Wind Hydro Integration on a Large Hydro System

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- Nordic area, hydro and market
- Balancing wind power in the markets or by a hydro-thermal producer, case Finland
- Simulation results from the Nordic countries,
  - EMPS model, Hannele Holttinen 2001
  - WILMAR model, Juha Kiviluoma, 2006

Wind & Hydro integration

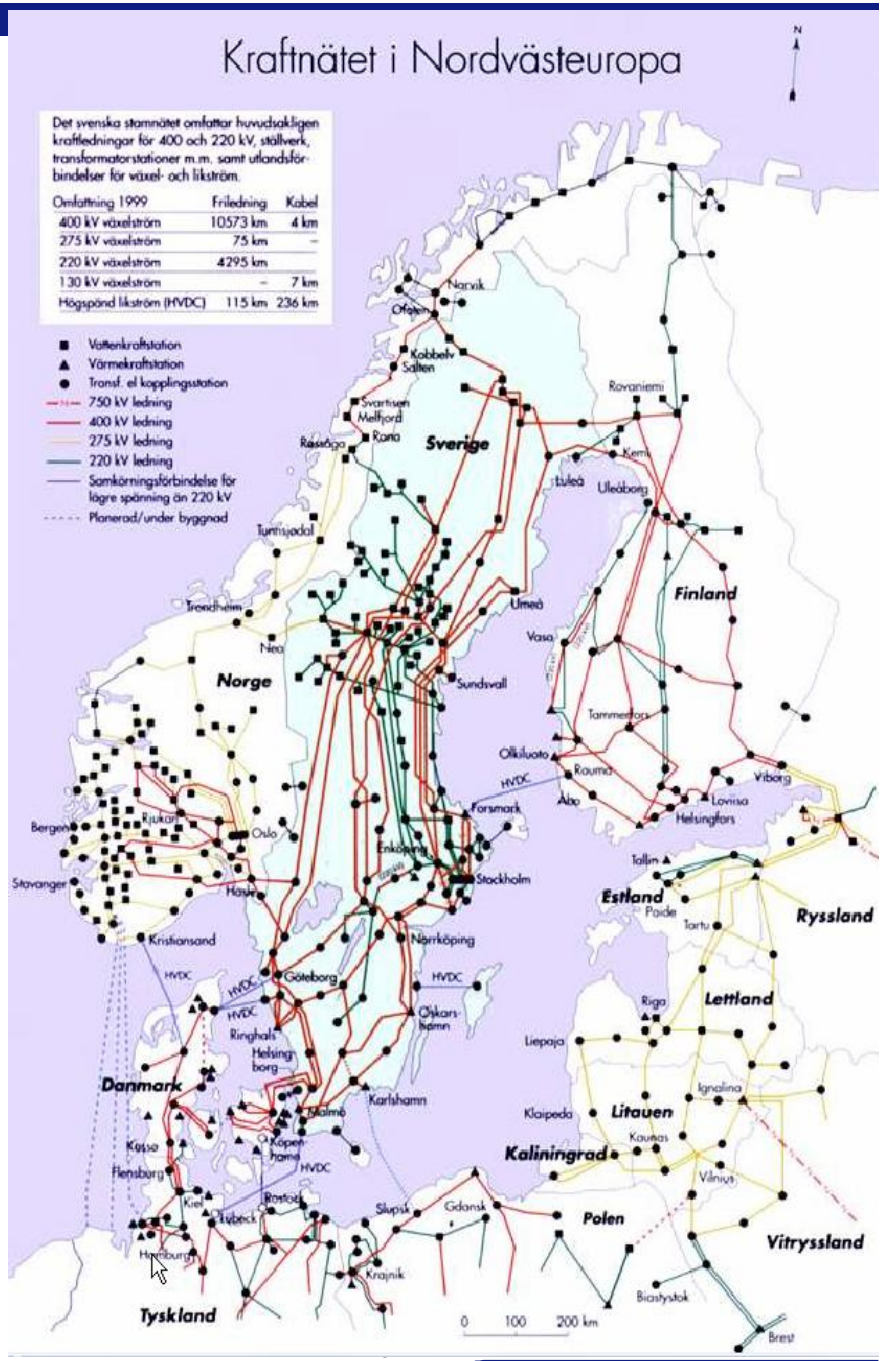
- More wind à more variability seen in power systems
  - How much - depending on load variability and forecast errors
- Hydro has flexibility in varying production level, quick to start/stop
  - How much – constraints in river flows
  - How costly – efficiency losses, cost of spinning
  - More cost effective than thermal, usually some changes from one hour to another are feasible in hydro with lower costs
- Benefits of adding wind to energy constrained system
  - Wind MWhs will save water in reservoirs to be used at another time
  - Constraints in this, too, at some level of penetration

Wind impacts on hydro power producers

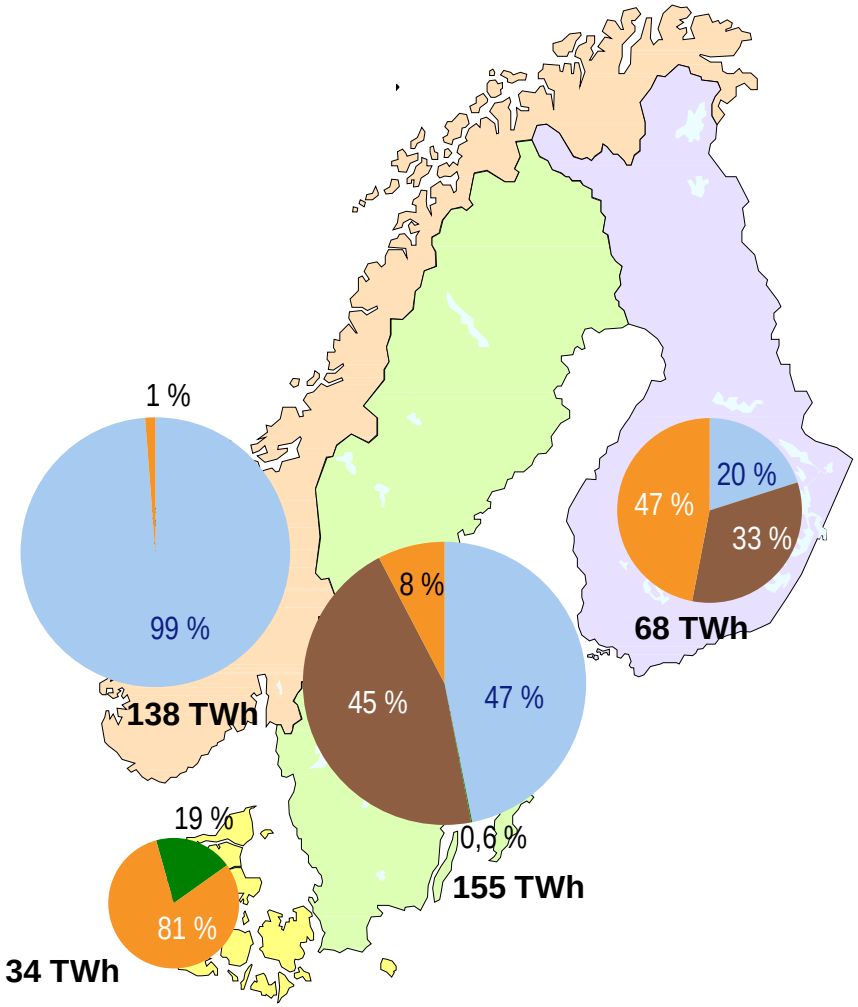
- In all scheduling time scales: long term, weekly, daily, hourly.
- **Long-term & seasonal planning:** thermal system/reservoir management/price forecasting à water values, maintenance planning
- **Short-term** (hours/days): wind/inflow/price forecasting spot/reg/market bidding, droop/spinning reserve, contract/load forecasting à generation scheduling
- **Real-term**: activation of regulating power, deviations of schedules

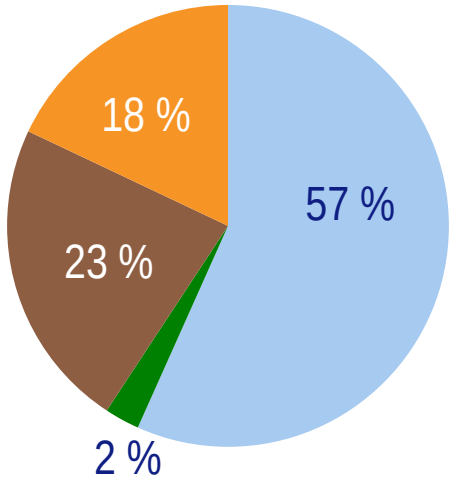
Nordic power system

- Interconnected system, a lot of exchange between the countries
- Gross demand about 390 TWh/a, production capacity about 90 GW, peak demand about 65 GW
  - SE 26 GW, NO 22 GW, FI 14 GW, DK 6 GW
- Wind power 4 100 MW: DK 3 130 MW, SE 570 MW, NO 310 MW, FI 90 MW
- 10 % wind power (of gross demand):
  - 19 000 MW, about 4800 MW in every country



Generation in the Nordic Countries 2005





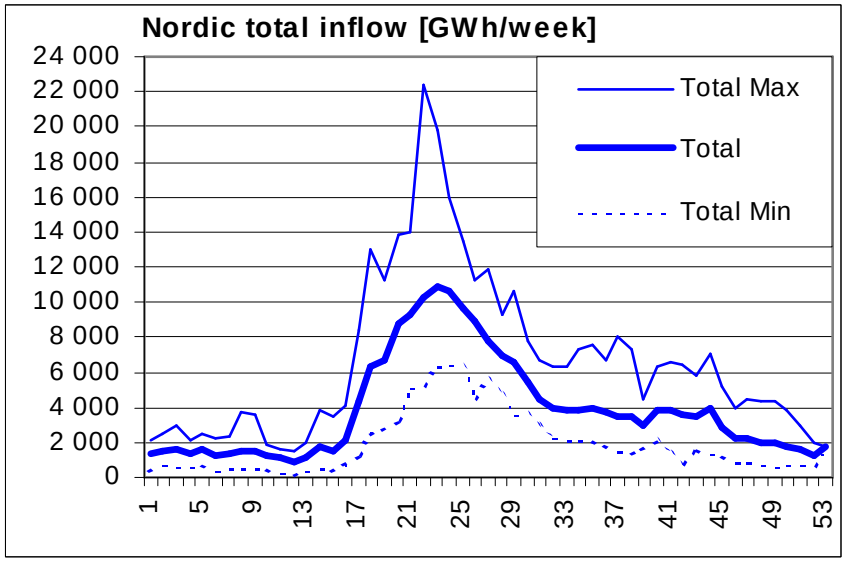
404 TWh

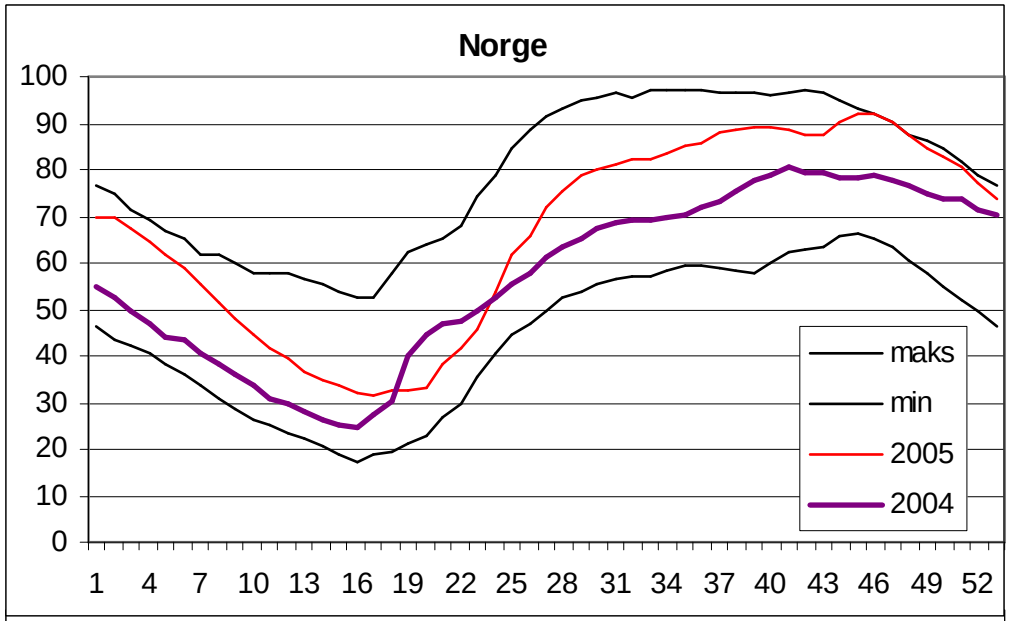
- Hydro power
- Wind
- Nuclear power
- Thermal power

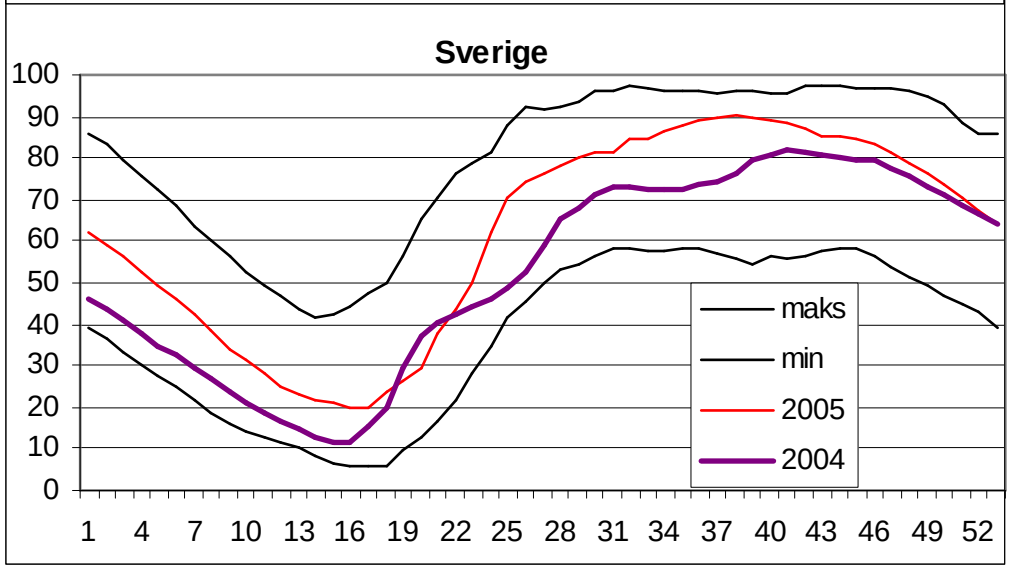
Hydro reservoirs

- Nordic inflow 200 TWh ± 50 TWh
- NO inflow 120 TWh reser. 82 TWh
- SE inflow 70 TWh reserv. 28 TWh
- FI inflow 12 TWh reservoir 5 TWh

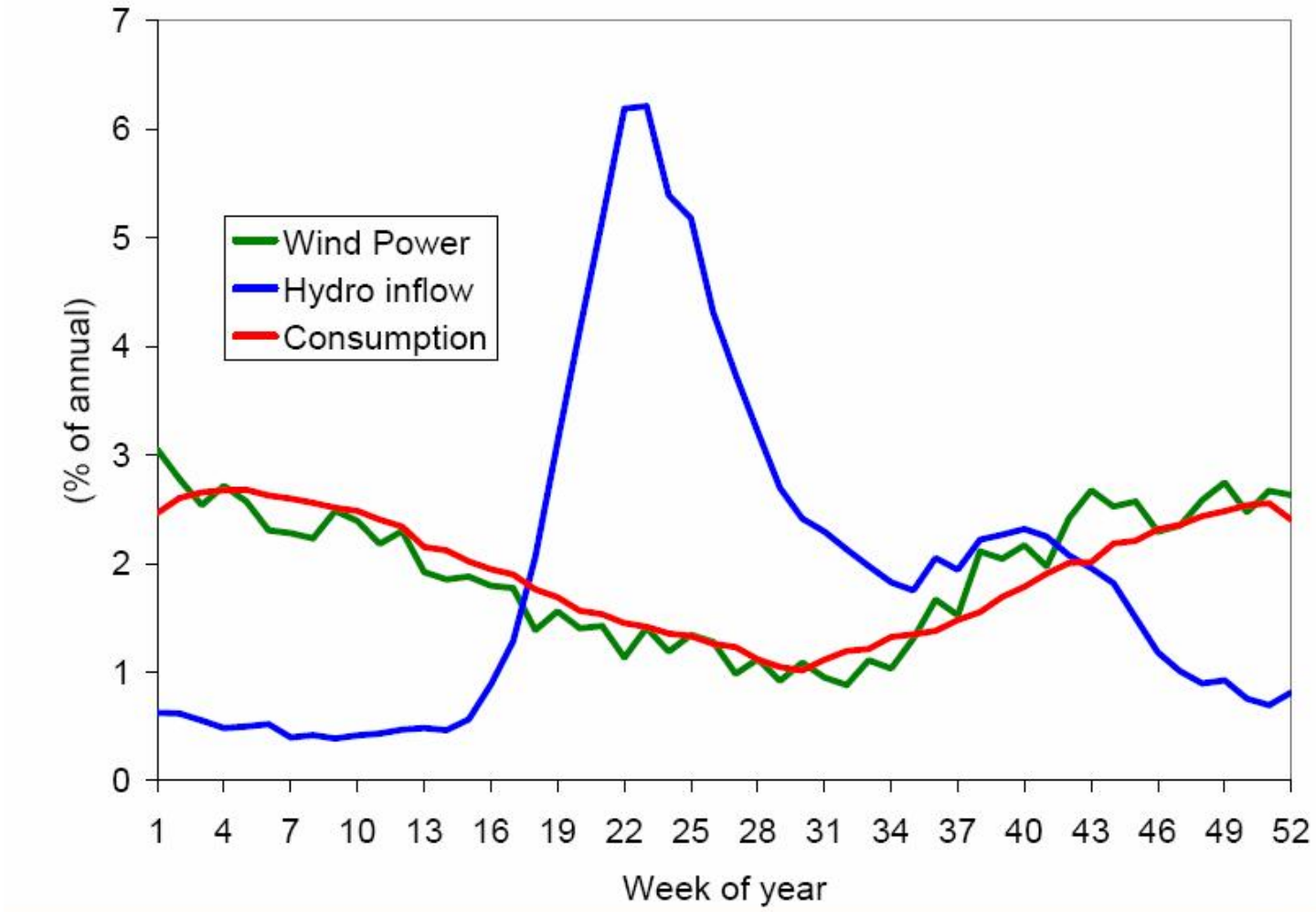
- About 18 TWh totally must-run, most hydro through reservoirs, flexibility







Weekly hydro inflow, wind and consumption



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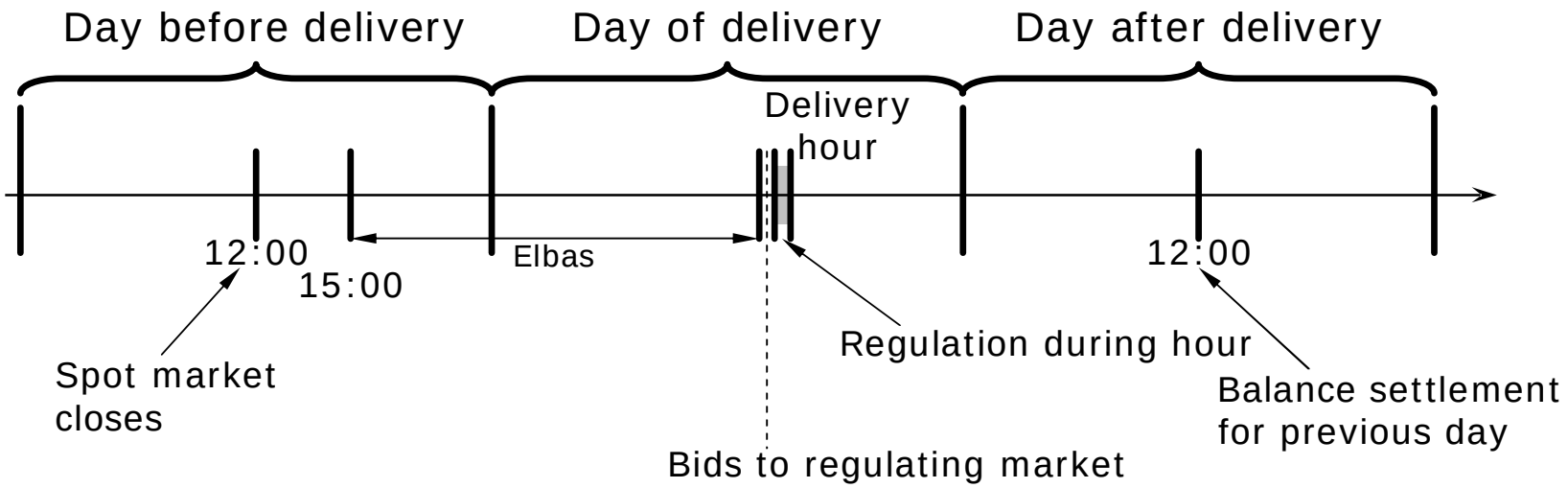
Nordic power market



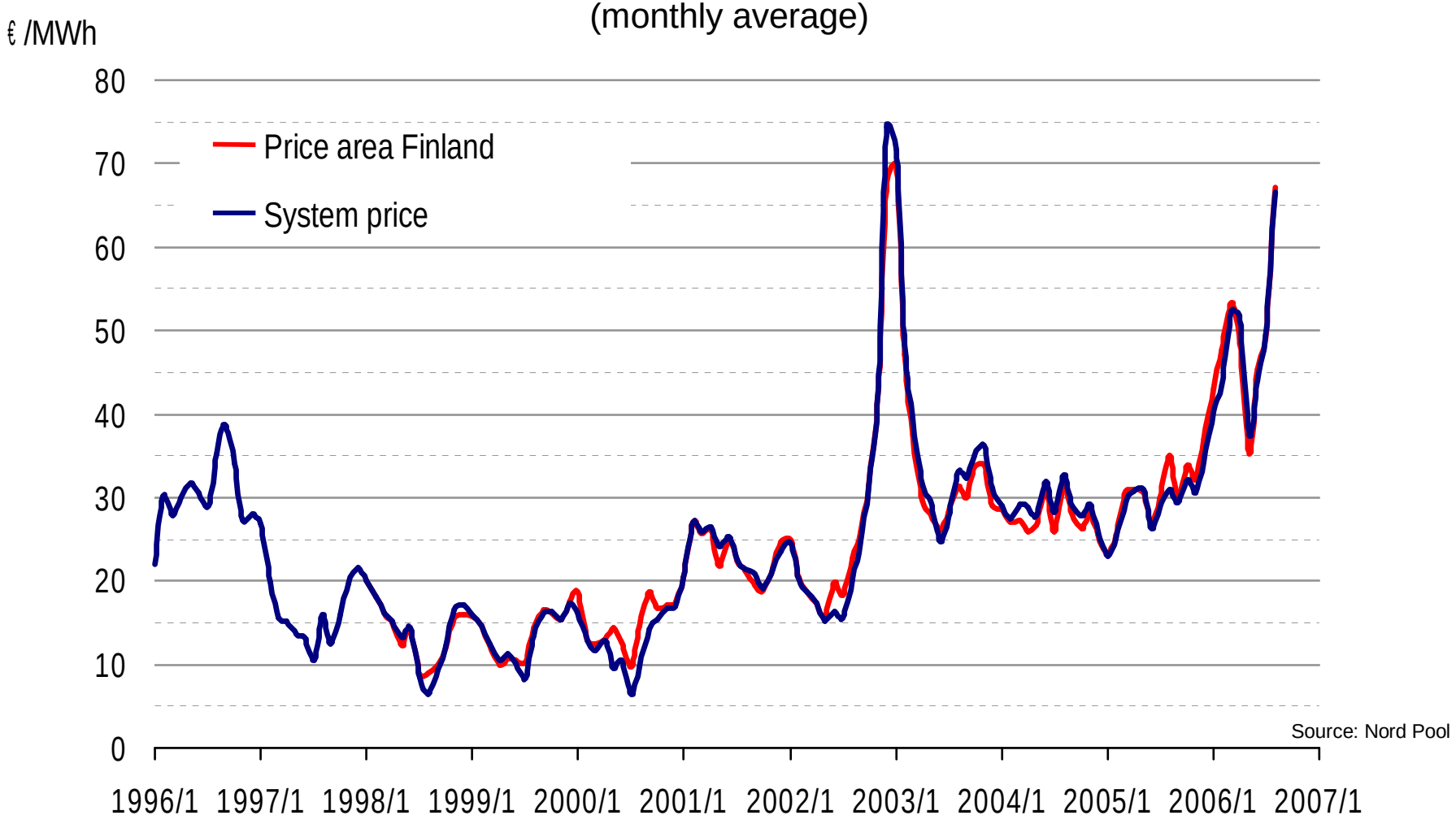
The share of electricity sold through exchanges is rising:

45 % of electricity through Nordpool spot market in 2005

Elbas intra-day market volumes still low

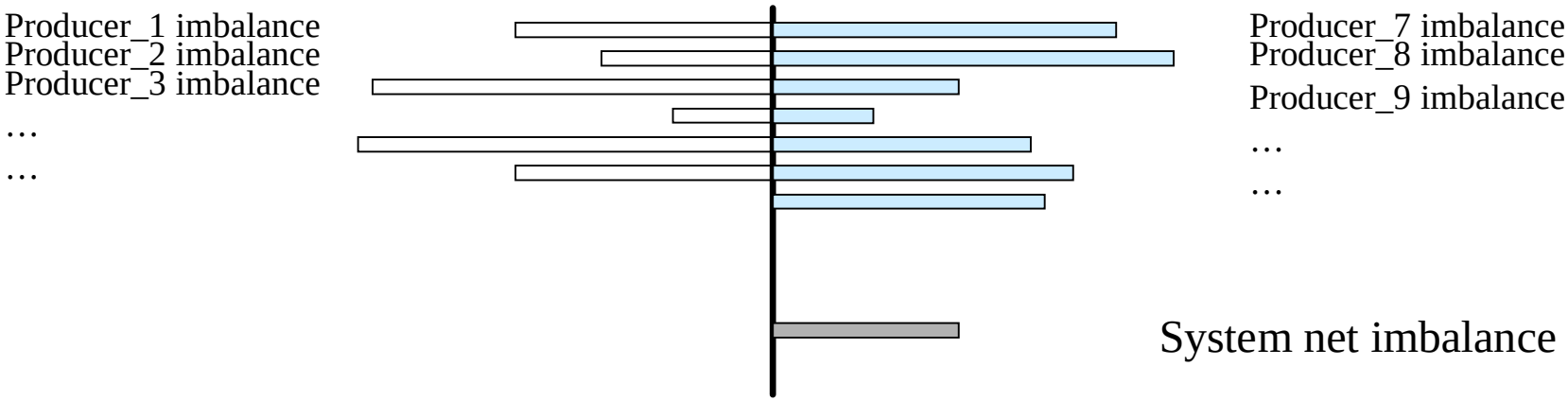
Elspot Prices (Nord Pool)

(monthly average)



Source: Nord Pool

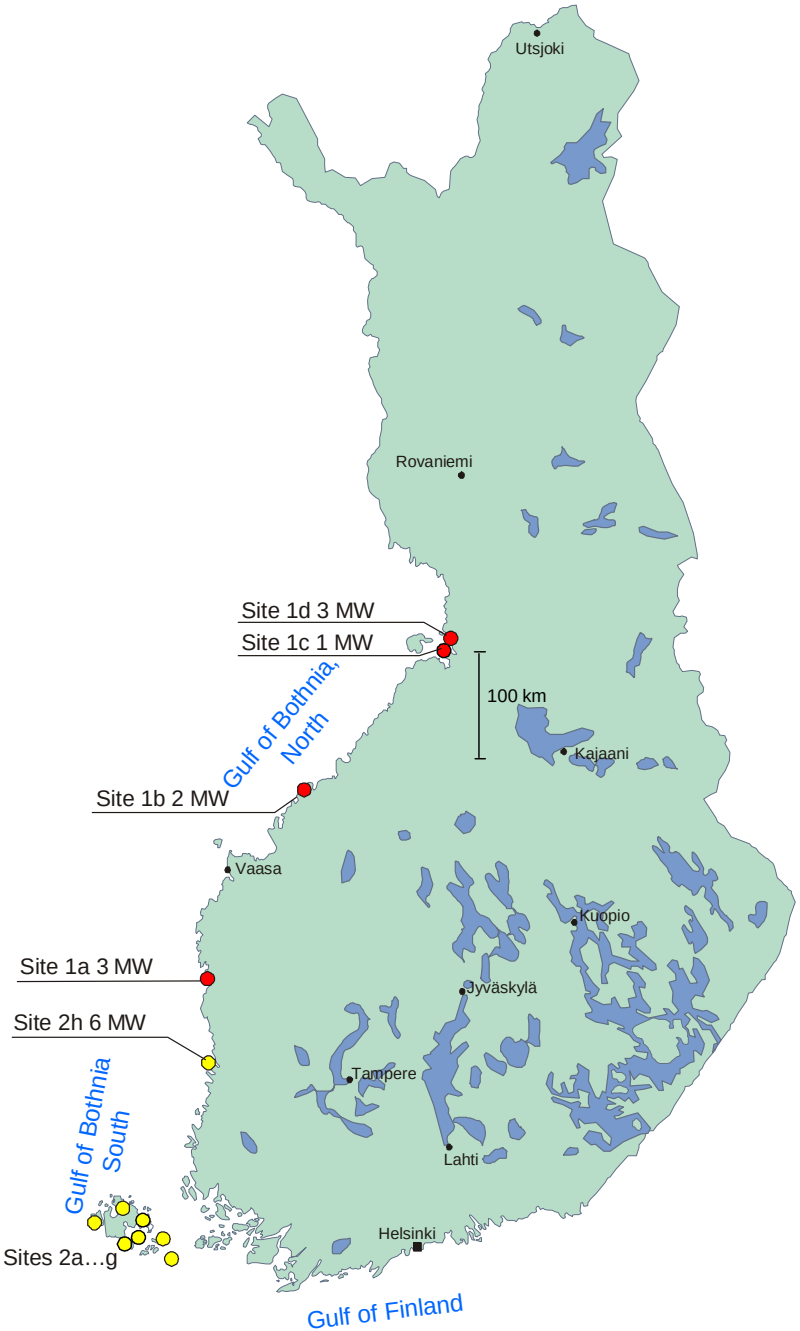
Imbalances are penalised – one or two price model



- Regulating power market is used to cover the system net imbalance à price for imbalances of that hour
- System operator charges regulating power price for imbalances from all producers that have had their imbalance in the same direction as the regulation need
- The producers that have had their imbalance in the opposite direction
  - pay/receive the spot market price for the imbalance (two-price model)
  - pay/receive the regulating market price (balancing fees are circulated; one-price model)

Wind power in the electricity market

- Large-scale wind power will affect the prices in the market:
  - decrease the price at spot markets about 2 €/MWh for each 10 TWh/a wind power added
  - raise the regulating power market prices
- Wind power producers pay imbalance payments for their prediction errors
  - Denmark 2-3 €/MWh – this goes through TSO and is socialised through tariffs to all consumers
  - Sweden and Finland 1-2 €/MWh
  - Norway near 0 €/MWh, one-price system for balance settlement in Norway is good for wind power producers



One producer in Finland

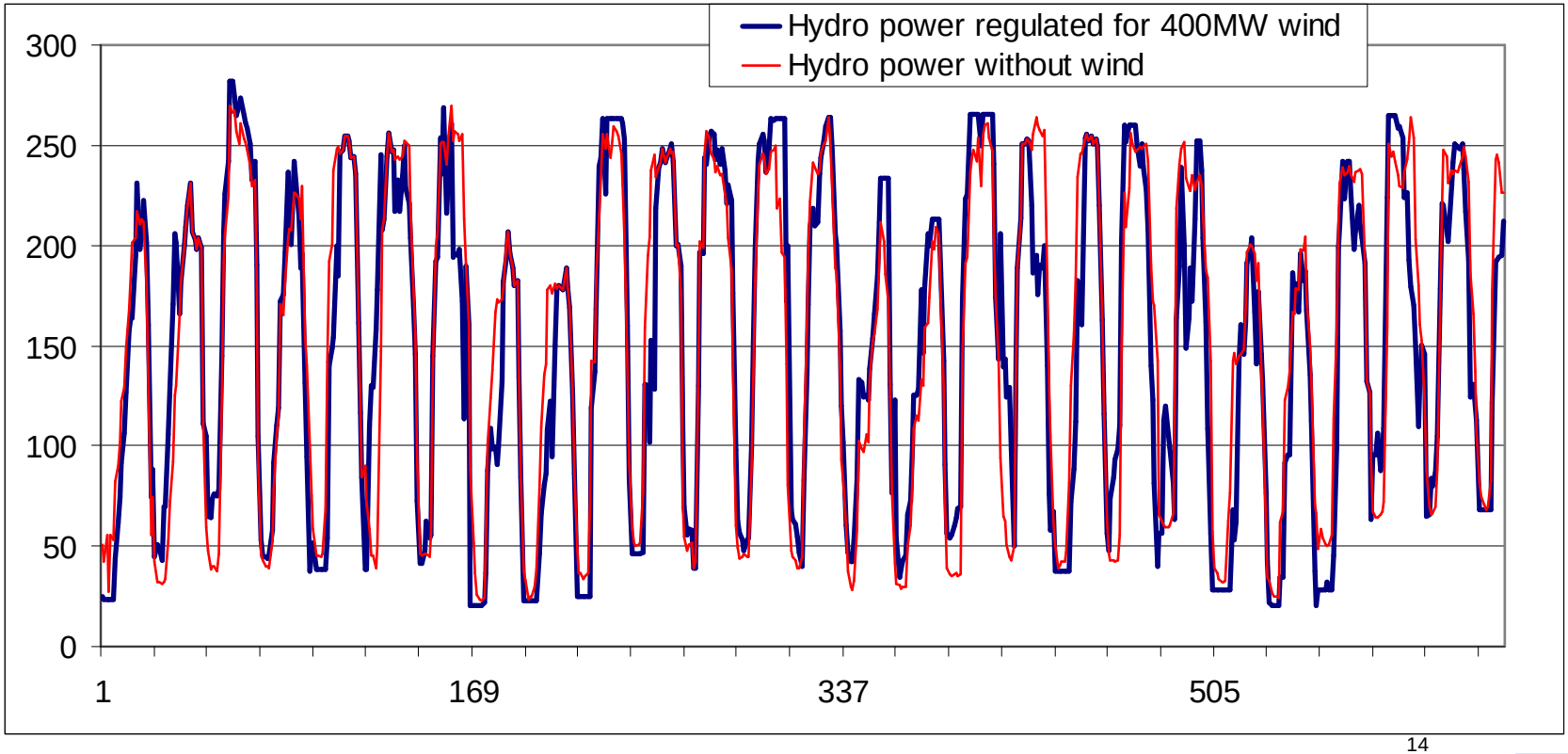
Hourly data year 2004:

- Load ~4000 MW
- Thermal power ~2800 MW
- Hydro power ~400 MW

- Wind power: 200 MW or 400 MW, data from 12 sites à max 600 km apart. Forecast errors to day-ahead spot market.

Using the hydro power regulating capacity of the producer

- Estimating the flexibility of the hydro power
  - Regulating capacity within daily Pmin and Pmax
  - Checking that daily production does not differ from schedule
- Result: 70-90% of wind power imbalances can be regulated



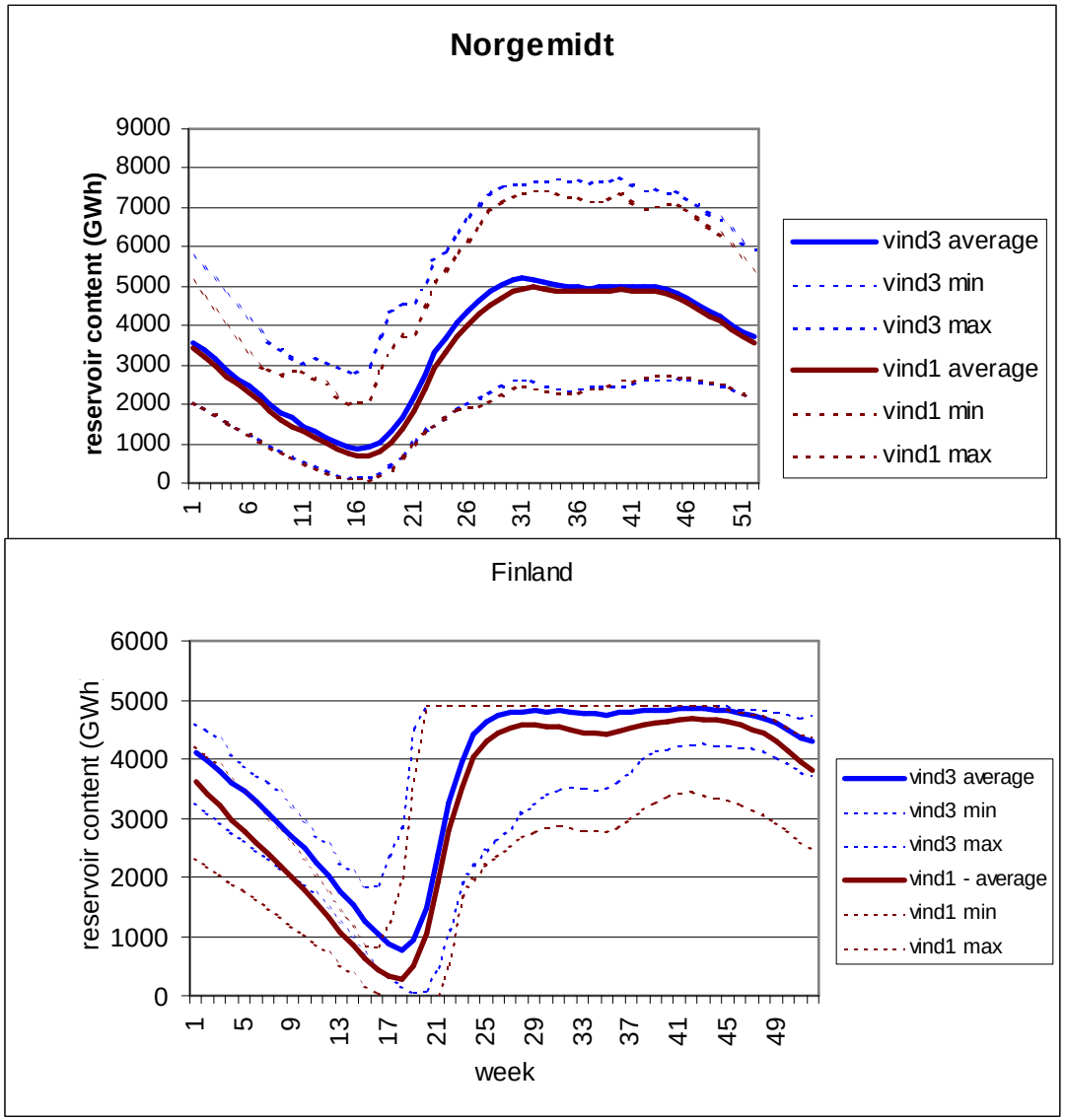
Summary case study Finland 2004

- Wind power imbalances are handled cost effectively at the market
  - 0.62 €/MWh balancing cost (dispersed wind power, day-ahead forecast)
- 400 MW hydro power: 90 and 70 % of imbalances for 200 and 400 MW wind
  - Regulation capabilities between daily Pmin…Pmax for individual plants
  - If only 1 €/MWh is taken for hydro regulation, balancing cost is 0.36 and 0.42 €/MWh for 200 and 400 MW wind
- Thermal and hydro: 97 and 85 % of imbalances for 200 and 400 MW wind
  - According to bids actually made to the balancing power market
  - With assumed cost for regulation bids, balancing cost is 0.41 and 0.46 €/MWh for 200 and 400 MW wind
  - Regulation power market value for the needed hours was more: 0.60 and 0.53 €/MWh
- Aggregating wind and load imbalances à costs reduced to 36 %

Wind impact on Nordic energy system, EMPS simulations

- Results from simulations, Nordic area, 30 years of inflow and wind data, weekly resolution:
  - Wind power will first decrease by-passed inflow
  - When wind power 12 % of gross demand, increase in by-passed inflow of the order of 1 % of the produced wind energy
  - Transmission will increase from Nordel to Central Europe
  - Bottlenecks can be increased, depending on where wind power is built. f.ex. in Norway wind power decreases transmission between the areas during dry years and increases it during wet years

EMPS: Effects on hydro power production



- Changes in reservoir contents/management
- Increased floodwater for 46 TWh/a wind:
  - average 0.5 TWh/a for ref2000
  - average 1 TWh/a for ref2010

Nordic + Germany, simulations with WILMAR - Juha Kiviluoma, PhD

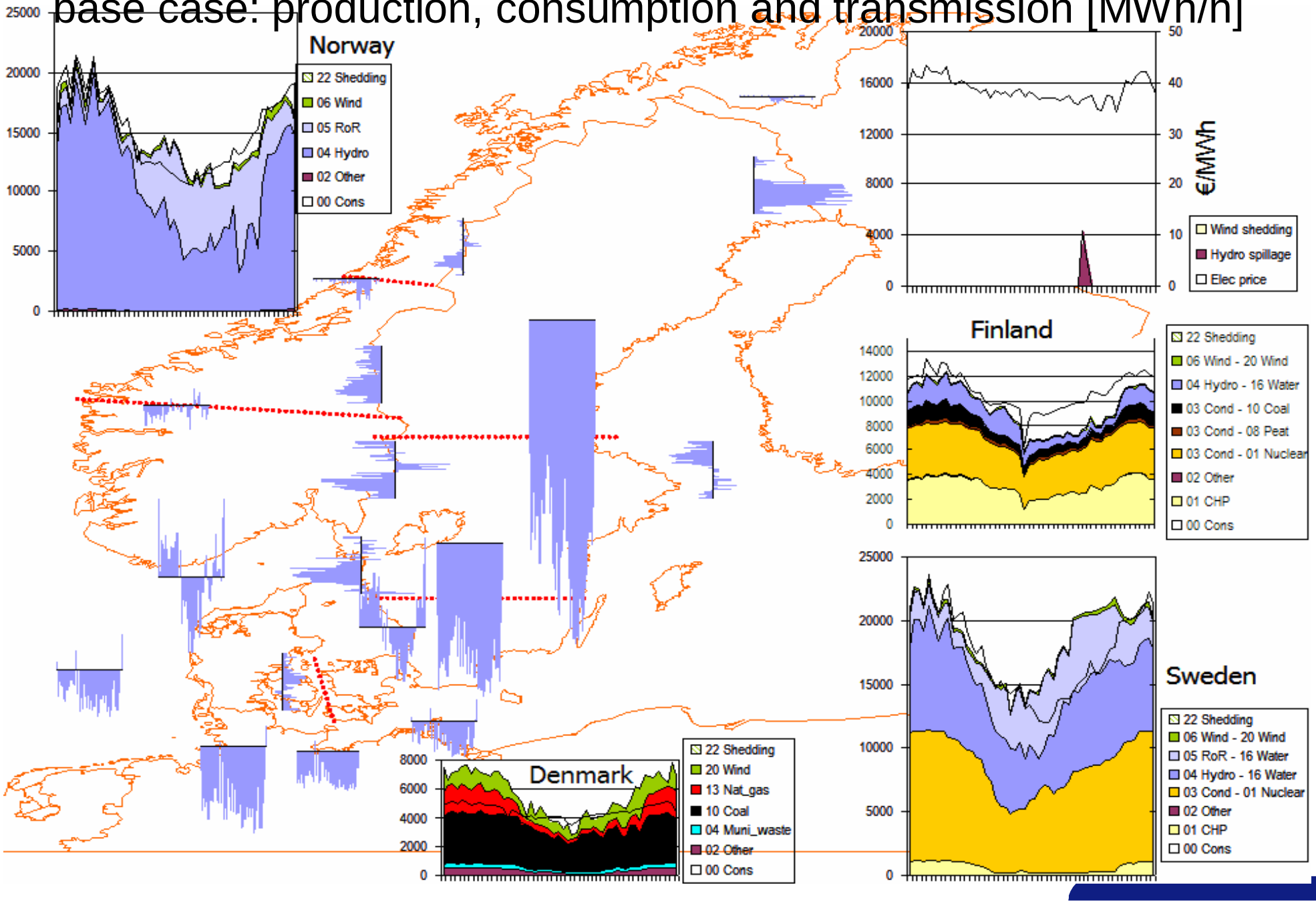
- Market model of Nordic countries and Germany
- Hourly time-scale
- Spot market horizon, but includes long term model for water values
- Primary and secondary reserves allocation dependant on wind
- Quite detailed unit presentation, also heat areas for CHP
- Presentation of hydro is not detailed enough
- Static transmission limits between regions
- Low regulation prices (technical cost not market cost)

Cases

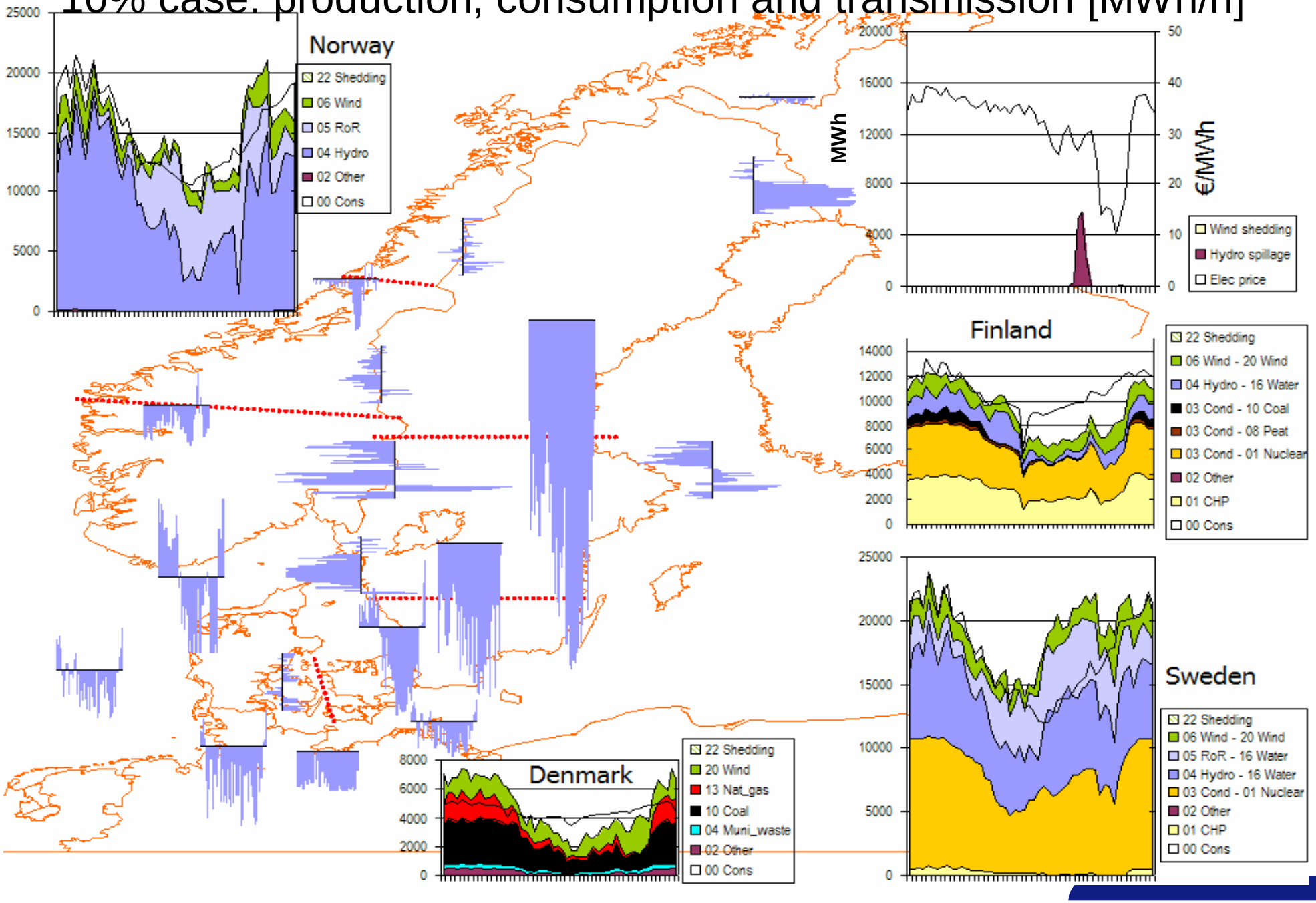
		base	10%	20%	
Wind capacity [GW]	NO+SE+FI	**2.5**	**17.8**	**35.7**	
	Germany	28.6	35.8	35.8	
	Denmark	4.1	4.6	4.6	
Energy from wind NO+SE+FI+DK [TWh]		16	49	87	

- **17 €/CO_2 ton emission permit prices**
- Planned transmission lines, power plants and decomissionings up to 2010
- **Wind is added as extra production, no capacity taken away**
- One year of simulation - year 2001 profiles for hydro, wind, load and heat demand: not very windy, average hydro year

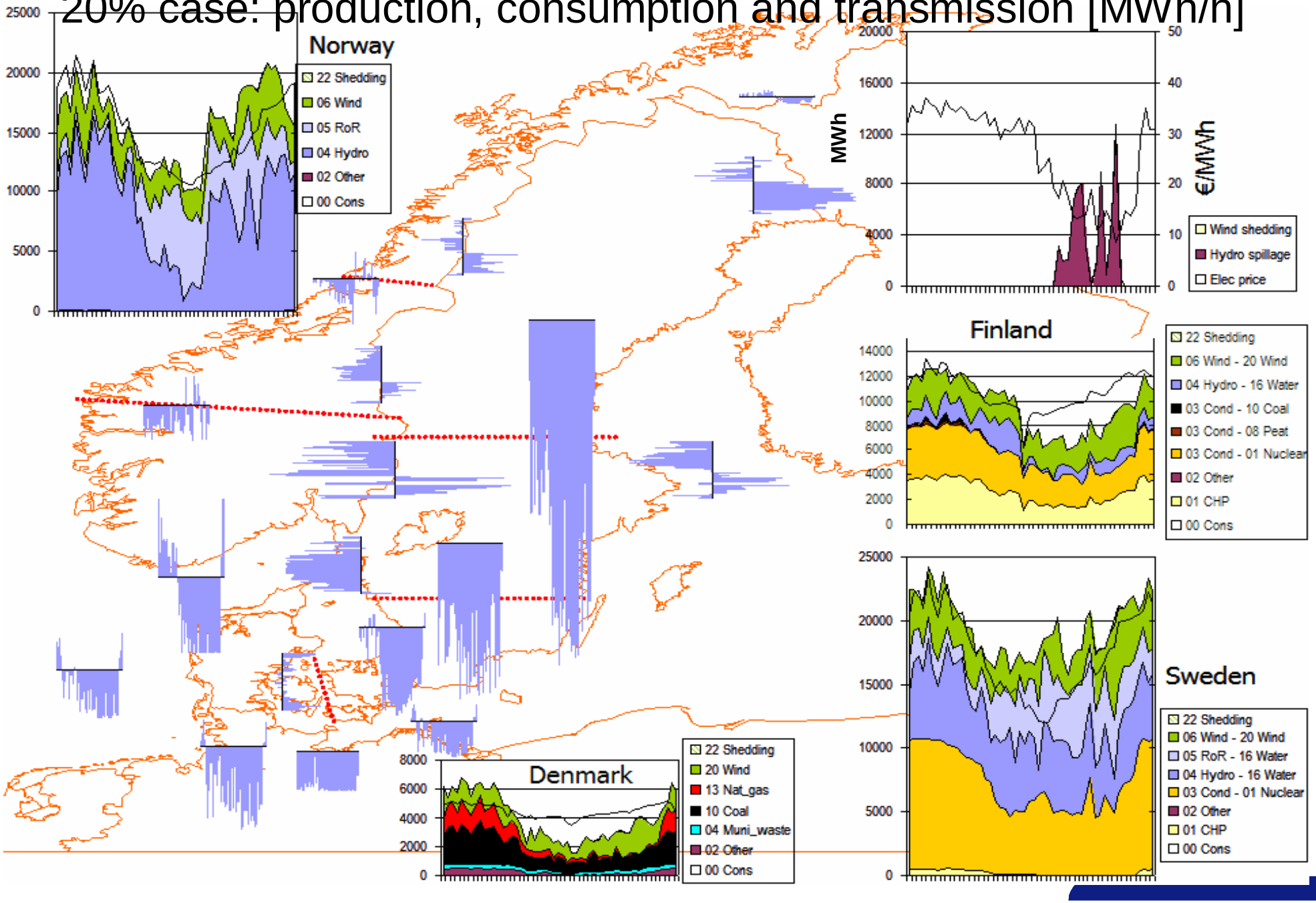
base case: production, consumption and transmission [MWh/h]



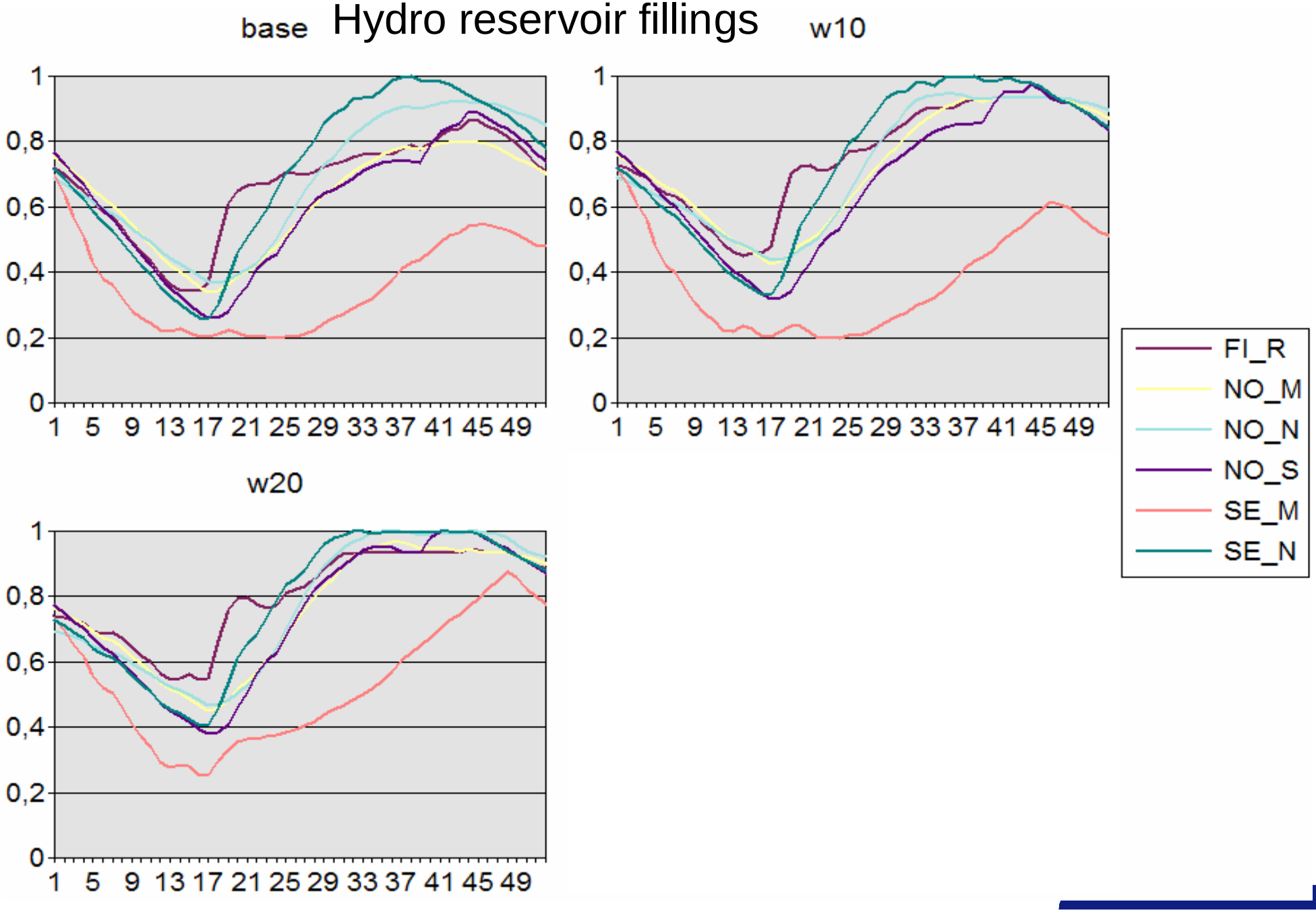
10% case: production, consumption and transmission [MWh/h]



20% case: production, consumption and transmission [MWh/h]

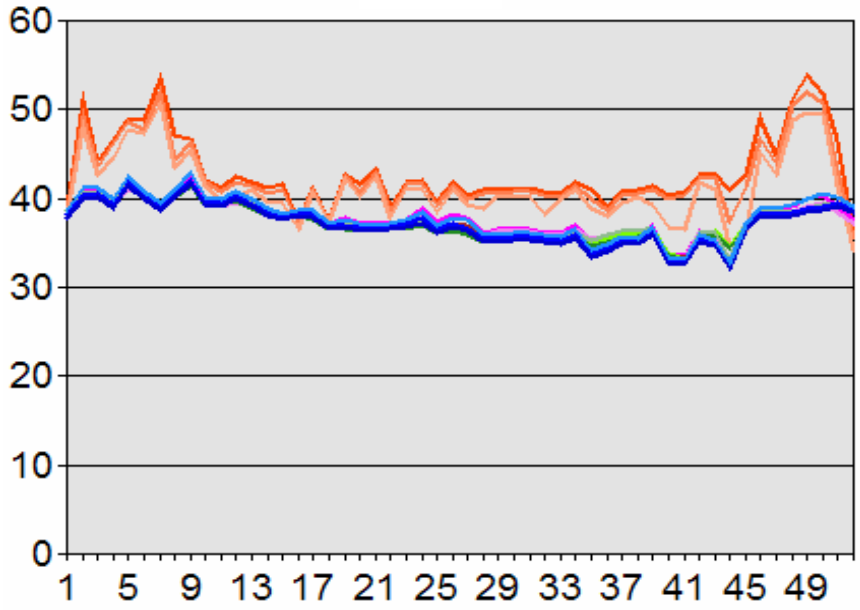


Hydro reservoir fillings

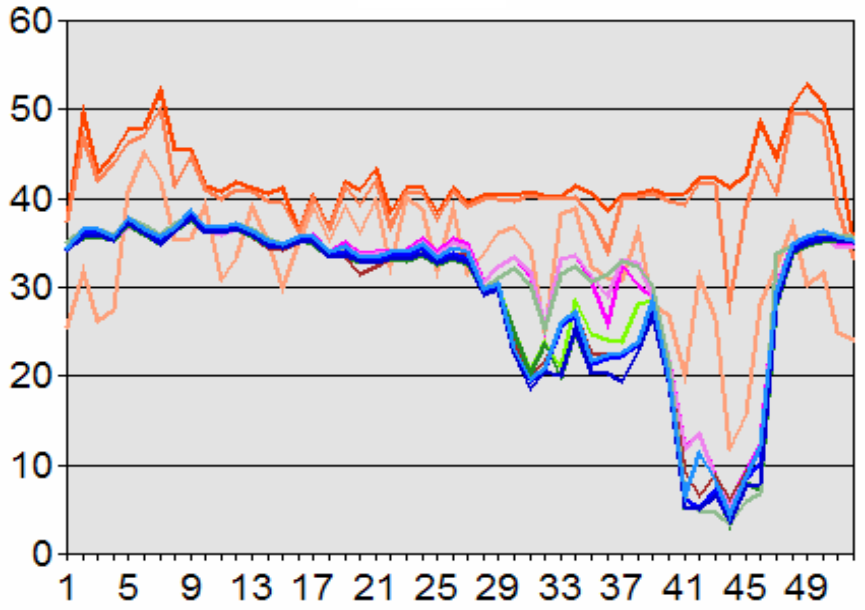


Prices [€/MWh]

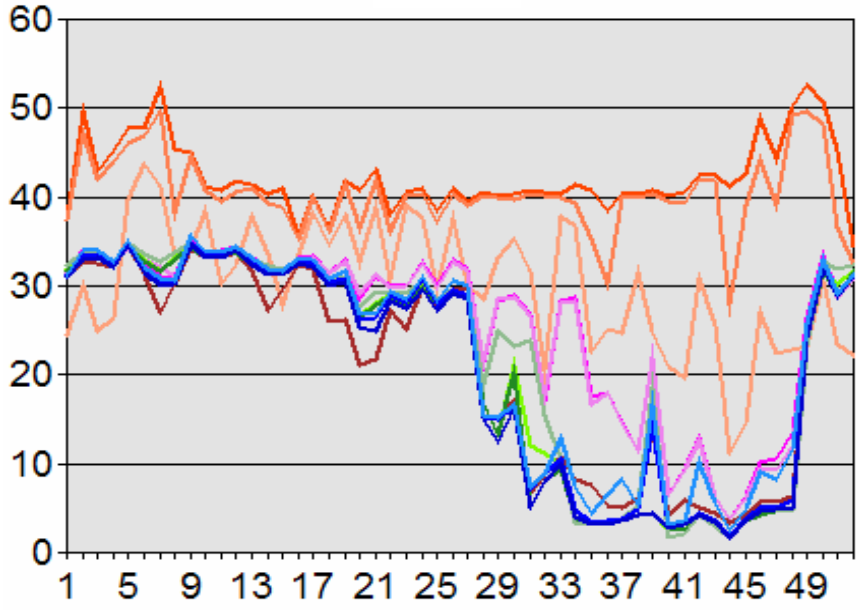
base



10 %



20 %



Summary WILMAR model runs

- 20-30% wind penetration changes the utilisation of other power production decisively
- Wind will affect power prices strongly if penetration gets high
- At least for the modelled year hydro/wind/demand profiles, hydro power can regulate wind to such extent that usage other condensing than nuclear is minimal (could be covered by demand side measures)
- Assumptions:
  - wind will get very competitive (price development) and no other limitations (grid, sites) exist
  - Wind is added as extra production, no capacity taken away
- Limitations for wind are most likely in available sites and transmission rather than in regulation

Thank you!

- International collaboration on wind integration:
  - www.ieawind.org