When the Wind Blows Over Europe - Technical and Economic Aspects

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Prof. Dr. Christian von Hirschhausen, Till Jeske, Florian Leuthold, Hannes Weigt

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“)

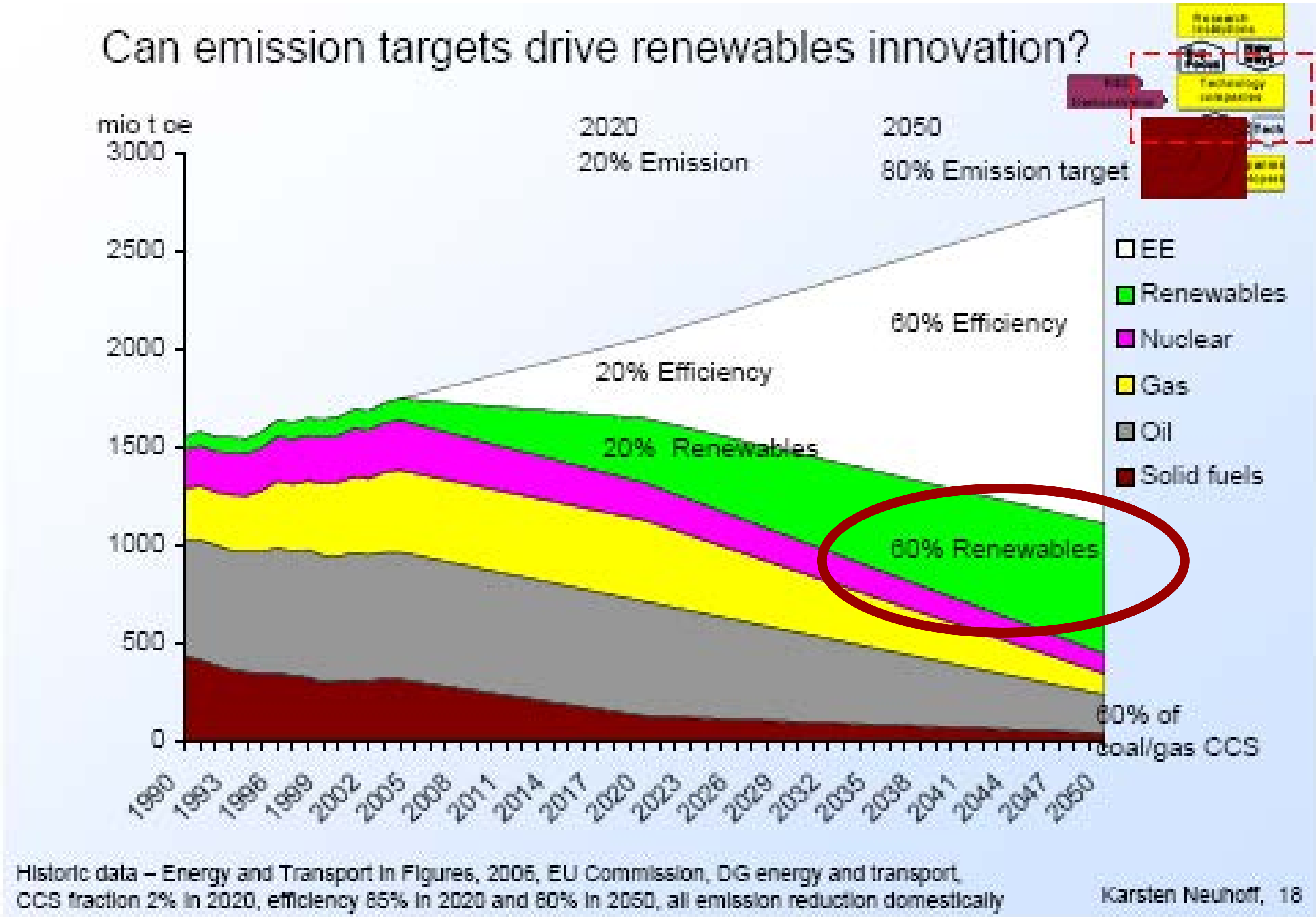
20^5 means: … by 2020:

- **20% share of renewables in primary energy consumption (and 10% biofuels)**
- **20% increase of energy efficiency**
- **20% reduction of CO_2 (compared to 1990): -50-80% by 2050**
  - **Current mindset: 450 ppm CO_2e, ~ 400 ppm CO_2**

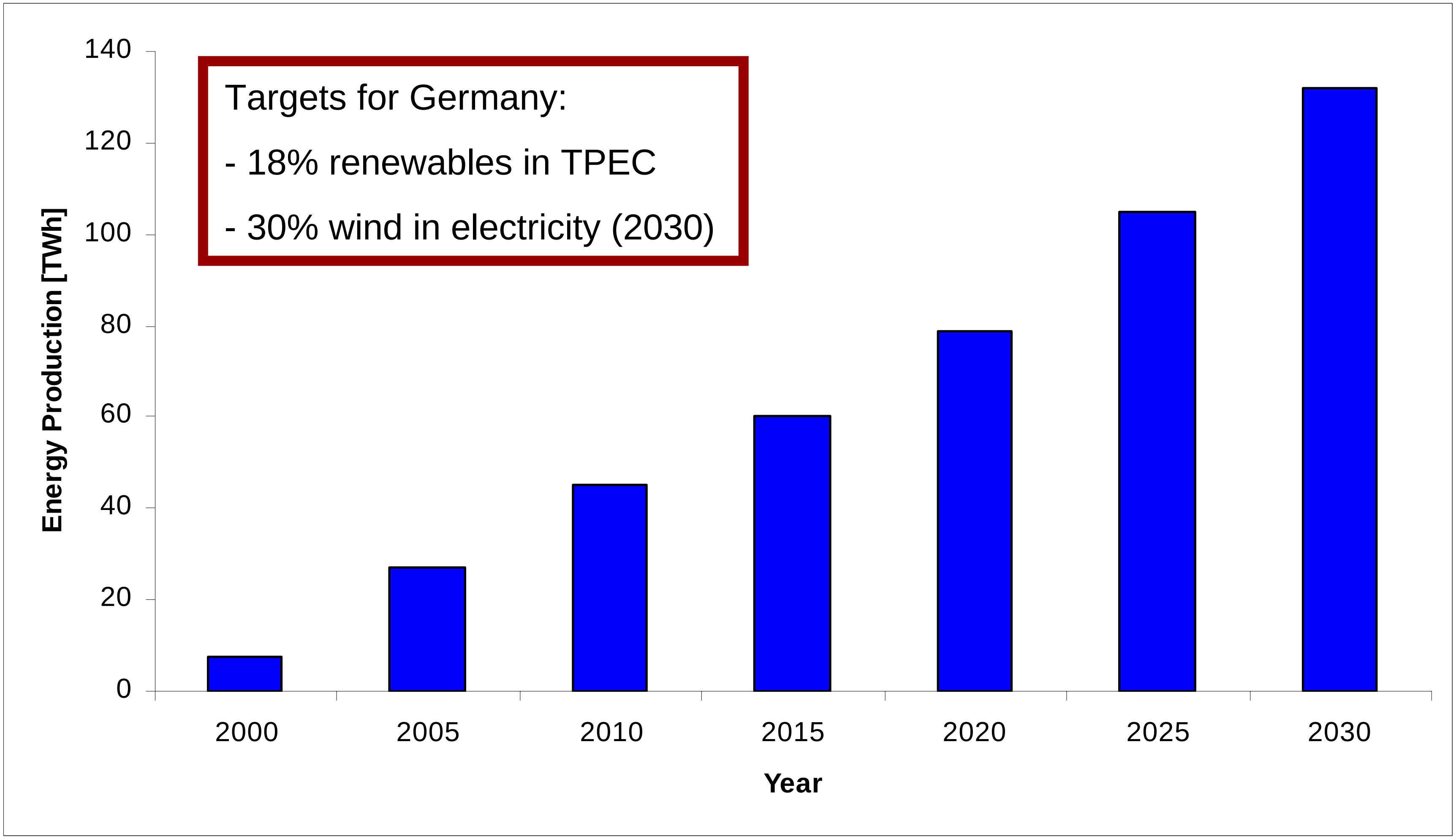
Everybody agrees, but nobody knows how to do it …

EE²

… except for Karsten Neuhoff (2007) …
→ Decarbonisation needs renewables



… and the German Ministry for Environment (BMU) – Reference Scenario for Wind Electricity (2007)



Source: BMU, 2008

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- **Even though wind „technology“ seems to reach saturation, wind energy is on a secular growth path, independently of the instrument chosen**

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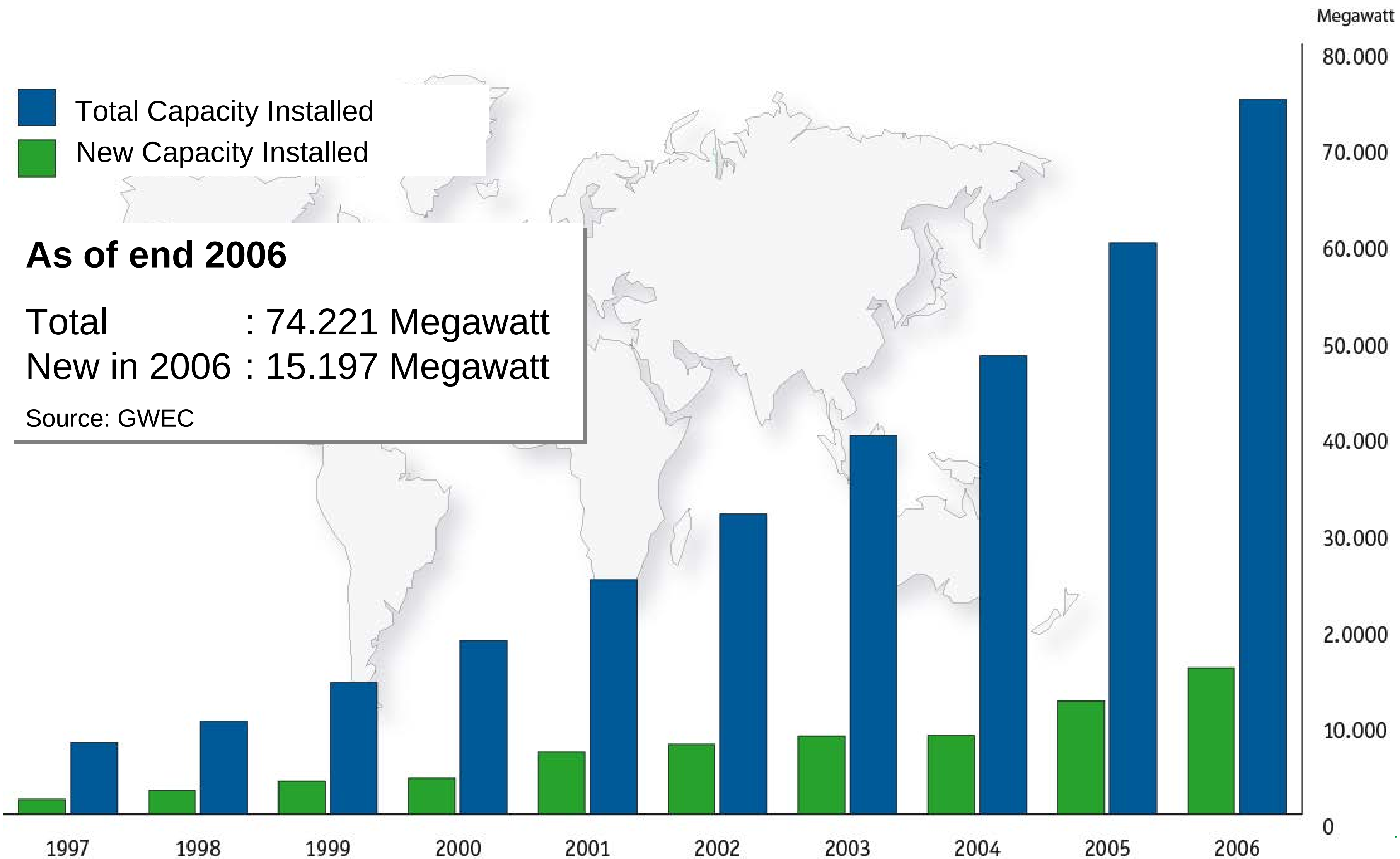
Global Wind Capacity Installed



As of end 2006

Total : 74.221 Megawatt
New in 2006 : 15.197 Megawatt

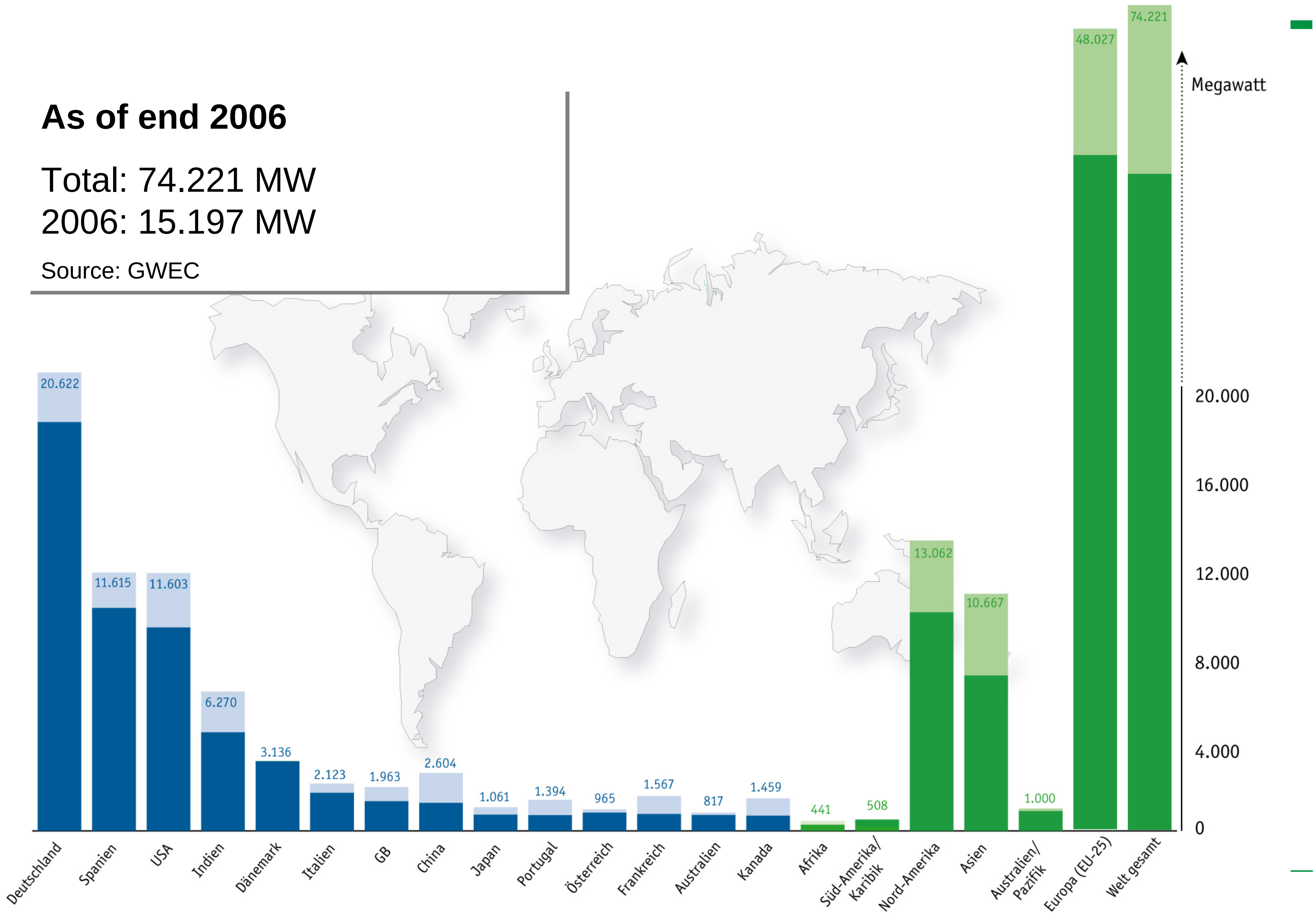
Source: GWEC

Global Wind Capacity Distribution

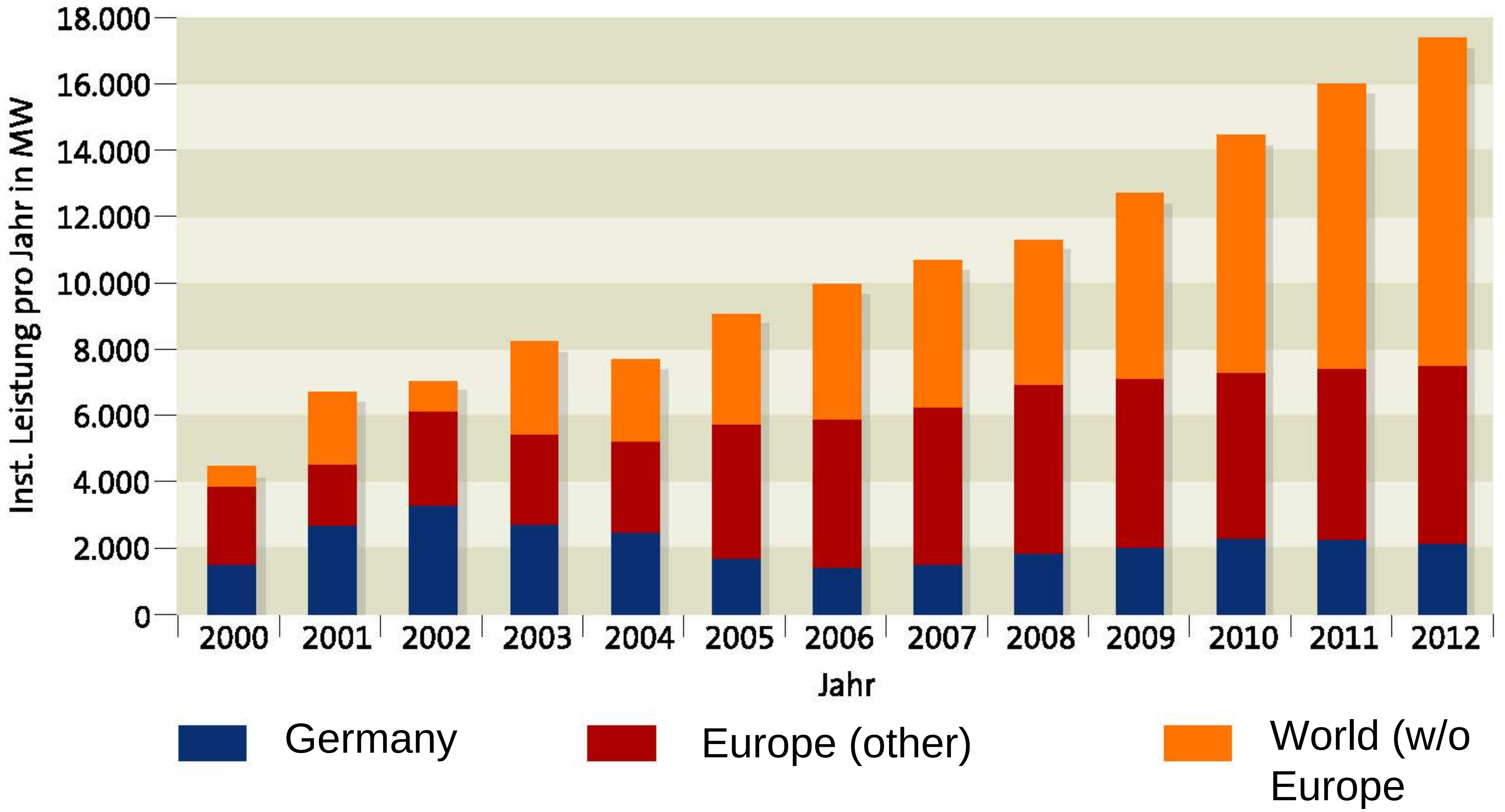
As of end 2006

Total: 74.221 MW
2006: 15.197 MW

Source: GWEC



Global Installed Wind Capacity
(installed capacity per year in MW)



Source: www.deutsche-windindustrie.de

Grafik: Solarpraxis/Sunbeam

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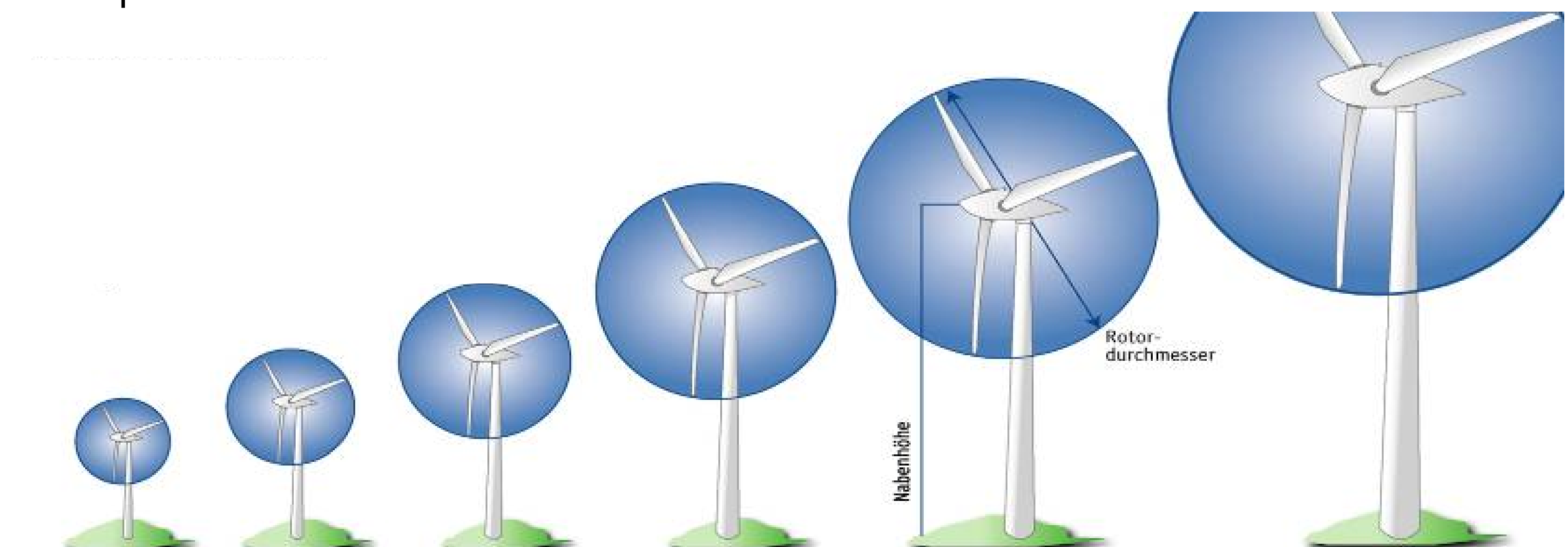
Wind Turbine Expansion Coming to an End …

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

Source: BWE

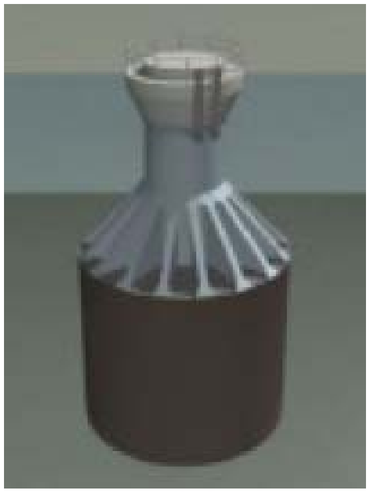


	1980	1985	1990	1995	2000	2005
Power	30 kW	80 kW	250 kW	600 kW	1.500 kW	5.000 kW
Rotor	15 m	20 m	30 m	46 m	70 m	115 m
Hight	30 m	40 m	50 m	78 m	100 m	120 m
Electricity	35.000 kWh	95.000 kWh	400.000 kWh	1.250.000 kWh	3.500.000 kWh	ca. 17.000.000 kWh

… but Offshore Wind Turbines Have yet to Prove their Viability

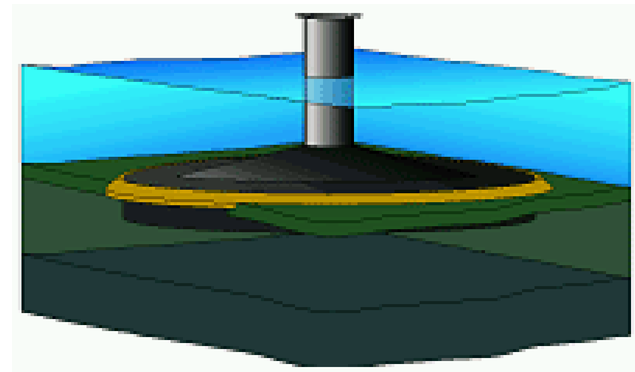
	Enercon E-126	Repower 5M	Multibrid M5000
Power	6 MW	5 MW	5 MW
Height	135 m	120 m	102,6 m
Rotor diameter	127 m	126 m	116 m
Locations	3 plants	10 plants	4 plants

Offshore Wind Pole Grounding Technologies

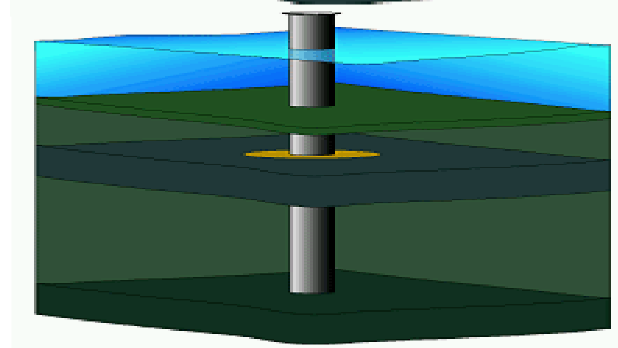


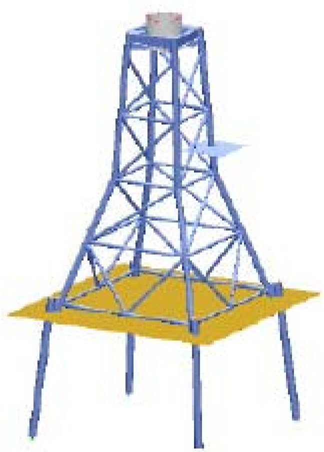
Bucket

Gravity Grounding



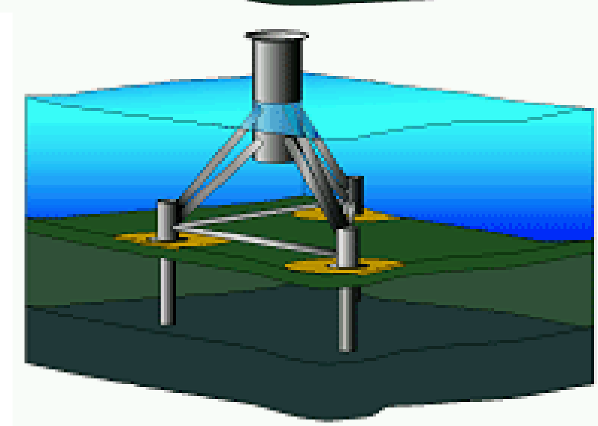
Monopile





Jacket

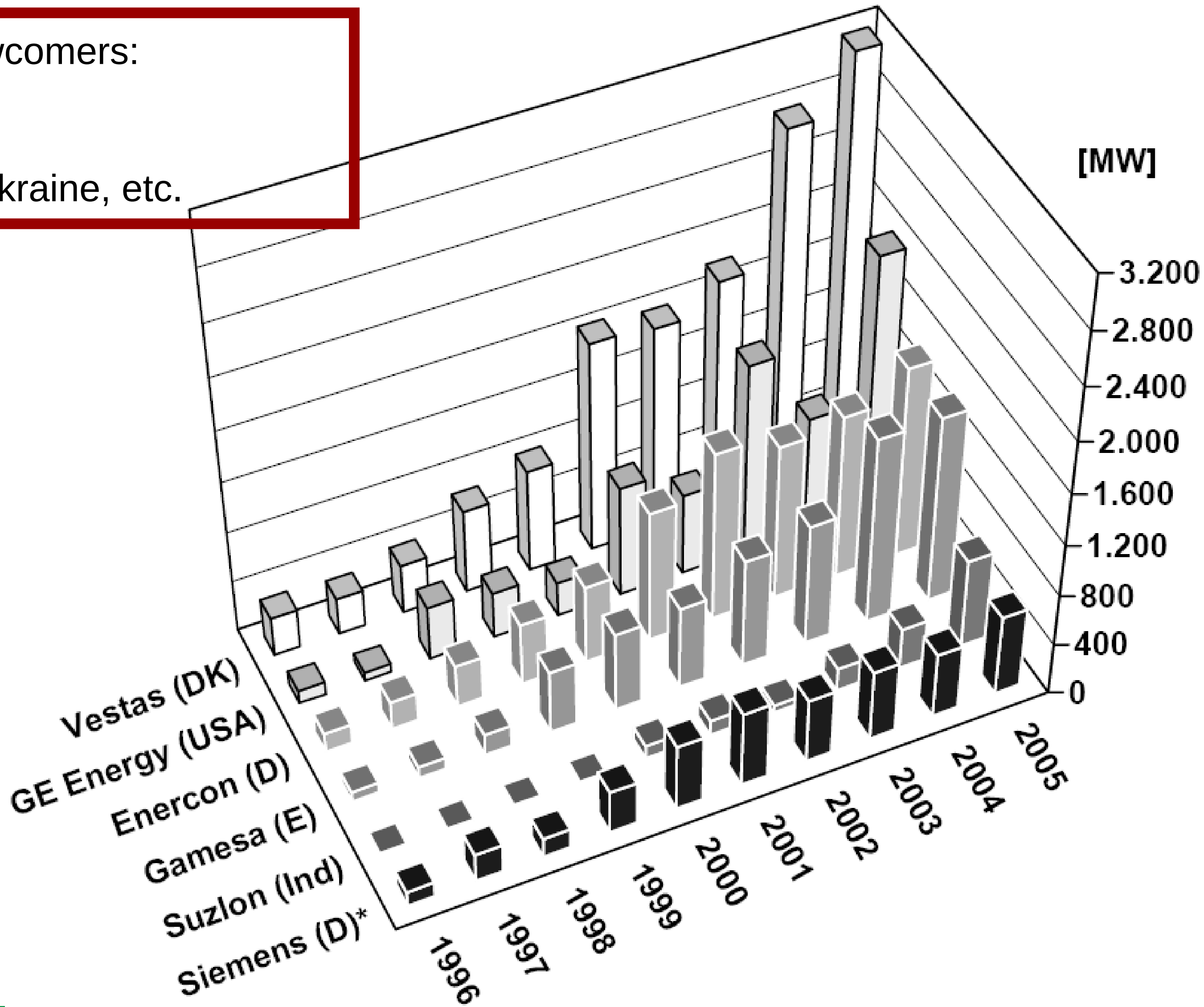
Tripod



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 <u>and</u> 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 PZl
  ./. „black power“ tariff (i.e. yearly average, ~3 €c/kW (128 PZl) 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 (11/2002 – 02/2003)

Source: BWEA

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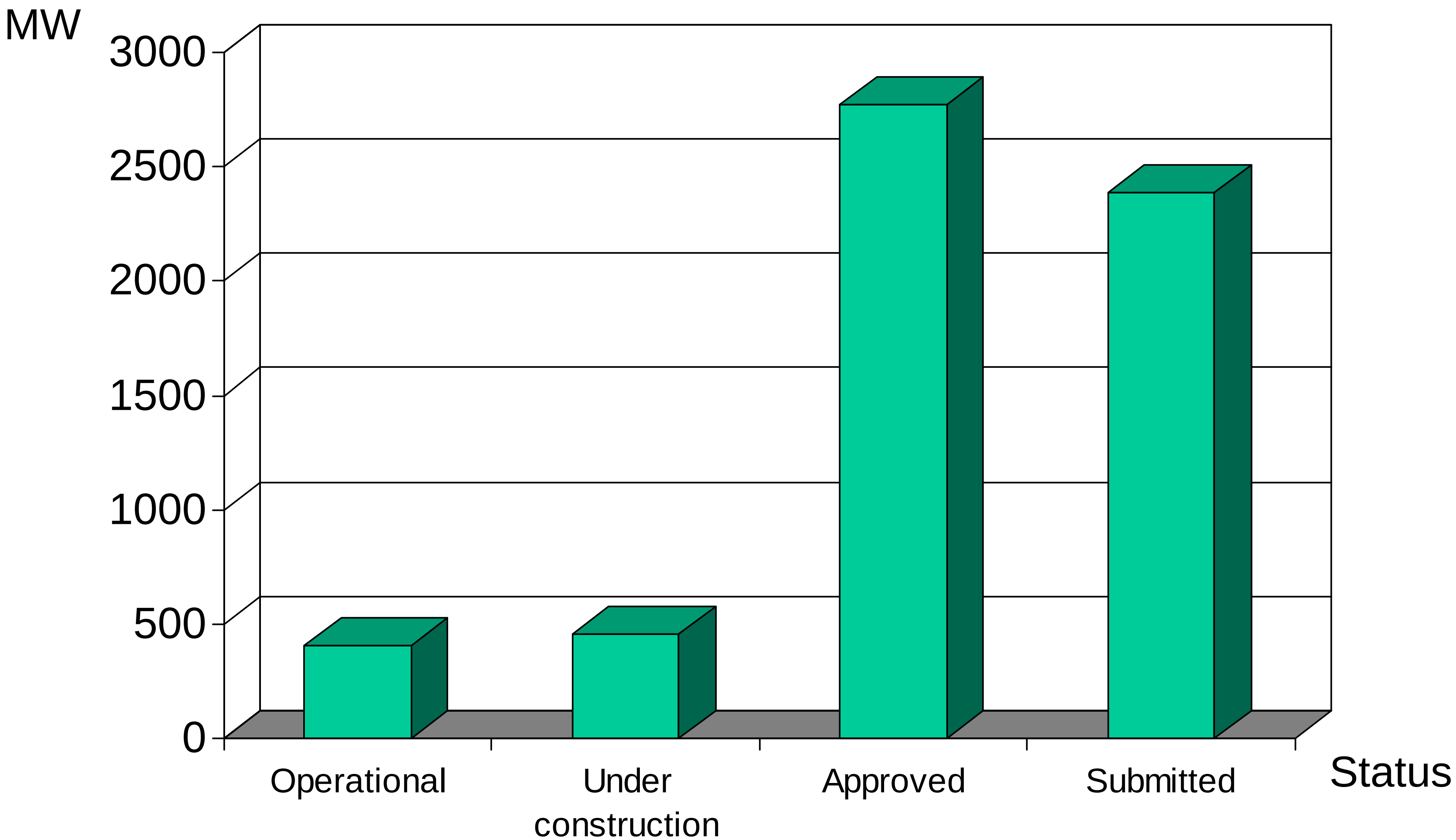
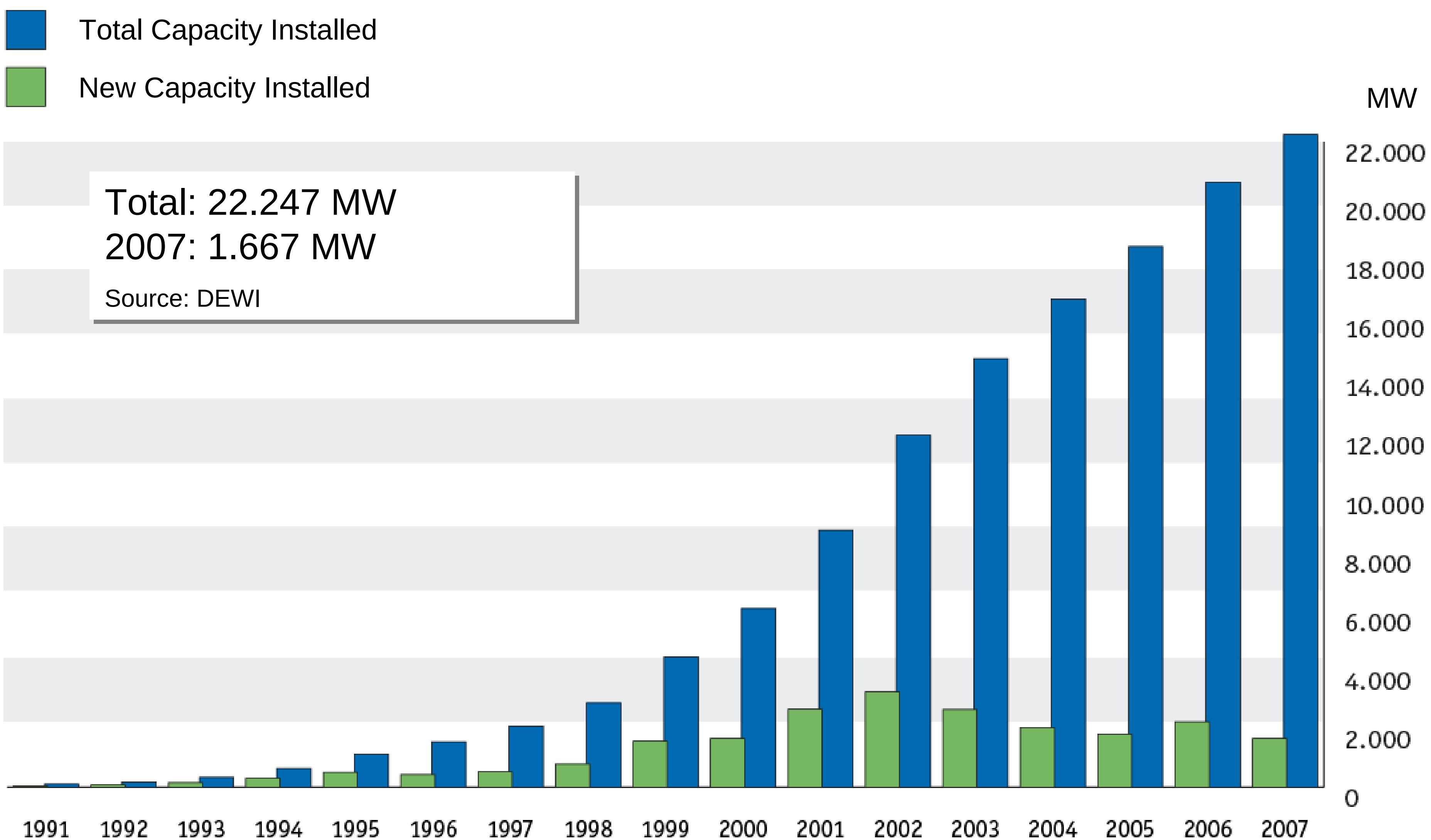
Offshore Wind Farms in the UK according to Status



Source: BWEA

Installed Wind Capacity in Germany



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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

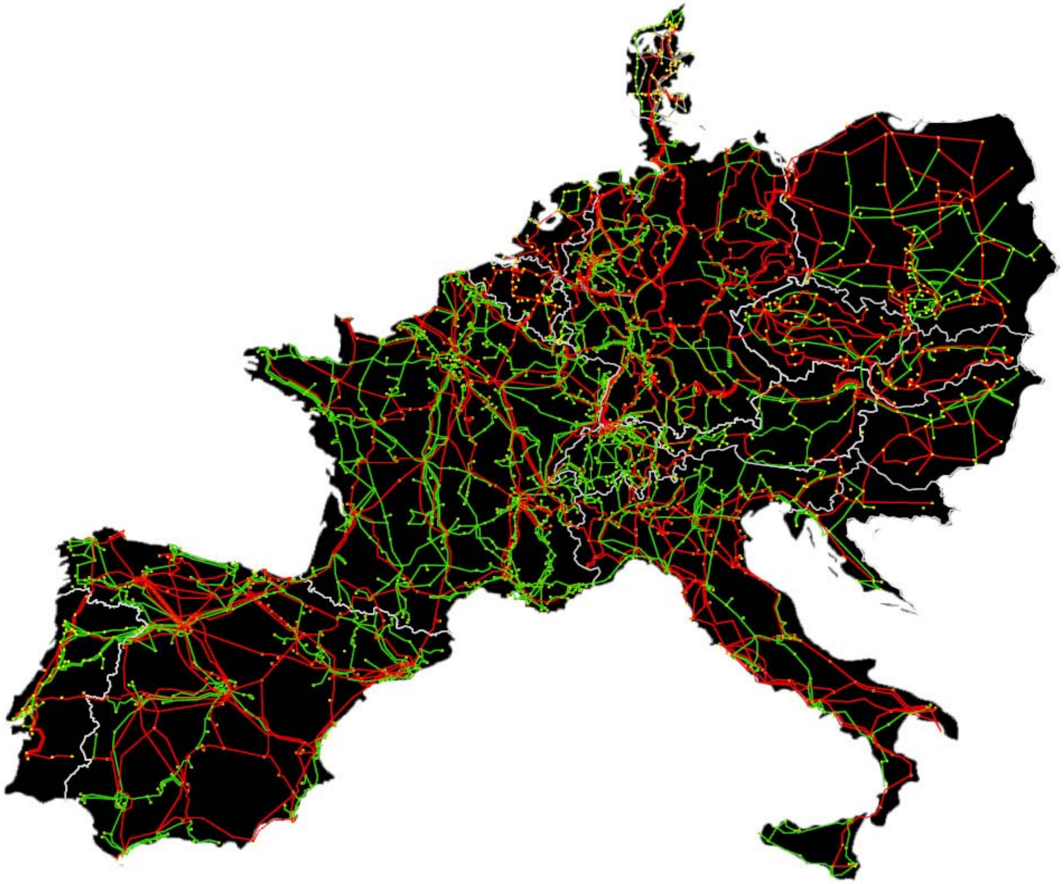
***Intersection OECD Europe + Poland/UCTE Europe/**linear interpolation. 2015 OECD Europe: 109 GW; 2030: 227 GW**

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

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

$$\max\left\{W=\sum_n\left[\int_0^{q_n^*}p(q_n)\boldsymbol{dq}_n-\int_0^{g_n^*}c(g_n)\boldsymbol{d}g_n\right]\right\}$$

Constraints

Power flow limit on the line i

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

Conservation of energy

g	generation
q	demand
L	losses

$$\sum_n g_n=\sum_n q_n+L$$

Limited **generation capacity** of power plants

t	per type of plant

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

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 ← ***higher*** | ***lower*** → **Stop**
Prior result is solution

Scenarios

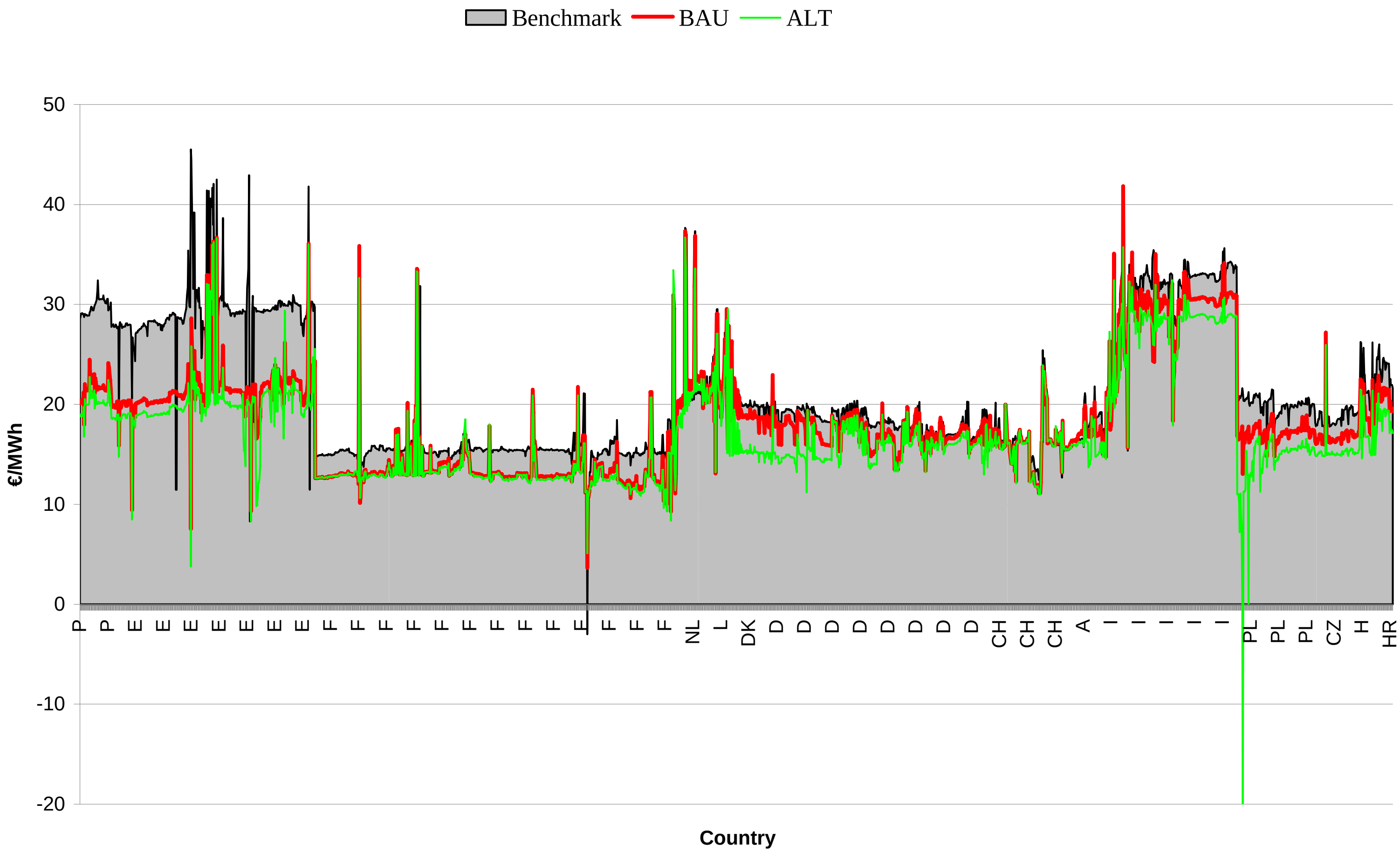
- **Scenarios**

Scenario	Installed Wind Capacities
Benchmark	44 GW
BAU (business-as-usual)	114 GW
ALT (alternative)	180 GW

- **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

Price Levels All Scenarios

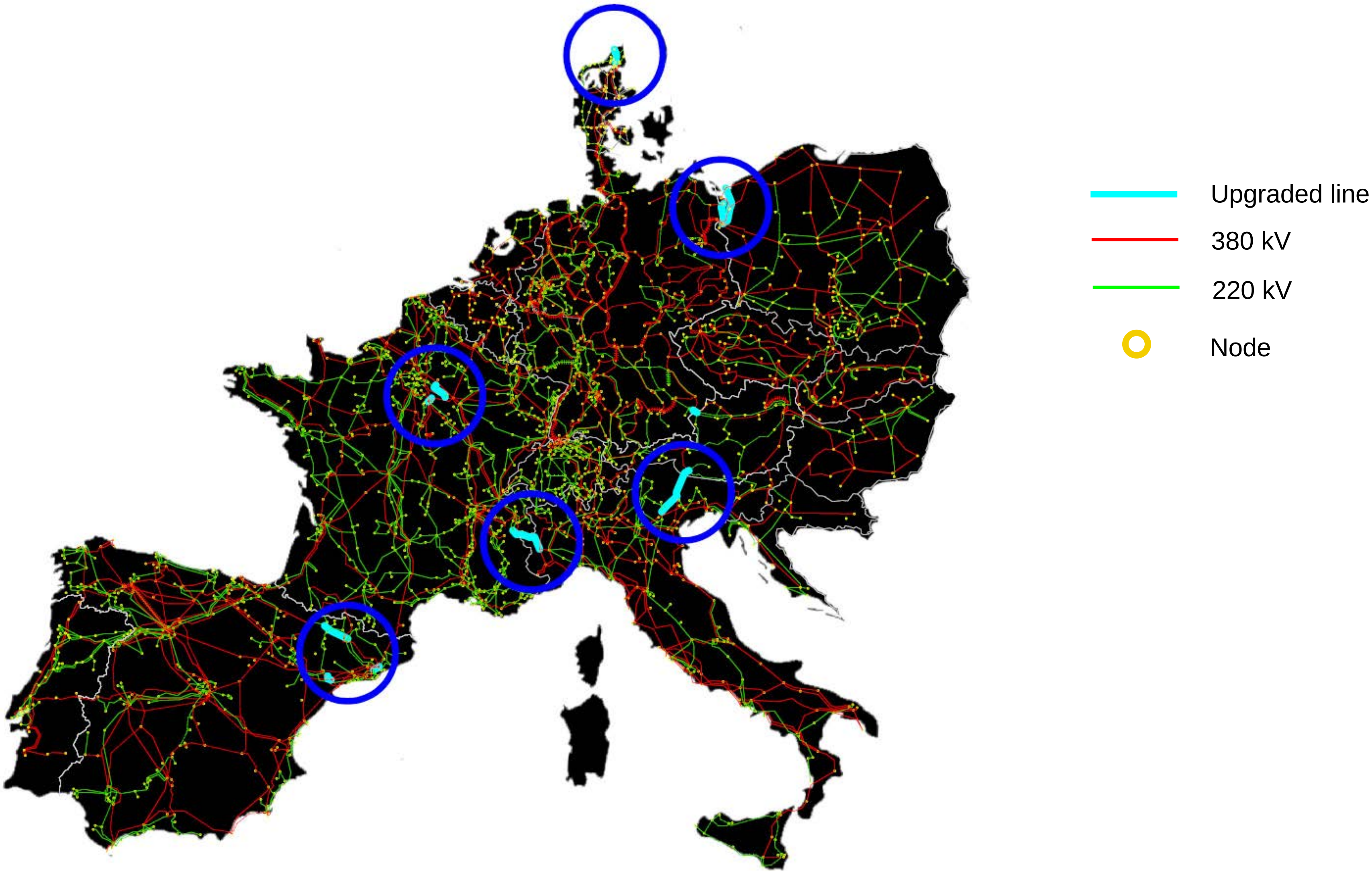
Price levels with grid extensions



→ 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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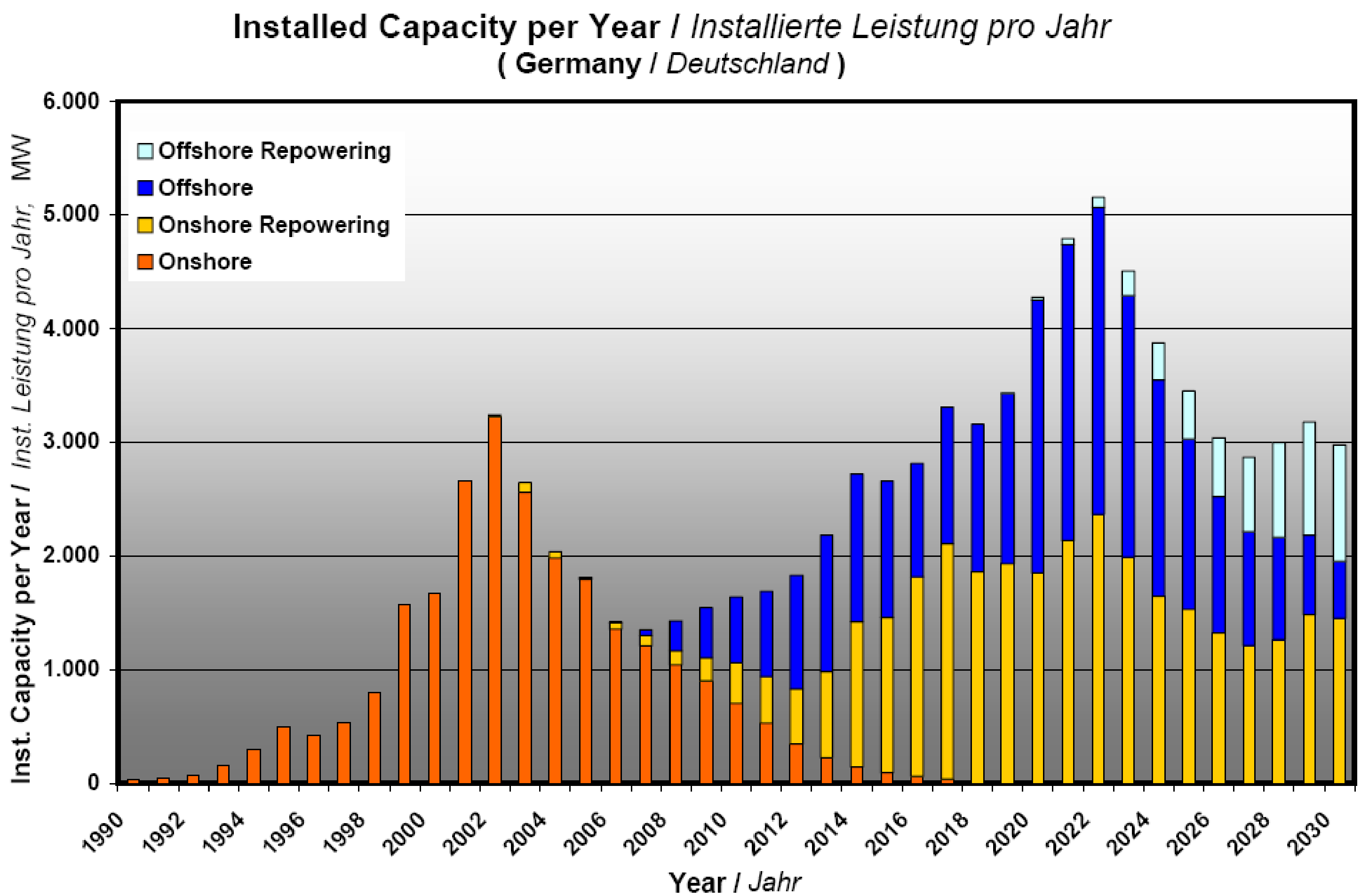
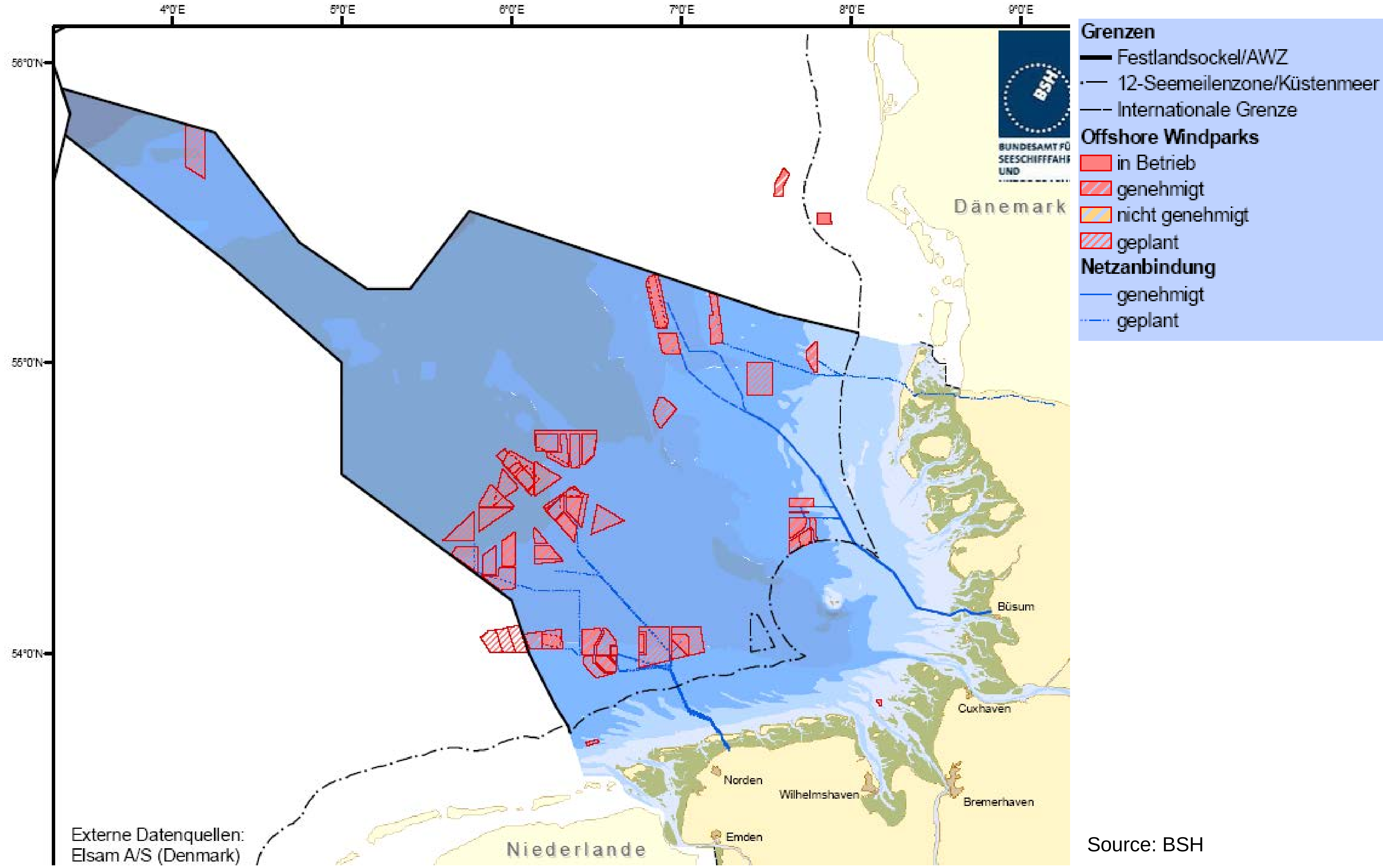
Wind – Potentials and Utilization



Source: DEWI

Offshore Wind Farms in the German North Sea



Source: BSH

Offshore Wind Farms in the German North Sea (2)

Windpark	Approved Capacity [MW]	No. of Turbines	Distance to coast or island [km]	Depth at site [m]	Area [km²]	Status
Alpha Ventus (B-West)	60	12	45	n.a.	n.a.	construction
Butendiek	240	80	34	20	37	approved
Borkum Riffgrund	231	77	34 / 38	23…29	35	approved
Borkum Riffgrund West	280	80	50	29…33	30	approved
Amrumbank West	Max. 400	80	35 / 36	20…25	32	approved
Nordsee Ost	Max. 400	80	30	22	50	approved
Sandbank 24	Max. 400	80	90	30	59	approved
ENOVA Offshore	Max. 216	48	39	29…35	28	approved
DanTysk	Max. 400	80	70	21…33	71	approved
Nördlicher Grund	Max. 400	80	84	21…33	55	approved
Global Tech I	Max. 400	80	93	39…41	41	approved
Hochsee Windpark Nordsee	Max. 400	80	90 / 100	n.a.	50	approved
Godewind	Max. 400	80	33 / 38	n.a	37	approved
BARD Offshore 1	Max. 400	80	89 / 126	n.a	58.9	approved
Meerwind Ost/Süd	Max. 2 x 200	2 x 40	24	n.a.	40	approved
He dreiht	Max. 400	80	85 / 152	37…43	40	approved

Source: BSH

Approved Offshore Wind Farm Grid Connections

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

Source: BSH

The Amendment of the Law on Renewable Energies (EEG, July 4, 2008)

	„Old version“ (2004)	Amendment
Onshore wind	8 c/kWh Reduction: -2%/a	9.2 c/kWh, for at least 5 years Reduction: -1%/a (after 2010) Re-Powering: bonus of 0.5-0. c/kWh Overall collar: 5,02 c/kWh
Offshore wind	10-12 c/kWh	13 c/kWh, + „sprinter bonus“ of 2 c/kWh until 2015 Reduction (after 2015): 5% Overall collar: 3.5 c/kWh
General provisions		Bonus for „system services“ of 0.5-0.7 c/kWh

+ 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

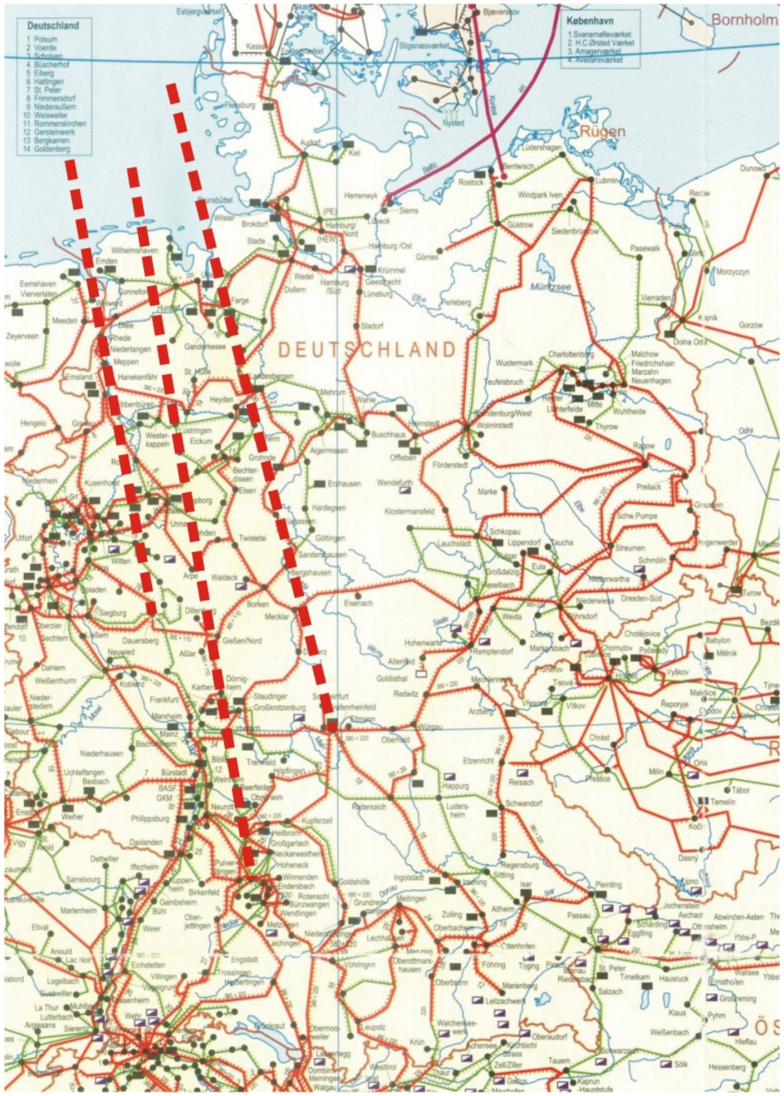
Alternatiave Scenario– Underground HVDC-Cable

- **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**

HVDC overlay grid

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)

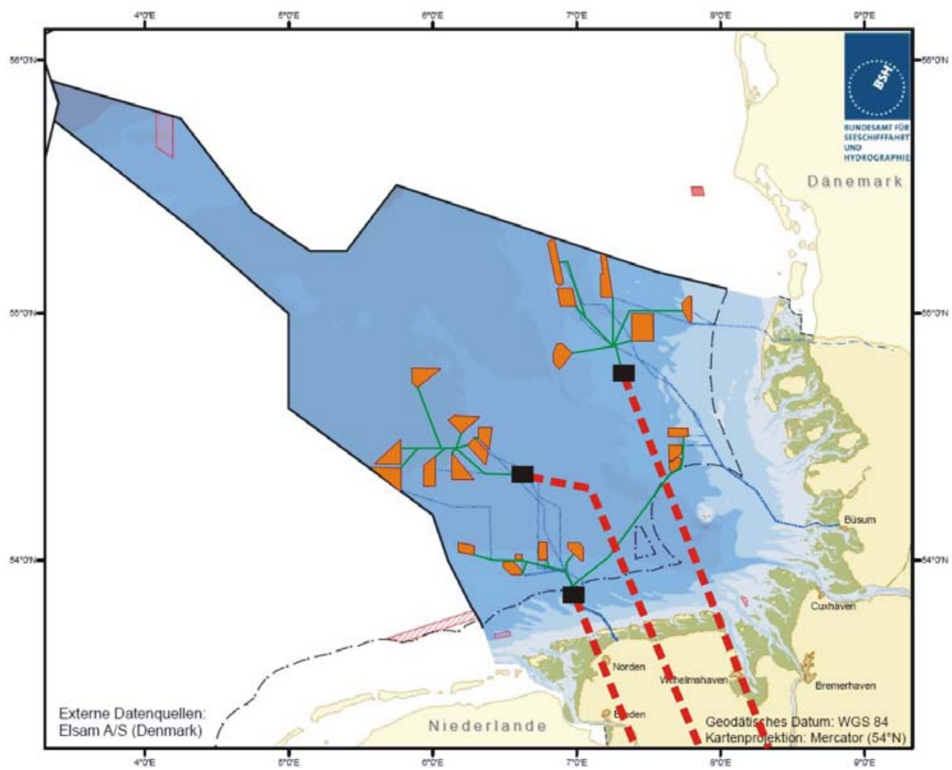
Low-section AC-cables connect each wind farm with a offshore converter station

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 €

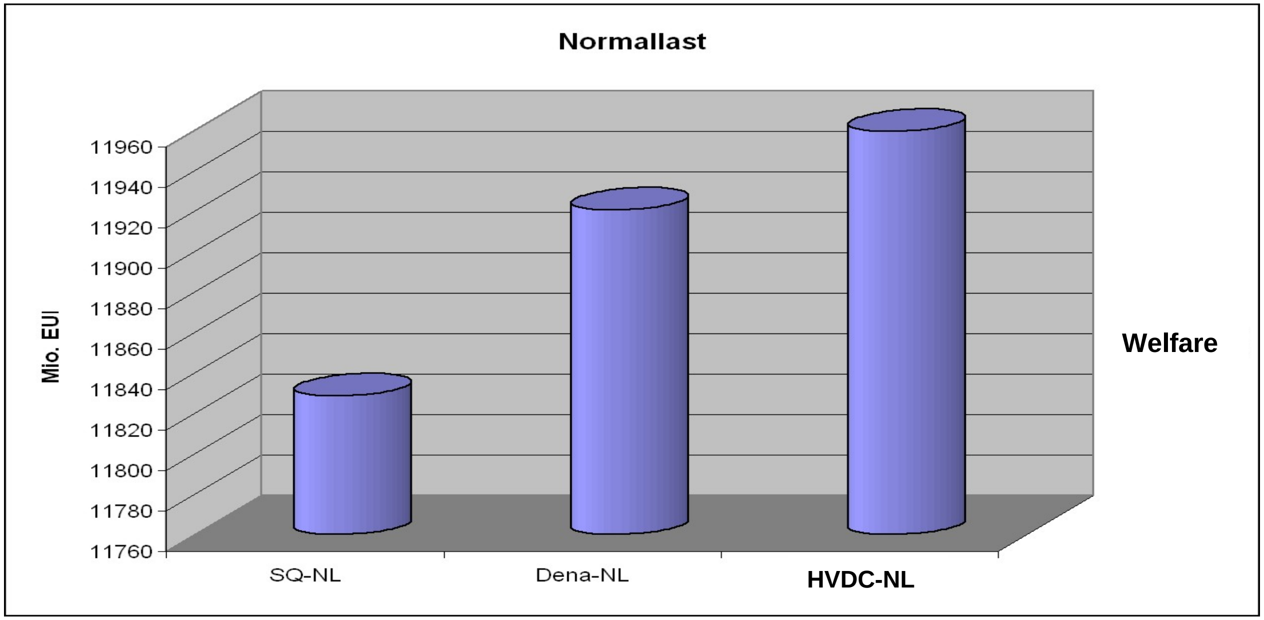
Investment costs OH-lines approx: 1,8 Billion €

Investment costs DENA-extension: 1,14 Billion €

*****Rudervall's numbers do not comply with publicated investment costs of 3GC/GG projects, for those could be realized much cheaper, so calculating with Rudevall'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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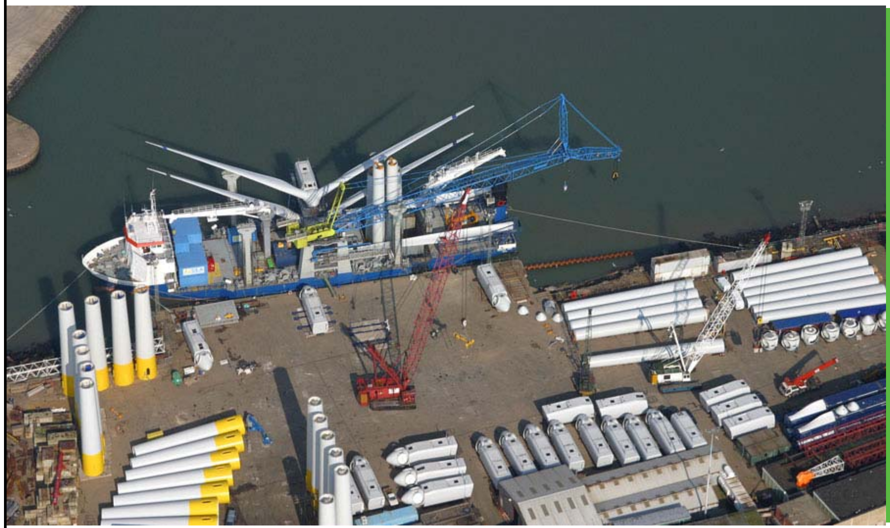

Thank you very much for your attention!

cvh@mailbox.tu-dresden.de

Chair of Energy Economics and Public Sector Management