# Continental Wind Resource and Variation

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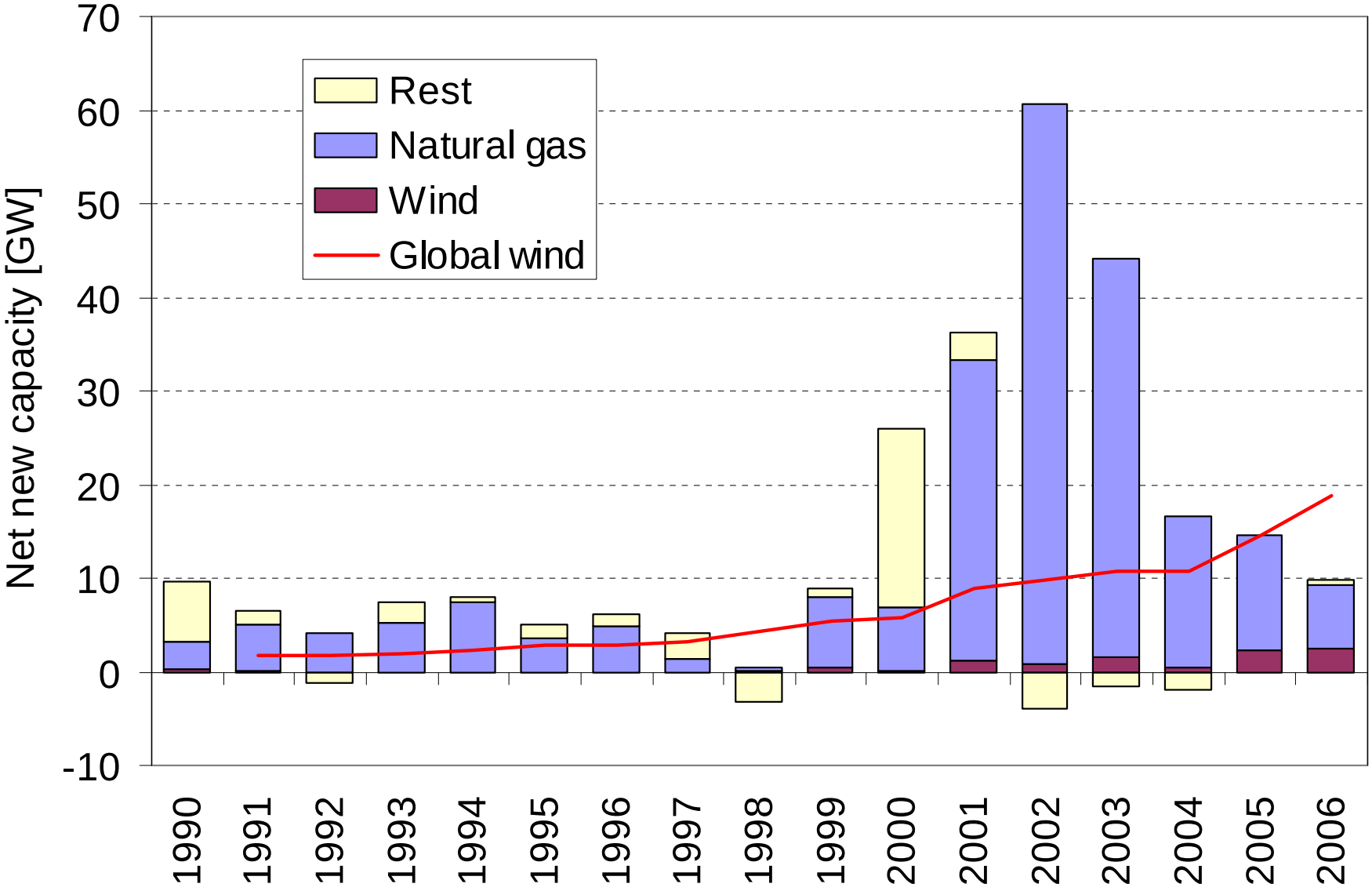
- Some estimates on wind resources
  - Problems of global assesments
  - Closer look at local scale
  - US
- Variation in wind power production at continental scale
  - What does variation mean
  - Assessing variation
  - Implications of smaller variation

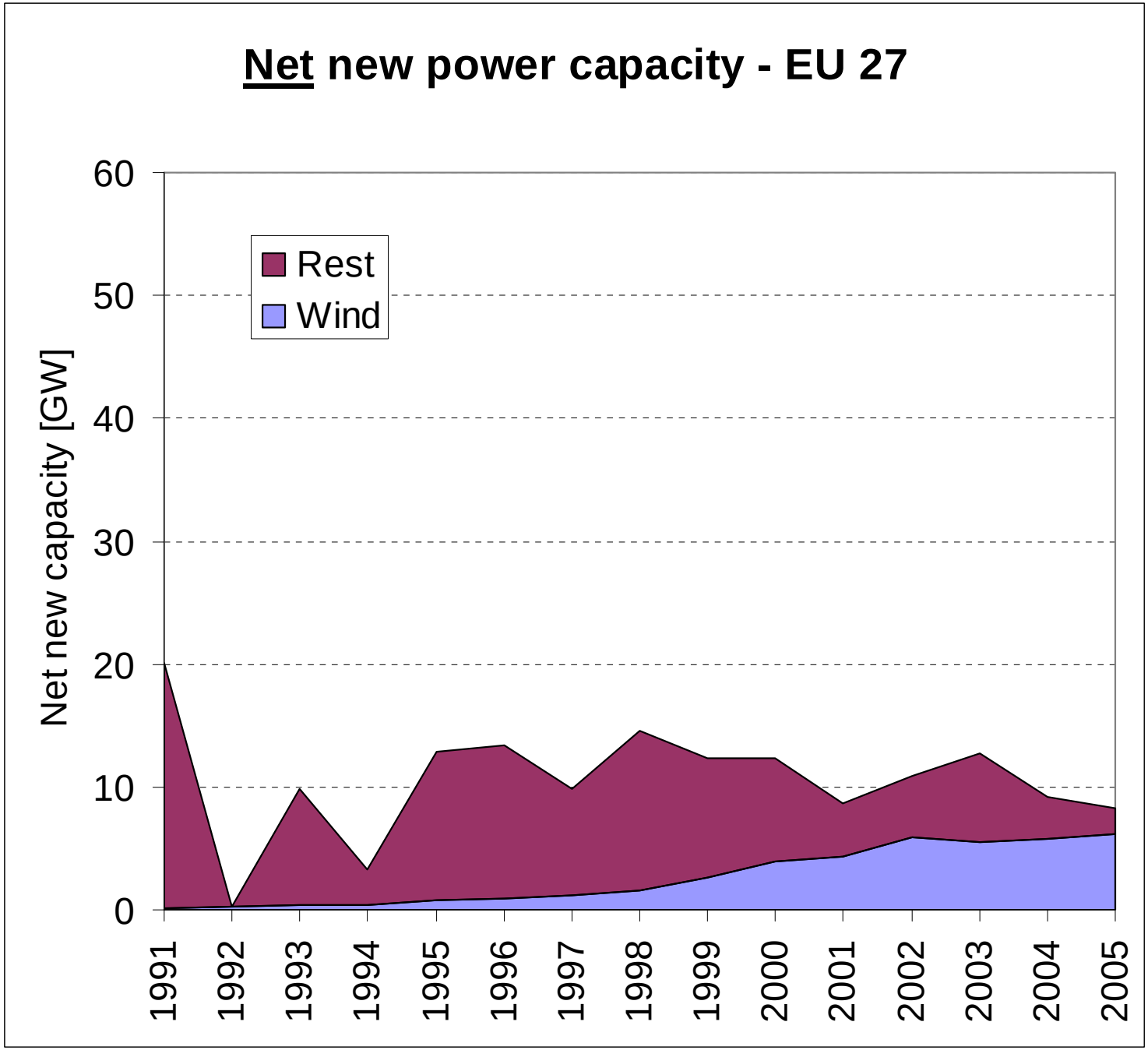
# A disclaimer and some rationale

- Exercise on what could be possible, not a claim what will happen or what is likely to happen
- Actual implementation will depend on the competitiveness of competing options
  - Future costs of wind vs. other power producing options
  - Building more transmission lines to smooth wind power output vs. dealing with the variation on more regional scale
- Trends that are making wind more competitive source in the future:
  - Restrictions on fossil fuel resources
    - Higher prices & volatility
    - Cost of GHG mitigation with CCS high
  - Wind and solar resource is very large
    - No fuel cost à reduced risk
    - Not fully mature à costs will come down
    - Good sites already competitive

# *Net* new power capacity in USA




EIA Annual Energy Review 2006 / GWEC

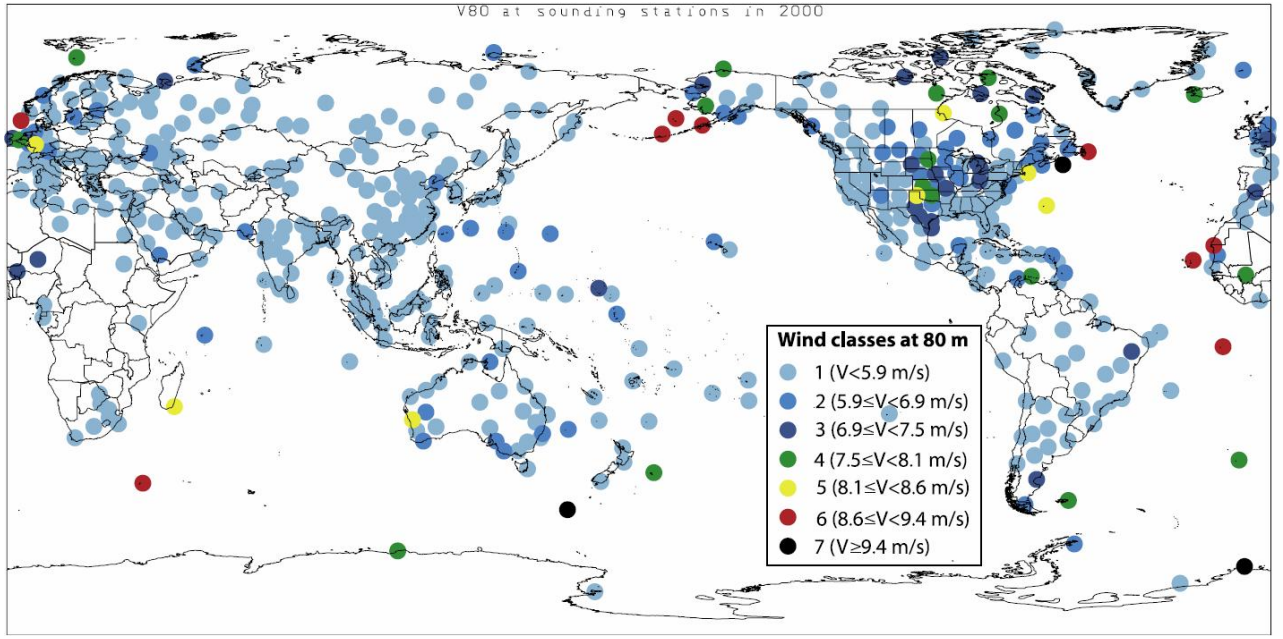


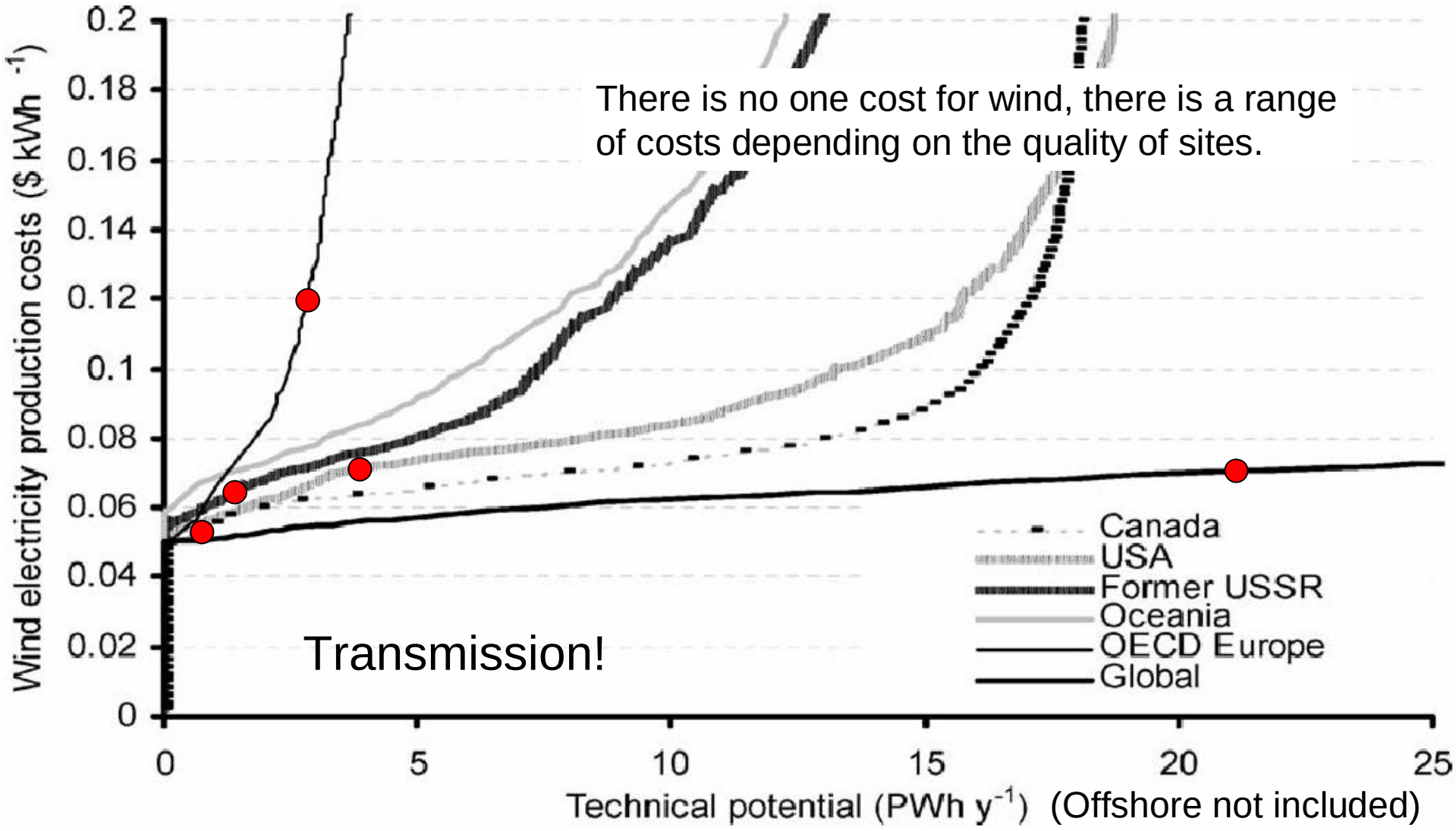

EIA Annual Energy Review 2006 / GWEC

# Archer and Jacobson 2004 @ Stanford

- At 80 meters class 3 wind sites (>6,9 m/s)
- 72 TW à 54.000 Mtoe à 2260 EJ
- ~10 times global primary energy consumption
  (when including the low primary energy consumption of wind power)
- Conservative methodology (acknowledged)
  - Example: Mostly extrapolated data from 10m: 10m stations often located at adverse places à too low wind speeds
- 80m vs. 100m
  (future turbines

  will be built higher)

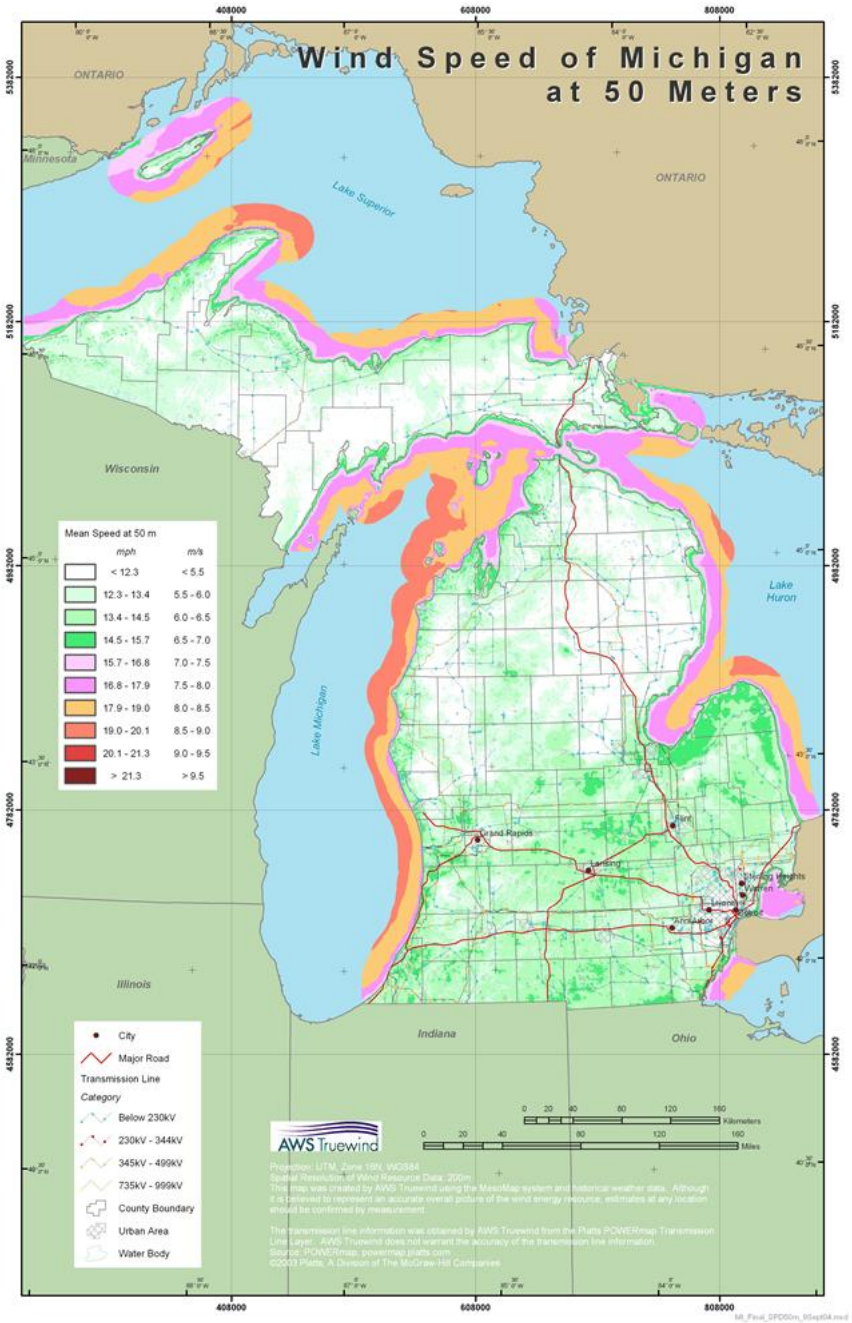





● Wind production equals 2002 electricity consumption in the region

Global resource estimate smaller than in the Stanford 2004 study

Hoogwijk, Vries & Turkenburg 2004



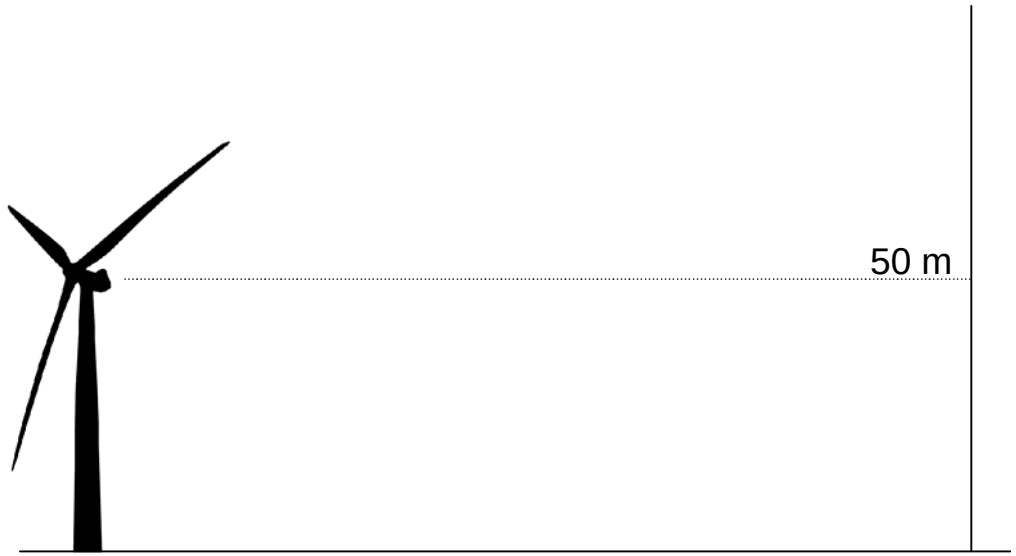

Source: AWS Truewind/NREL

# Large increase in resources when going higher

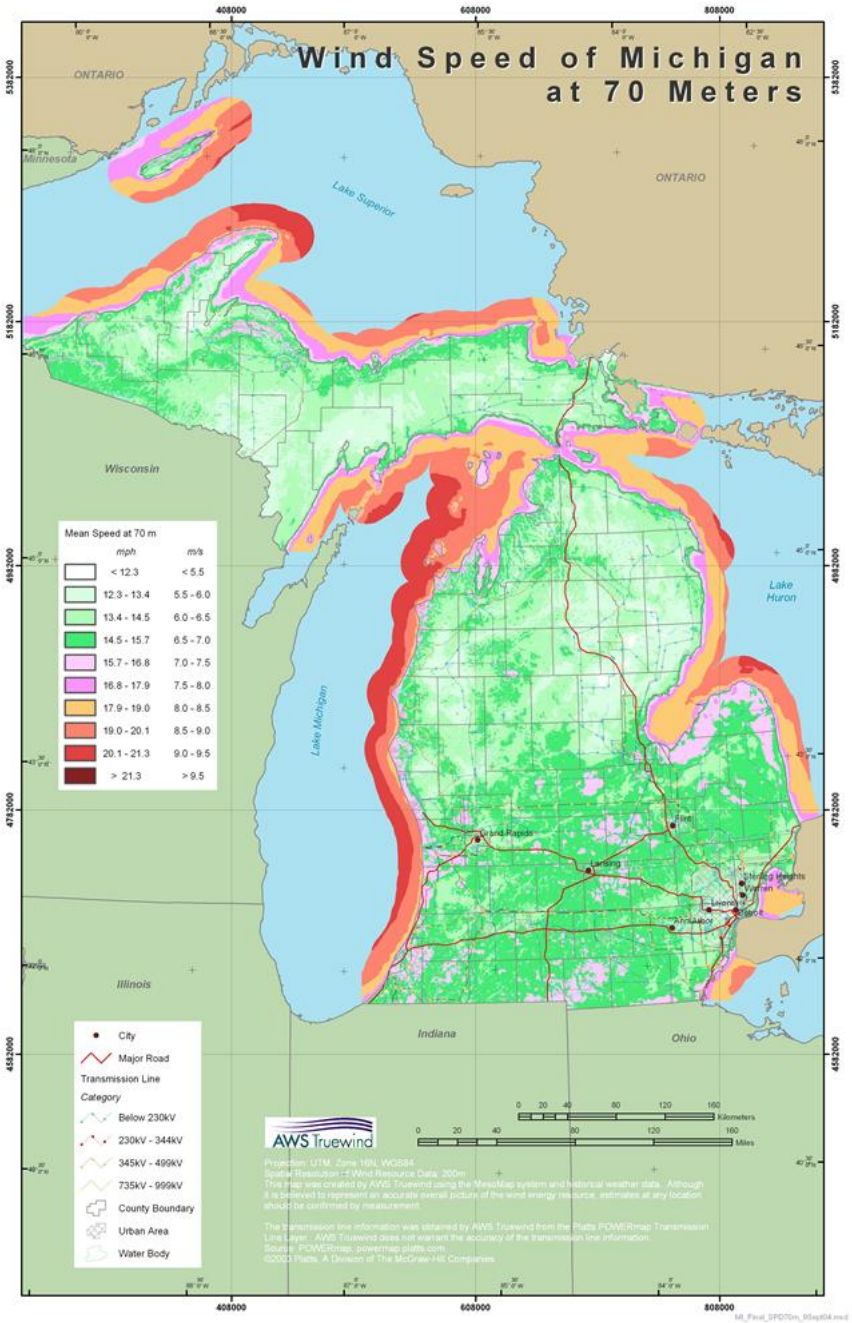
6 m/s à 7 m/s: +25-30% increase in prod.
7 m/s à 8 m/s: +20-25% increase in prod.

| **Color** | **Average WSpd** |
|---|---|
| Green | 6.5-7.0 m/s |
| Light purple | 7.0-7.5 m/s |
| Purple | 7.5-8.0 m/s |
| Orange | 8.0-8.5 m/s |

Reasonable production when >7 m/s




600 kW
1997-98

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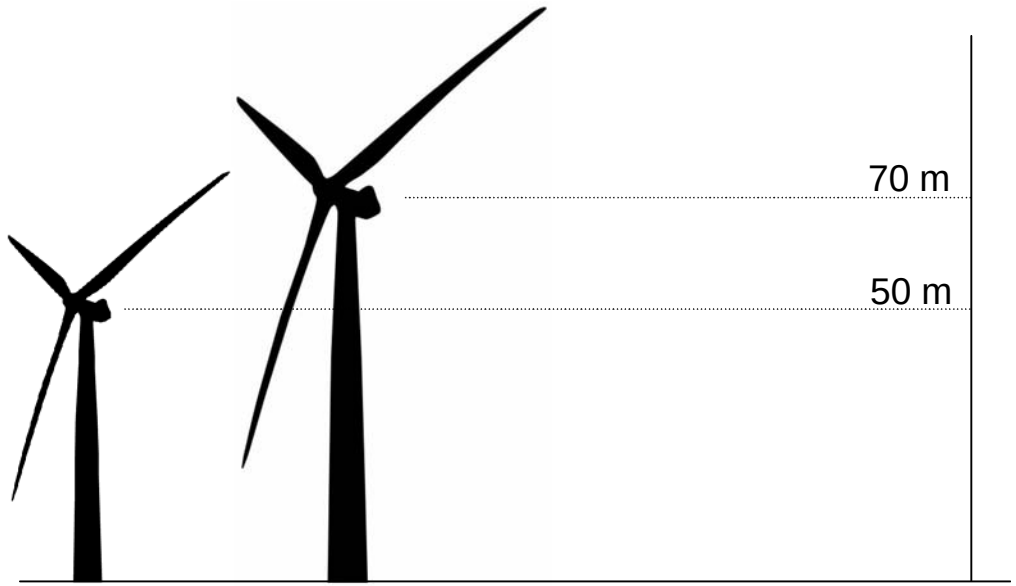
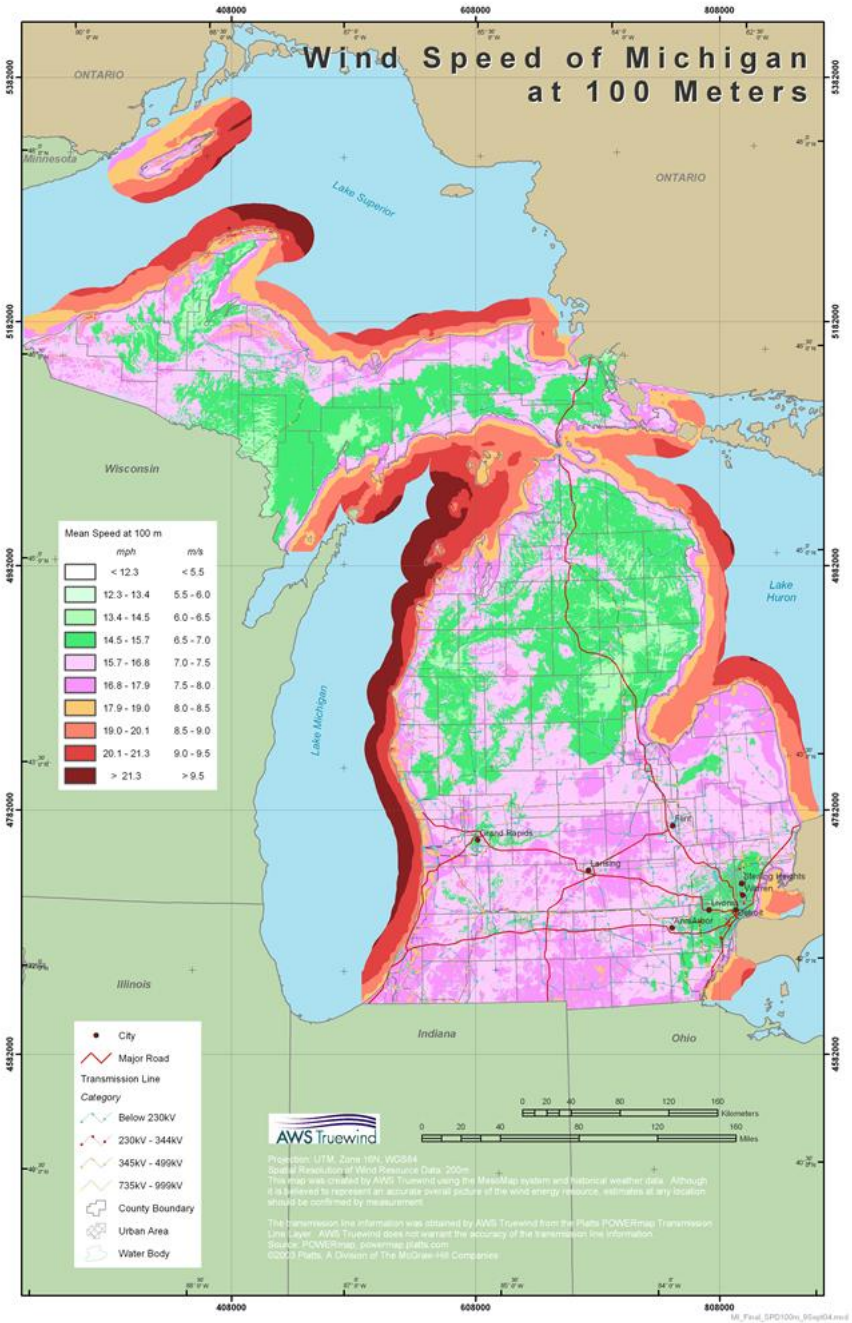



600 kW
1997-98

1.5 MW
2006

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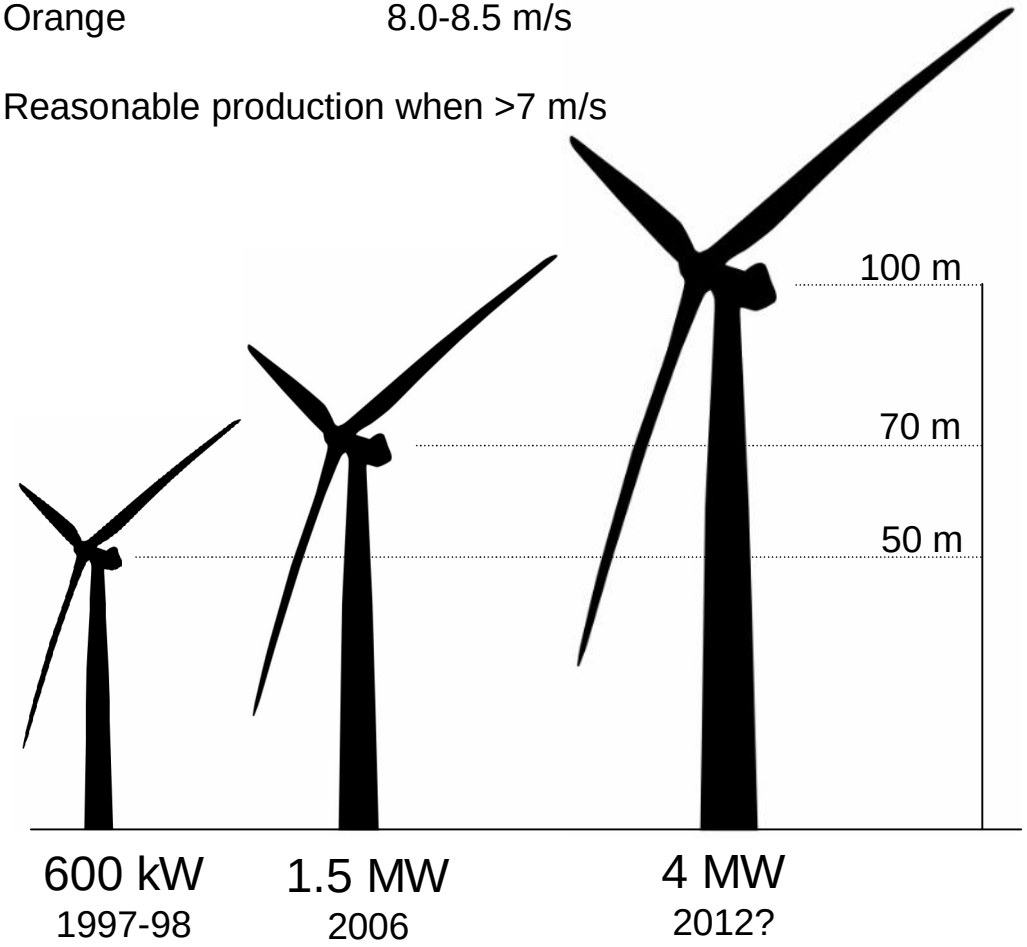
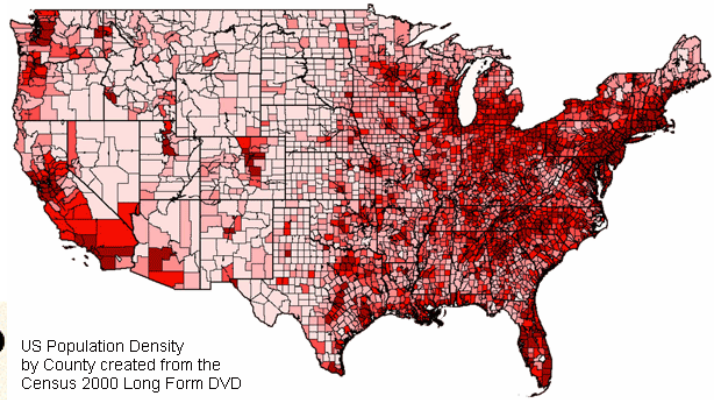


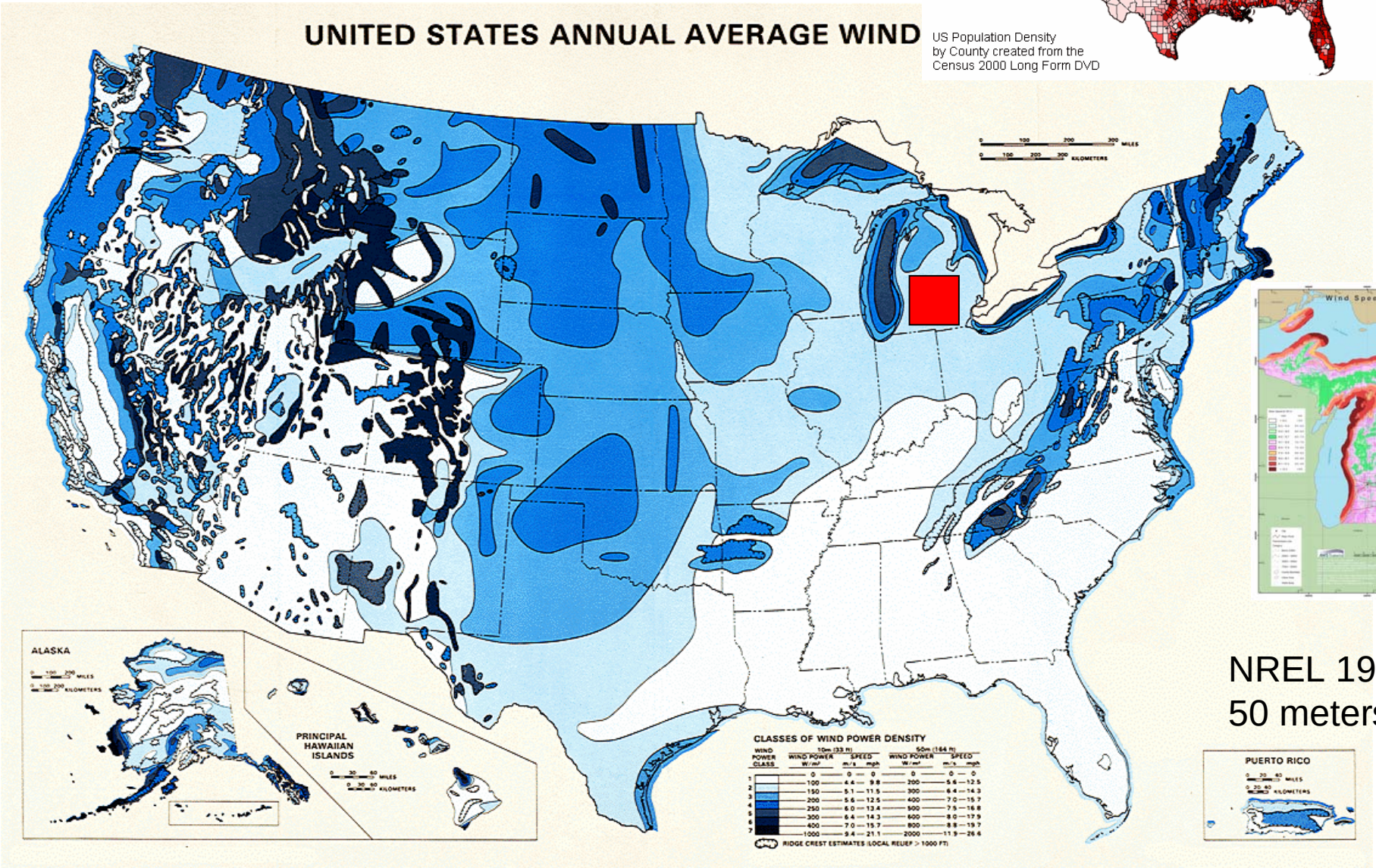
200 km x 200 km, 10 MW/km$^2$, 2800 h/a

1120 TWh/a

US electricity production 2006: 4060 TWh



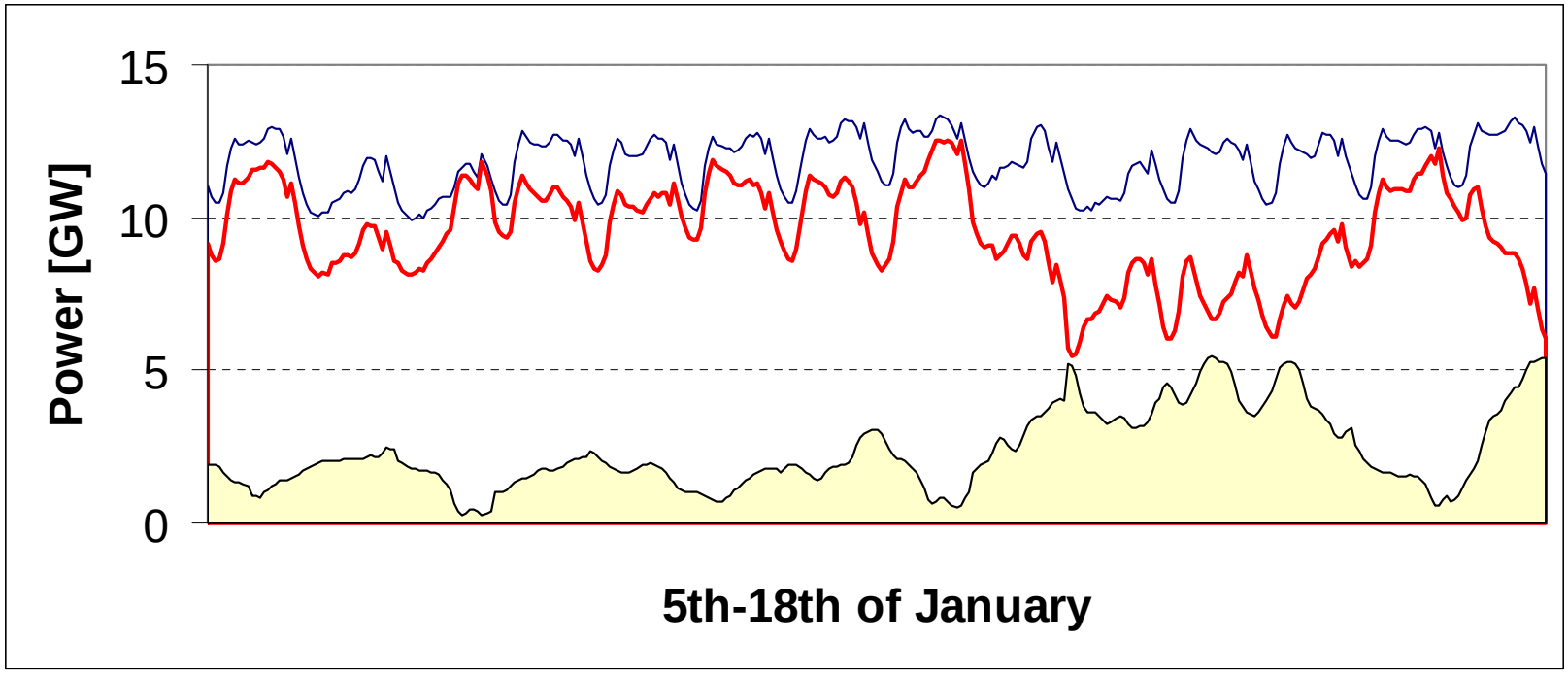
US Population Density
by County created from the
Census 2000 Long Form DVD



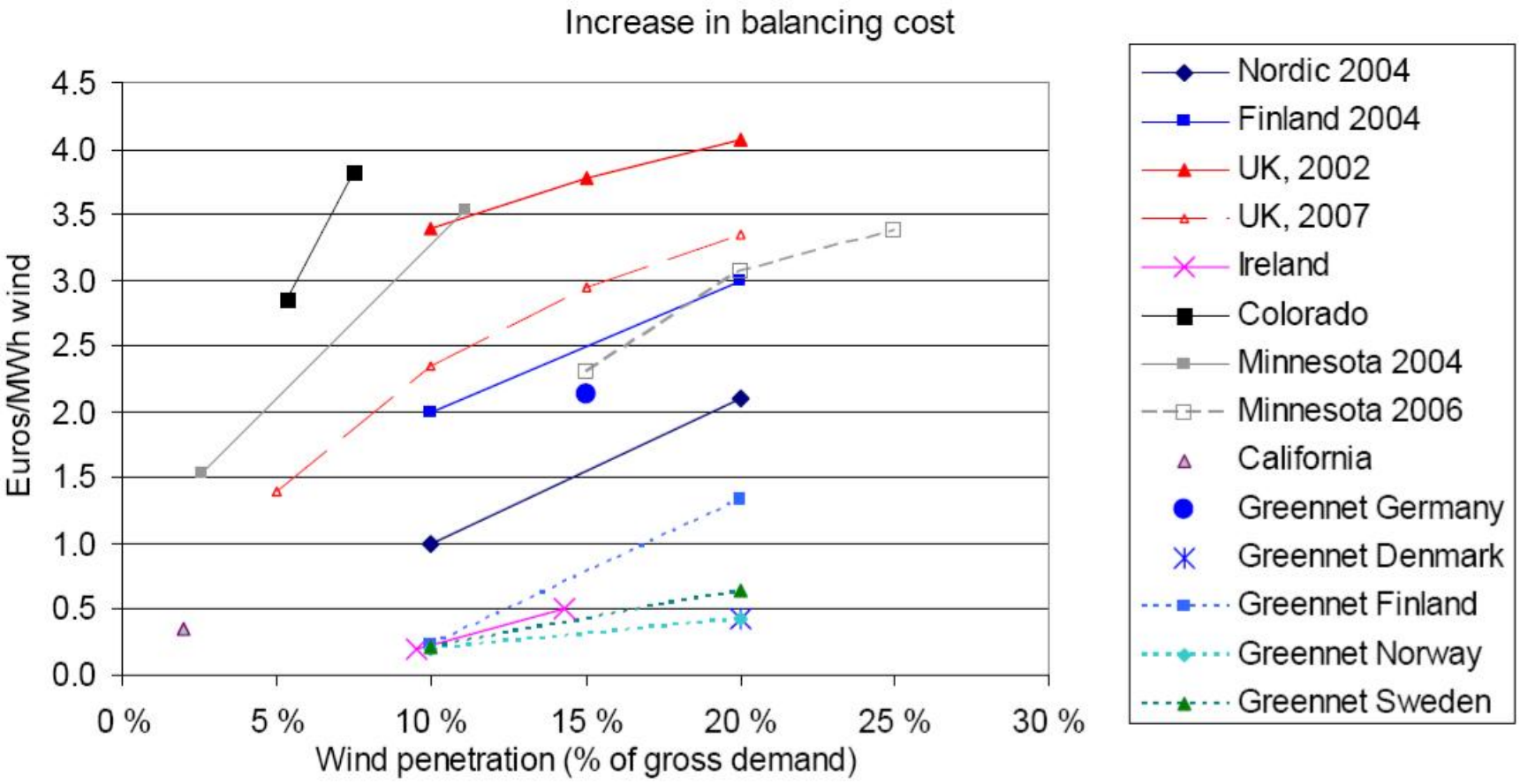


NREL 1985
50 meters

# Additional Variation from Wind on Top of the Variation in Consumption




Blue curve is the hourly electricity demand in Finland during two weeks. Shaded area is upscaled wind power production (20% energy penetration). Red curve is demand minus wind, which is what the rest of the power plants have to deal with once there is that 20% of wind.



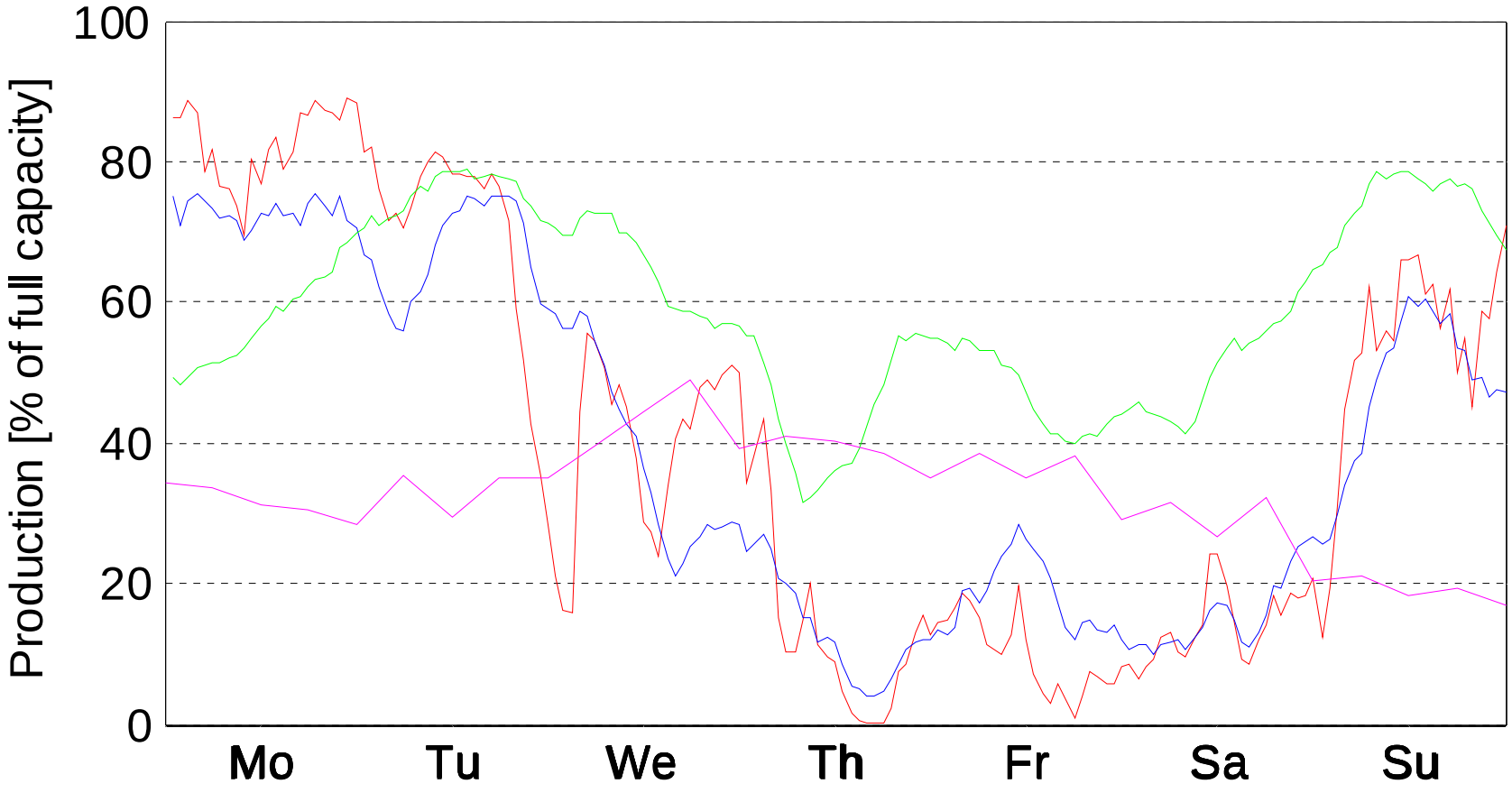

Additional cost from balancing the system with more variable production.
This should be added on the top of the wind power production costs of around 40-60 €/MWh.

Holttinen et al 2007 – Design and operation of power systems with large amounts of wind power

# Flexibility in the power system

- Conventional power plants
- Demand side measures
- Electricity storages
- Plug-in electric vehicles
- Heat/cool pumps & storages, electric boilers
- Hydrogen production via electrolysis
- **Transmission connections**

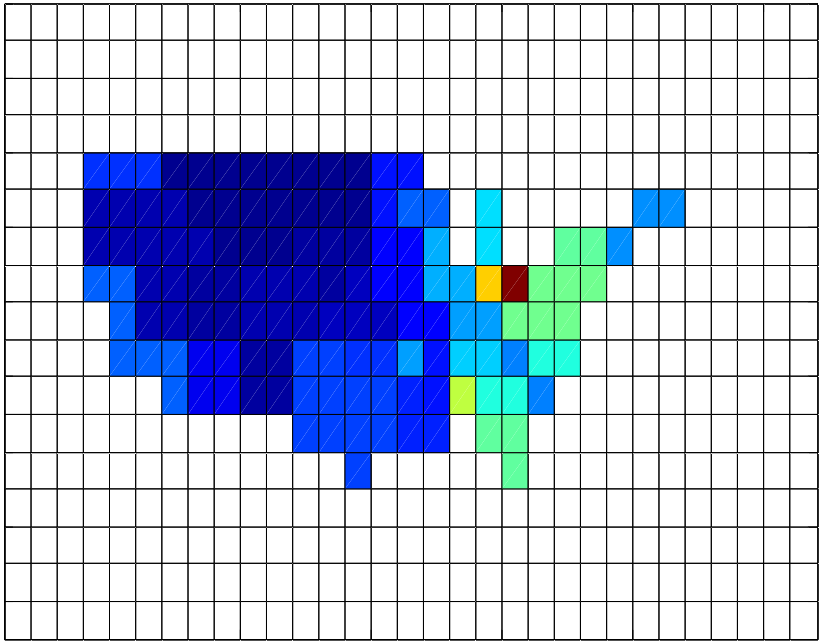
Variation in wind power production in regions of different size



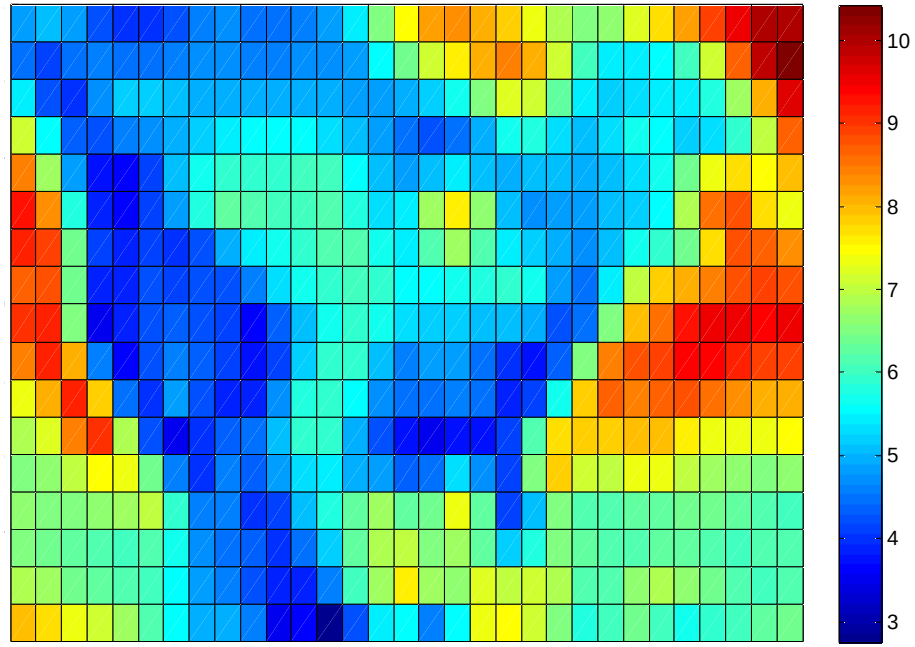

Red – small area in Western Finland
Blue – Finland
Green – Nordic countries
Magenta – Extended Europe (6-hourly data)

Data sources:
Hannele Holttinen, VTT Technical Research Centre of Finland
NCEP/NCAR Reanalysis Project

Consumption

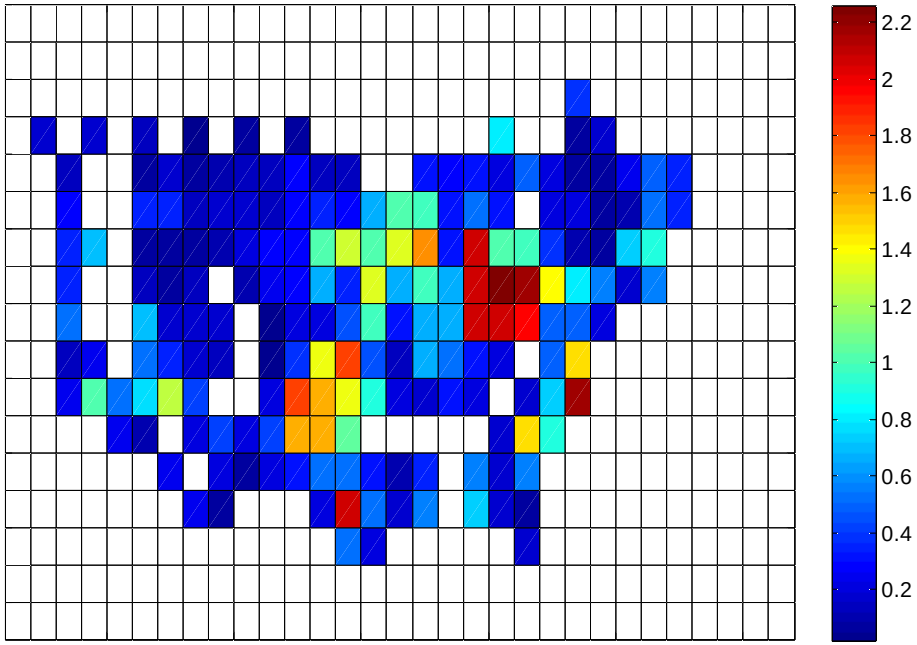


Average wind speeds




Data: NCEP/NCAR Reanalysis

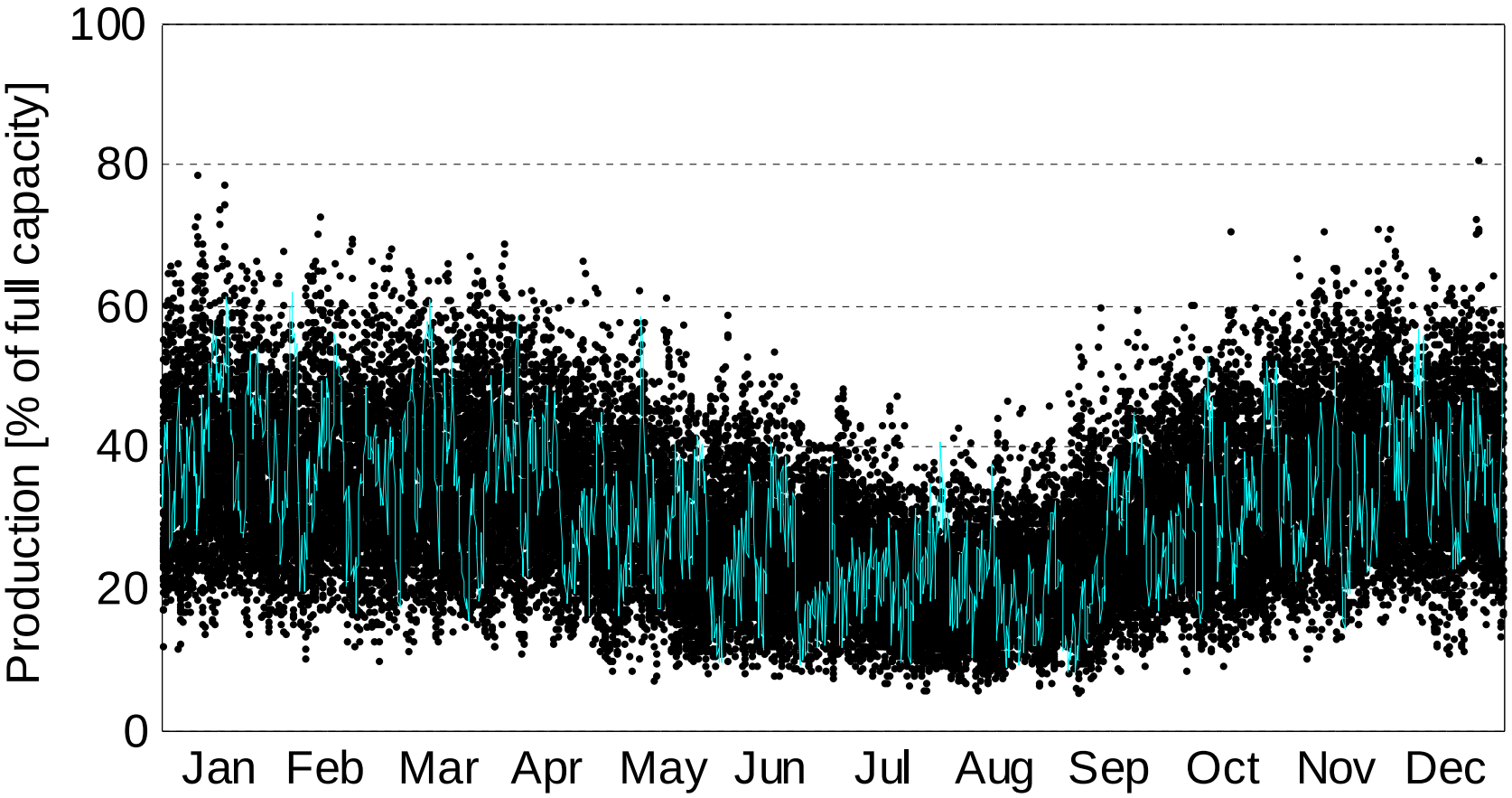
Regions with high consumptions have gotten more wind power but mostly in places with good wind speeds.



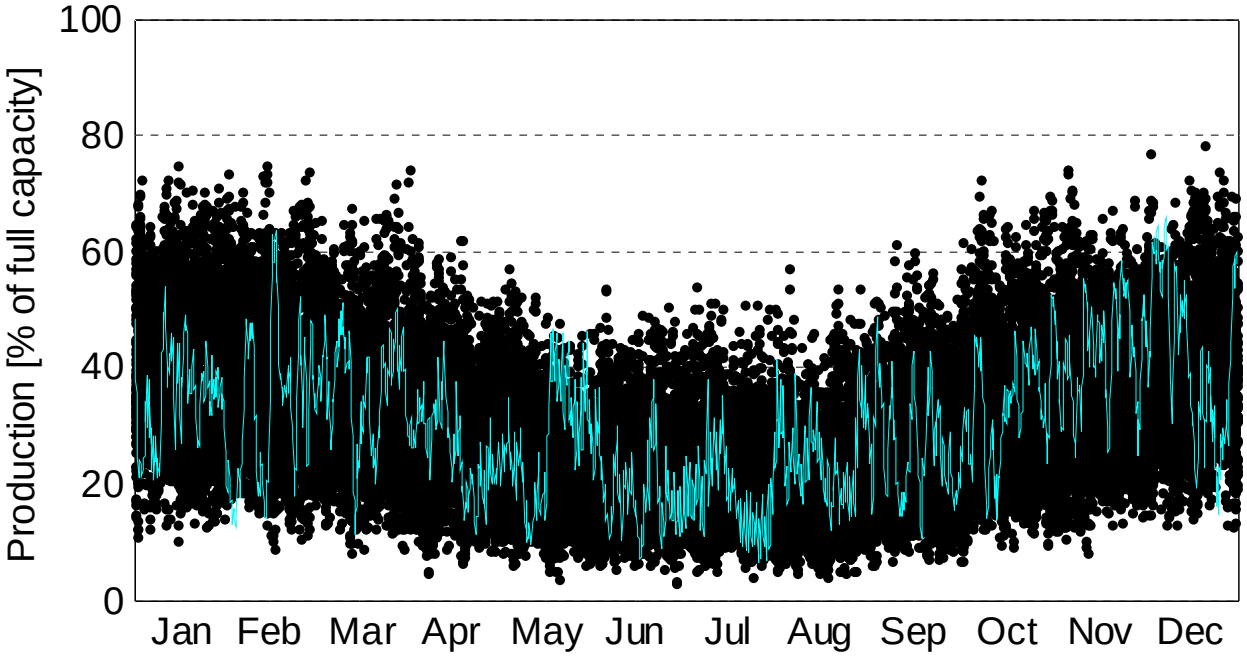

Installed wind in this exercise

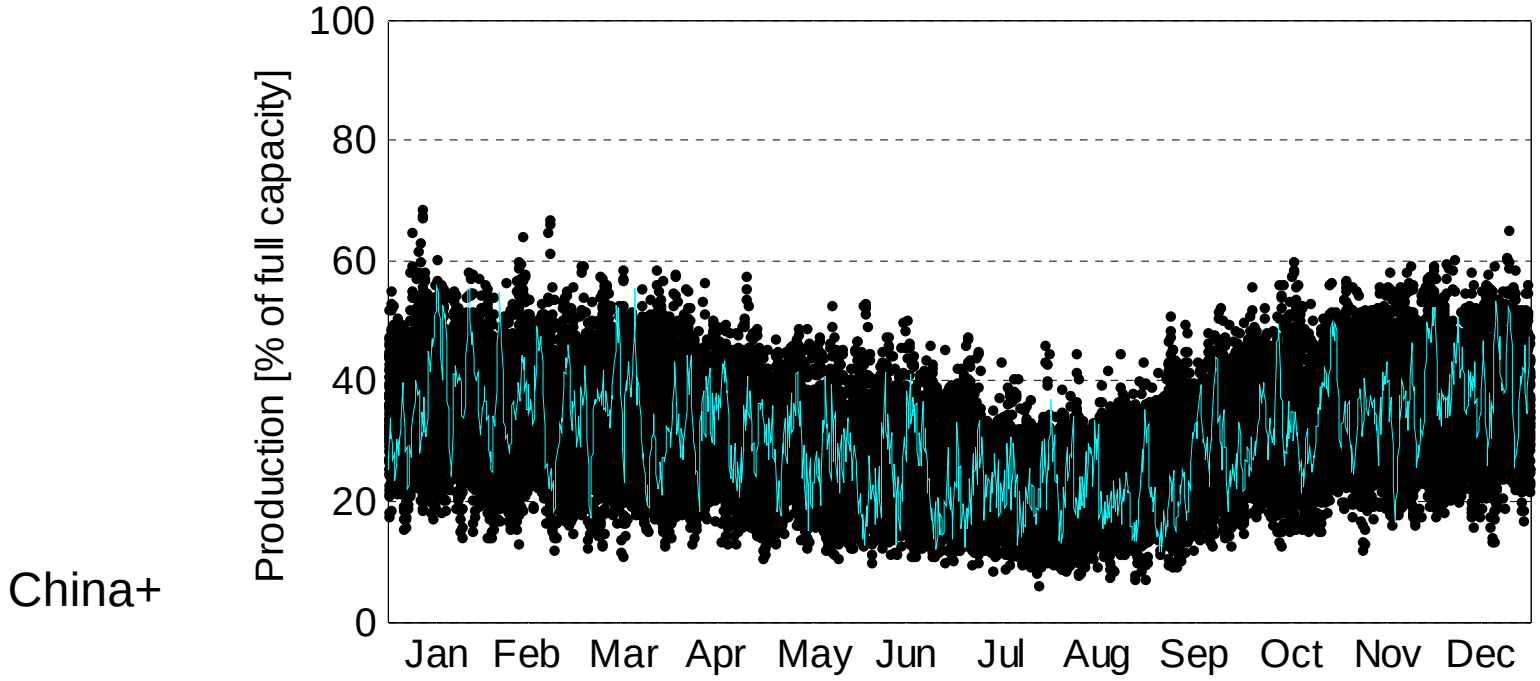
Grid size 2.5°
175-250km x 275 km

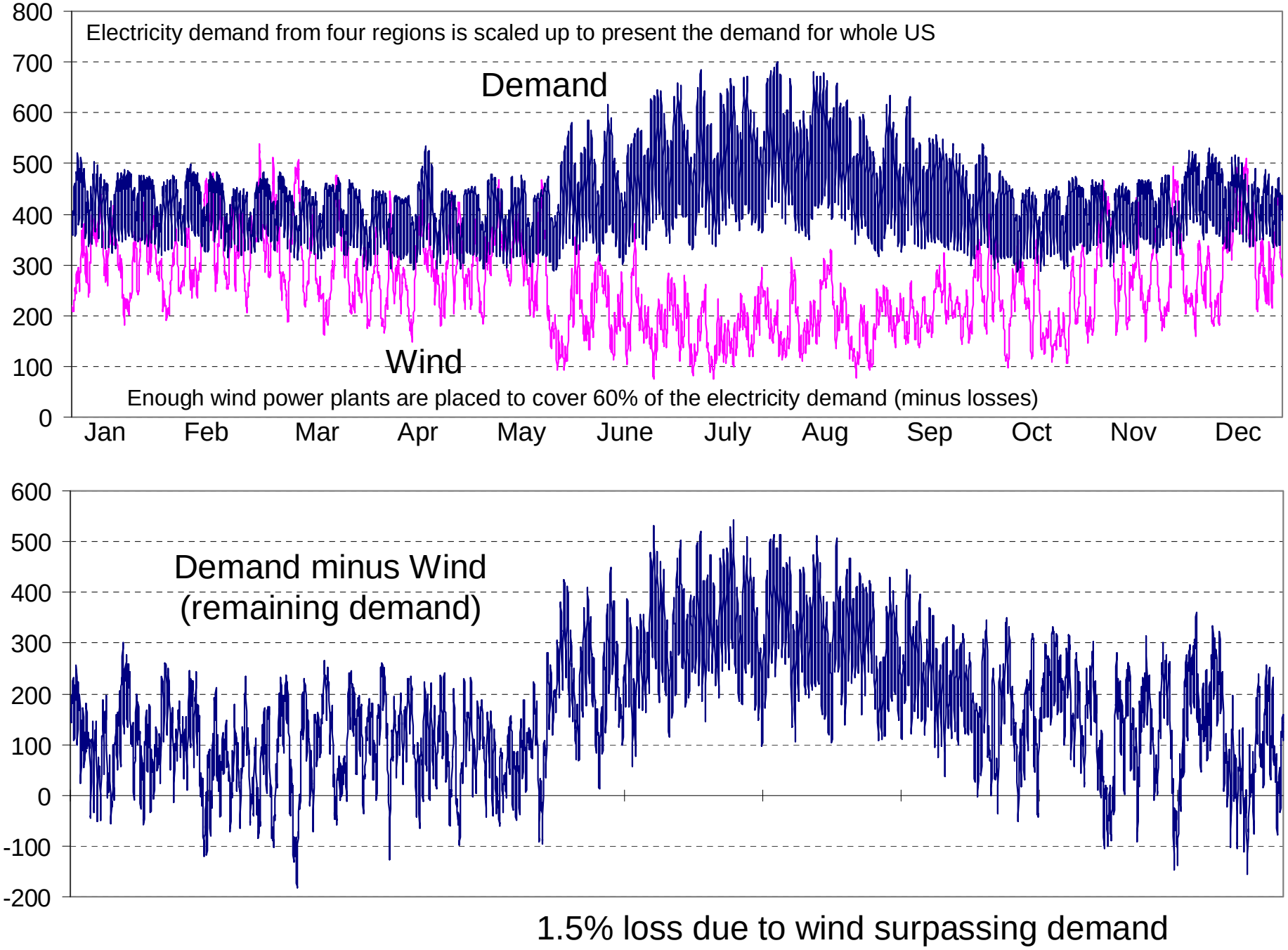
Variation in continental scale wind power production 1980-2006, US+

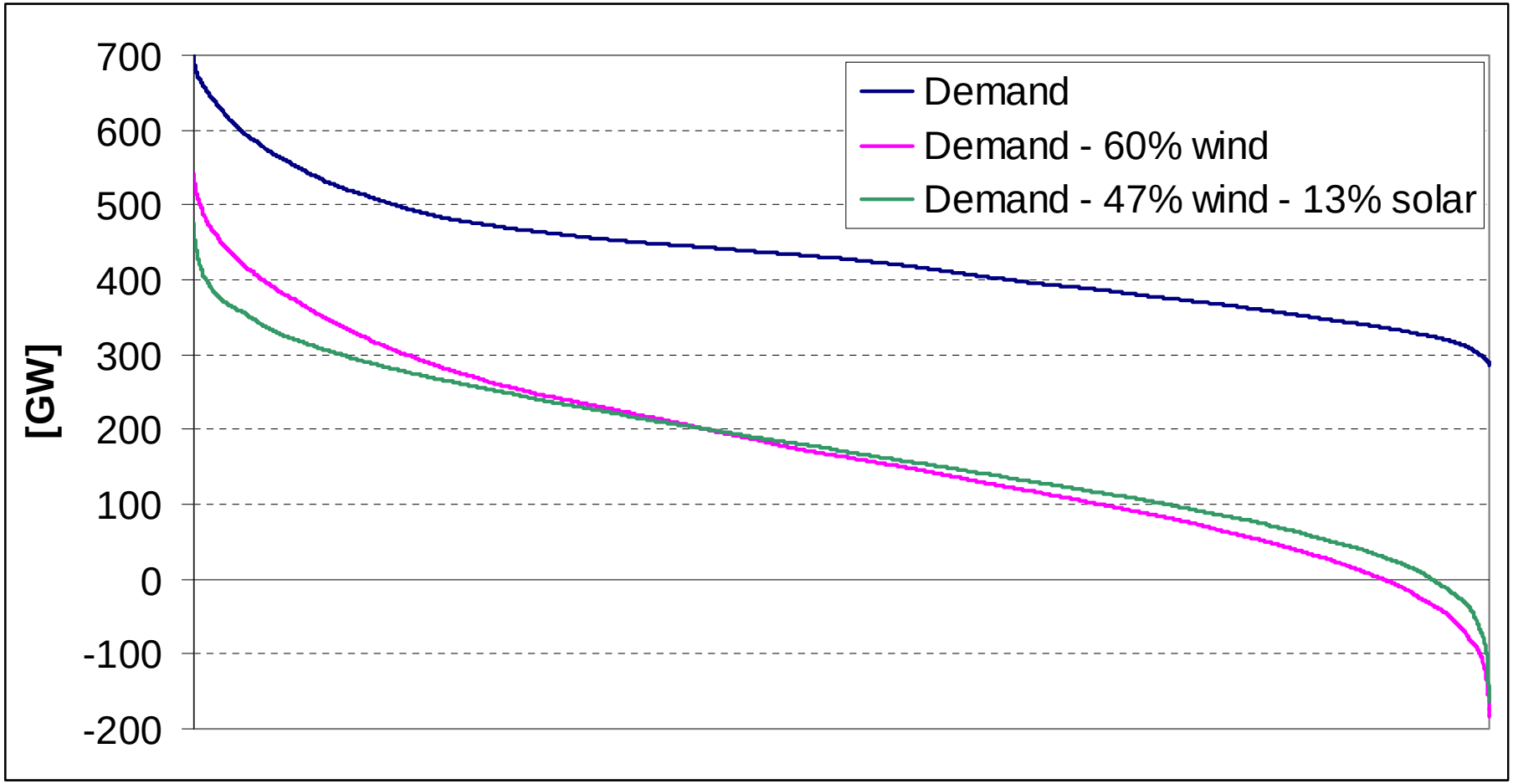



- Cyan line is year 2006, data points from 1980-2005 are dotted
- Lower-48 USA, Northern Mexico and Southern Canada **without tranmission restrictions**
- 6-hour time steps, wind data from NCEP/NCAR Reanalysis Project


Europe+
Production [% of full capacity]
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


China+
Production [% of full capacity]
100
80
60
40
20
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

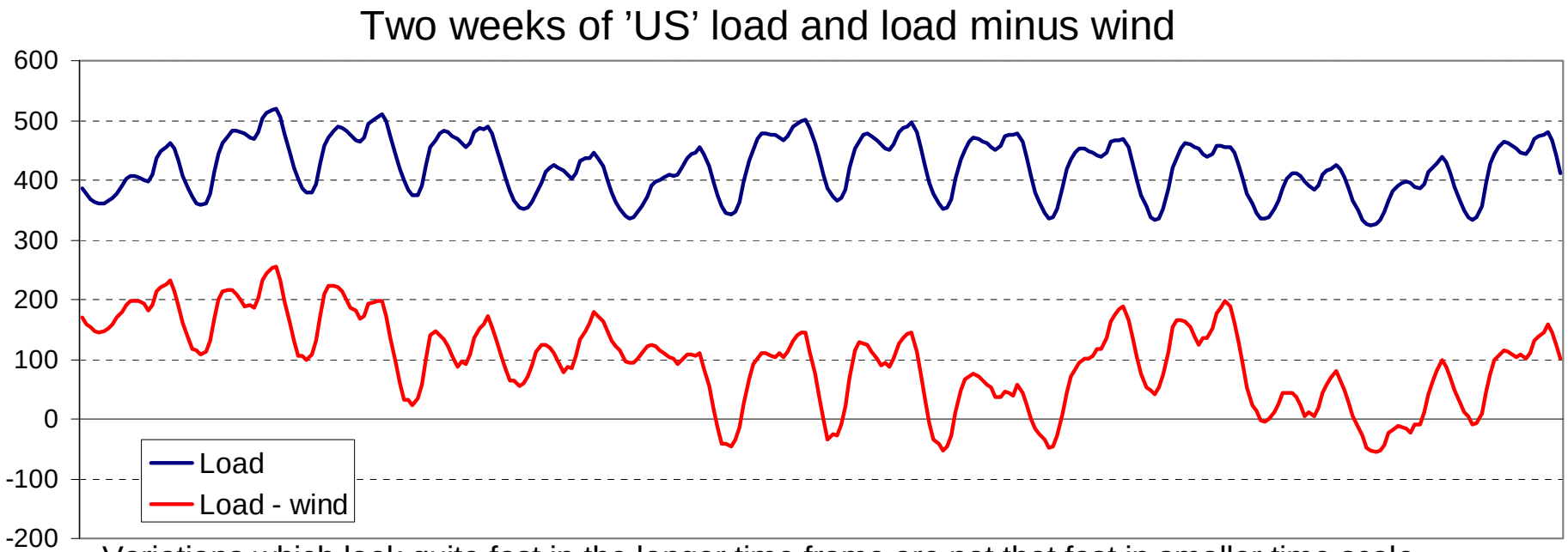

Electricity demand from four regions is scaled up to present the demand for whole US
Demand
Wind
Enough wind power plants are placed to cover 60% of the electricity demand (minus losses)
800
700
600
500
400
300
200
100
0
Jan
Feb
Mar
Apr
May
June
July
Aug
Sep
Oct
Nov
Dec
Demand minus Wind
(remaining demand)
600
500
400
300
200
100
0
-100
-200
1.5% loss due to wind surpassing demand



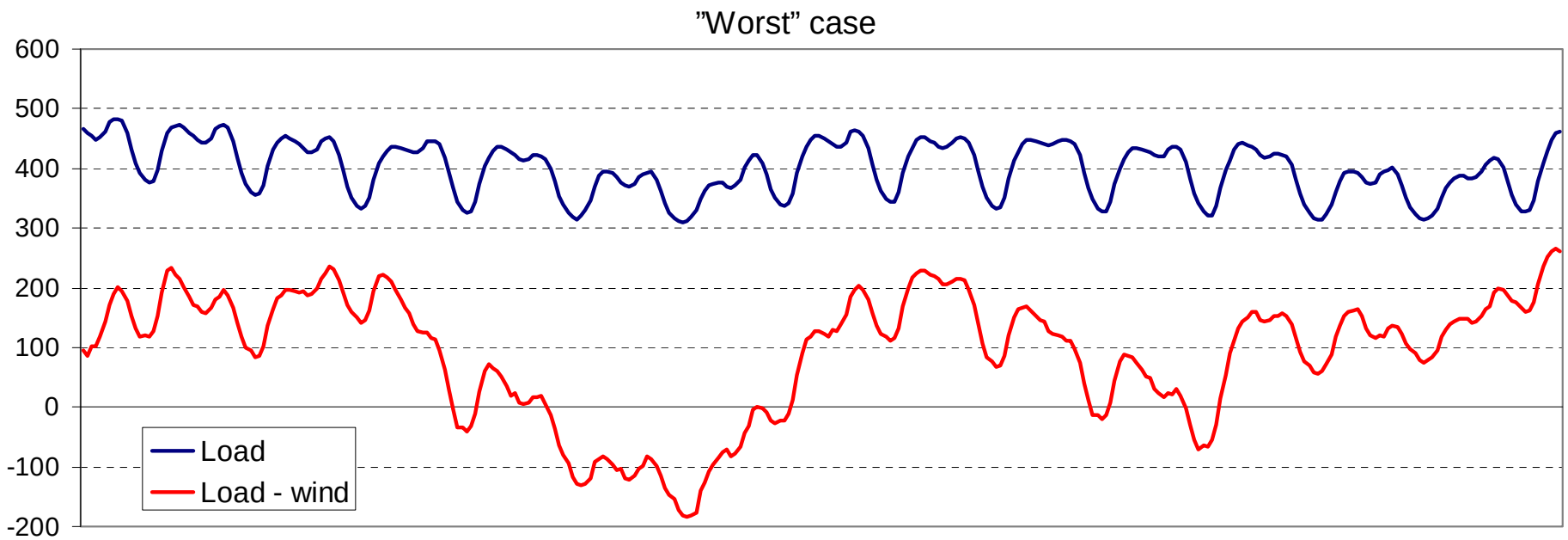

Duration curves for the previous time series
This illustrates how the system will need less baseload units and more intermediate and peak load plants, when there is more wind power.

Which system is cheaper? Will depend on capital costs of power plants and transmission lines as well as on fuel and other operational costs that include externalities.

Also a case with part of the load served with solar (very rough methodology)



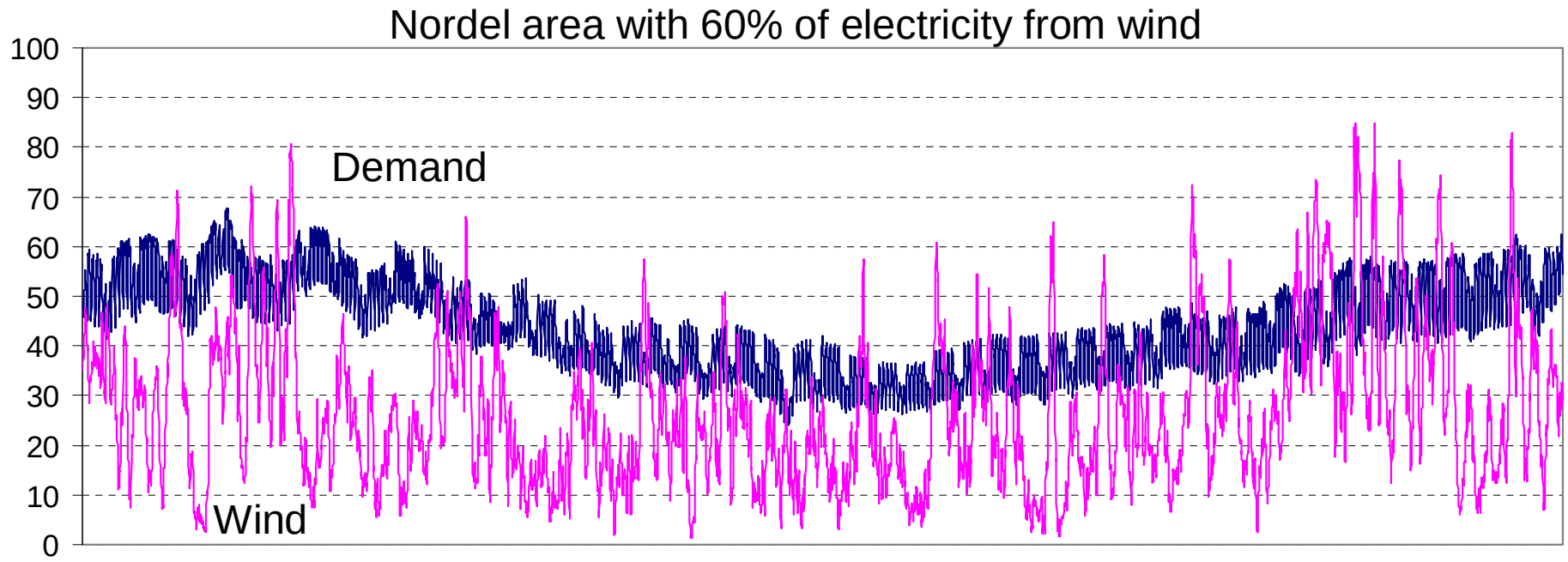

Variations which look quite fast in the longer time frame are not that fast in smaller time scale.
The rate of change is quite managable for the power plant technologies we have today.



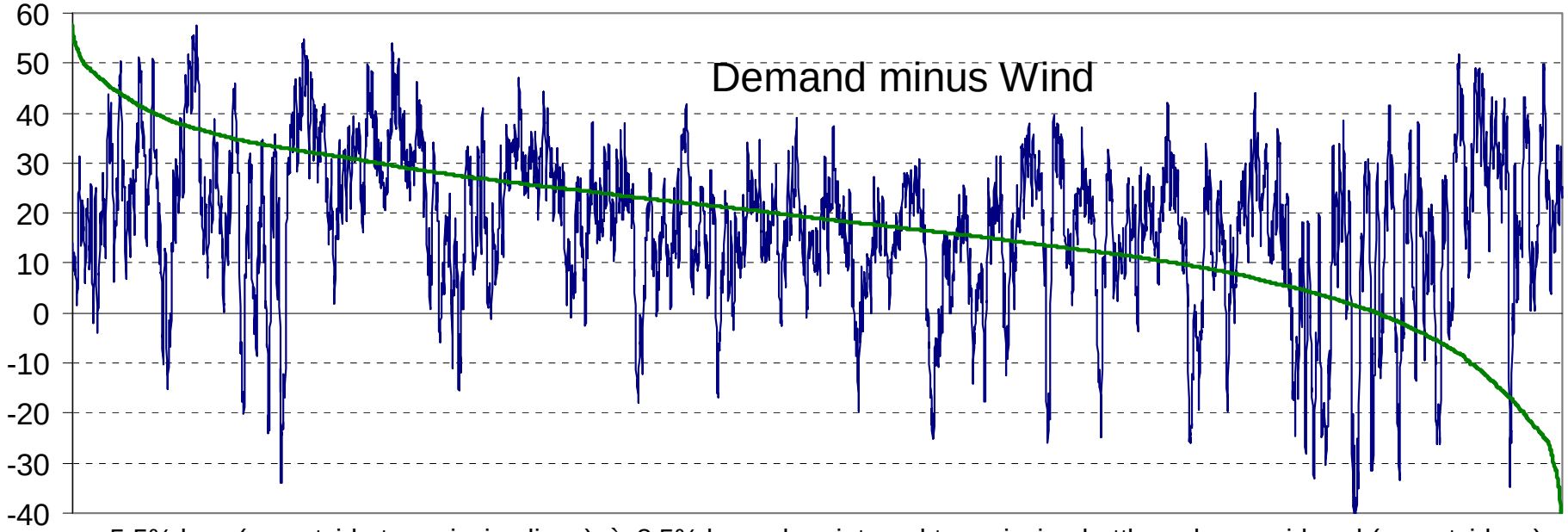
# Problems with continental data

- Local winds
- Data source is not good estimate of actual wind speeds, it only gives a good profile for times series
- Scaled values
- Placing wind production based on rough estimates of consumption and wind resources

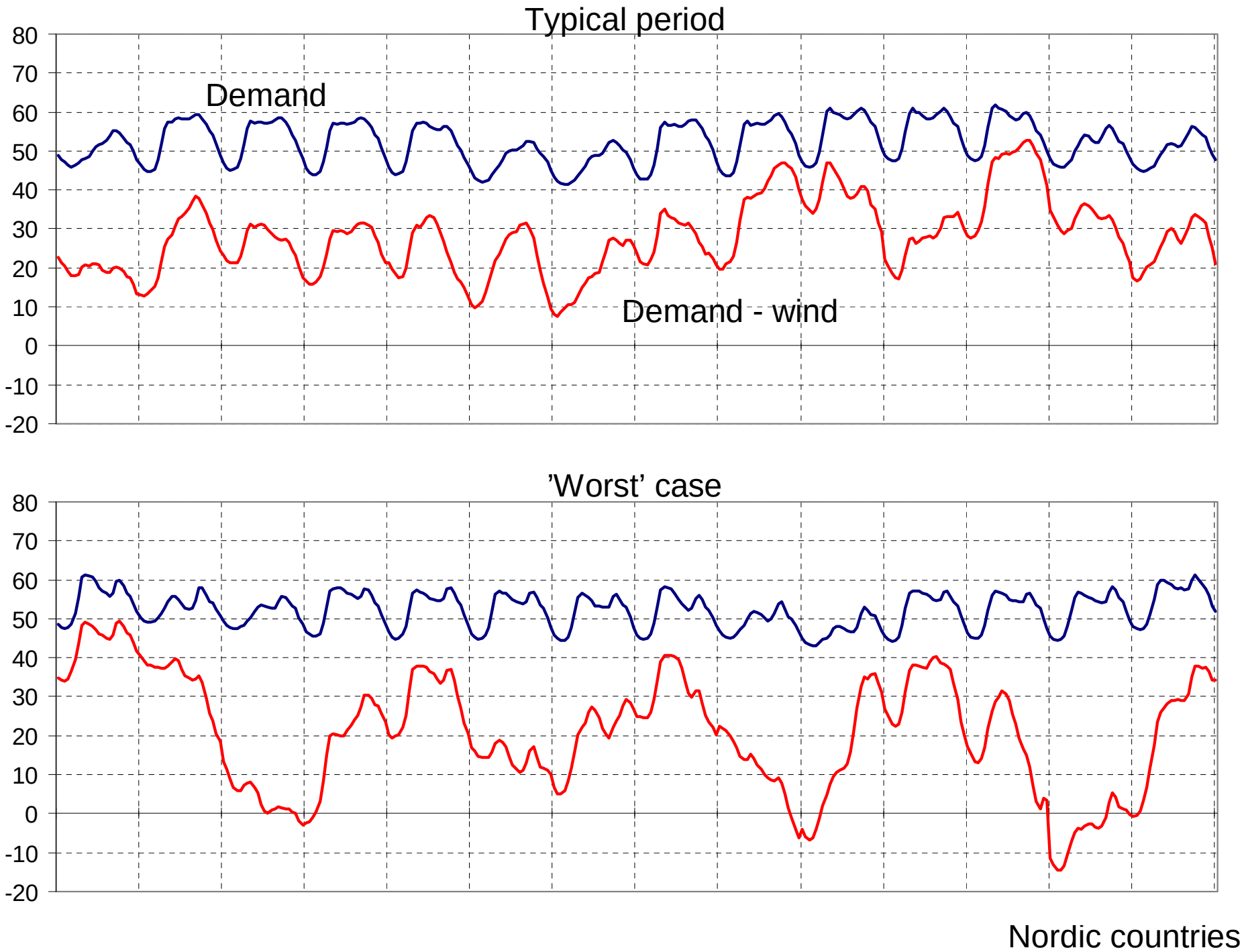
- Which is cheaper, to build a large tranmission line network to smooth wind in continental scale or to deal with more variation in more regional networks?




Nordel area: Finland, Sweden, Norway, Denmark. One market area, fairly good internal transmission connections




5.5% loss (no outside tranmission lines) à 8.5% loss when internal tranmission bottlenecks considered (no outside…)
Reduced to 7.2% with some new tranmission in key bottlenecks.
Flexibility measures listed before could also help.

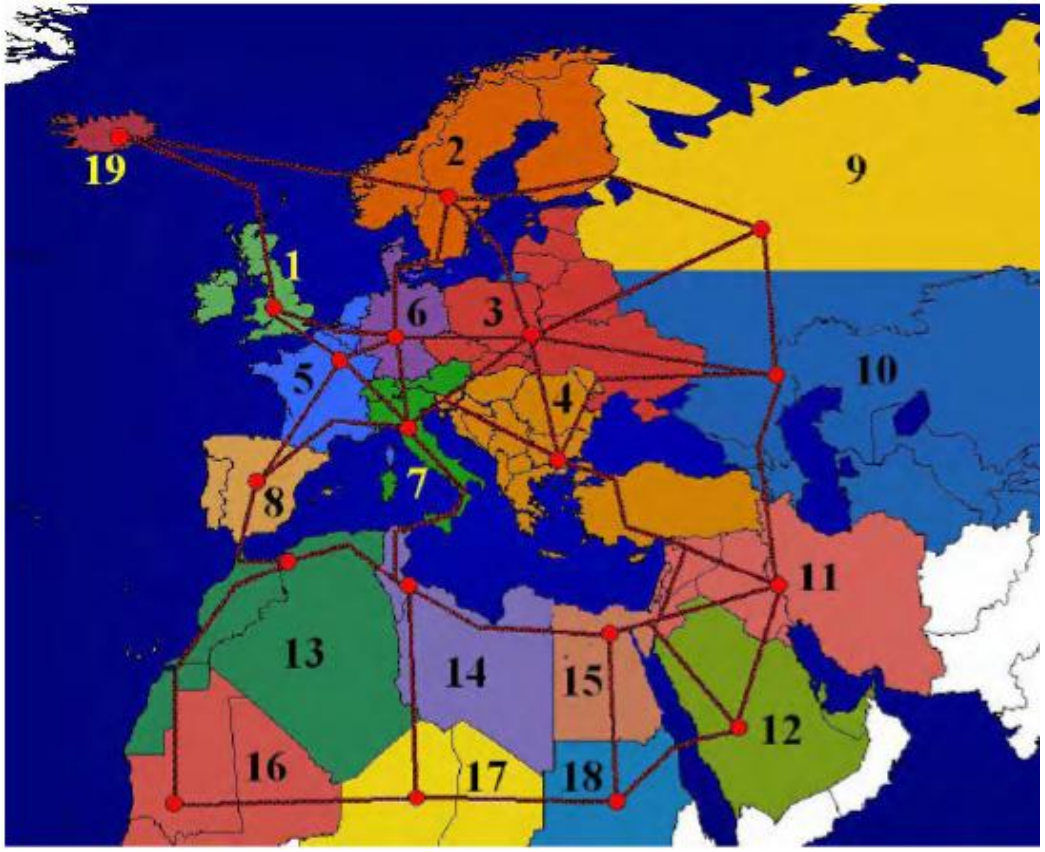

Typical period
80
70
60
50
40
30
20
10
0
-10
-20
Demand
Demand - wind
'Worst' case
80
70
60
50
40
30
20
10
0
-10
-20
Nordic countries

- Which is cheaper, to build a large tranmission line network to smooth wind in continental scale or to deal with more variation in more regional networks?

- Optimum is quite likely to use both to some extent, but to get to know the relative share of the measures, there’s a need for lot more research (I’m working on  it…)

# Other work

- Czisch, Giebel, Schmid 2007: 100% renewable system in Europe
- Czisch, Ernst 2001, ”High wind power penetration…”
- Similar results



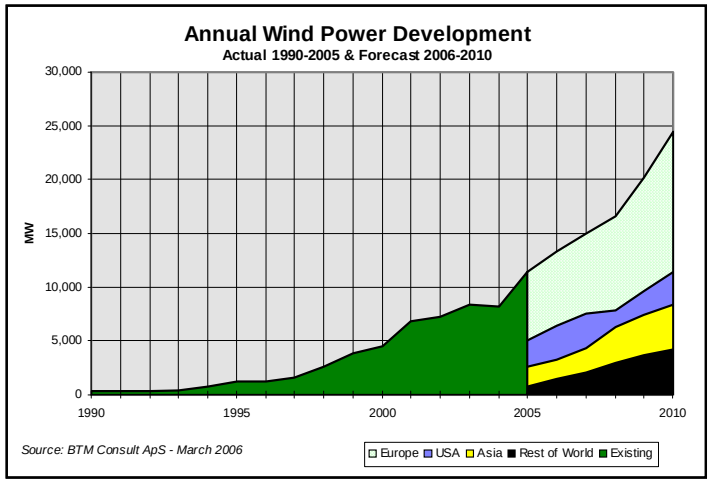
# How fast and far will wind grow? Some influencing factors.

Competition: Solar, Nuclear & CCS

Increased use of electricity in transportation and space heating/cooling: more demand and more flexibility

(International) Policy uncertainty

Large resource



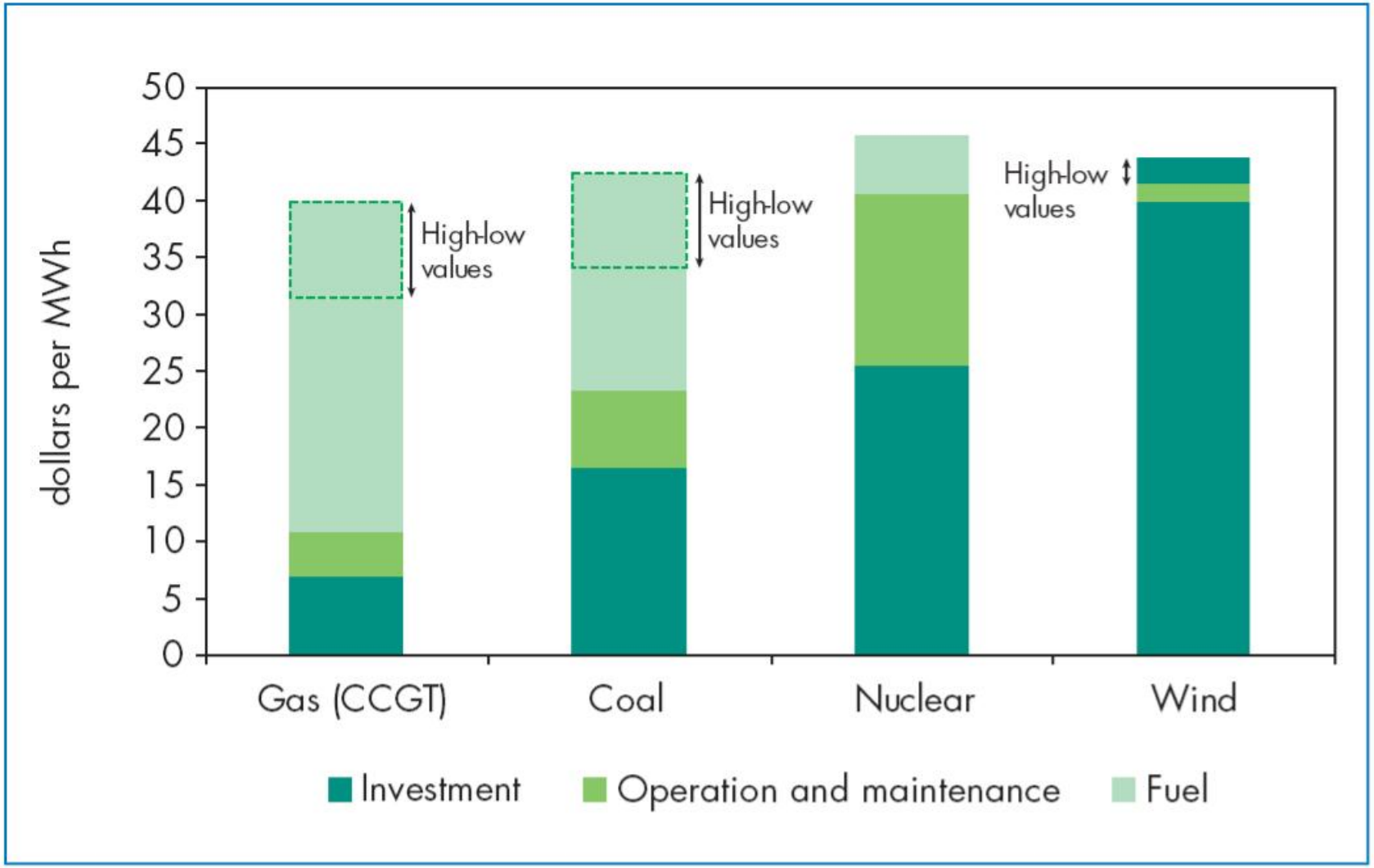

Competition: Cost of CCS & Fuel cost risk

Variability not a big problem (technical & economical issues)

# What should be done

- Wind atlases for 100-150 m
  - Modelling with dense grid
  - Calibrated on mast and sounding station data
- GIS based resource estimates
  - Resource size, location, estimated cost
  - Including transmission costs
  - Restrictions on land use
  - Land cover effects on wind power production
  - Optimatisation routines (like Jeff's CCS)
- Basis for power/energy system long-term planning
  - Building transmission for the resources is a key issue
- Reliable policy measures to promote growth!
  - Subsidies/externalities, R&D policy, market structures

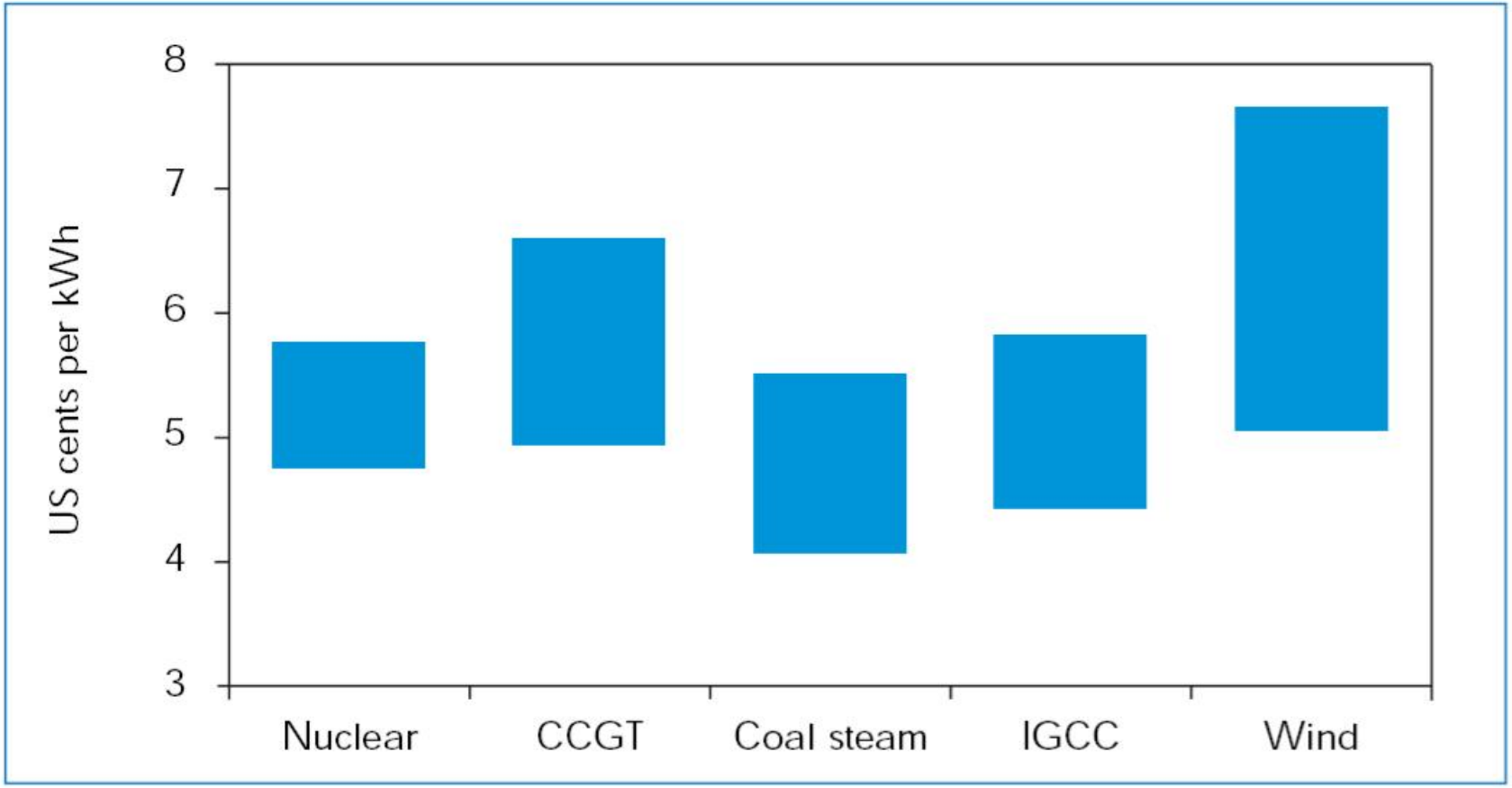
*Figure 6.3:* **Indicative Mid-Term Generating Costs of New Power Plants**




Natural gas $3 - $4.5 / MBtu

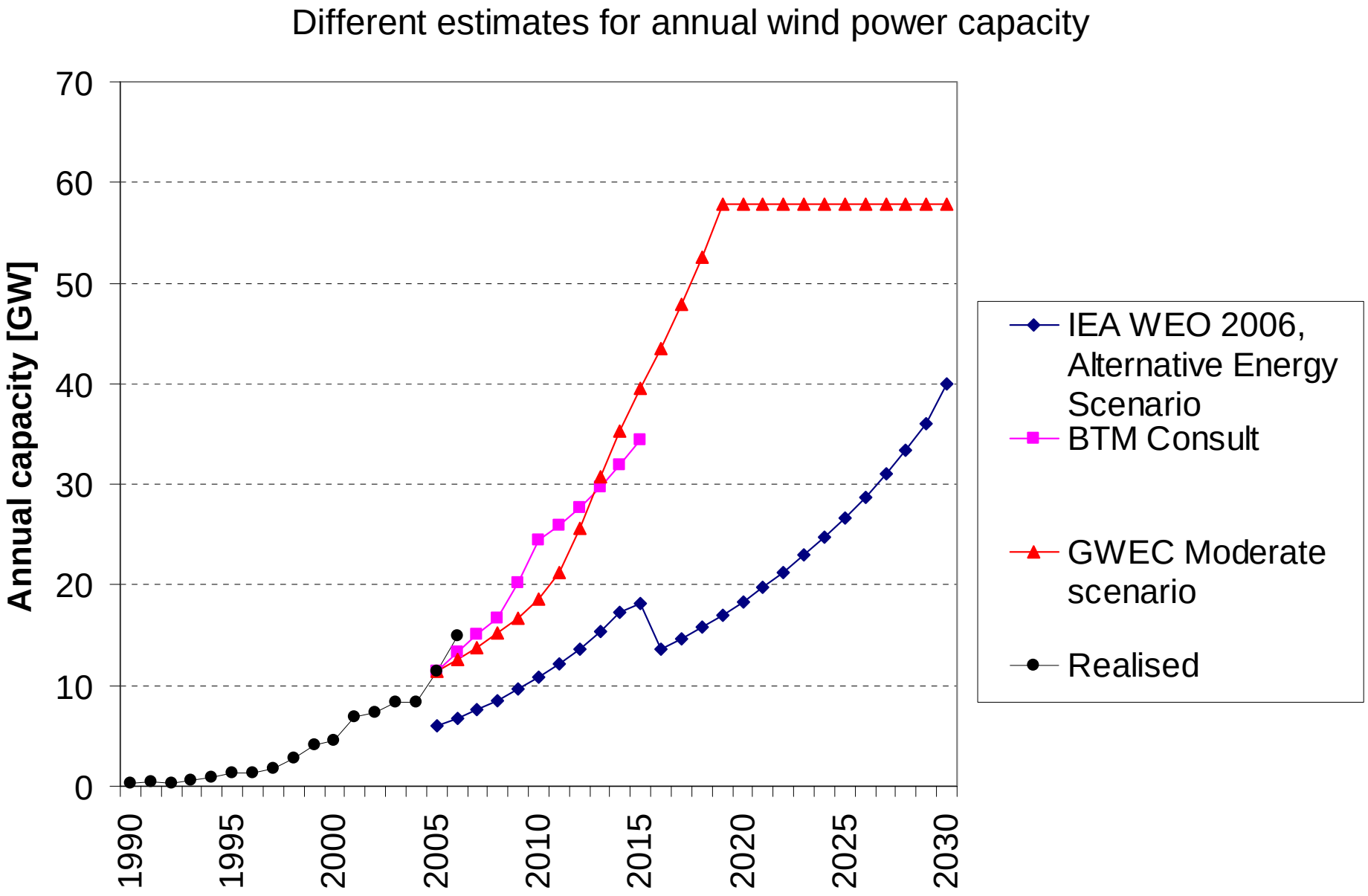
World Energy Outlook 2004

*Figure 6.7:* **Electricity Generating Cost Ranges of Baseload Technologies**




Note: The ranges of capital and fuel costs largely reflect regional differences. *Capital costs* range as follows: $2 000 to $2 500 per kW for nuclear; $550 to $650 per kW for CCGT; $1 200 to $1 400 per kW for coal steam; $1 400 to $1 600 per kW for IGCC and $900 to $1 100 per kW for onshore wind. *Fuel cost* ranges are $0.4 to $0.6 per MBtu for nuclear; $5 to $7 per MBtu for gas and $40 to $70 per tonne for coal. Wind average capacity factor ranges from 25% to 32%.

World Energy Outlook 2006




*IEA numbers are made by fitting their growth estimate to their capacity estimates of 2004, 2015 and 2030