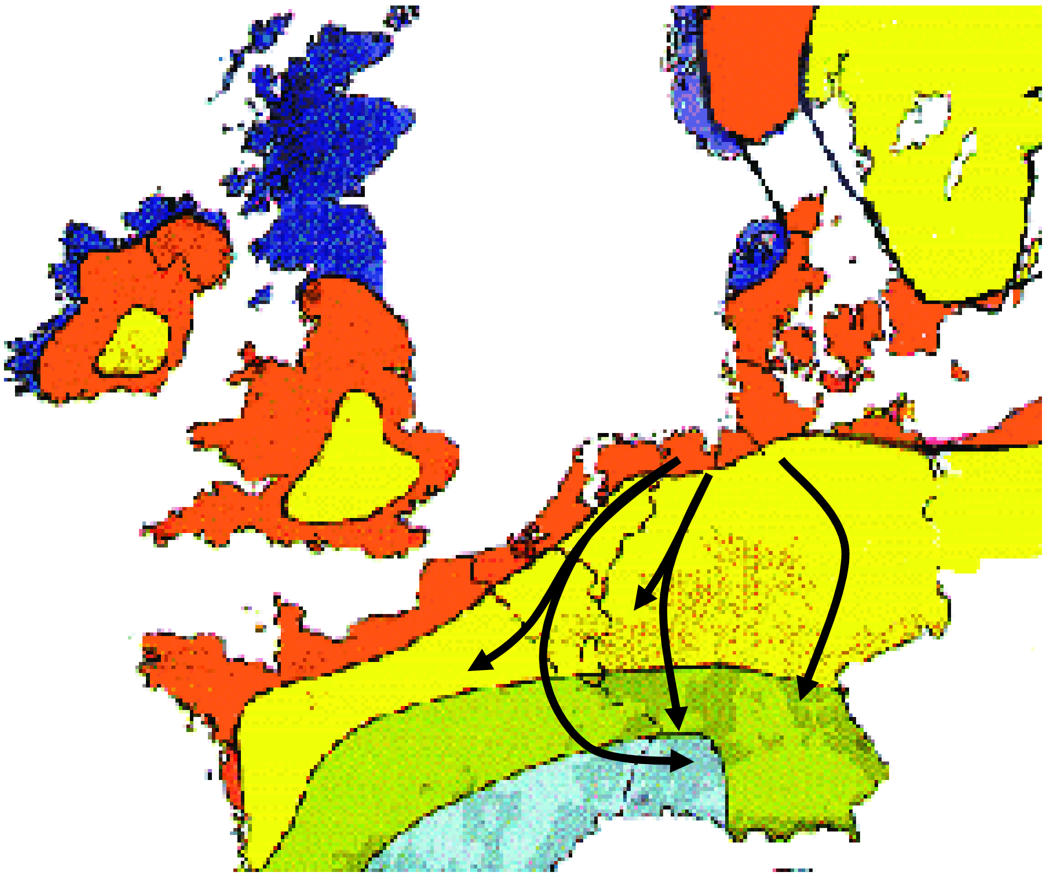
Introduction / Problem
Expected wind capacity extension in Germany



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

Introduction / Problem
Localized generation of wind



Average wind speed

Colour On Map	Open Plain
	>7.5
	6.5 – 7.5
	5.5 – 6.5
	4.5 – 5.5
	<4.5

Power flows

Wind capacities are mainly located along the coast line.

Offshore capacities in will increase the feed in structure.

Source: Riso, 2006

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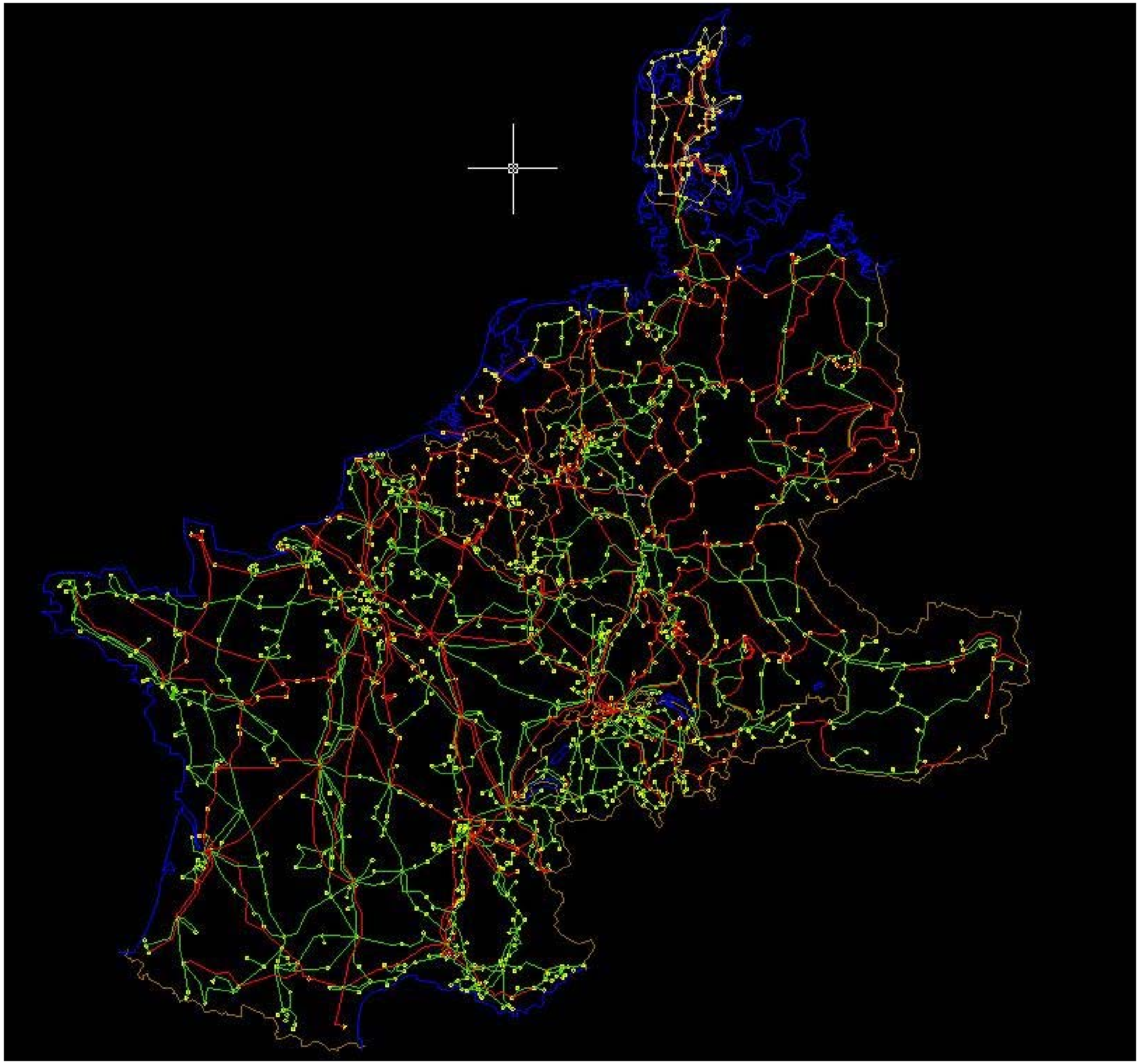
Elmod
Overview



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	Susceptance of line i
Q_{jk}	Phase angle of voltages U_j and U_k

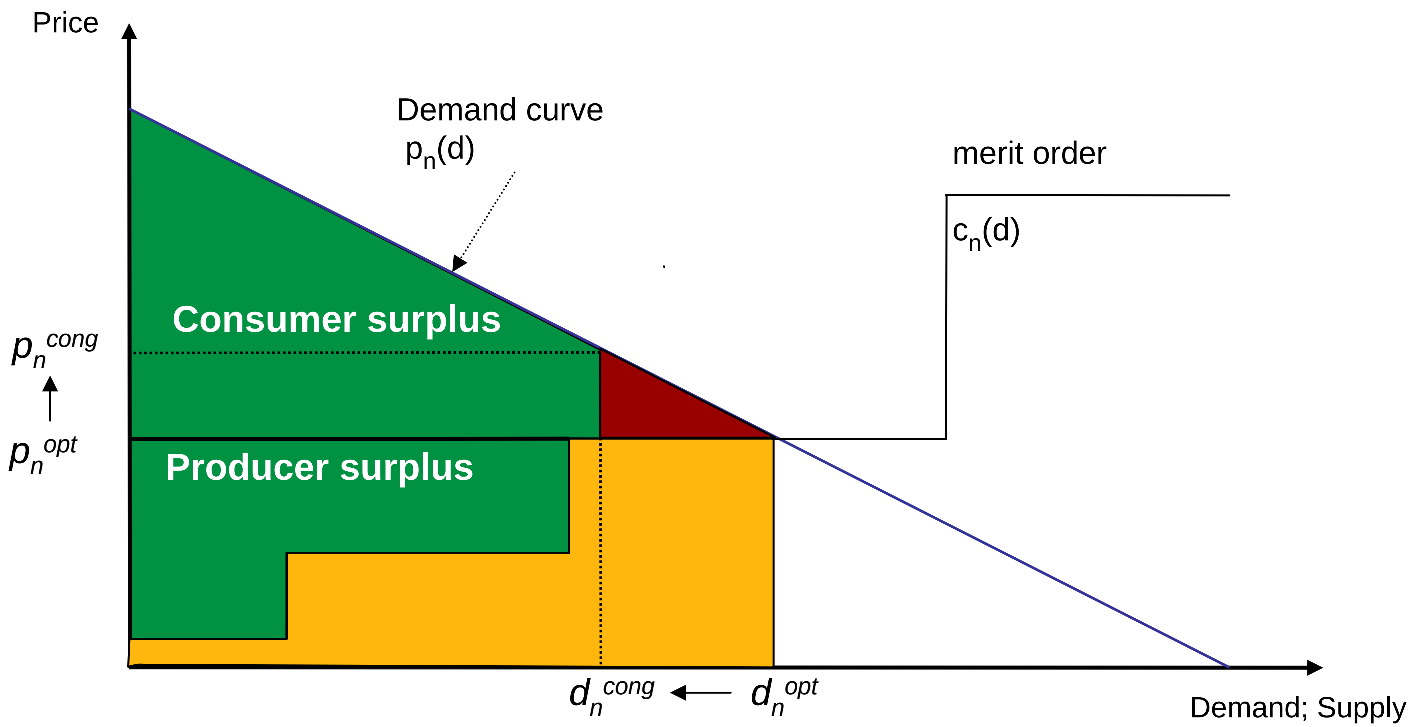
$$P_{jk} = B_i \cdot \Theta_{jk}$$

Losses L on line i from node j to node k

R	Active resistance of the line

$$L_{jk} = R_i P_{jk}^2$$

Nodal Pricing
Welfare Economic Approach



Social welfare

Marginal costs of total production

p_n^{cong} *In the case of congestion the nodal price deviates from the optimum*

Loss of social welfare

Source: own presentation

Model
Formal Implementation

Welfare-maximization

n	number of nodes
d_n	demand at node n
g_n	generation at node n
$p(d_n)$	price at node n
$c(g_n)$	generation costs at node n

$$\max\left\{W = \sum_n \left[\int_0^{d_n^*} p(d_n)\mathbf{d}d_n - \int_0^{g_n^*} c(g_n)\mathbf{d}g_n\right]\right\}$$

Constraints

Power flow limit on the lines

P_l	power flow on line l

$$|P_l| \leq P_l^{\max}$$

Conservation of energy

g	generation
d	demand
L	losses

$$\sum_n g_n = \sum_n d_n + L$$

Limited **generation capacity** of power plants

t	per type of plant

$$g_n^t \leq g_n^{t,\max}$$

Data
Generation

Generation capacity per type of power plant:

Fuel	Total capacity [GW]	Fuel	Total Capacity [GW]
Nuclear energy	57.4	Natural gas	25.5
Lignite	22.3	Oil	22.4
Coal	89.6	Hydroelectric (Water)	29.6
CCGT	10.9	Pumped-storage	12.1
Wind	21.8	**Total**	**291,4**

Marginal costs of generation per type of power plant:

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

Source: VGE (2005), Schröter (2004)

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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Problem 1

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:

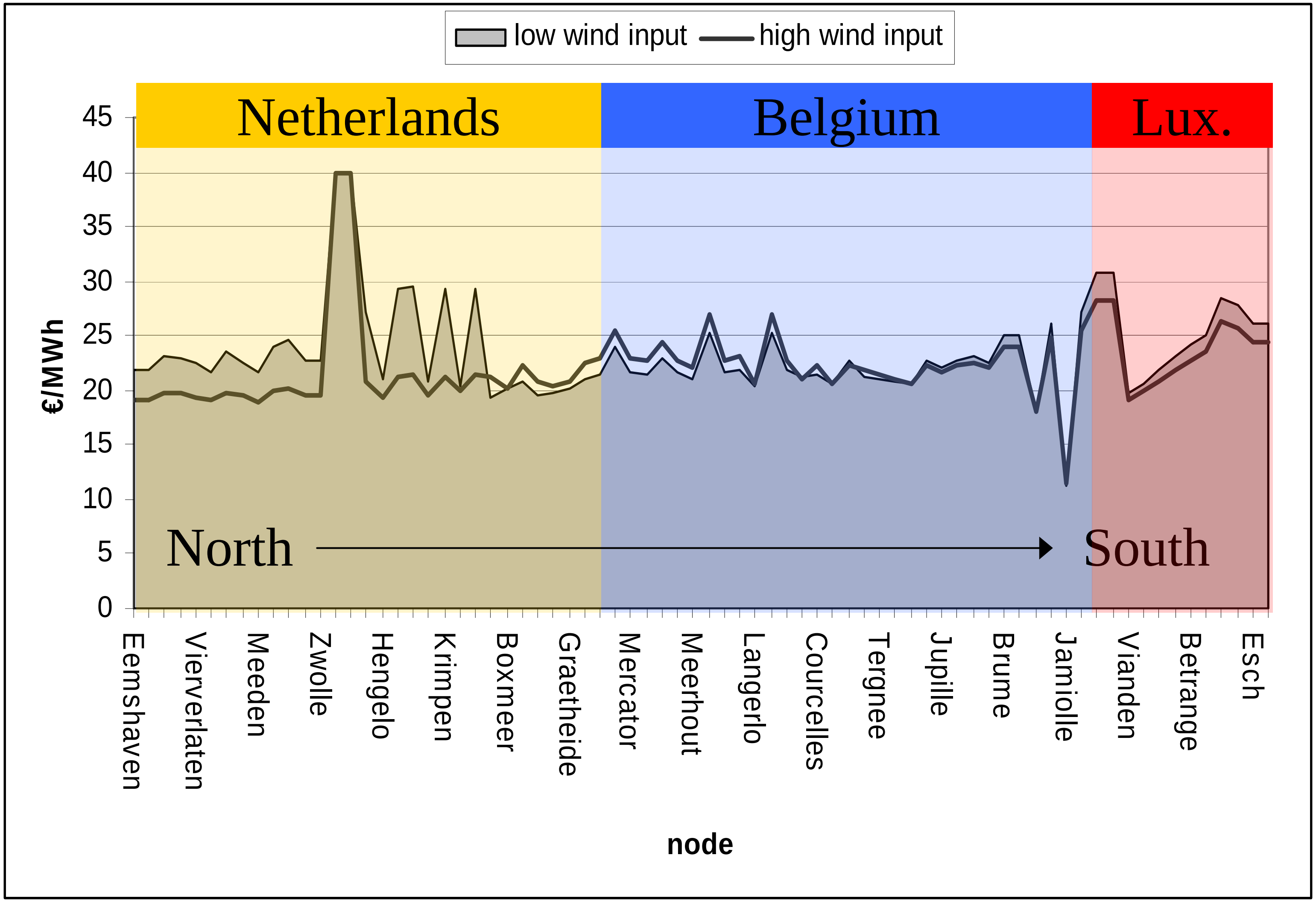
- Low, average and high load
- Low and high wind input

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

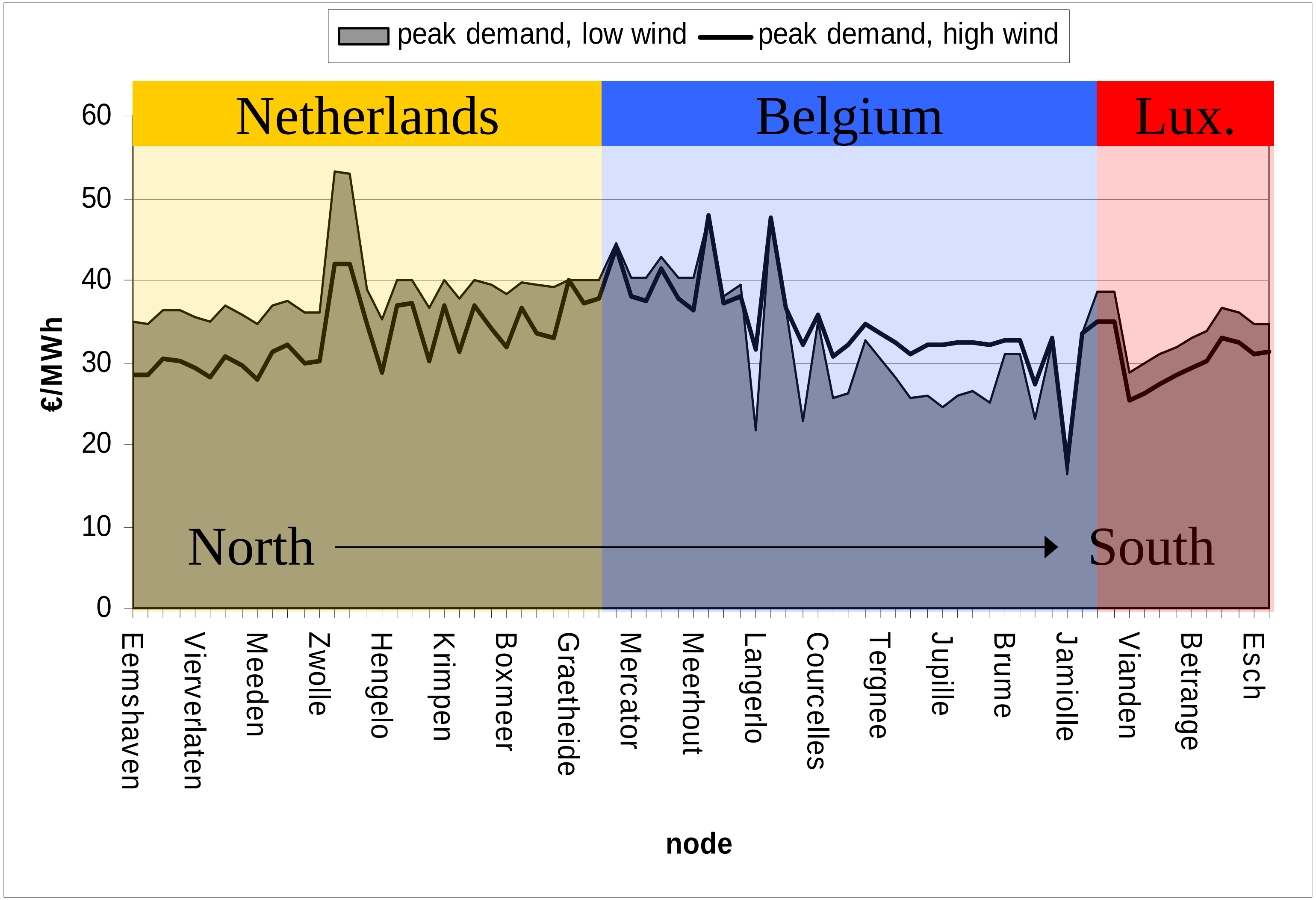
Average Demand Case



Source: own calculation

Results 1 – Impact of Wind Power on Benelux Grid

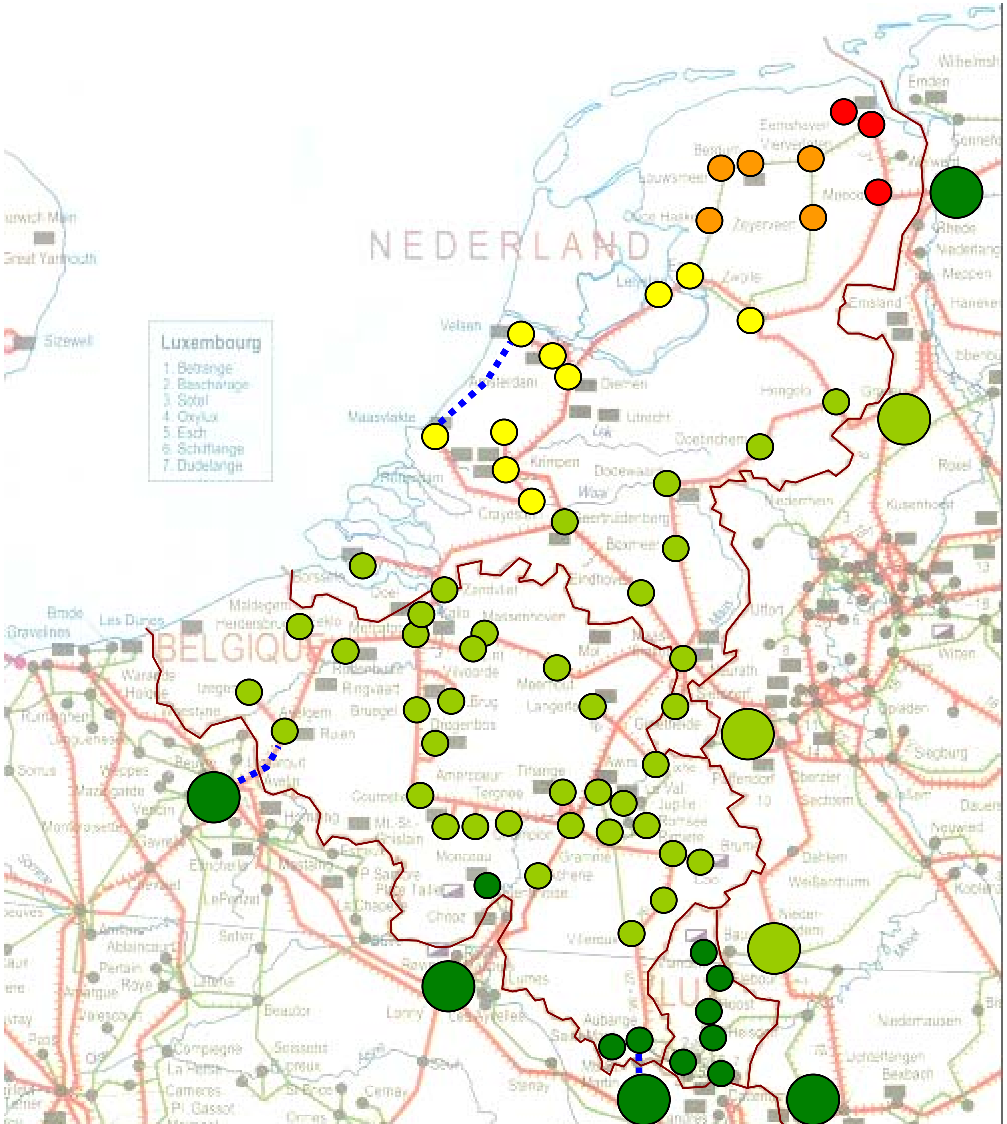
Peak Demand Case



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 2015

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 respectivly, local prices differ significantly

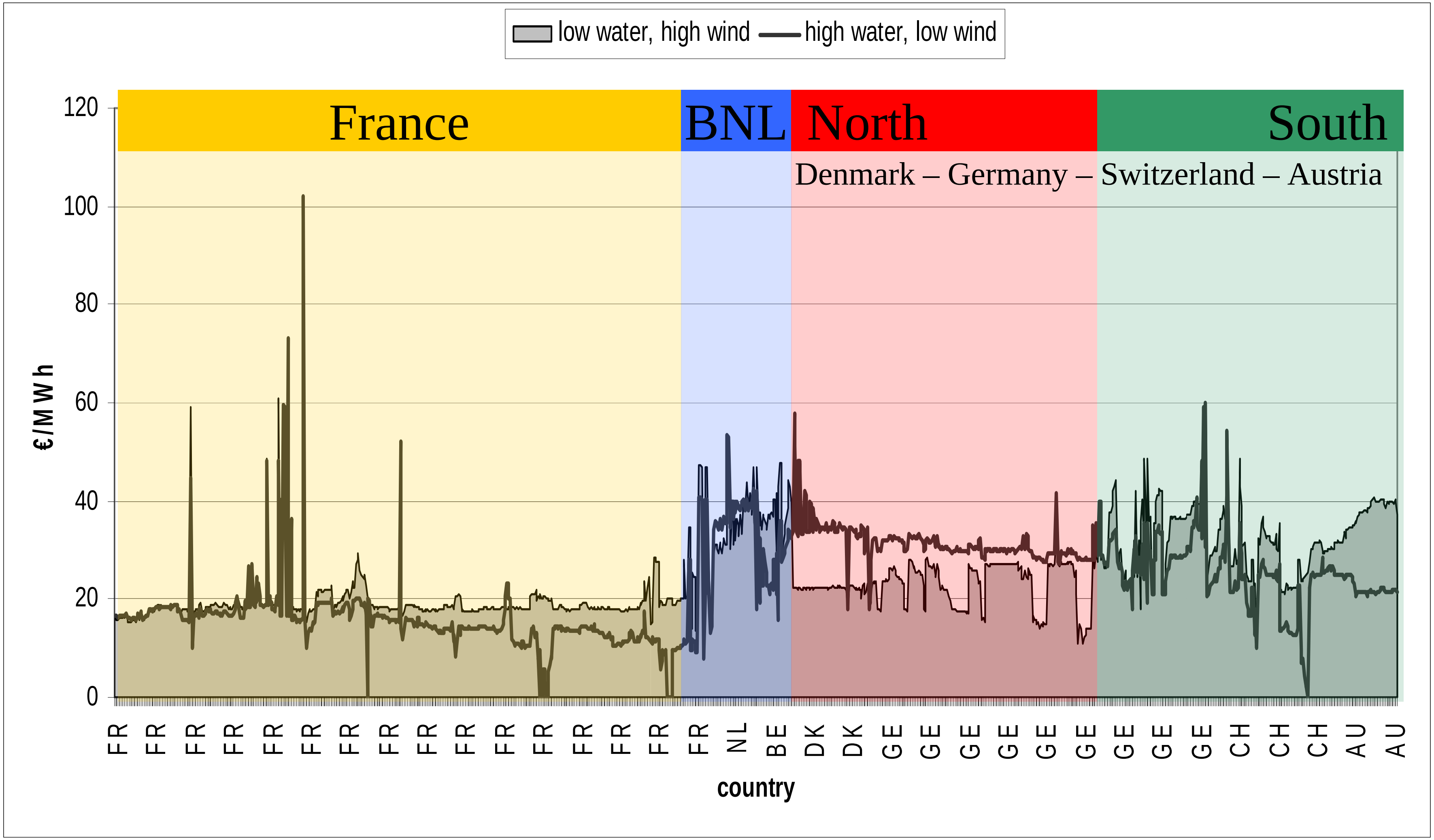
Results 2 – Wind/Water Swing

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

Source: own calculation

Results 2 – Wind/Water Swing

Nodal Prices with different feed-in scenarios



Source: own calculation

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Conclusions

German wind power extension

$\Rightarrow$ congestion impact on Benelux must be taken into account

planned grid extensions and own wind capacities

$\Rightarrow$ 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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