European Wind Integration Experience

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Outline

- Introduction: Danish & German Wind Development
- Q: System Balancing Reserves;
- Q: Wind Forecasting
- Q: Capacity value
- Q: Strategies -> Minimizing Cost
- Q &A

Network Perspective

	Germany	Denmark (W+E)	Spain	Ireland
Peak Demand 2004 [GW]	77.2	**3.7+2.6=6.3**	38.2	**4.5**
Minimum Demand 2004 [GW]	38	**1.2+0.9=2.1**	15.3	**1.65**
Wind Power Capacity 2004 [GW]	16.6	**2.4+0.7=3.1**	8.3	**0.3**
Max Penetration (Wind/Minimum Demand)	**44 %**	**W: 200 %** **E: 77 %**	**54,2 %**	**18,2%**
Interconnection transfer capability 2005 [GW]	16.6	**2.7+2.4 =5.1**	1.8-2.8	0.5
Max Penetration with Interconnection (Wind/Min. D+Inter.)	**30 %**	**W: 61,5 %** **E: 21,2%**	**45 to 48 %**	**14 %**

Areas With Highest Wind Share

Country/ Region	Installed Wind Capacity (2002)	Total Installed Power Capacity	Average Annual Penetration Level	Peak Penetration Level
Western Denmark:[3]	2,315 MW	7,018 MW	~ 18 %	**> 100 %**
Thy Mors	~ 40 MW	Part of the Western Danish System	>50 %	**~ 300 %**
Germany:	12,000 MW	119,500 MW	~ 5 %	
Schleswig Holstein	1,800 MW	Part of the German System	~ 28 %	**> 100 %**
Papenburg	611 MW	Part of the German System	~ 55 %	**> 100 %**
Spain:	5,050 MW	53,300 MW	~ 5 %	
Navarra	550 MW	Part of the Spanish System	~ 50 %	**> 100 %**
Island Systems:				
Swedish Island of Gotland	90 MW	No Local Generation in normal state	~ 22 %	**> 100 %**
Creak Island of Crete	70 MW	640 MW	~ 10 %	N. A.
Wind-Diesel System Denham, Australia	690 kW	2,410 kW	~ 50 %	**~ 70 %**

Wind Energy Targets

	Germany	Denmark (W+E)	Spain	Ireland
Targets GW [Year]	50.3 [2020]	**3.6+1.2 [2020]**	13.0 [2011]	1.0 [2010]
Max. Penetration Level with Constant Interconnection Capacity	92 %	**W: 92 % E: 36 %**	75 %	46 %
For Comparision today's max. penetration level with Intercon. Cap.	30 %	**W: 61,5 % E: 21,2 %**	45 to 48 %	14 %

Denmark

Regulatory Background

- Fixed Feed in Tariff: Utilities have to pay! (and connect if possible)
- Wind power and (small CHP) priority production
- TSO Balance Responsible

Eltra/Energinet.dk Transmission System Operator in (Western) Denmark

- Responsible for:

  Planning, operation and maintenance of the primary grid.

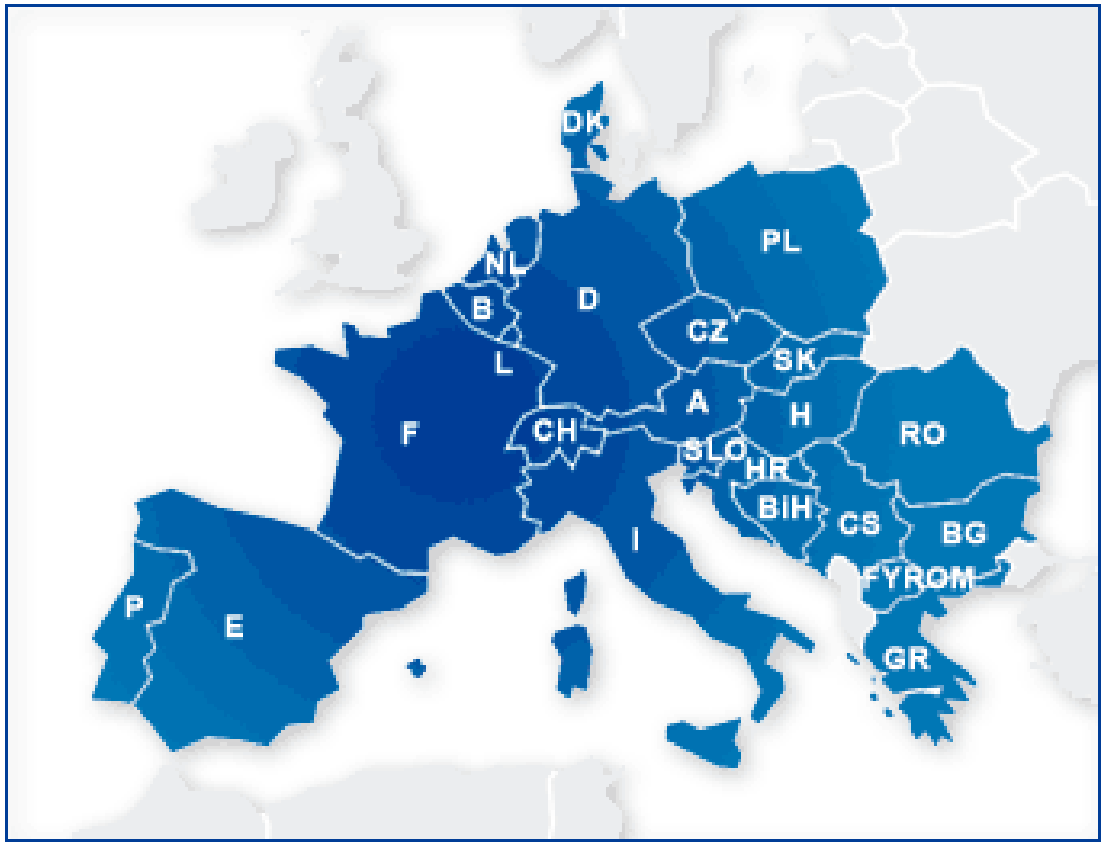
  Maintaining the physical balance in the system and creating equal conditions for all balance responsible market players

  Co-operation between neighbouring system operators.

  Handling of priority production, including – priority wind turbines.

  Settlement of market players.

Eltra - part of the European transmission system -



The surroundings of the Western Danish Power System

DK West is a regular transit area with large interconnections to the neighbouring areas:

Norway (HVDC ”Skagerrak”):
Capacity, import: 1,000 MW
Capacity, export: 950 MW

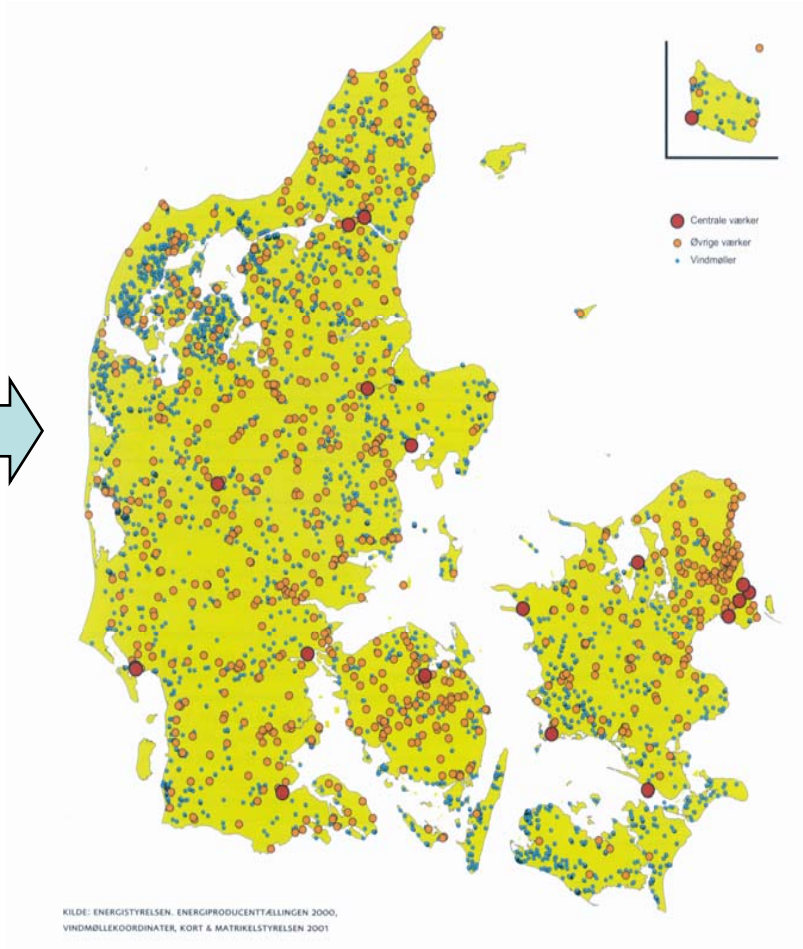
Sweden (HVDC ”KontiSkan”):
Capacity, import: 460 MW
Capacity, export: 490 MW

Germany (AC):
Capacity, import: 800 MW
Capacity, export: 1,200 MW

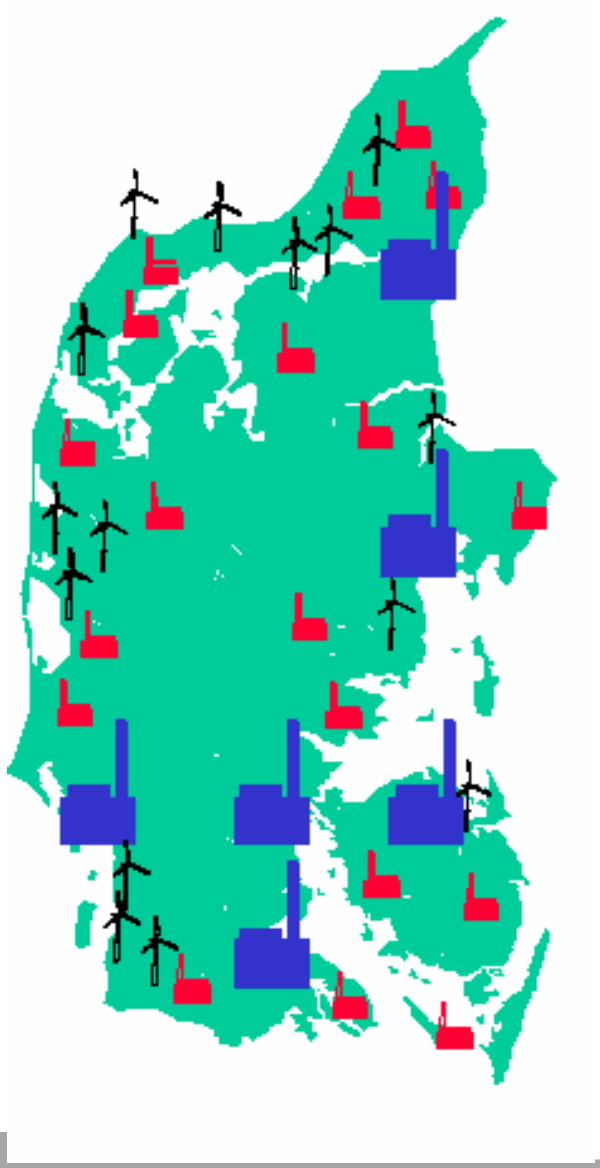
Development from the 1980s to the 1990s

Primary generation

Local generation

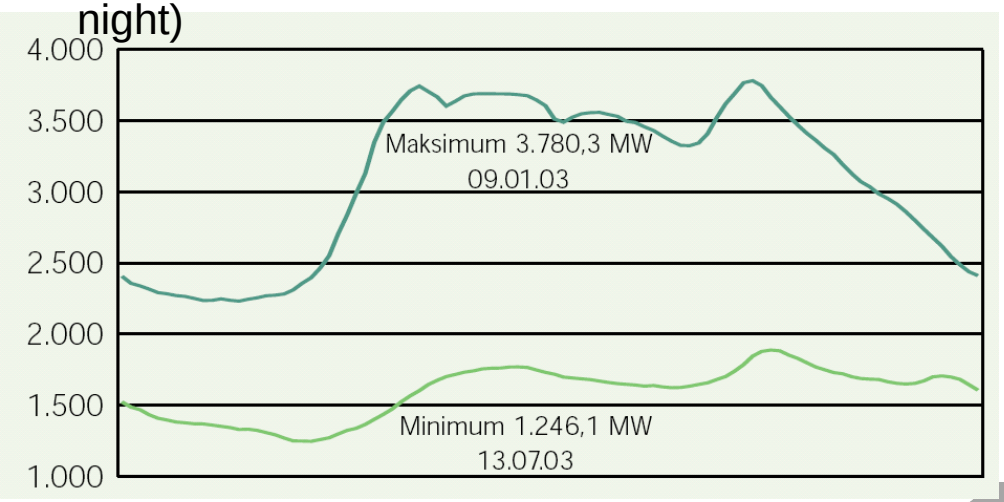


The Western Danish Power System

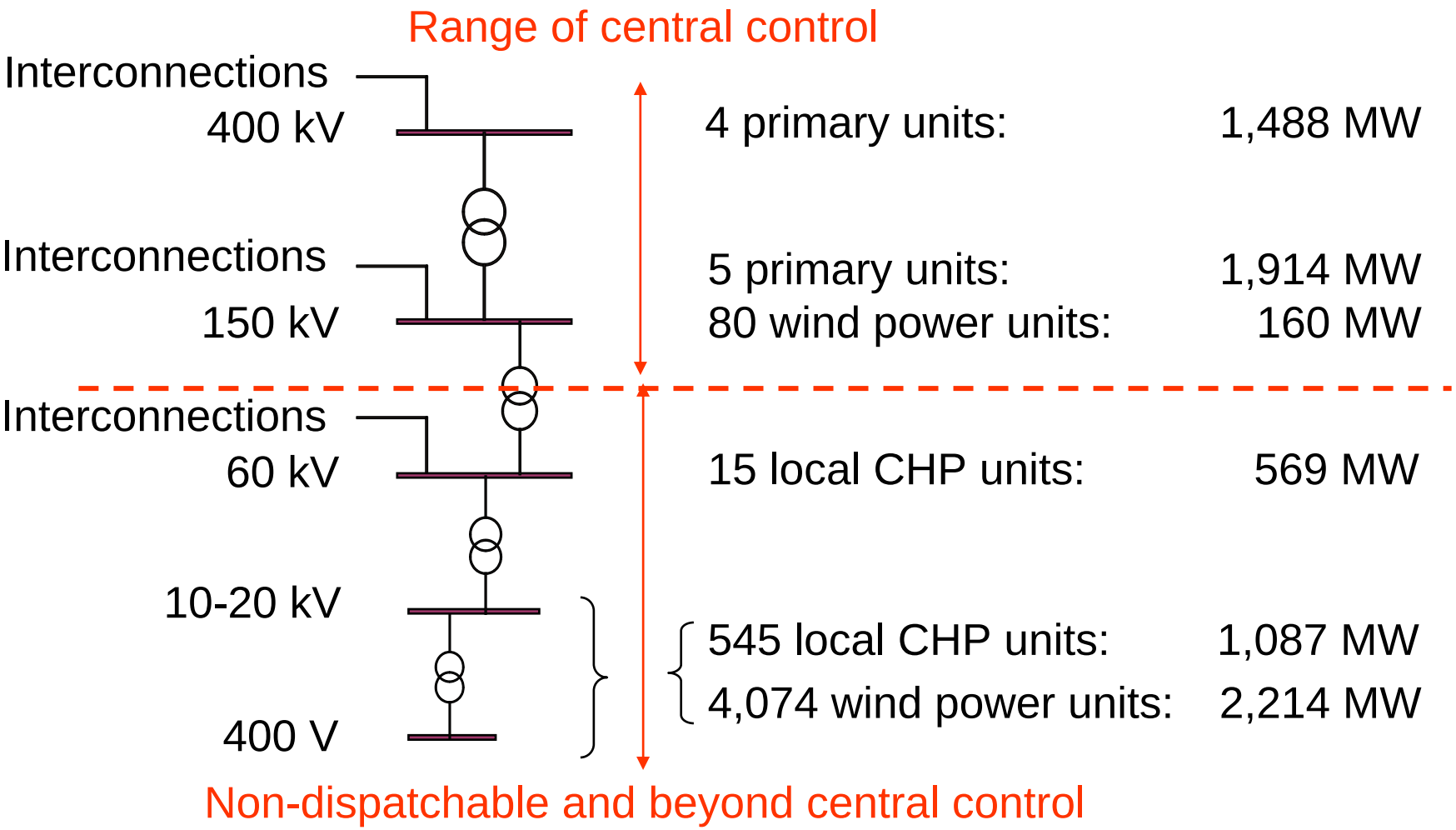


Total production capacity	**7,457**	**MW**
11 Central power plants	3,516	MW
560 Combined Heat and Power plants	1,567	MW
4,156 Wind turbines	2,374	MW

Load:
- maximum 3,800 MW (winter midweek day)
- minimum 1.150 MW (summer weekend night)



Distribution of Production Capacity

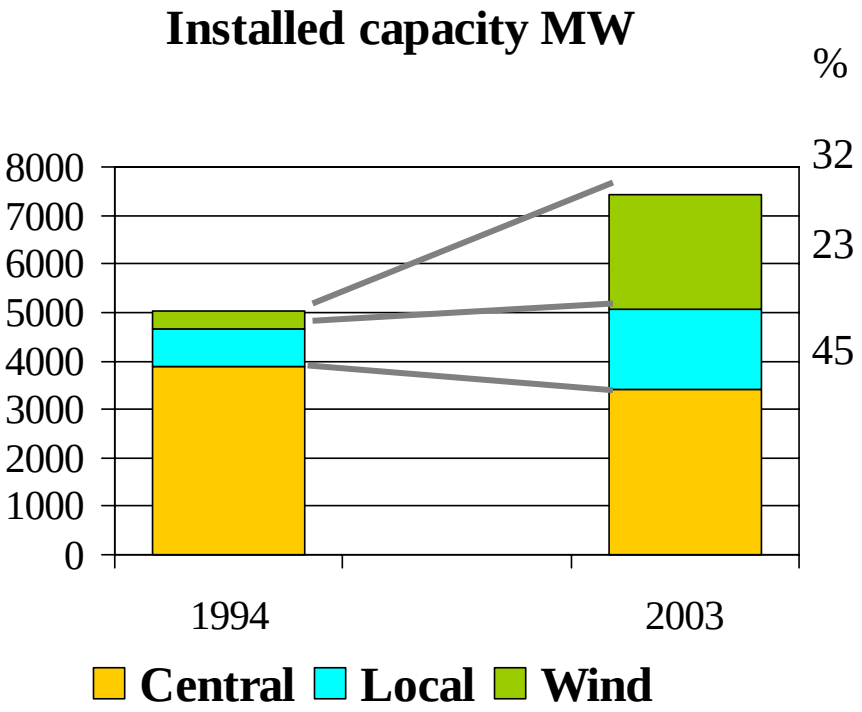


Historical Key Figures

	1998	1999	2000	2001	2002	2003
Consumption TWh	20.4	20.5	20.7	20.9	20.9	21.0
Production TWh	24.9	22.6	21.0	23.1	23.5	27.4
CHP TWh	6.2	6.4	6.2	6.8	6.7	6.8
Wind power TWh	2.1	2.4	3.4	3.4	3.8	4.4
Wind power in % of consumption	10.3 %	11.7 %	16.4 %	16.3 %	18.2 %	21.0 %
Exchange TWh	- 4.5	- 2.1	- 0.3	- 2.2	- 2.6	- 6.3

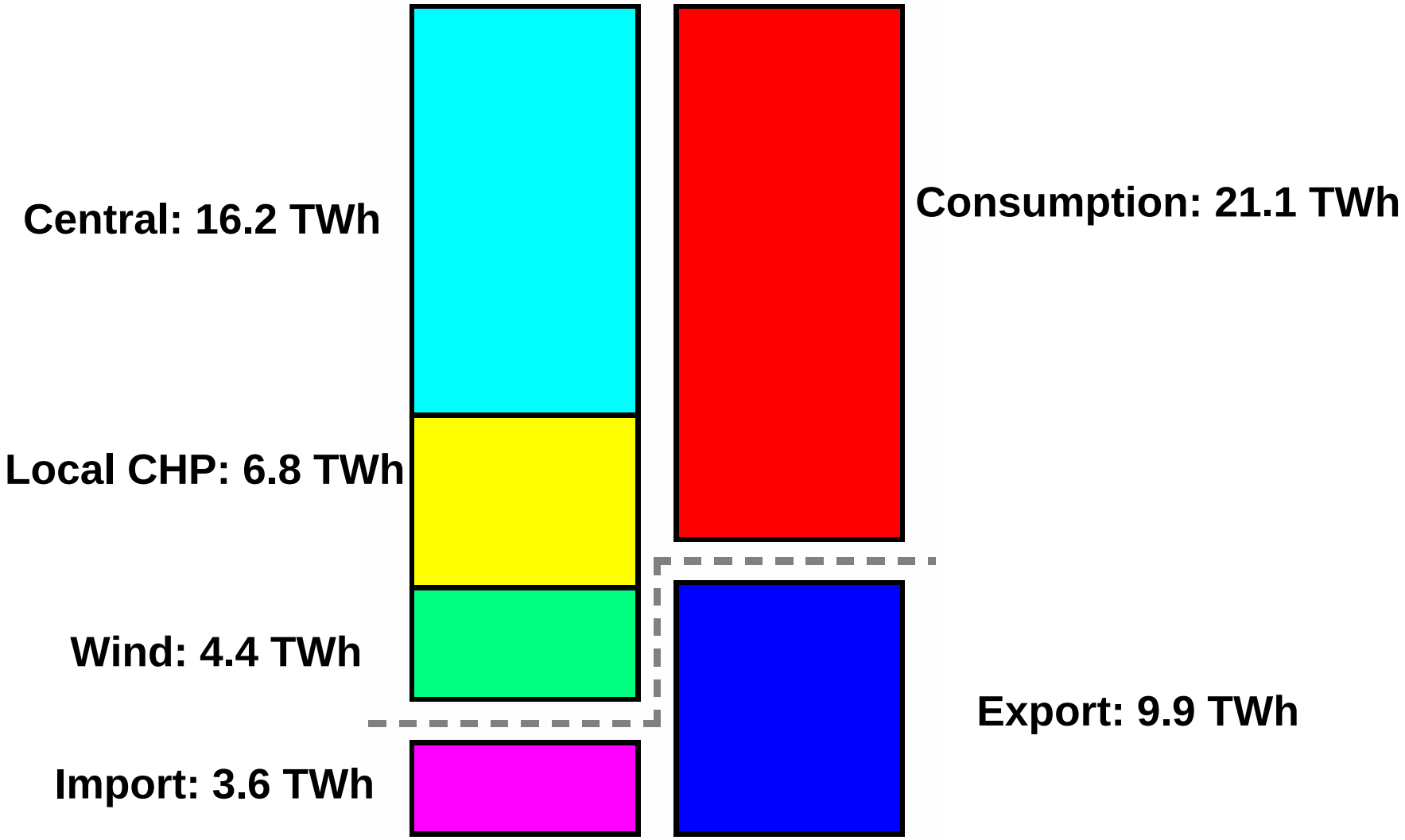
A Complete Change

- More than 50 % local installed capacity
  - Prioritized
  - Installed in local grids
  - Beyond normal regulation
- 21 % wind energy
  - Wind power exceeding system load in several cases



It was not planned exactly that way

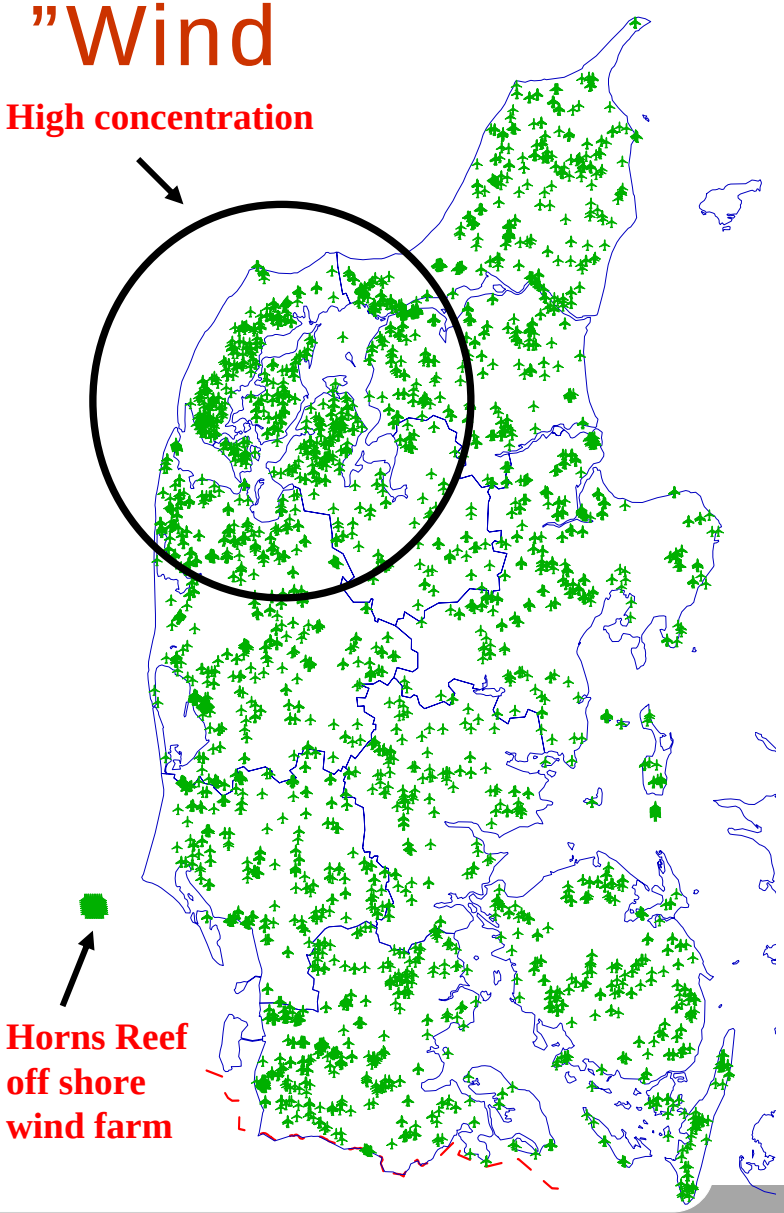
Balance 2003



The Western Danish ”Wind Power Carpet”

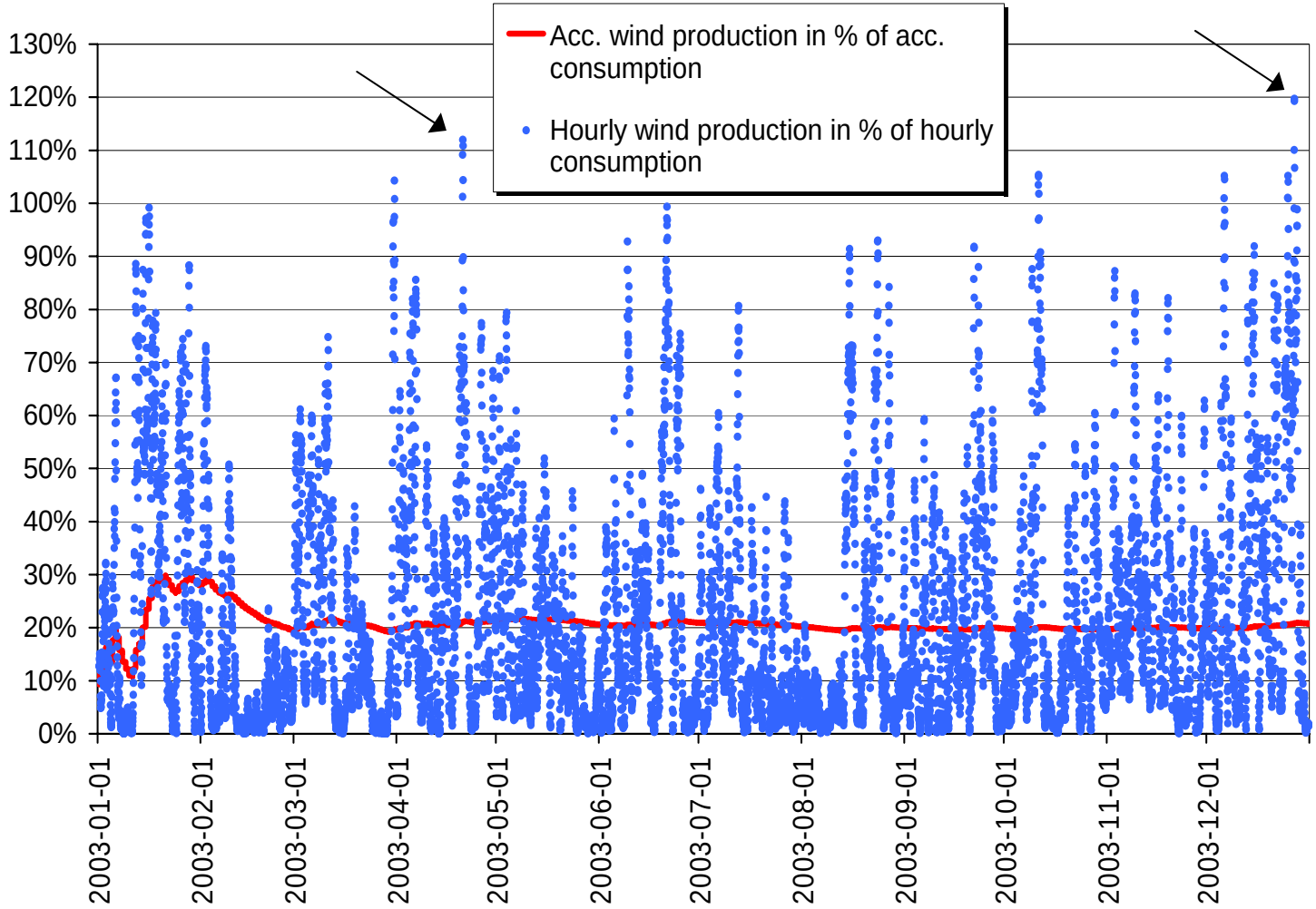
By March 1st, 2004:

- **4,175 wind turbines: 2,374 MW**
- **Average size of wind turbines: approx. 570 kW**
- **Average rotor diameter: approx. 40 meters**
- **Average hub height:**
- **approx. 40,5 meters**
- **75 per cent of the installed wind capacity in Denmark.**

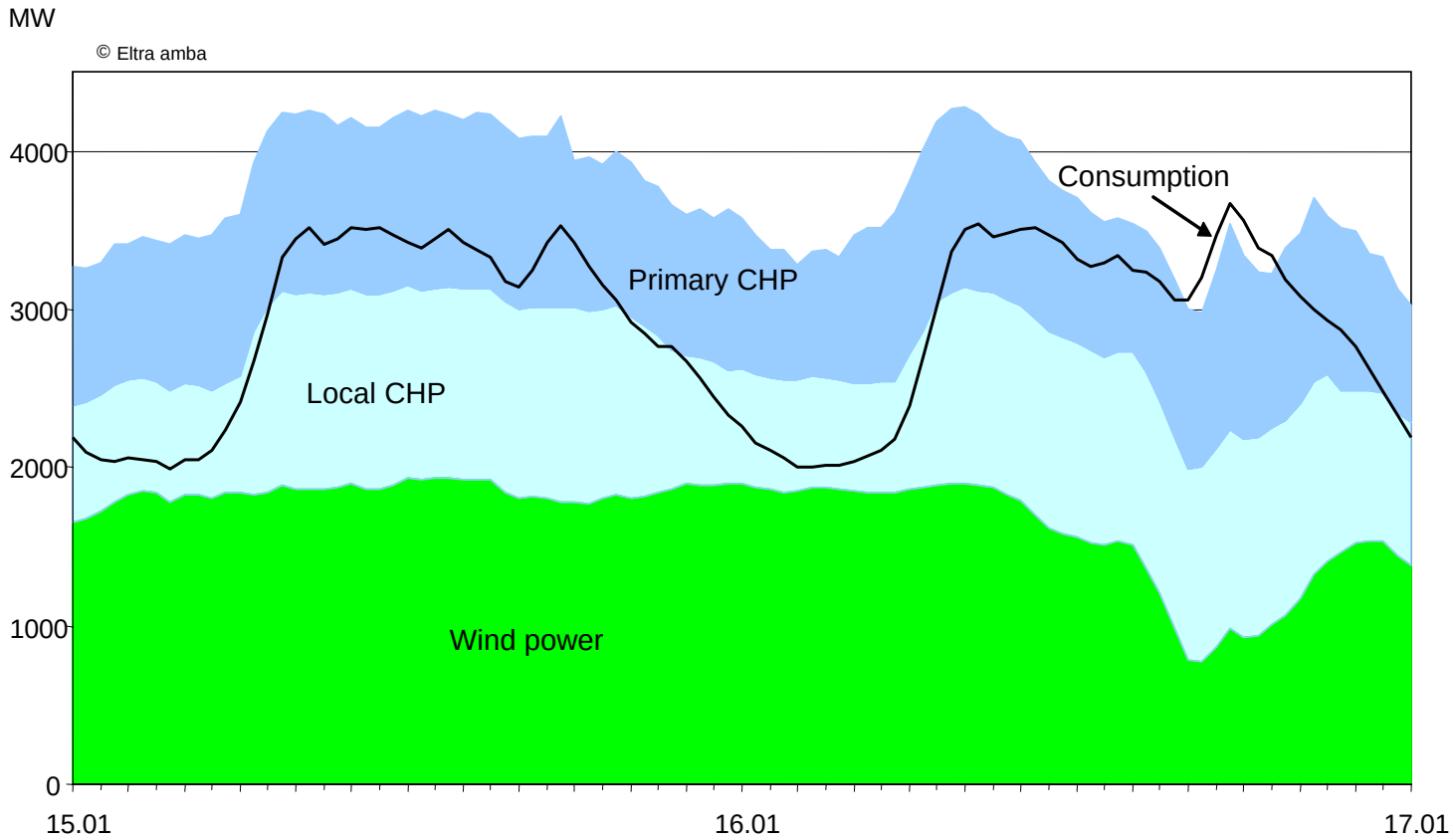


Wind Power Year 2003

(2004 max: 120 %)



Production and Consumption
Two days in January, 2003



Germany

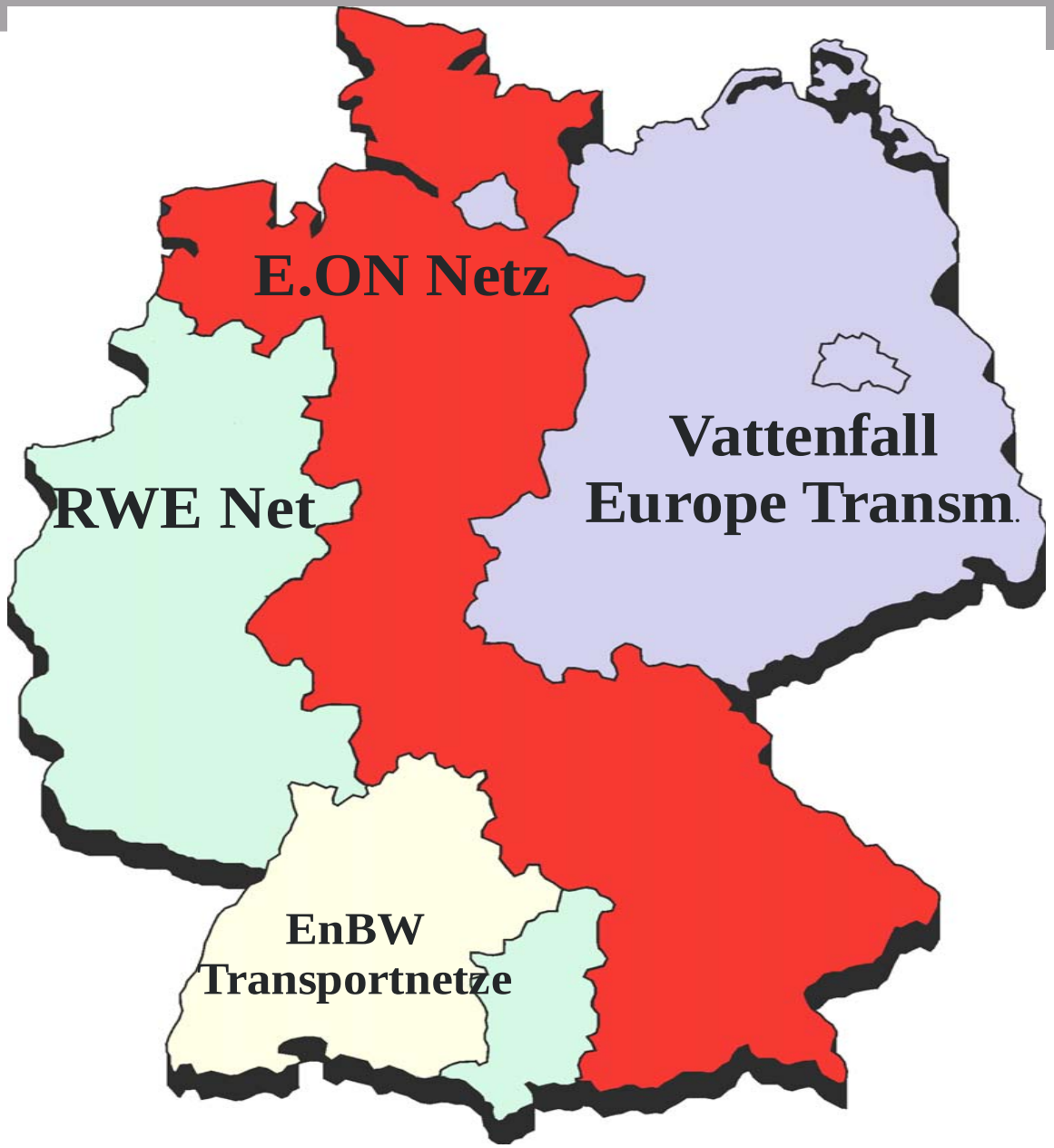
Feed-in Tariff (Germany)

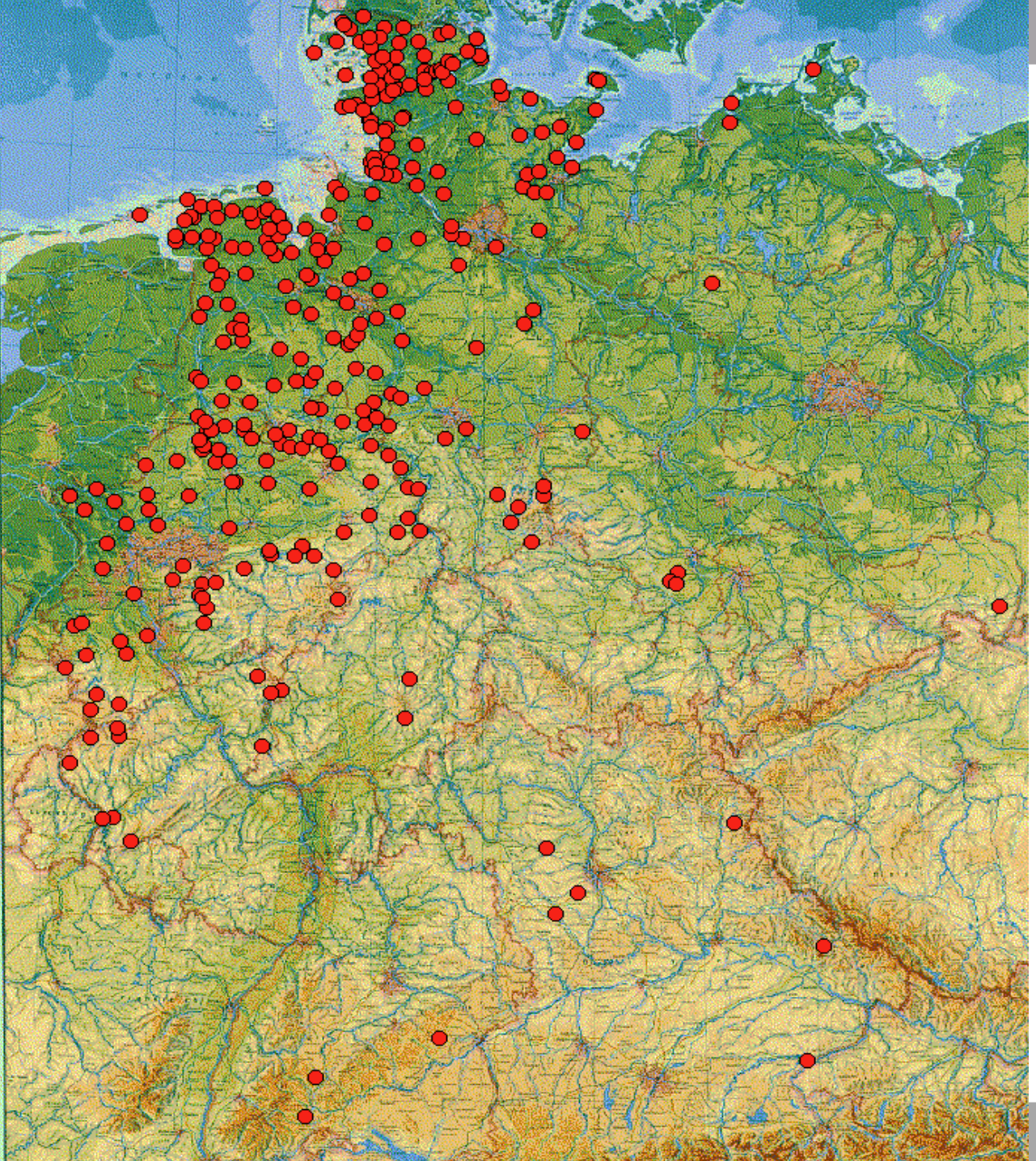
Fixed Tariff: ~ 7 - 8 €cent / kWh, depends on location

- Utilities have to pay! (and connect if possible)
- Turbine prices up to 40 % higher than in competitive markets

Pool Price:	3 - 4.5 €cent/ kWh
Wind Costs:	~ 5 - 6 €cent/KWh (6 – 7 m/s)

- 4 TSO's
- Day-ahead market
- No regulation market yet (in work)
- Wind power: priority production – TSO's balance responsible
- Curtailment allowed in extreme situations

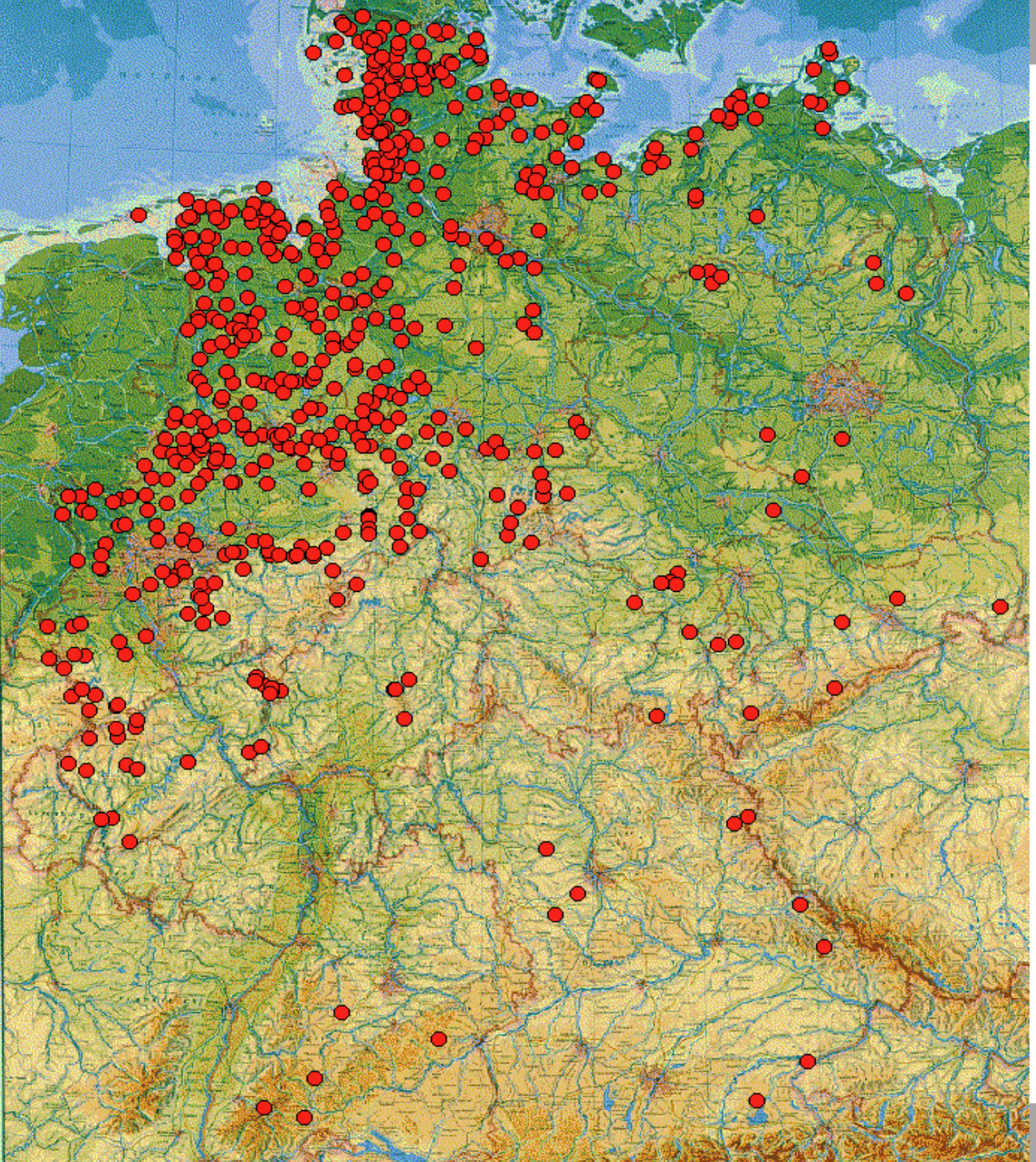




● Wind Turbine/
Wind Farm Sites

The German „Wind Power Plant“

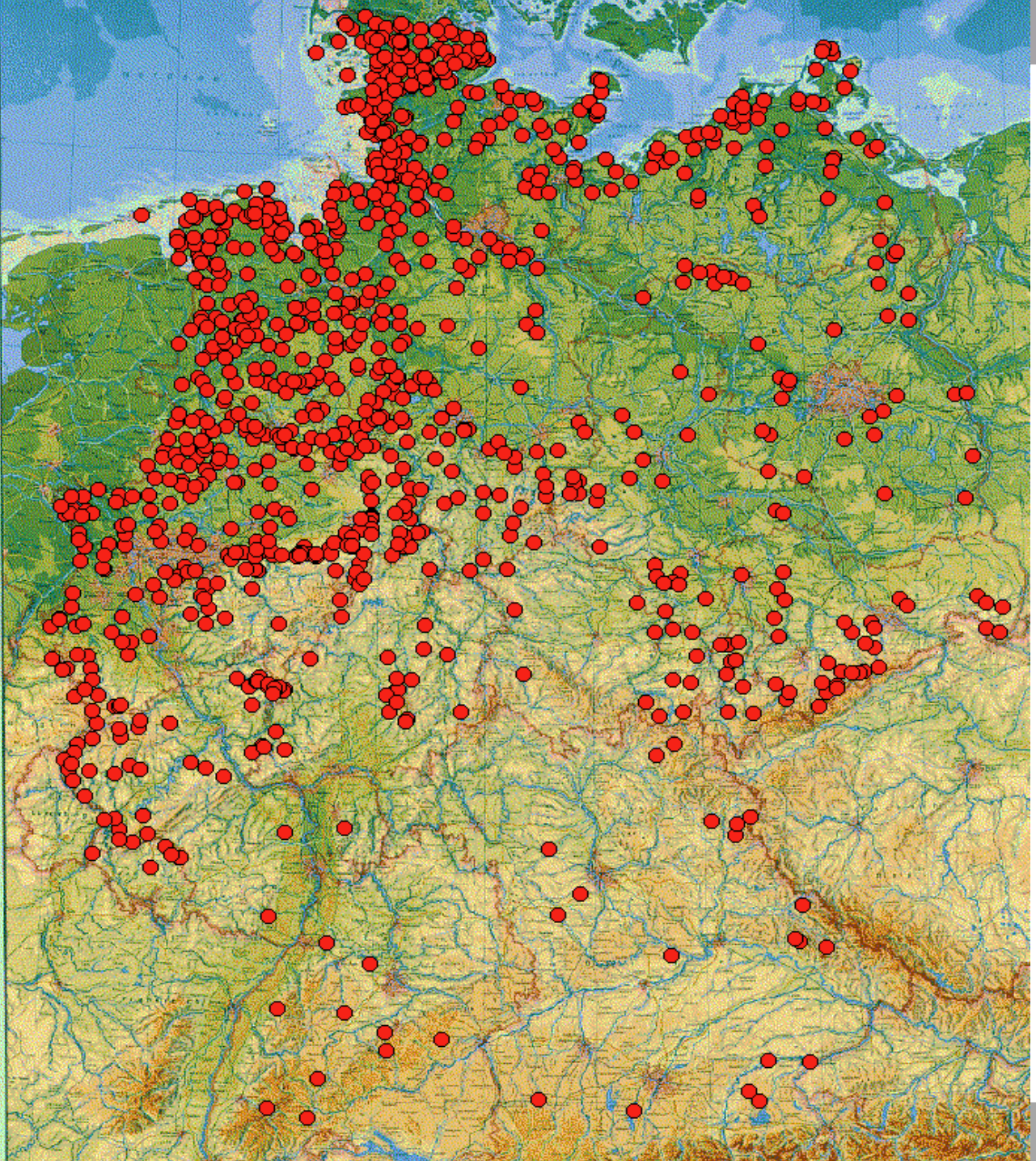
1991



● Wind Turbine/
Wind Farm Sites

The German
„Wind Power Plant“

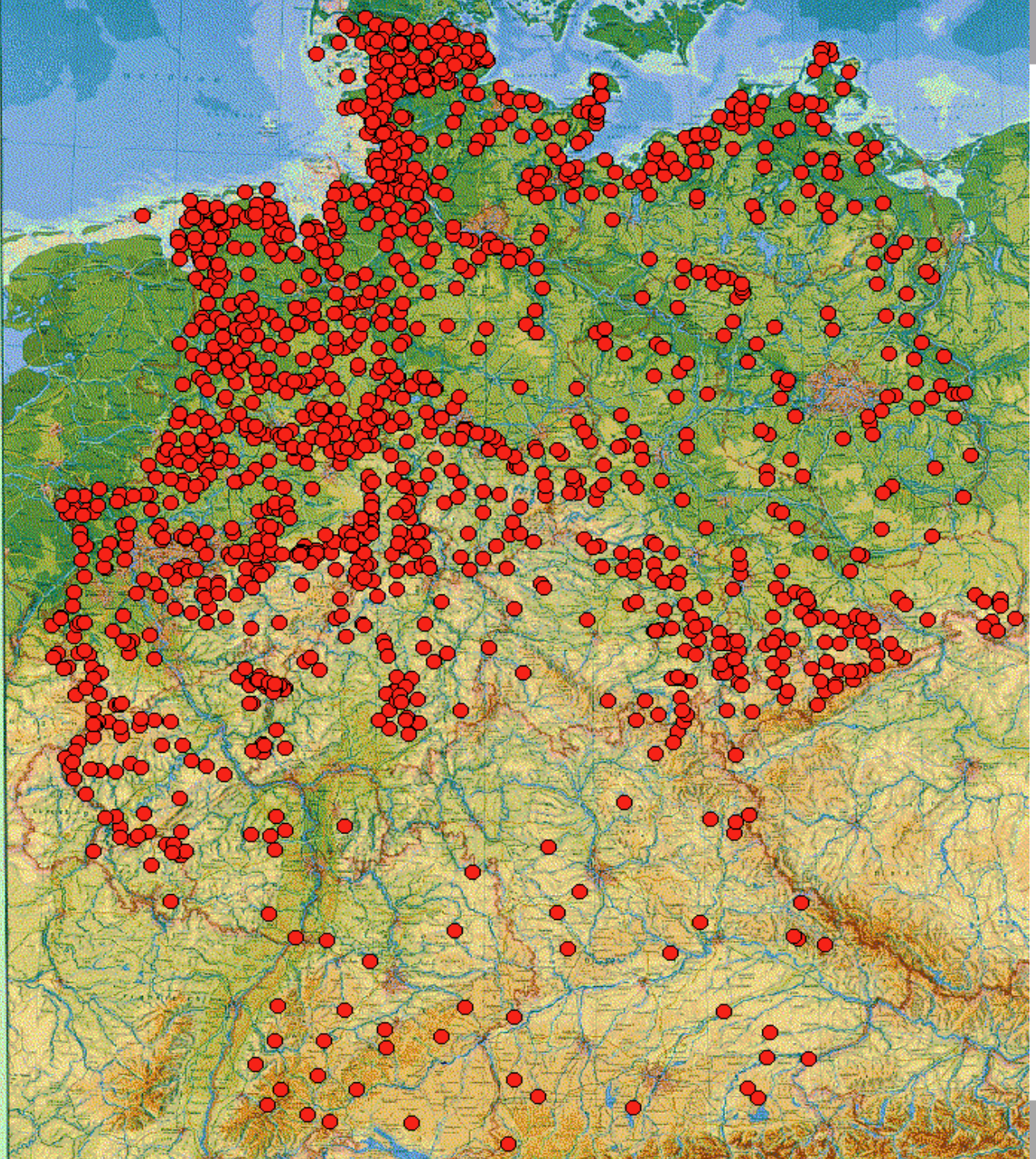
1993



● Wind Turbine/
Wind Farm Sites

The German
„Wind Power Plant“

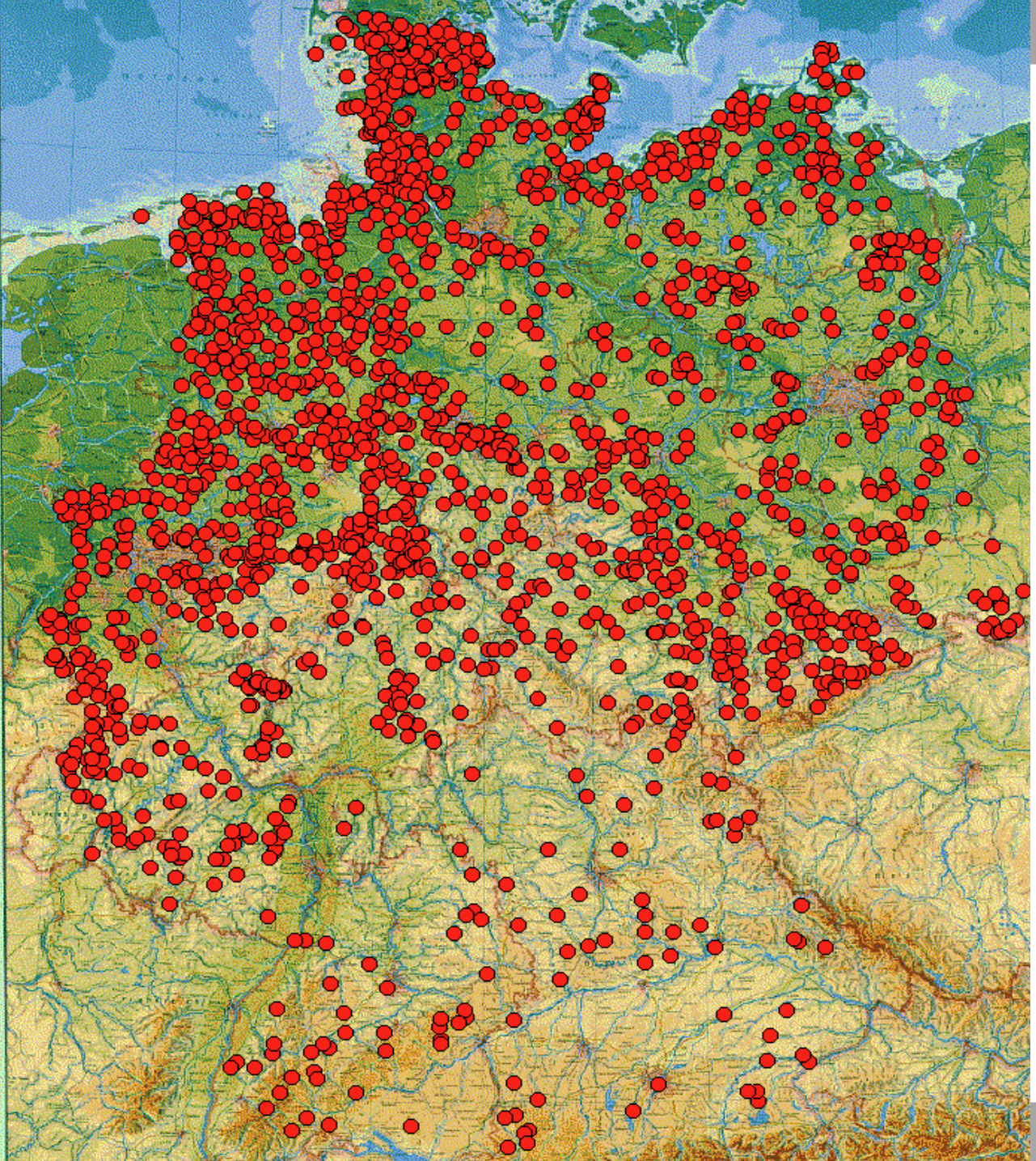
1995



● Wind Turbine/
Wind Farm Sites

The German „Wind Power Plant“

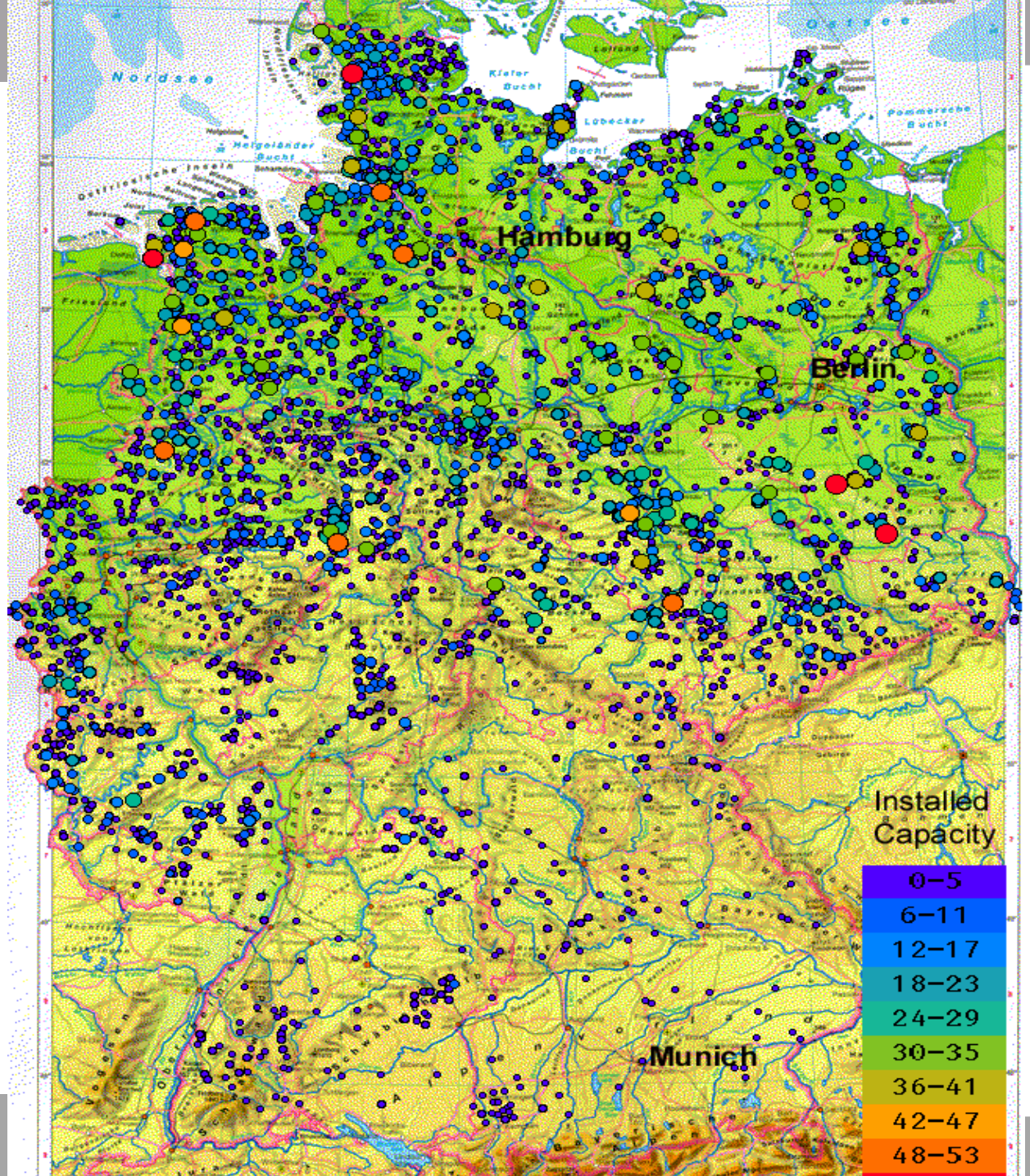
1997



● Wind Turbine/
Wind Farm Sites

The German „Wind Power Plant“

09/2000



The German „Wind Power Plant“

End 2003

~14,000 MW

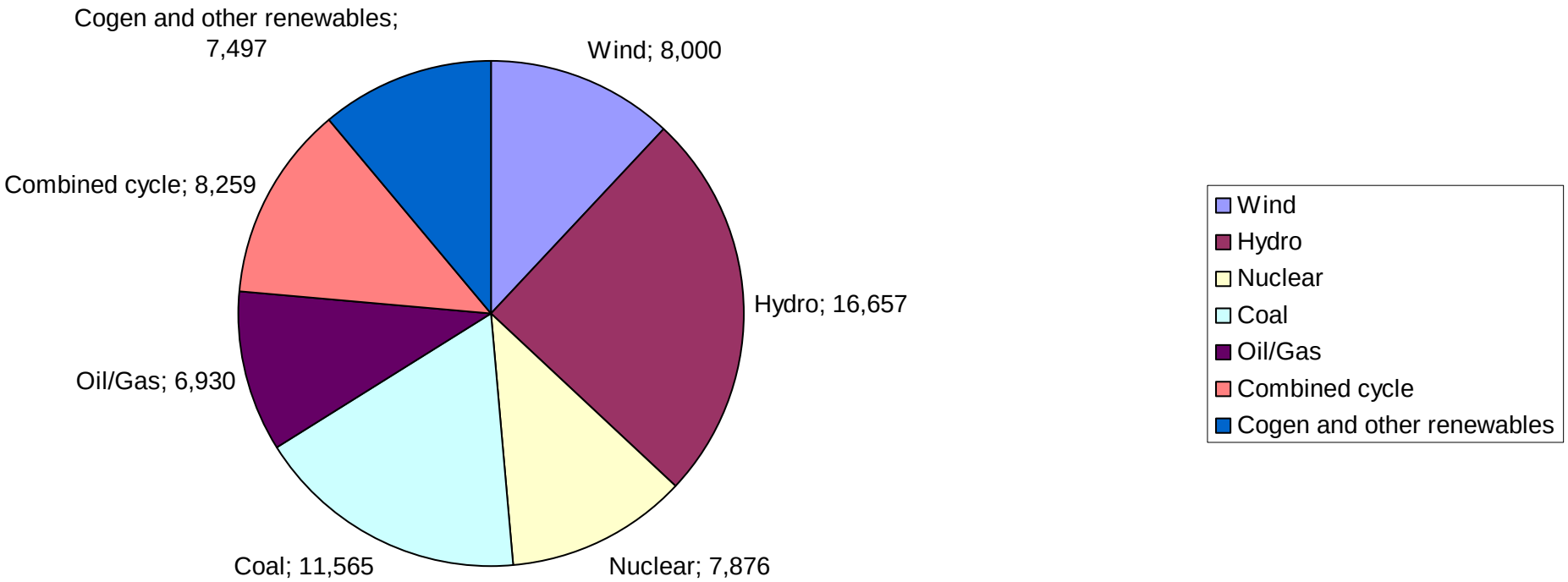
Currently:

~20,000 MW

Spain

Generation

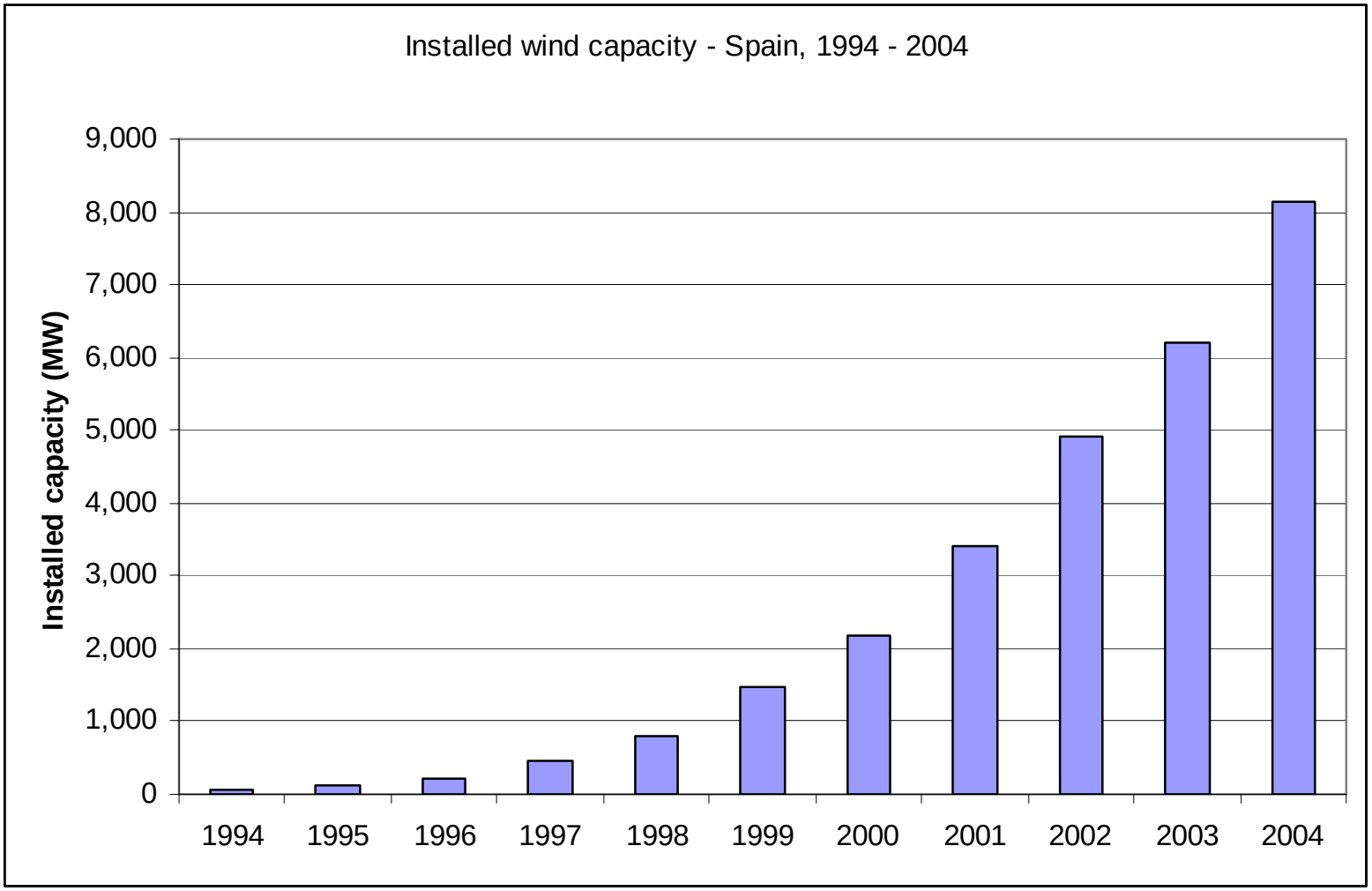
Installed capacity (MW) by generation source



International exchange

- Limited interconnector capacity makes the system inflexible in comparison to other European countries.
- The total interconnector capacity is about 3% of total generation capacity (similar to GB).
- In 2004, net export of 1.2% of annual production (significant differences between years).

Country	**Import [MW]**	**Export [MW]**
France	1000-1400	750-1000
Portugal	600-850	750-1050
Morocco	350-550	300-400
TOTAL	**1950-2800**	**1800-2450**


Installed wind capacity - Spain, 1994 - 2004
Installed capacity (MW)
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

Growth of wind energy

- Rapid growth is directly due to the premium price.

- Legislation in 1994, 97, 97, 2004
- Applies to renewable generators < 50 MW

- Electricity companies must purchase the power:
  - either a fixed tariff, adjusted annually
  - or market price plus premium
    - risk of penalties for deviations from forecast.

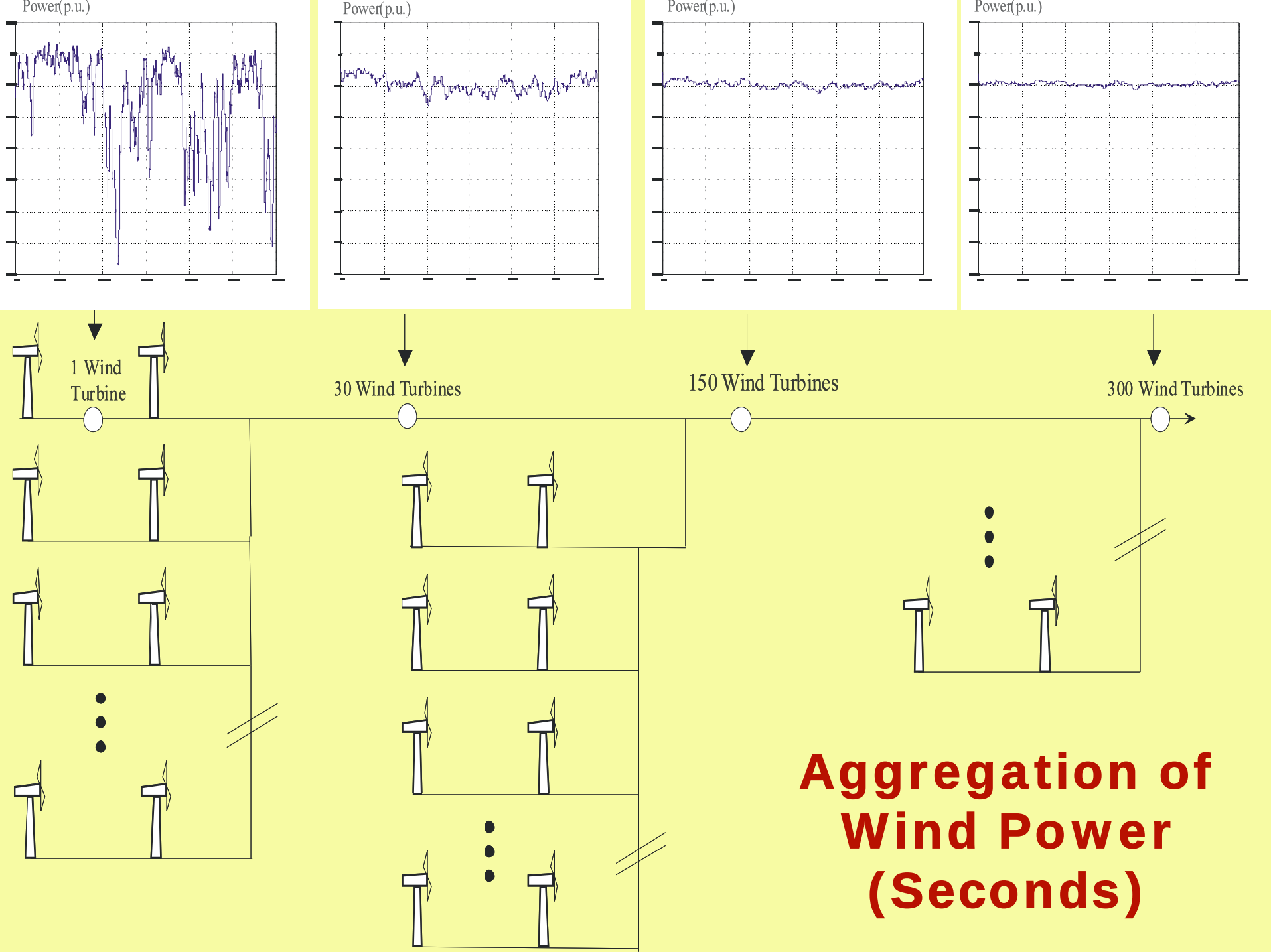
Curtailment

- REE has the right to curtail output. This was very rarely used until 2004, except in an area of Galicia, which has high hydro capacity, where wind curtailment has reached 12% of annual output.
- In 2004, REE started to curtail wind generation when penetration exceeded 12% during periods of low demand.
- As wind capacity is growing 10x faster than demand, curtailment will get worse.
- Technical and legal basis for 12% limit is being disputed.

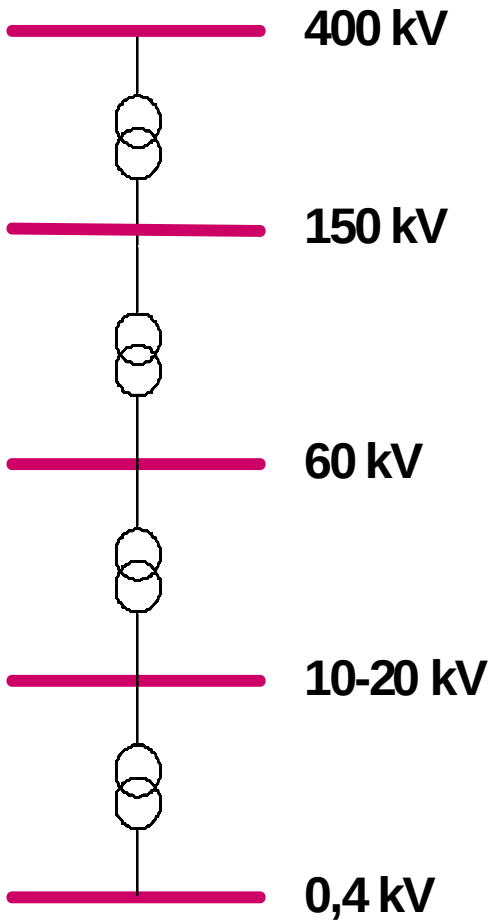
Balancing Reserves I

- Q: How much additional system balancing reserves have European utilities required to integrate increasing amounts of wind?
  - UCTE -> 1 MW wind = 1 MW Back-up
  - UCTE/Germany: 7000 MW balance power if 36000 MW Wind:

    http://www.etso-net.org/upload/documents/2005-00205-01-0.pdf
  - In the following Danish approach;


Power(p.u.)
Power(p.u.)
Power(p.u.)
Power(p.u.)
1 Wind Turbine
30 Wind Turbines
150 Wind Turbines
300 Wind Turbines
Aggregation of Wind Power (Seconds)

Voltage Level and Local Generation in Denmark



4 central CHP units (1488 MW)

6 central CHP units (2014 MW)
Horns Rev offshore wind farm (160 MW)

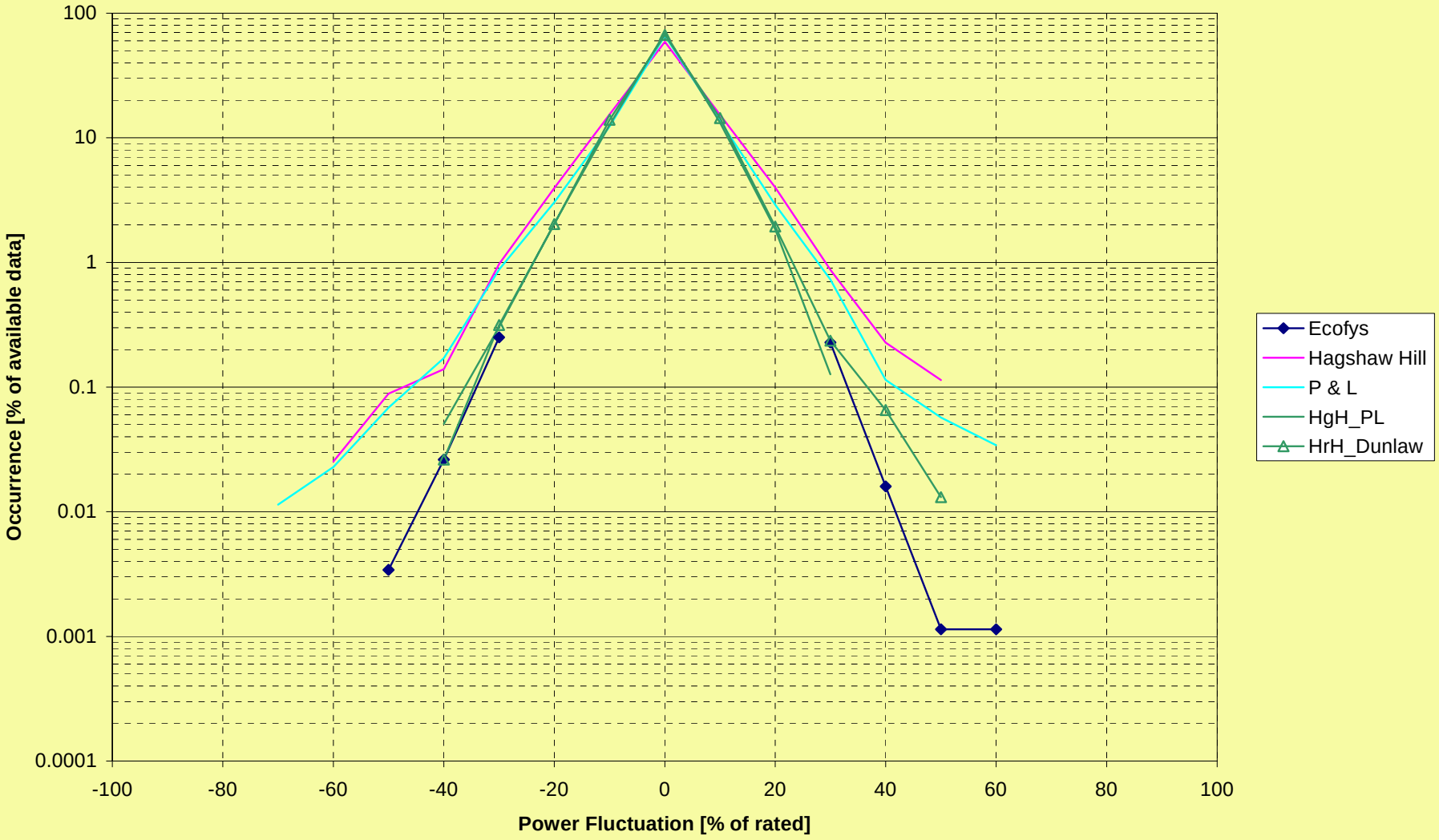
17 dispersed CHP units (569 MW)
34 wind turbines (41 MW)

475 dispersed CHP units (991 MW)
2180 wind turbines (1597 MW)

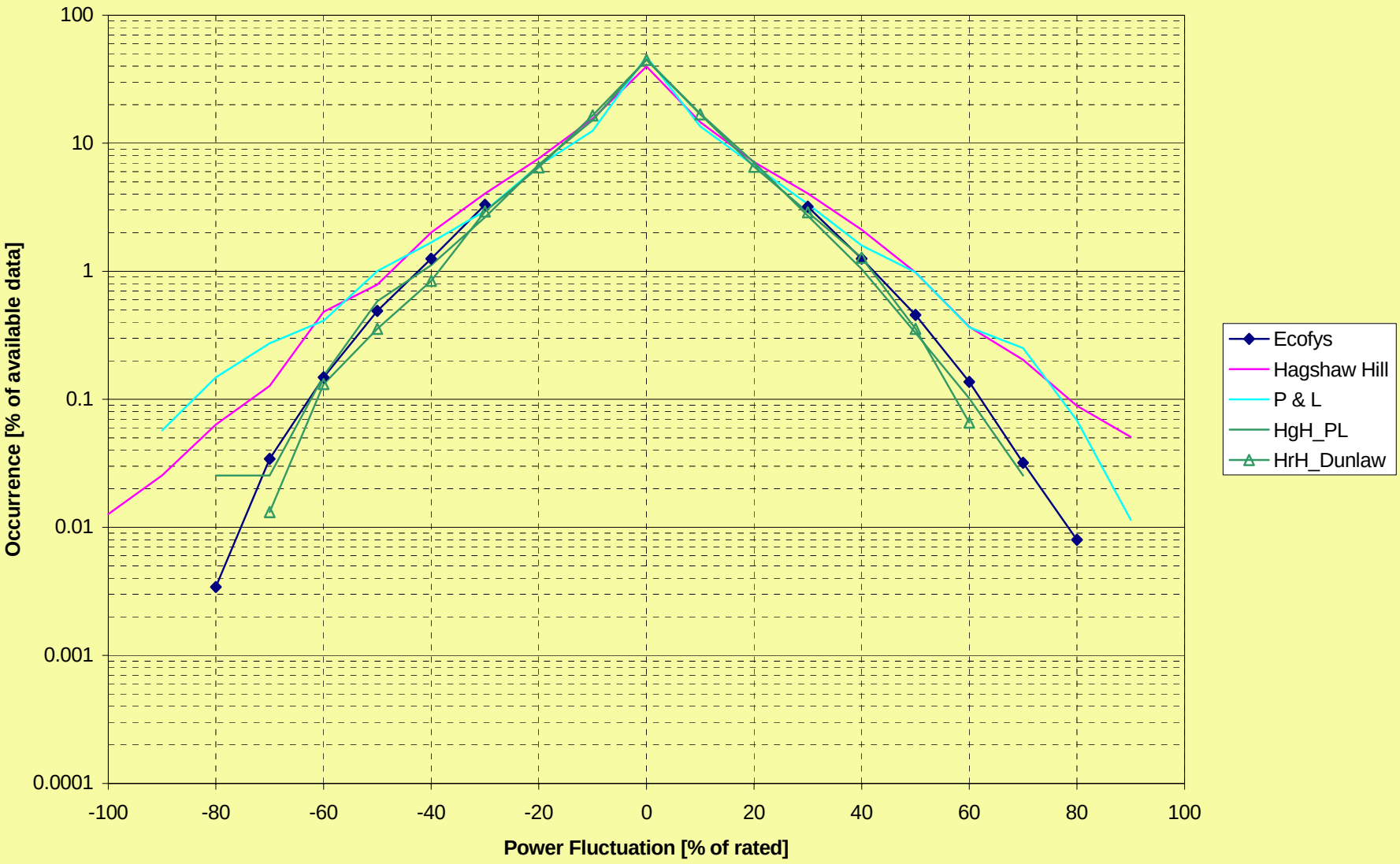
260 dispersed CHP units (83 MW)
1860 wind turbines (576 MW)

Figure 1: Wind and CHP penetration within Eltra's service Area

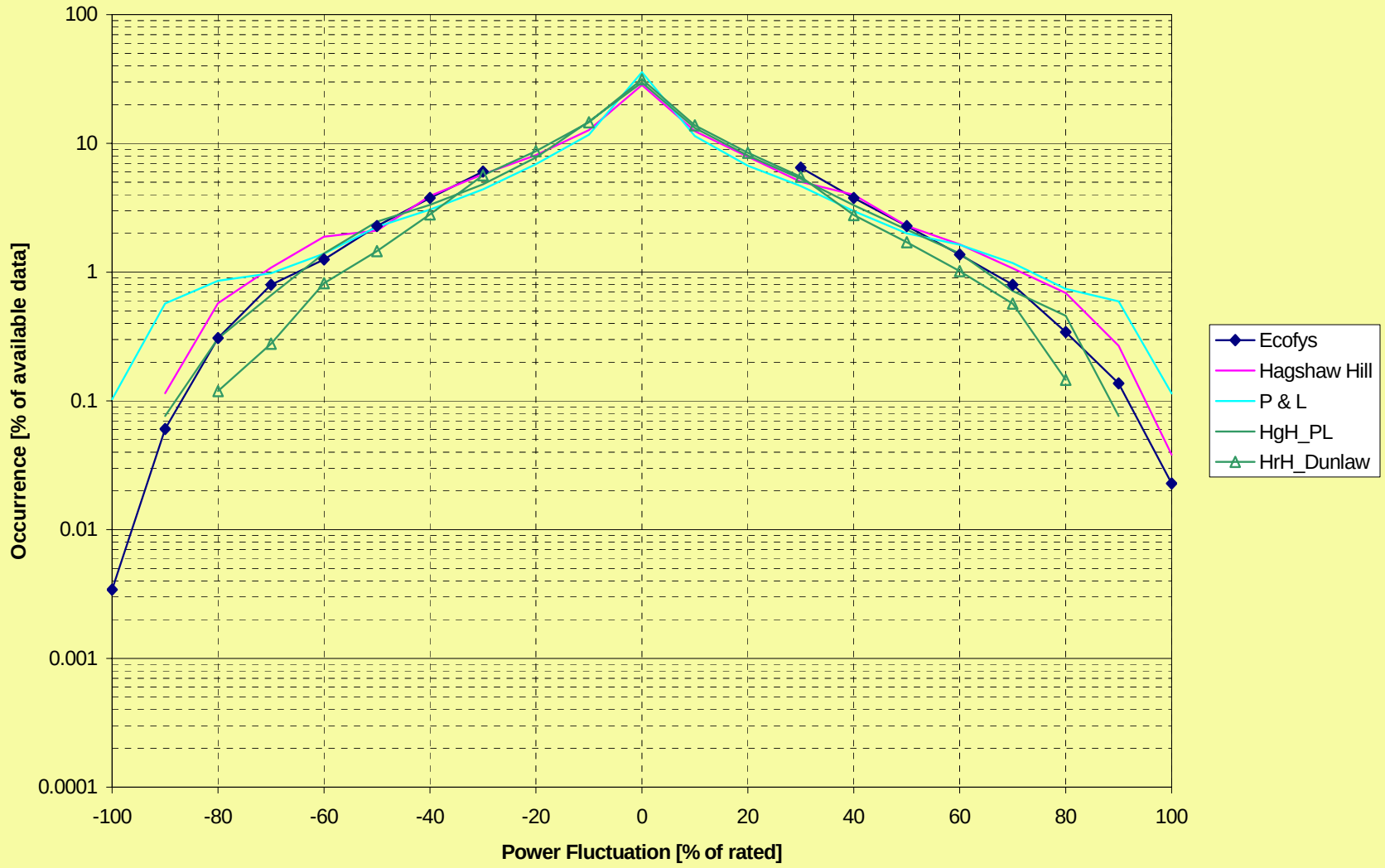
Aggregation within a Wind Farm (Fluctuation in 1 hour)



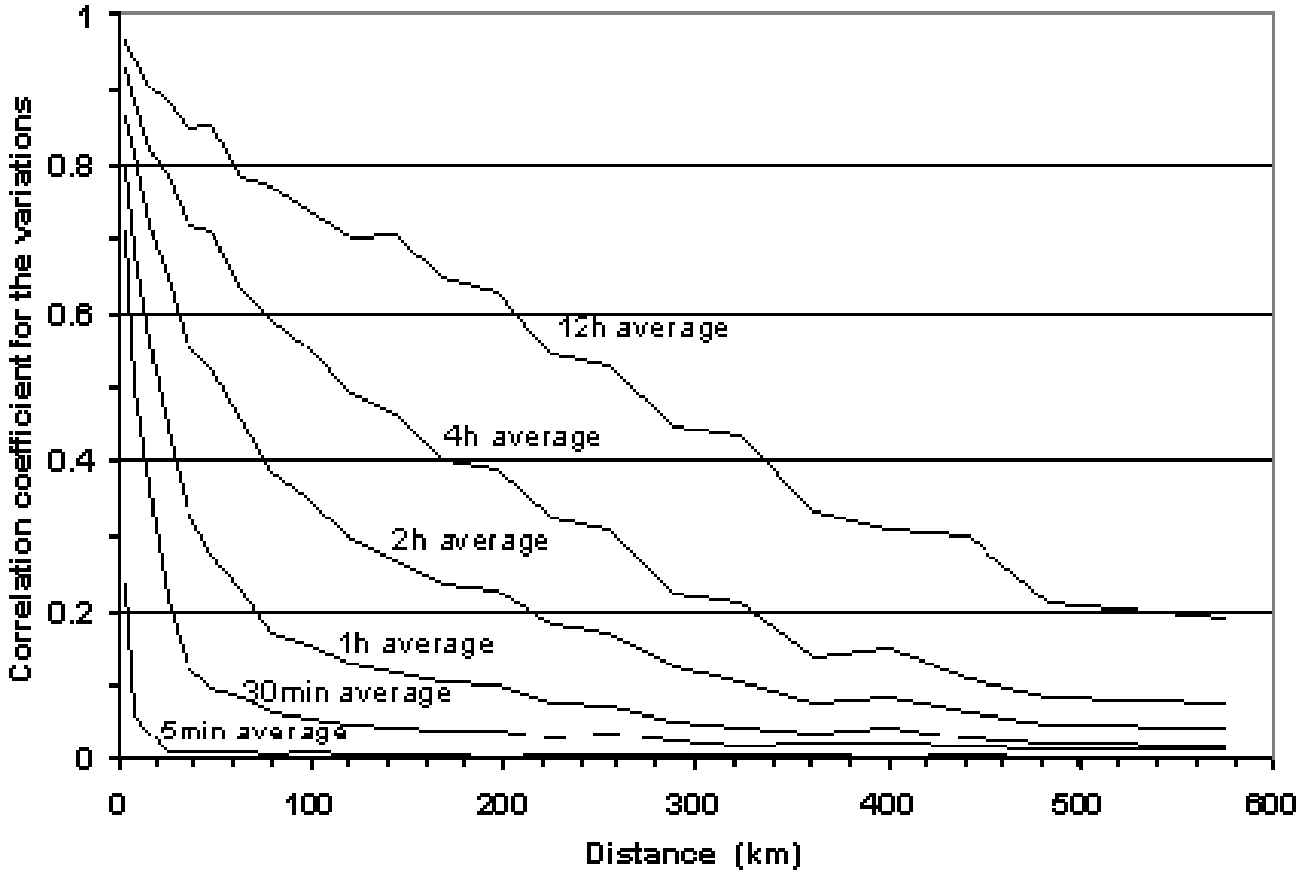
Aggregation within a Wind Farm (Fluctuation in 4 hour)

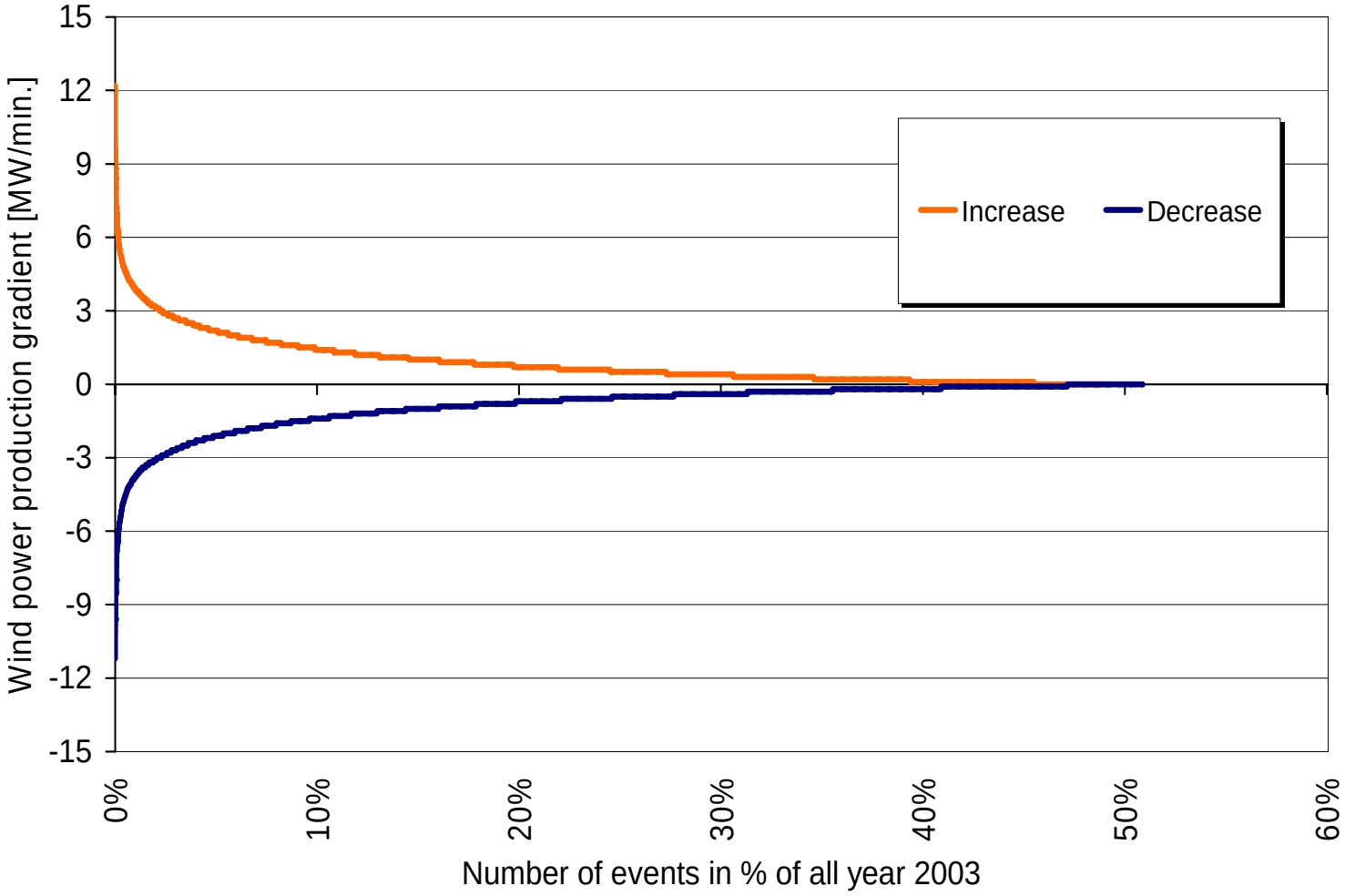


Aggregation within a Wind Farm (Fluctuation in 12 hour)



Correlation of variations for different time scales, example from Germany




15
12
9
6
3
0
-3
-6
-9
-12
-15
Wind power production gradient [MW/min.]
Increase
Decrease
0%
10%
20%
30%
40%
50%
60%
Number of events in % of all year 2003

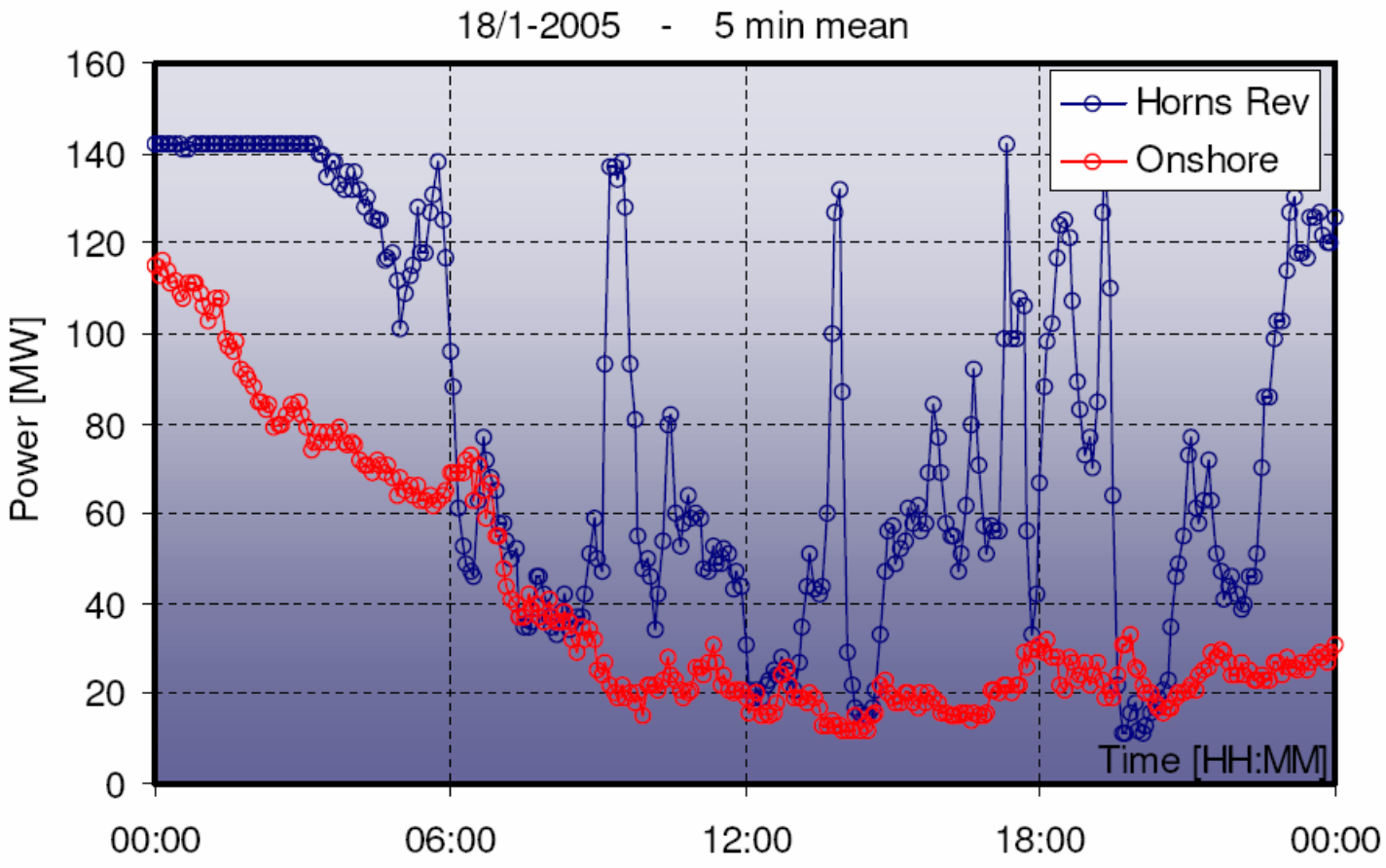
Ramp Rates in the German and Danish System

	E.on Netz		Eltra	
	For 4,000 MW	*Per 1,000 MW*	*For 2,300 MW*	*Per 1,000 MW*
Increasing	250 MW/15 min	4.1 MW/1 min	8 MW/1 min	3.5 MW/1 min
Decreasing	400 MW/15 min	6.6 MW/1 min	15 MW/1 min	6.5 MW/1 min

Large US Wind Farms have
Ramp Rates 30-50 MW/min per 1000 MW

Power Fluctuation

Distributed versus Large Wind Farm



Cause: Significant local temperature differences

Regulating Reserves

To regulate the imbalances caused by forecast errors, incidents, failures etc. the TSO needs regulating reserves, automatic and manual:

Automatic regulating reserve ("Load Frequency Controller"):

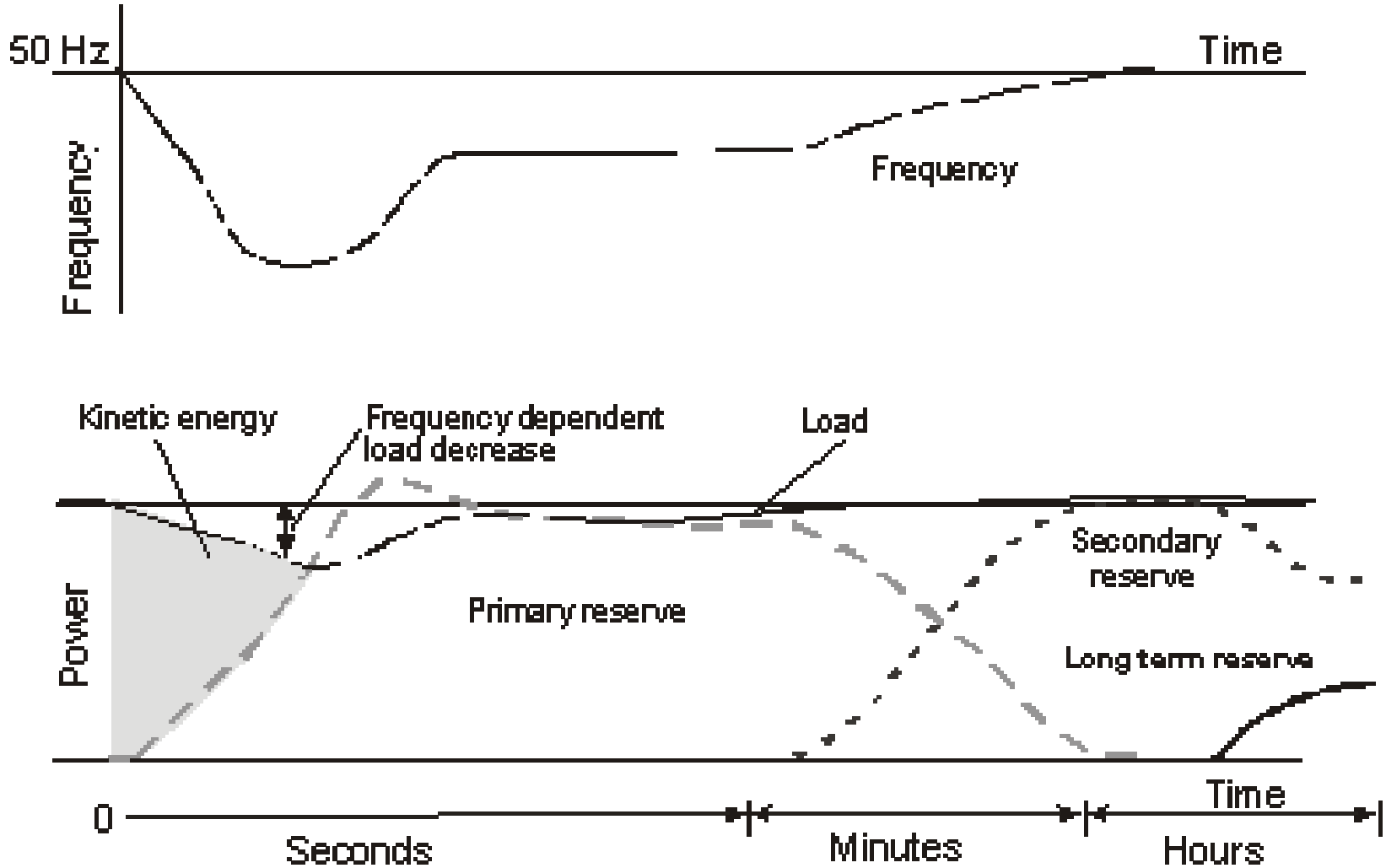
- Up regulating reserve: 100 MW
- Down regulating reserve: 100 MW

Impact Wind Power: Very LOW!

Specific requirements:

- Must be activated within 30 seconds after an incident
- Must be fully activated within 15 minutes

Source: Eltra


50 Hz
Time
Frequency
Frequency
Kinetic energy
Frequency dependent
load decrease
Load
Power
Primary reserve
Secondary
reserve
Long term reserve
0
Time
Seconds
Minutes
Hours

Regulating Reserves II

Manual regulating reserve

(activated by Eltra's Control Center):

- **Up regulating reserve: up to 520 MW**
- **Down regulating reserve: 200 MW**

Impact Wind Power: Very High!

Specific requirements:

- Must be fully activated within 15 minutes from the order
- Must be available for the common Nordic power regulating market

Source: Eltra

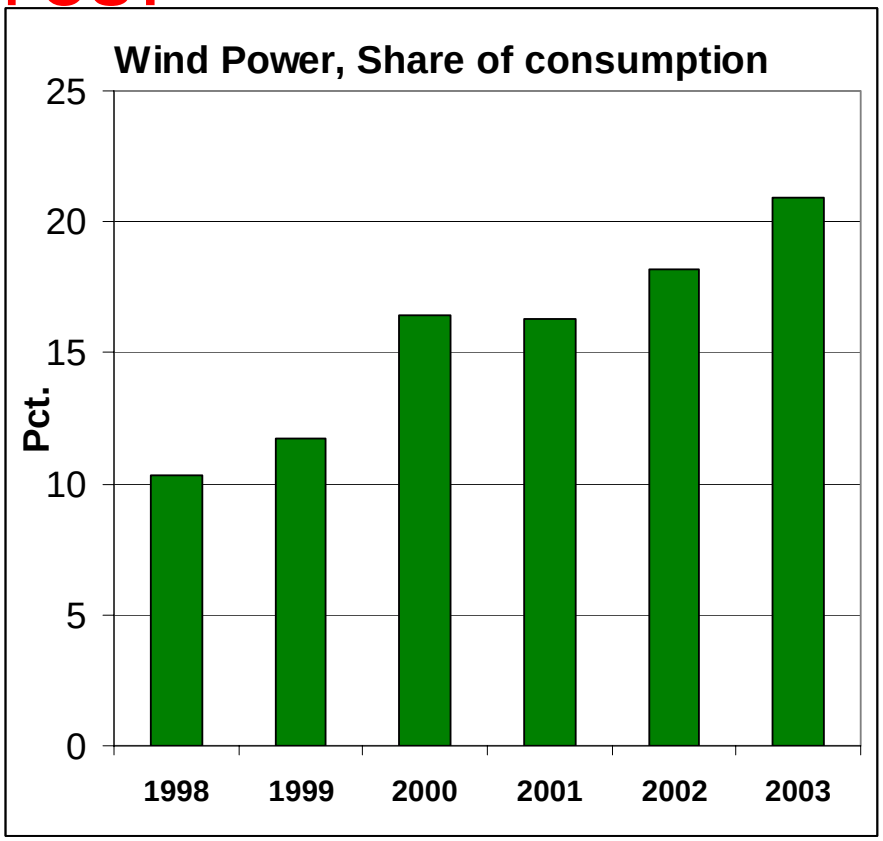
Imbalance Costs 2002

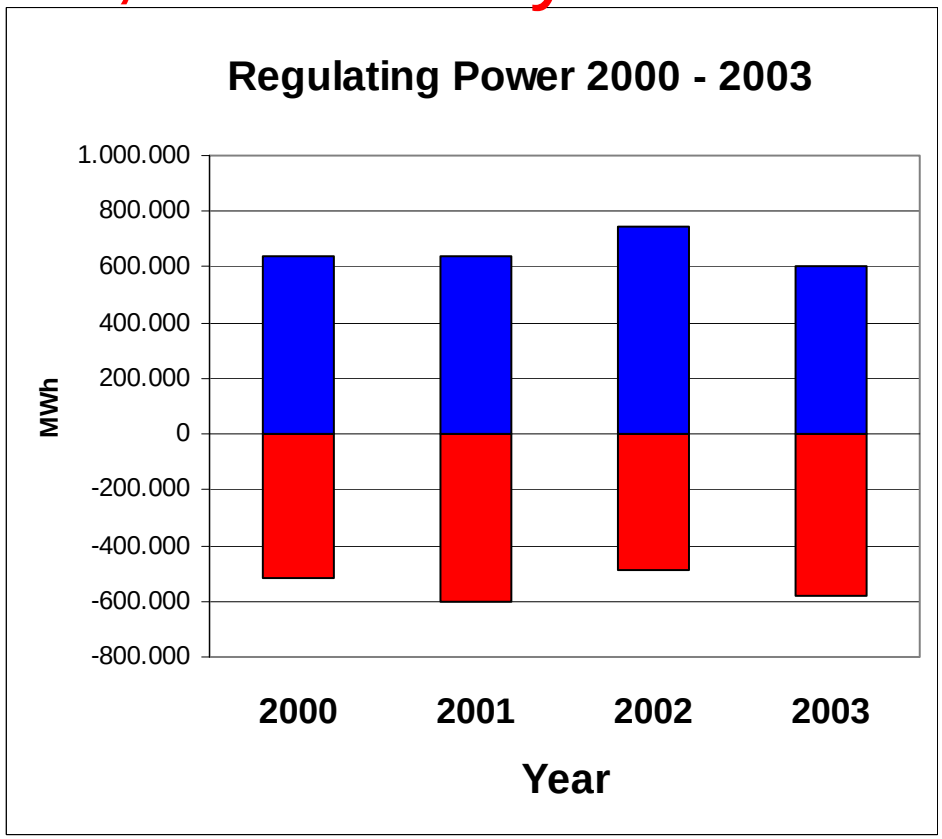
- Total costs: 10 Million Euro
- 0.0027 Euro/kWh wind
- Socialized, i.e. all network customers pay for it.
- Future: Costs will soon be responsibility of wind farm
- Issue: More flexibility needed (CHP also priority production)

More Wind Power => More Regulating Power?

Yes!

No, not really…





Spain

- In Spain secondary reserve (~5 minutes) has been proved not to be necessary to increase due to wind penetration. In fact with more than 8.4 GW the real system operation indicates that there is no significant need of more secondary reserves than without wind power generation.

- However, for longer term balancing reserves (15 minutes to 5hours) the inherent wind power forecast error implies a bigger usage of this type of slower reserves and depending on the term considered REE has to take into account that the wind power may range from 80% to 20% of nominal power presently corresponding to the reduction of 5 GW in about 8 hours.

Balancing Reserves II

- Q: What have been the major differences across utilities and regions, and which types of power facilities have provided such reserves?
  - Denmark: Elsam Issues
  - Germany: Market Issues (+ Nulcear)

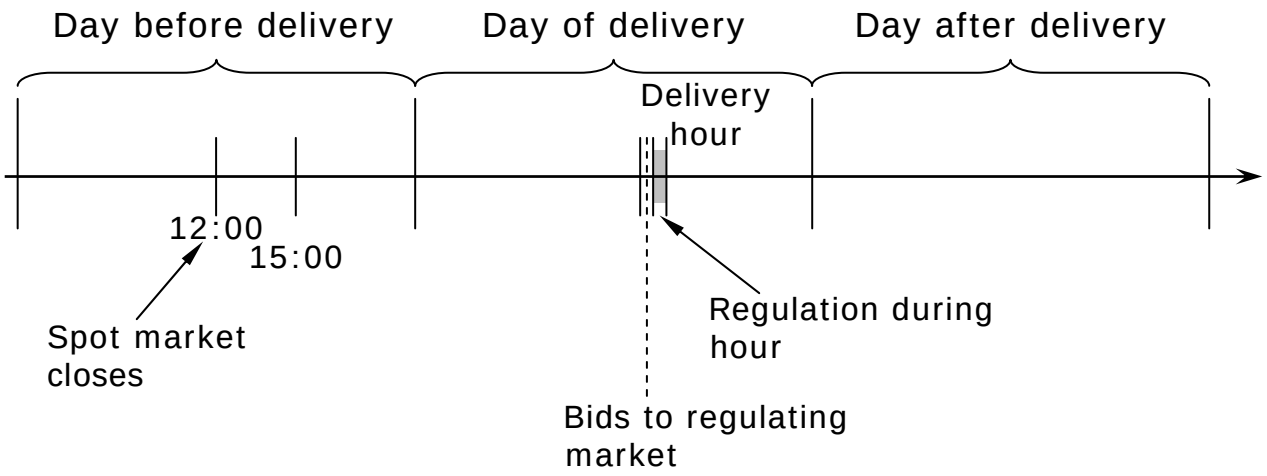
  Summary European Balance Approach:

  http://www.etso-net.org/upload/documents/BalanceManagemeninEurope.pdf

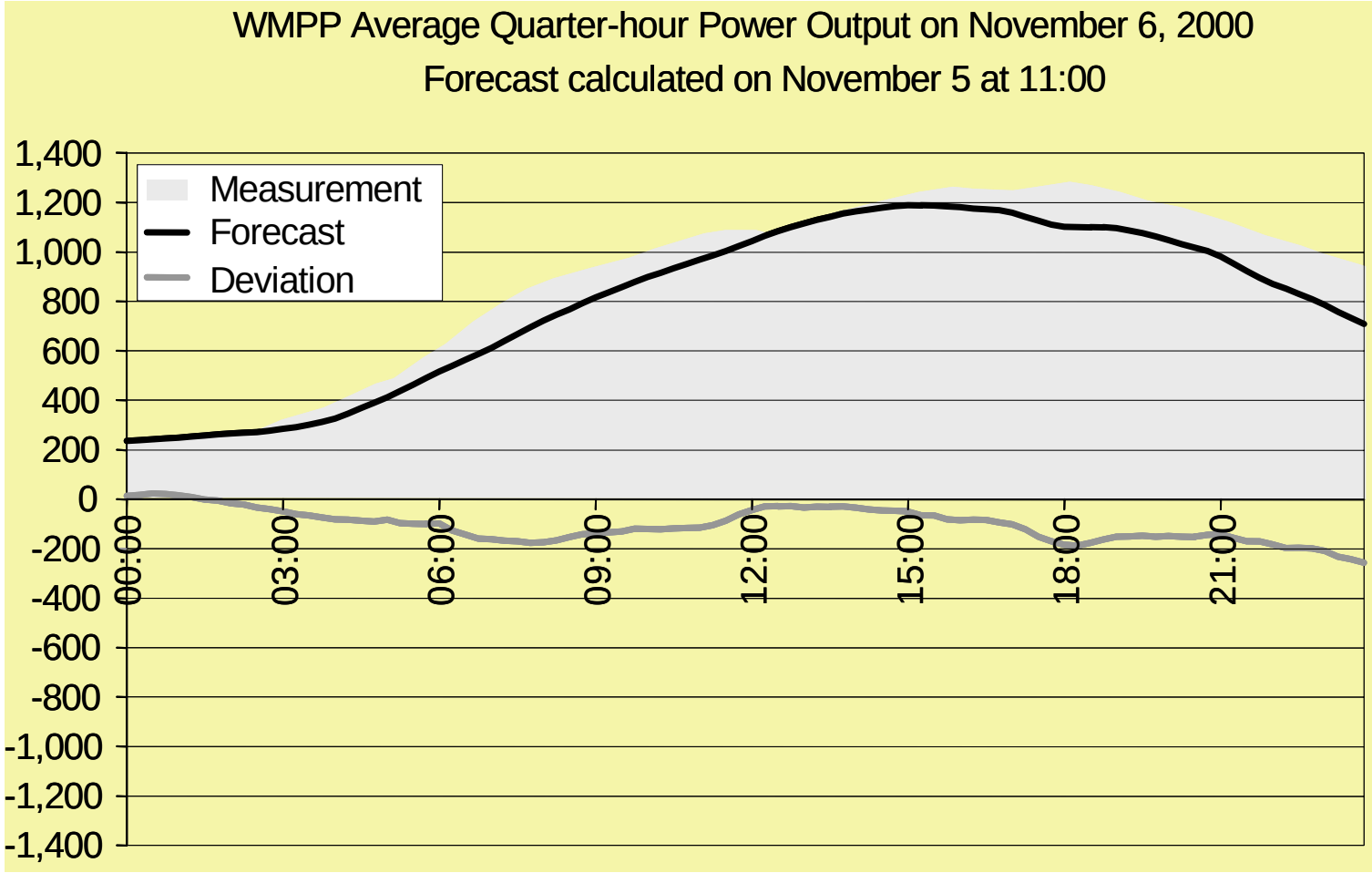
  http://www.etso-net.org/upload/documents/ETSOReport%20onRES.pdf

- Q: Has a preferred statistical methodology to calculate these impacts emerged?
  - Not aware of any preferred method (little interest so far)

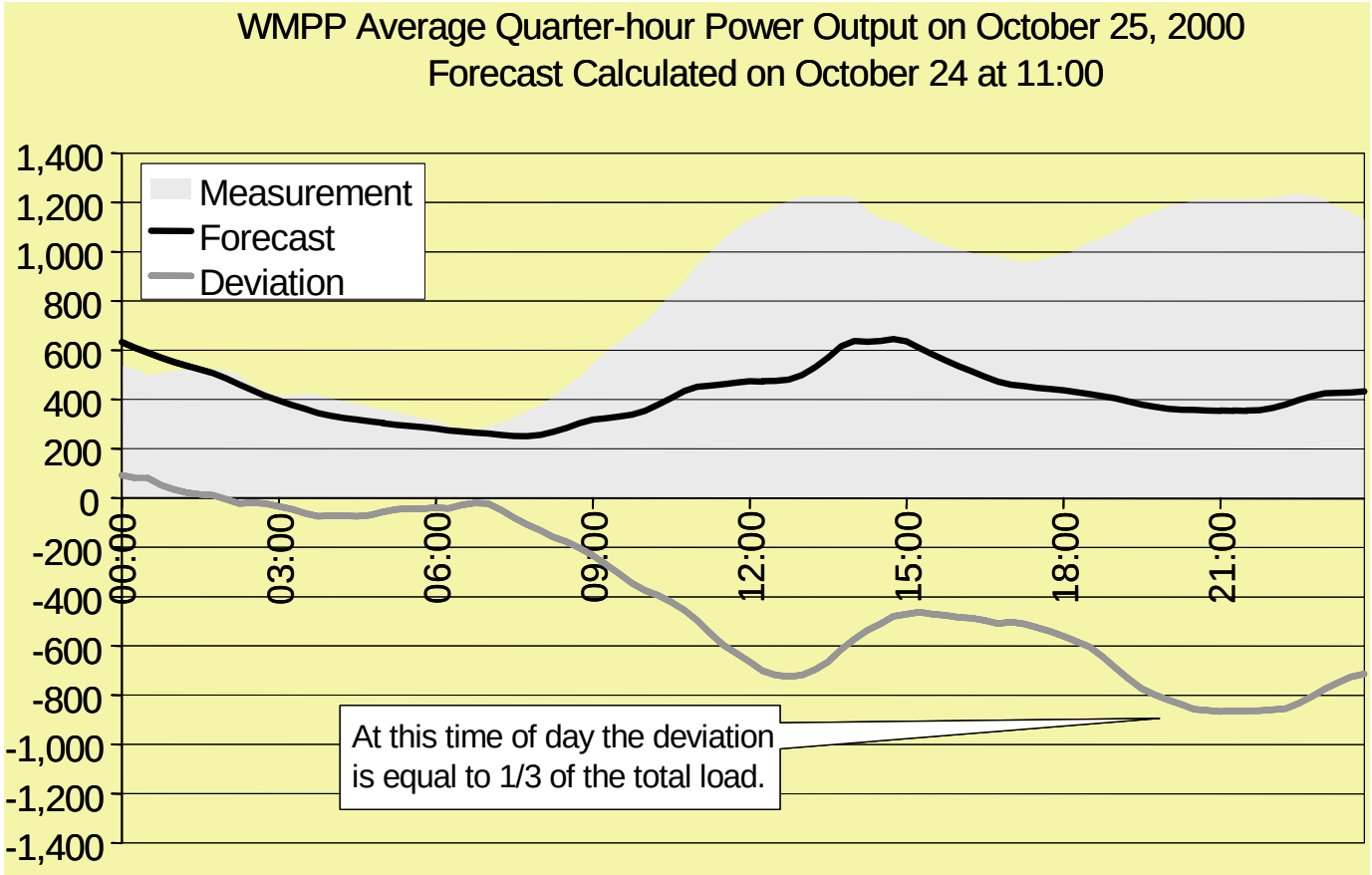
Nordic power market



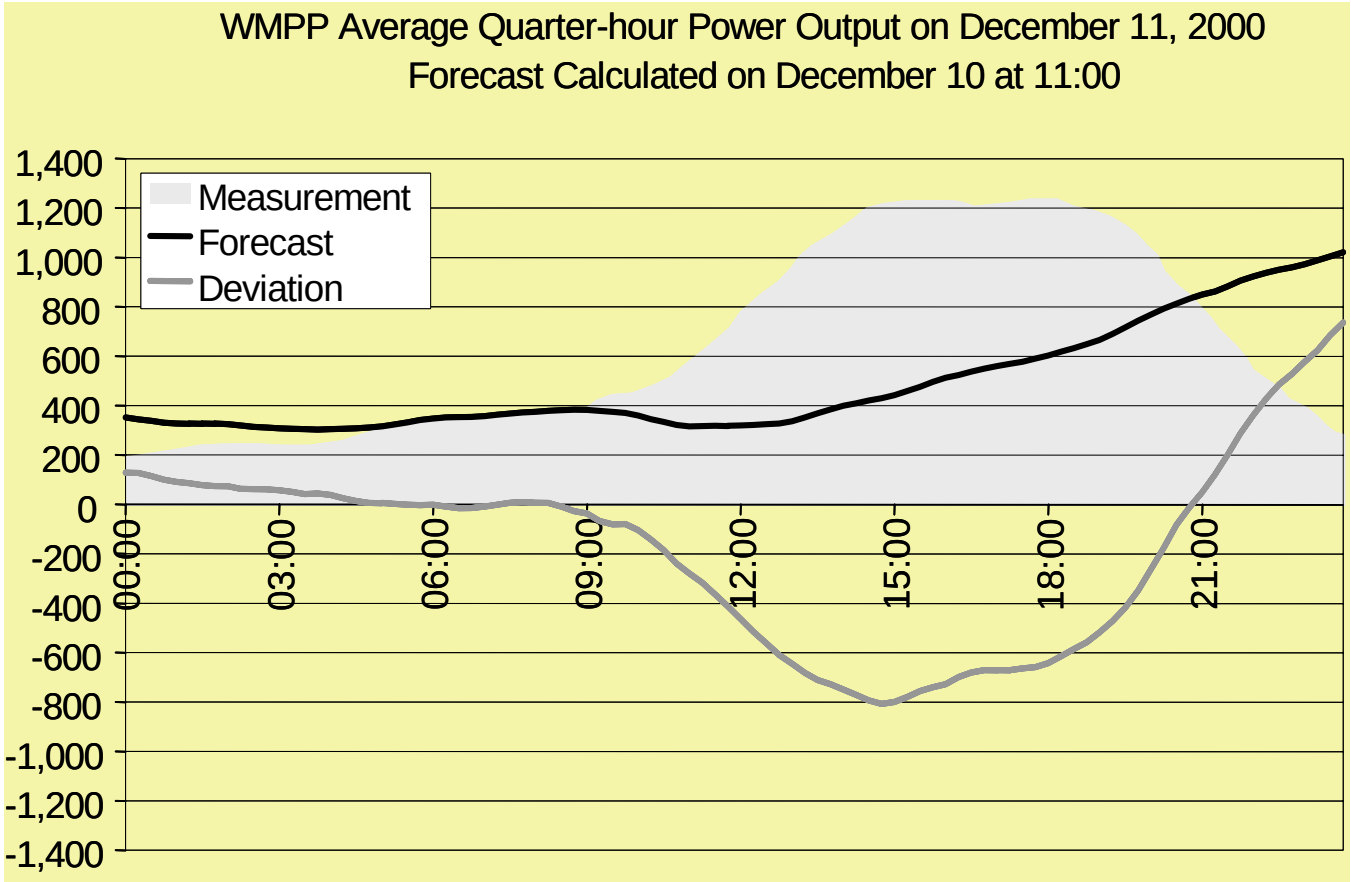
Good Forecast



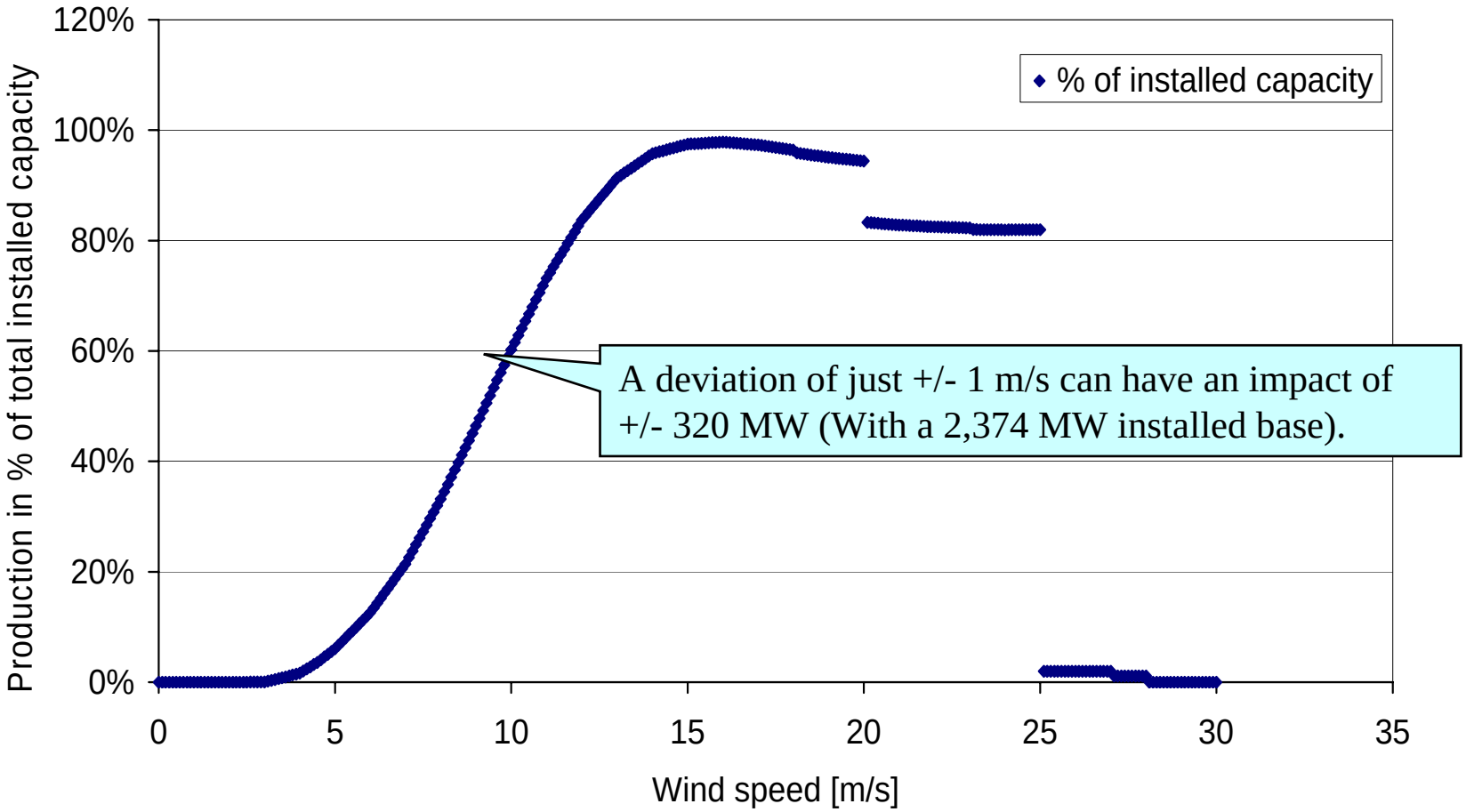
The Bad Forecast



The Ugly Forecast



Aggregated Wind Production Curve (PC) for Western Denmark



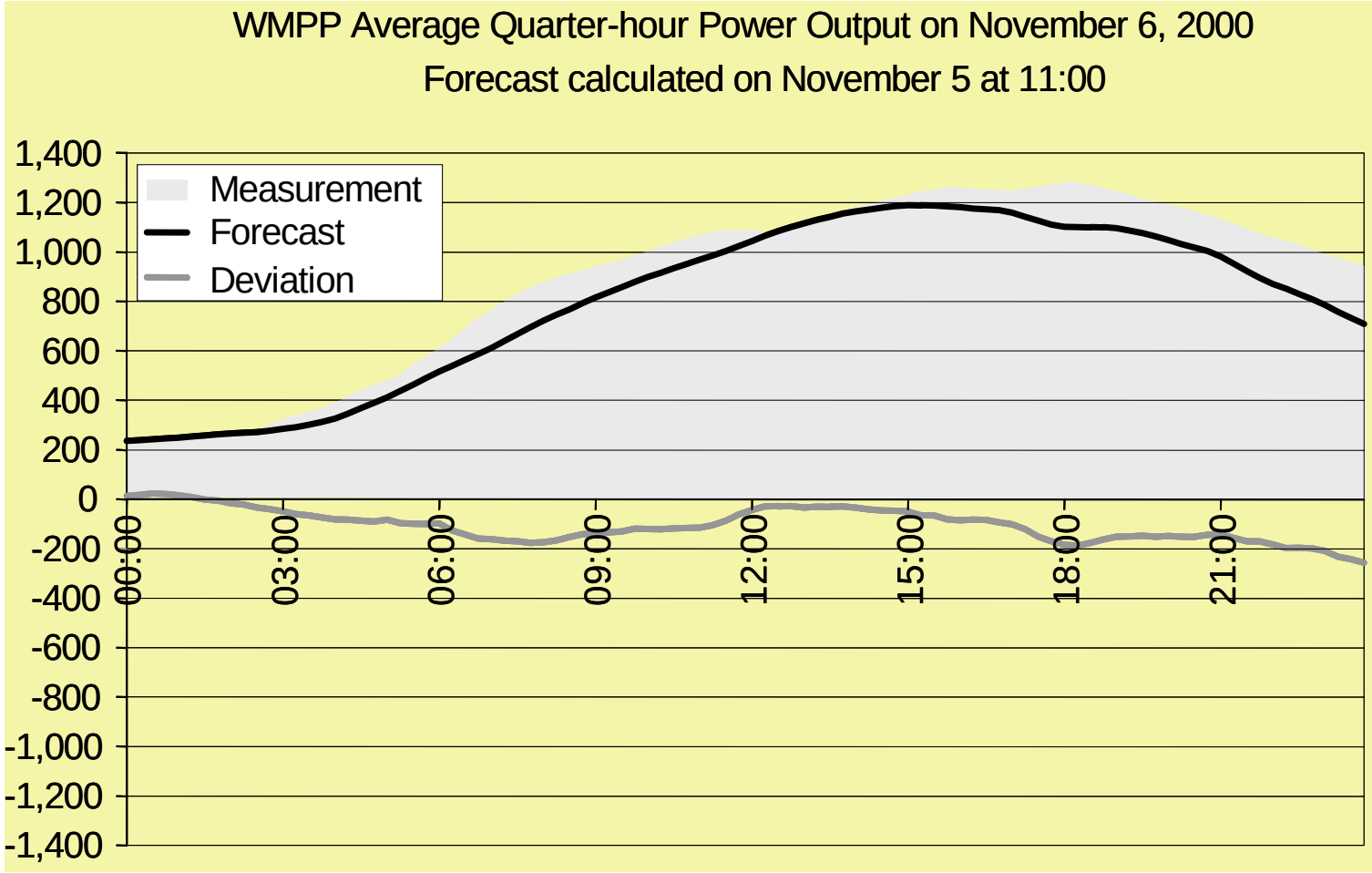
Wind Forecasts

- Based on the forecasts of DMI (Danish Meteorological Institute).
- The Wind forecasts for the next 24 hours are very unreliable (average deviation: 35 per cent. Max. deviation: 60 per cent).
- Imbalances up to 1.100 MW in some hours !!!
- The wind forecast error determines the direction of the imbalance in the system 80 per cent of the time!
- The imbalances caused by the unpredictable nature of the wind power is the main reason, that Eltra has to secure a relatively large regulating reserve.

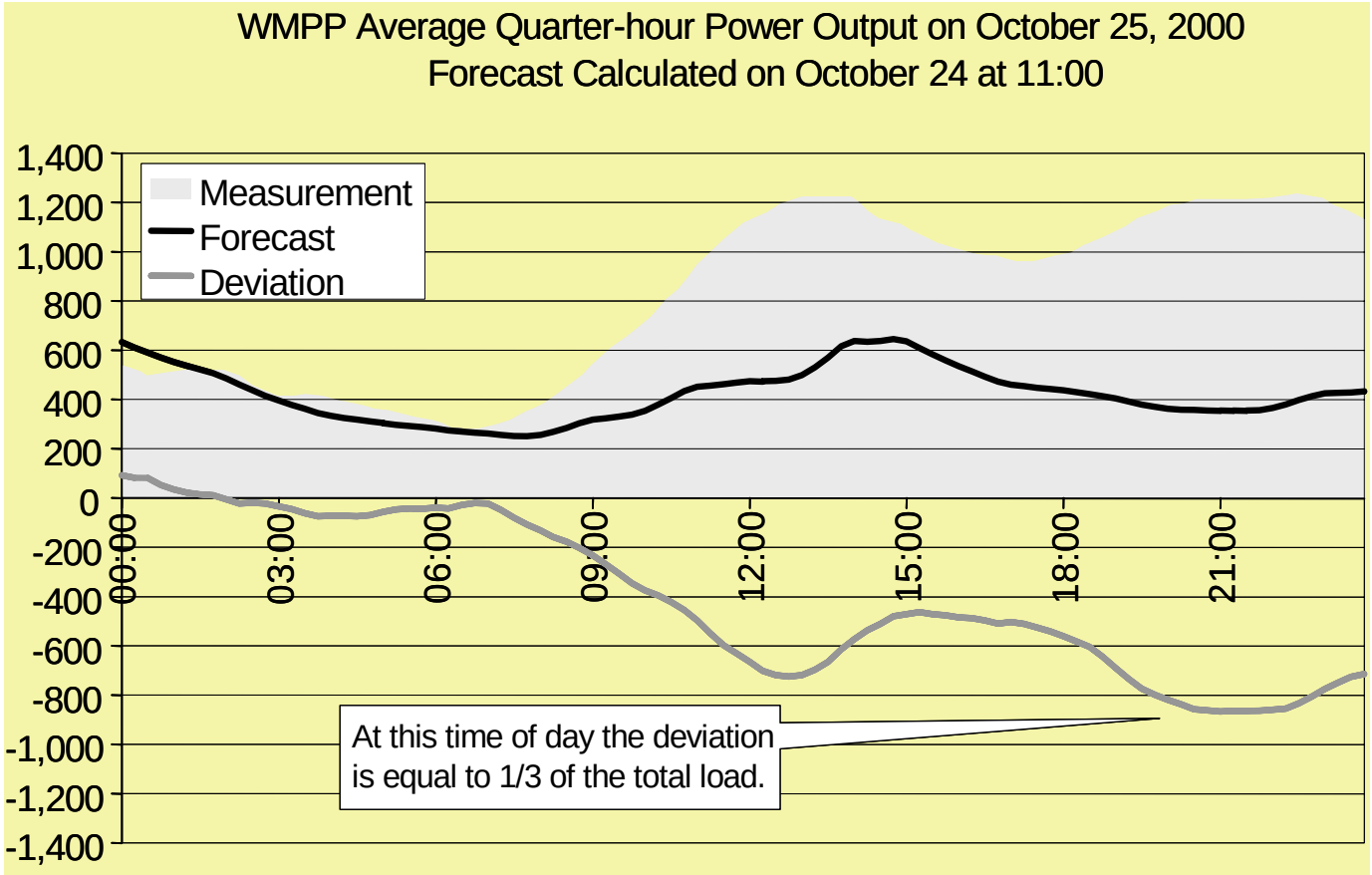
Wind Forecasting I

- Q: How has wind forecast uncertainty/error impacted day ahead and hourly operations?
  - Danish example in the following

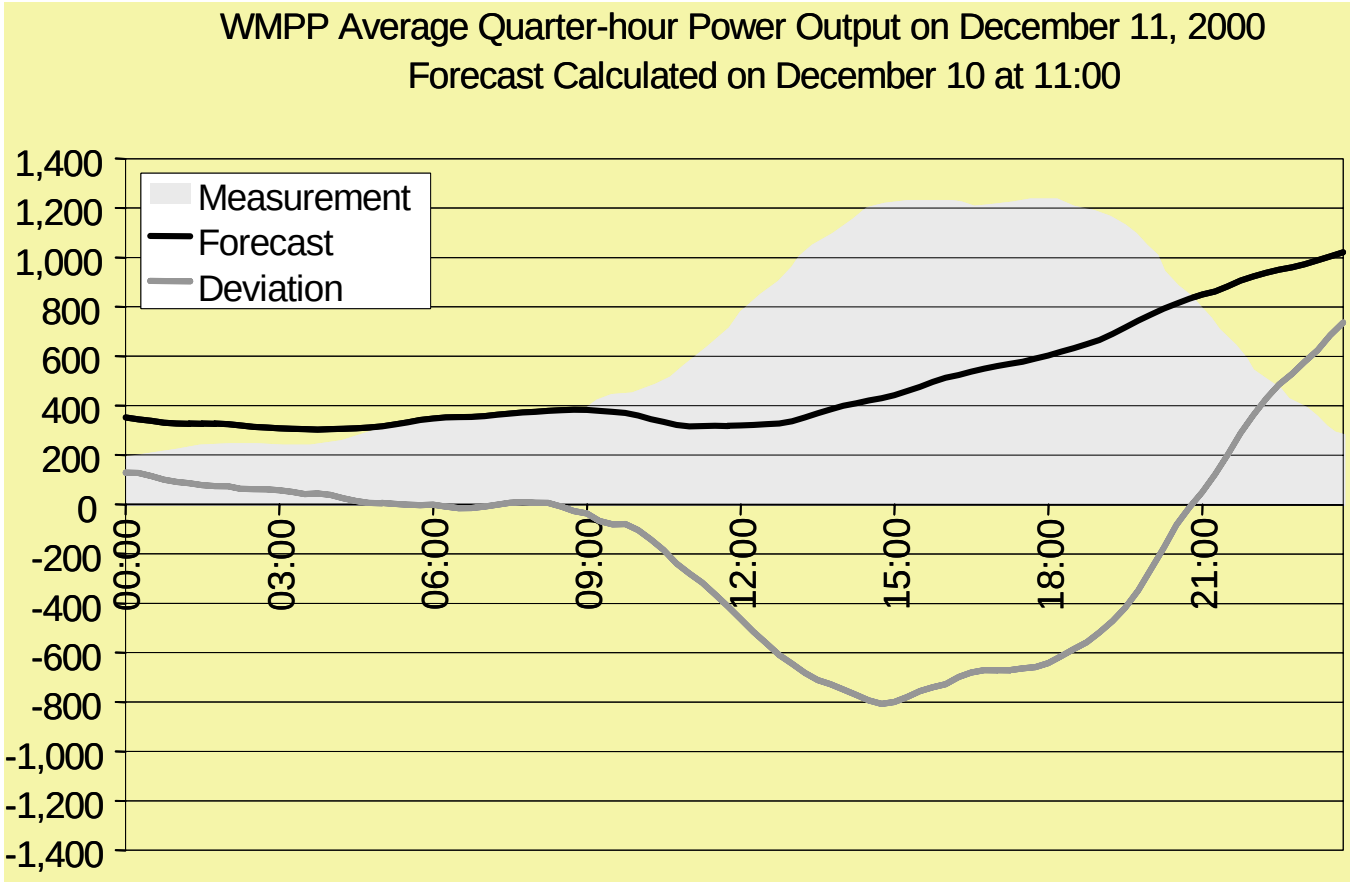
Good Forecast



The Bad Forecast



The Ugly Forecast



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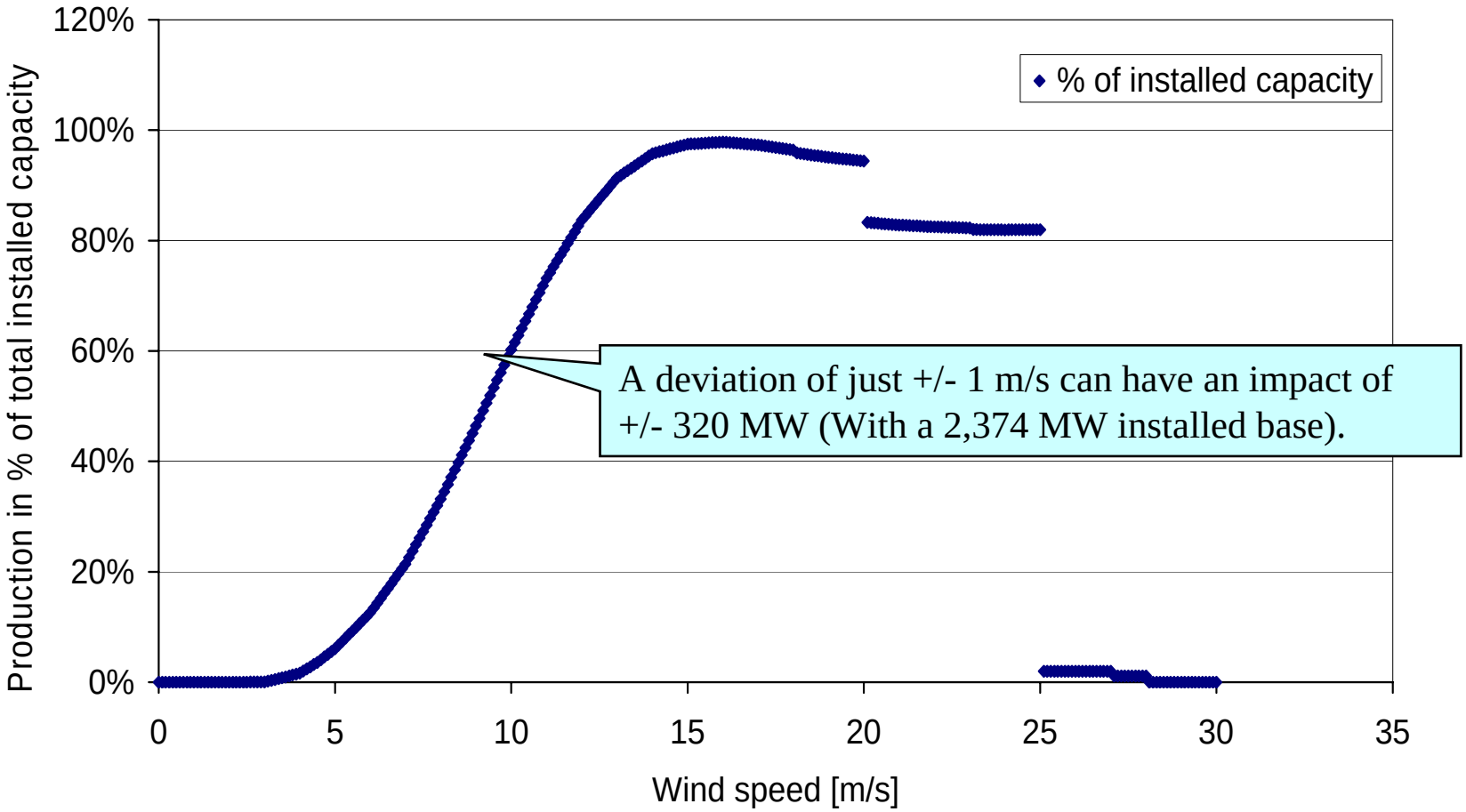
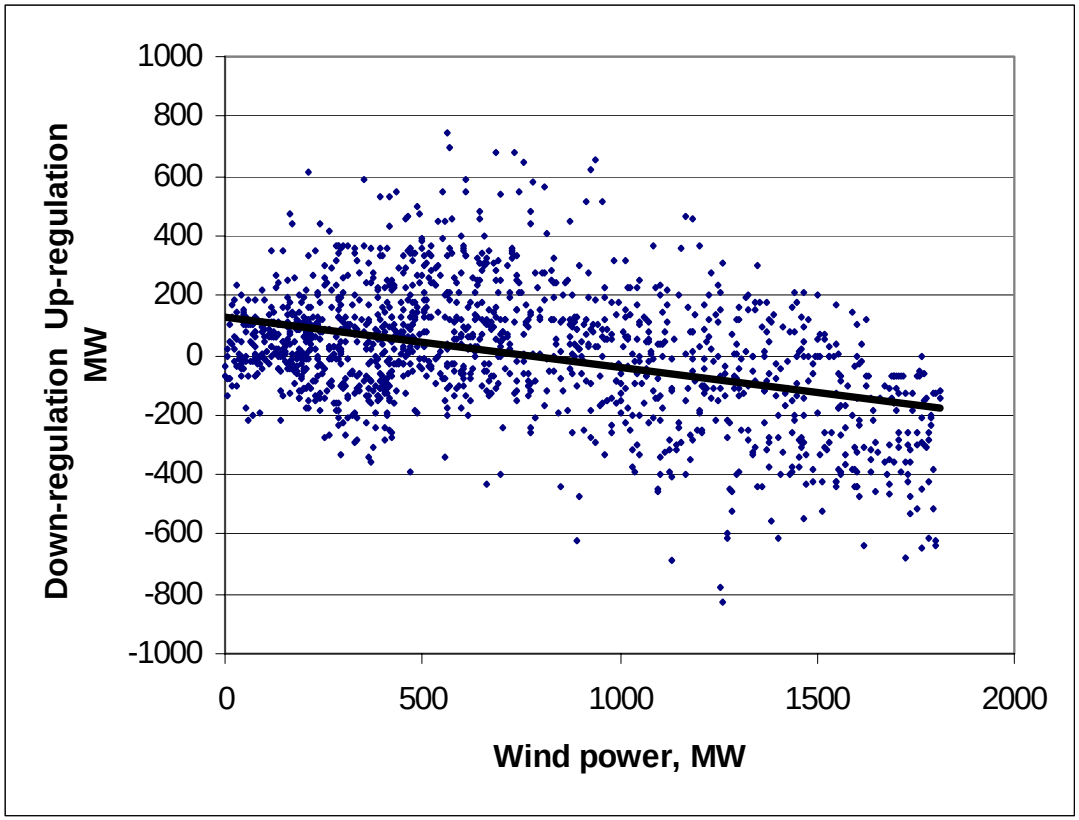


Regression analysis of down or up-regulation against the amount of wind power for the Jutland/Funen area.

Hourly basis for January-February 2002



Source: *Poul Erik Morthorst , Riso*

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Wind Forecasting II

- Q: How does forecast error drive the need for additional balancing reserves, and how can these impacts be quantified.

  Relevance clear – quantification difficult

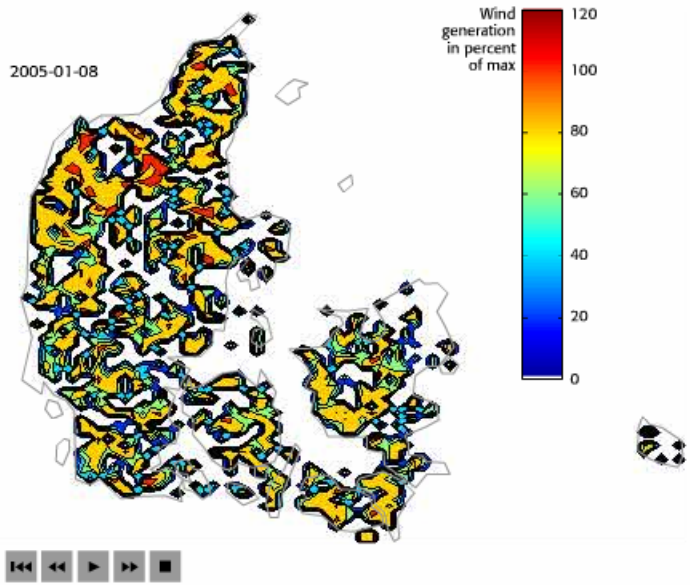
  Focus Europe: What drives forecast error:

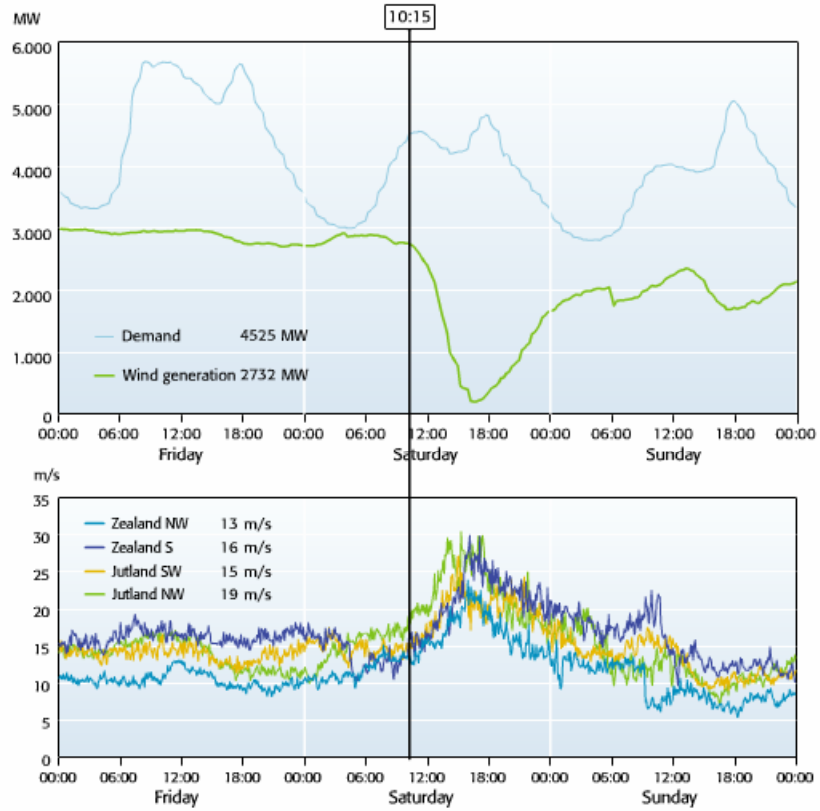
  – Forecast horizon important (UK: 1 h)
  – Tools and location important (see following)

  – Extreme events important: Storm (!)

Storm

The January Hurricane

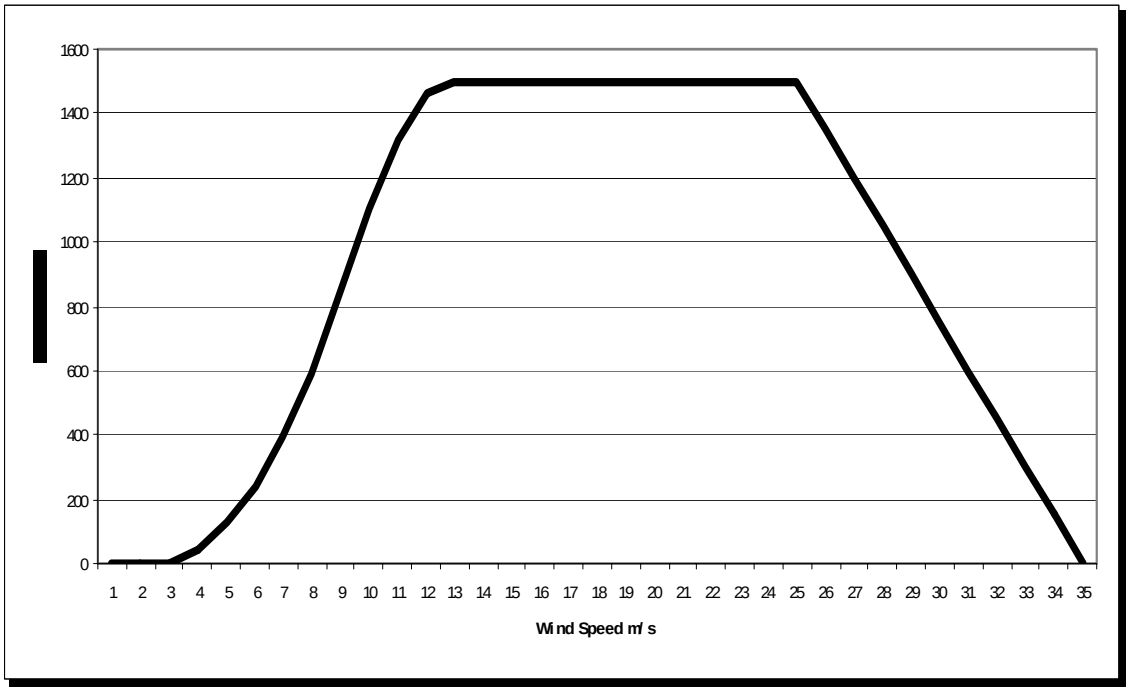




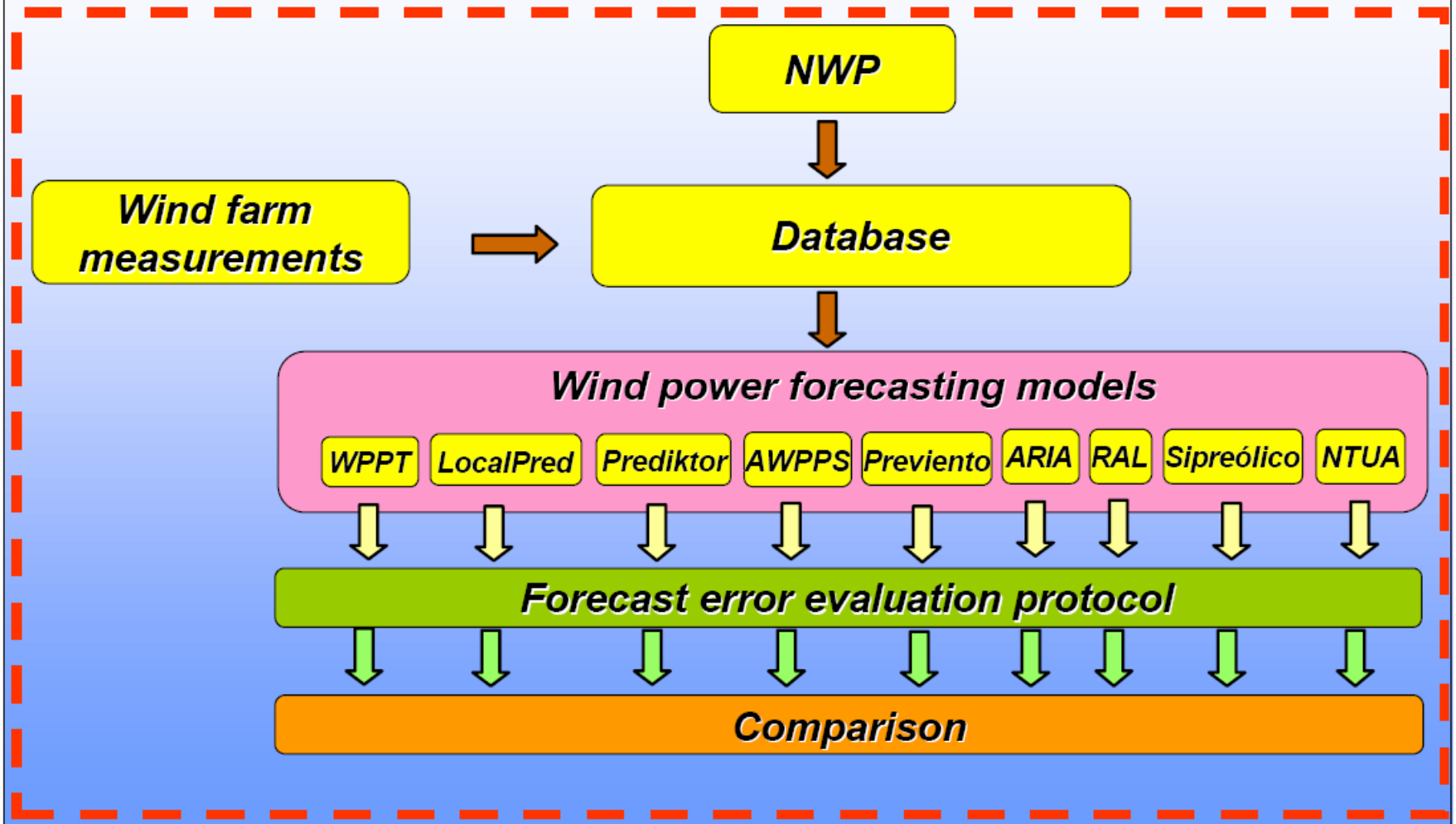
Energinet.dk

Elkraft eltra gastra

Possible Solution: Different Power Curve

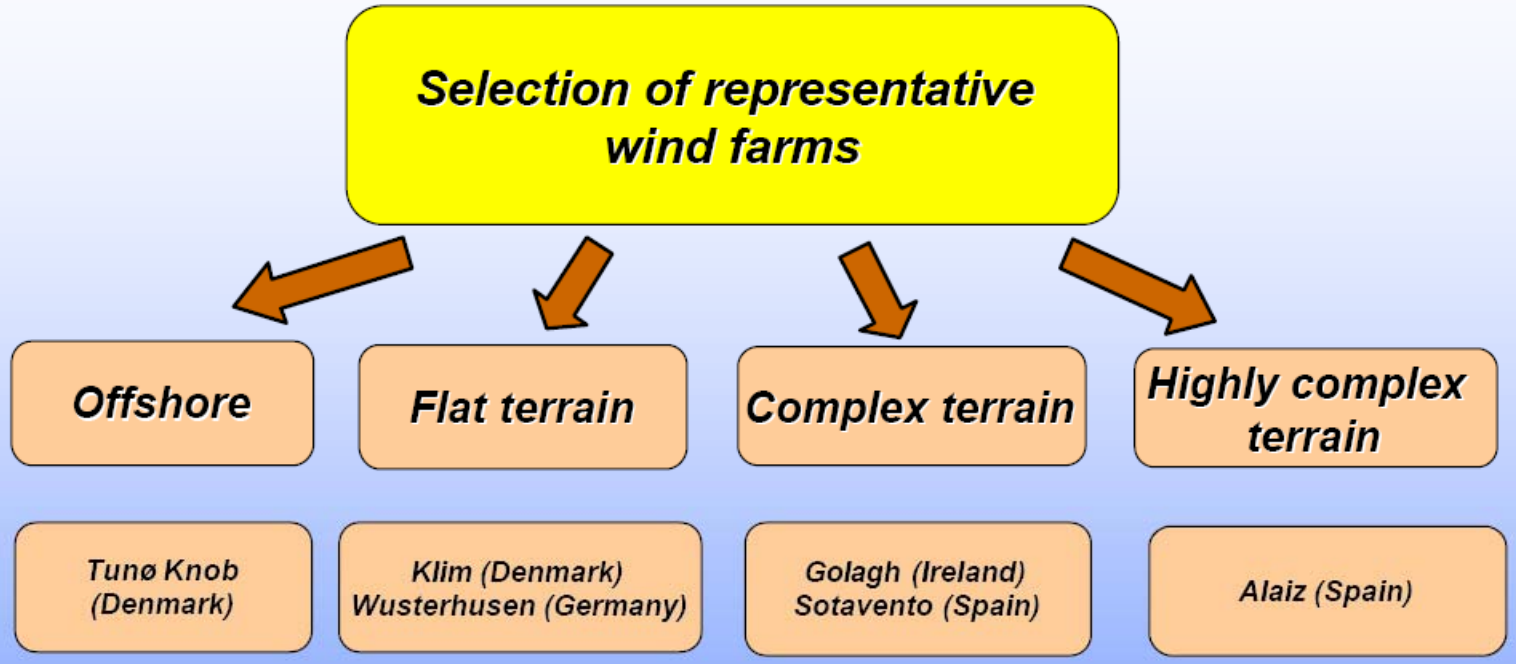


Design of the benchmarking



Virtual Laboratory

Design of the benchmarking



- 4 European countries represented. Spain, Denmark, Ireland and Germany.
- 4 environments considered from flat to highly complex terrain, including an offshore wind farm.

Design of the benchmarking

Numerical Weather Prediction Models (NWP)

HIRLAM

DM

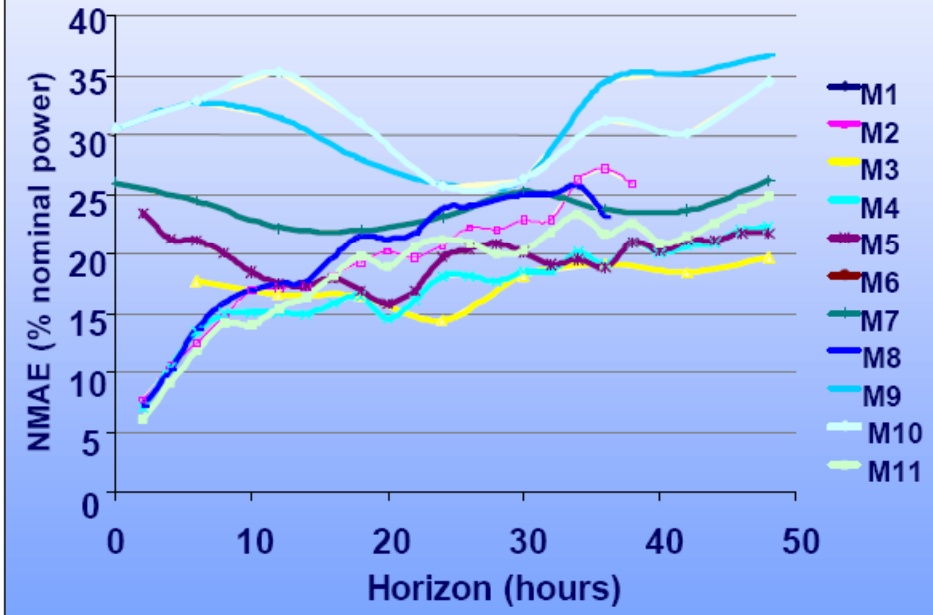
Spain (INM), Denmark (DMI) Ireland (Met Eireann)

Germany (DWD)

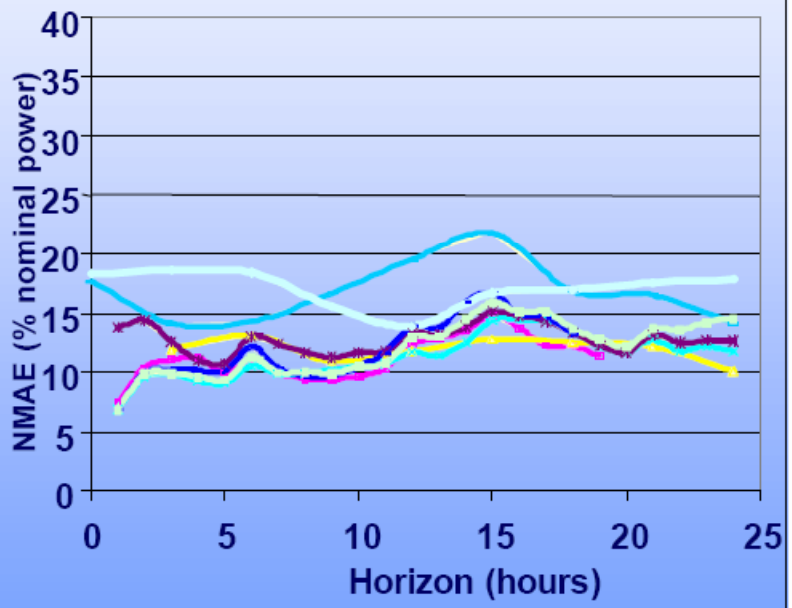
- **Numerical Weather Prediction models were used for each country as input to the wind power prediction models:**
  - High Resolution Limited Area Model (HIRLAM).
  - Deutschland-Modell (DM).

Results of the benchmarking

A Highly complex terrain (Alaiz-ES)



B Complex terrain (Sotavento-ES)

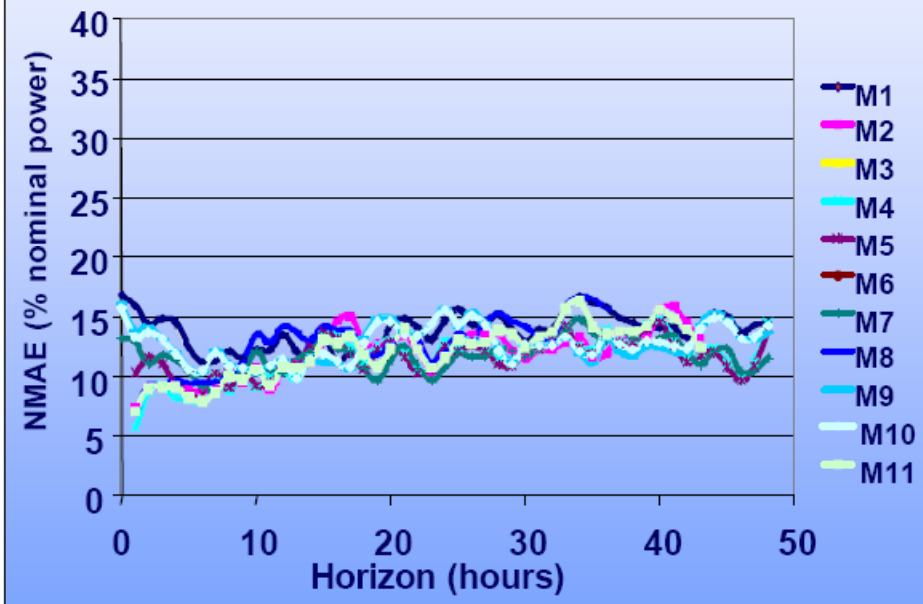


- **Higher level of prediction errors.**
- **Higher dispersion between prediction models.**

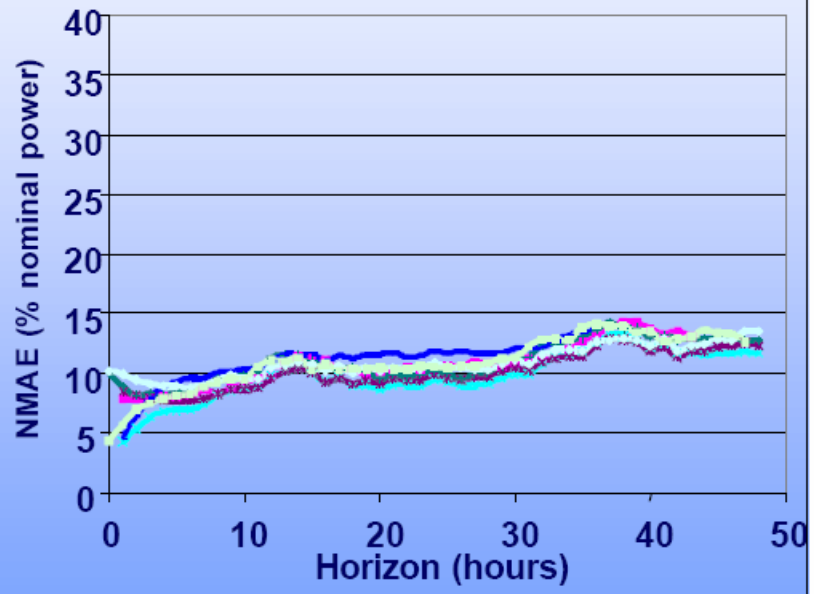
NMAE: Normalized Mean Absolute Error

Results of the benchmarking

C Hilly terrain (Golagh-IE)



D Flat terrain (Klim-DK)

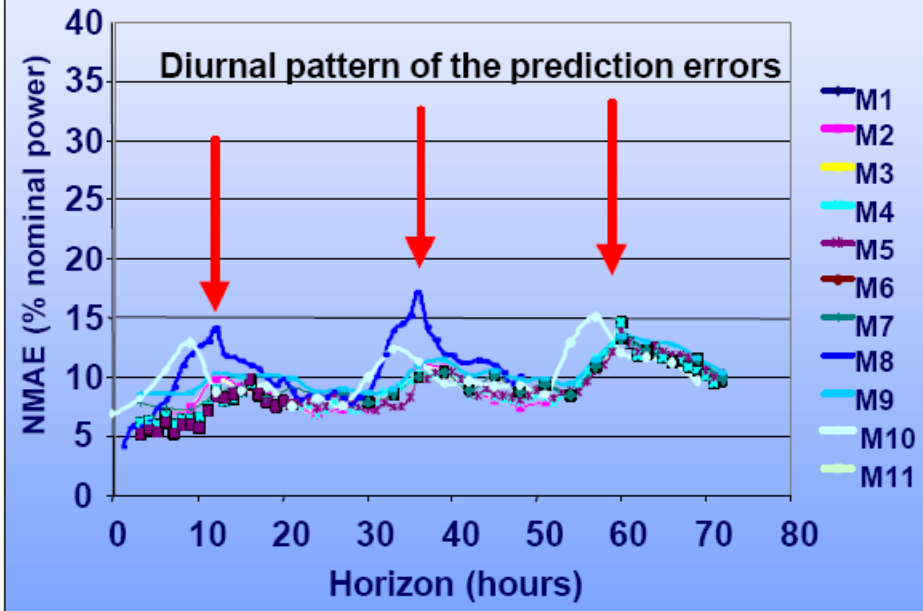


- **Lower level of prediction errors.**
- **Lower dispersion between prediction models.**

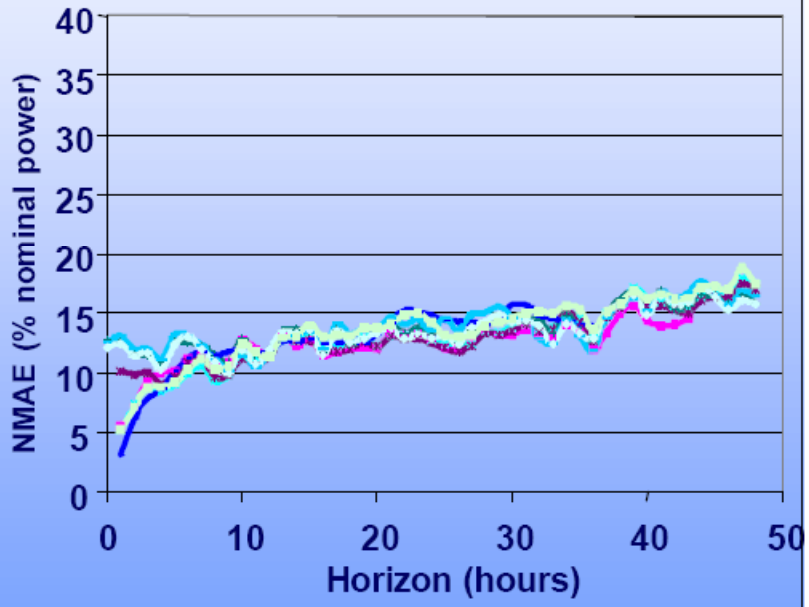
NMAE: Normalized Mean Absolute Error

Results of the benchmarking

E Flat terrain (Wusterhusen-DE)



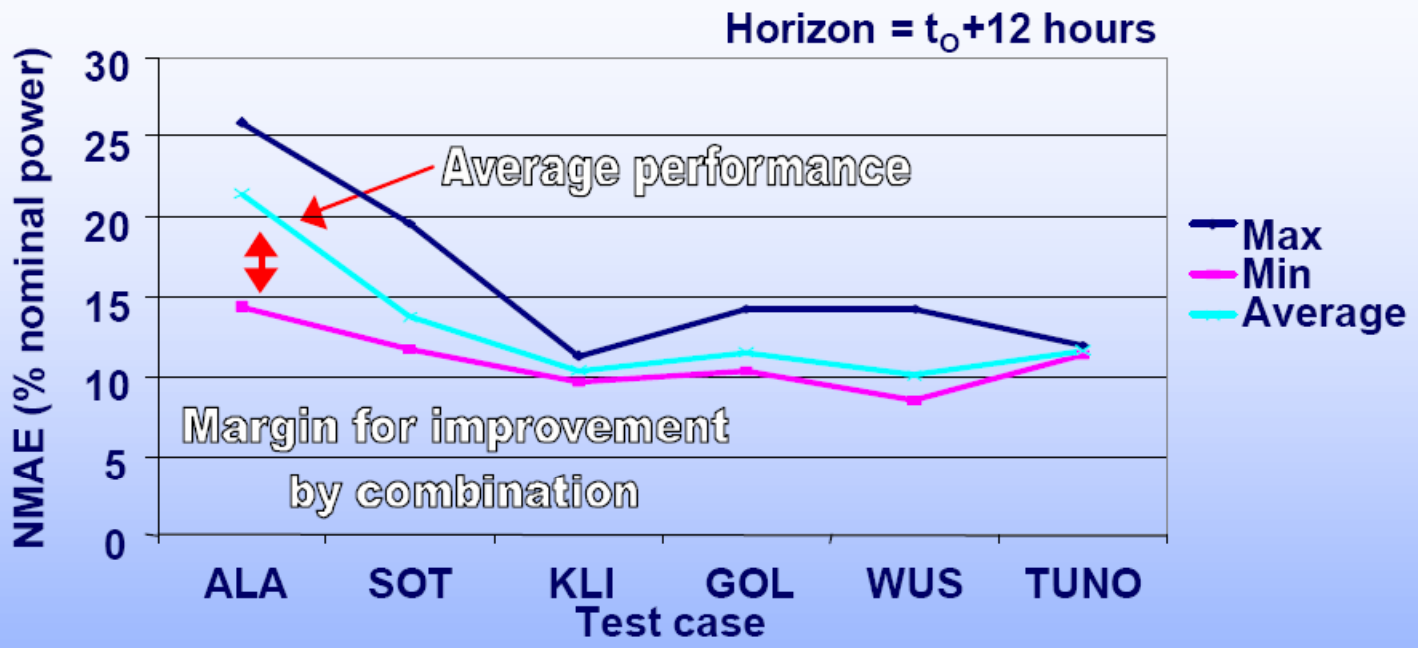
F Offshore (Tuno Knob-DK)



- **Low level of prediction errors.**
- **Performances of expert models are close.**

NMAE: Normalized Mean Absolute Error

Performance vs wind farm



Best 12 hours forecast for each test case					
ALA	SOT	KLI	GOL	WUS	TUNO
M2	M3	M4	M5	M3	M4

- **Absolute deviations (% of nominal power) range between 10% and 21% for +12 hours forecasts.**
- **There is a margin for improvement by combination of the forecasts generated by the different prediction models.**

Capacity Value

- To what extent have European utilities been assigning a *capacity value* to wind and how has this been reflected in long-term planning, i.e. have utilities actually acknowledged a reduction in their peak generating requirements because of the introduction of wind, or have such capacity value determinations been primarily a statistical phenomenon with no practical implications for short-term operations?

  - UCTE typically assigns no capacity value to wind;

  - Europe is deregulated without capacity markets (only Ireland is considering a capacity market) – hence capacity value is often more an academic/political discussion (European research results = Capacity value close to capacity factor)-> TSO/utilities are often not responsible for security of supply;

  - Ireland: 20 % capacity value (CF in Ireland = > 30%);

  - Comment: Danish discussion on winter peak

Integration Cost

- Have any innovative strategies for minimizing the costs of wind integration emerged on the continent? Have any of them involved cooperation among multiple utilities or the development of markets for new products and services?
  - Regulation Markets (under development in central Europe: should be open to different countries to reduce market power issues);
  - Open regulation markets to additional generation sources (Denmark: DG – may be wind)

Thanks you for your attention