



NTNU – Trondheim
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Market aspects of balancing

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Renewables and their market characteristics

Non-dispatchable



- Wind power and wave power
 - Highly variable
 - Difficult to predict
 - Zero marginal costs – reduces spot prices
- Solar power and tidal power
 - Diurnal and seasonal variations
 - More predictable than wind
 - Zero marginal costs – reduces spot prices
- Run-of-river hydro
 - More steady than wind but large seasonal variations
 - More predictable than wind
 - Zero marginal costs – reduces spot prices

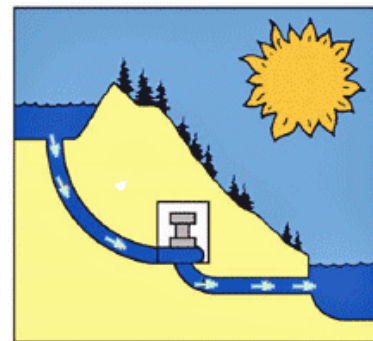
Dispatchable



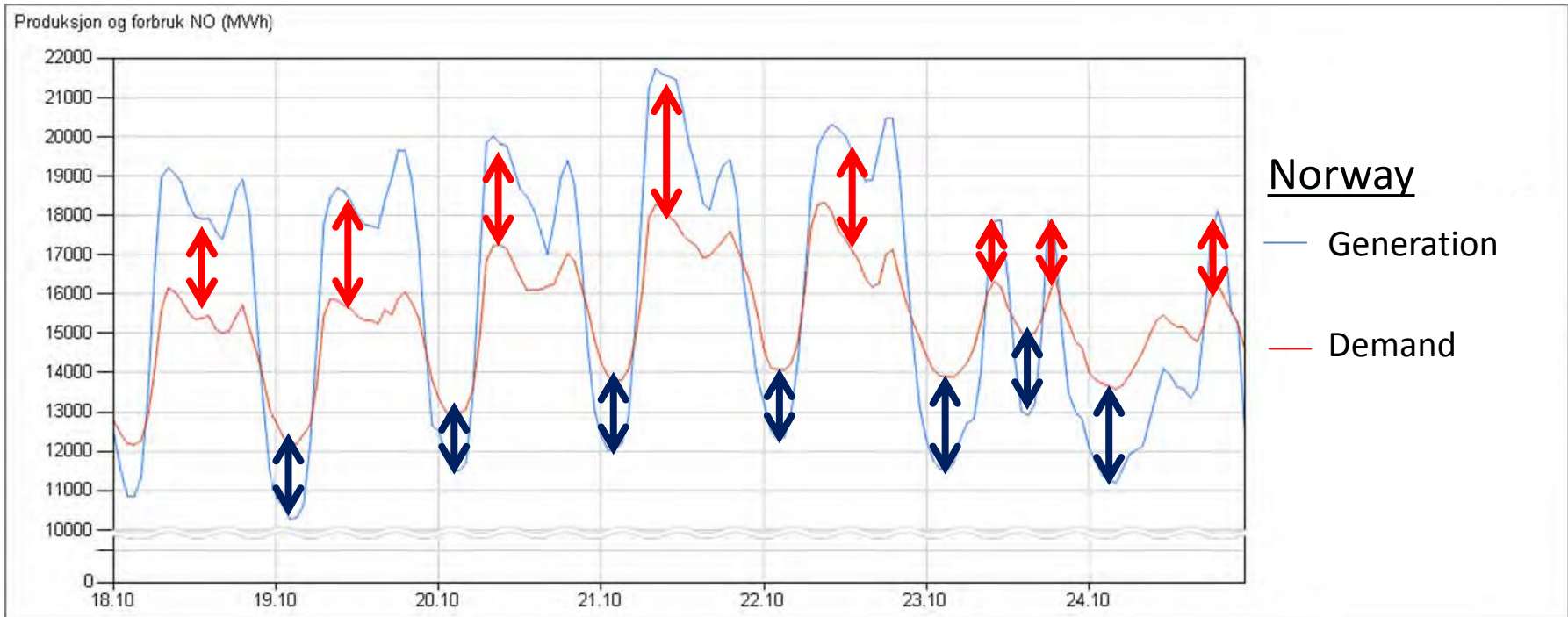
- Hydro with reservoir
 - Fully dispatchable within reservoir limits
 - Marginal cost given by the value of stored water
- Bio power
 - Fully dispatchable
 - Marginal costs given by efficiency and fuel costs
- Energy storage
 - Provides flexibility
 - Cost and efficiency is crucial

Norwegian hydropower for balancing

- The reservoirs are natural lakes
 - Multi-year reservoirs
 - Largest lake stores 8 TWh
 - Total 84 TWh reservoir capacity
- Balancing capacity estimates 2030
 - 29 GW installed at present
 - + 10 GW with larger tunnels and generators
 - + 20 GW pumped storage
 - 30 GW total new capacity
 - Within today's environmental limits
 - Requires more transmission capacity



Indirect storage with today's system

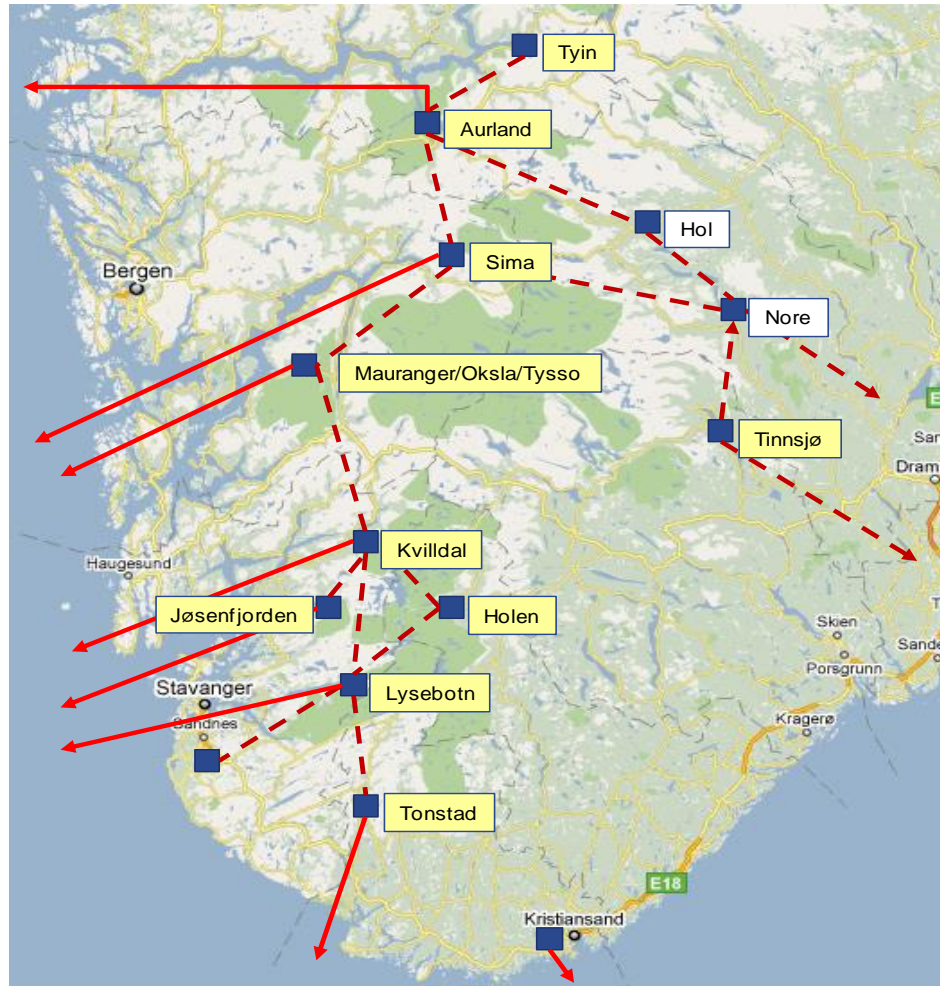


↕ Export
↕ Import

Source: Jan Hystad, Statnett

$\Delta \text{Generation} - \Delta \text{load} :$
 $11\,500 - 6\,200 = 5\,300 \text{ MW of balancing}$

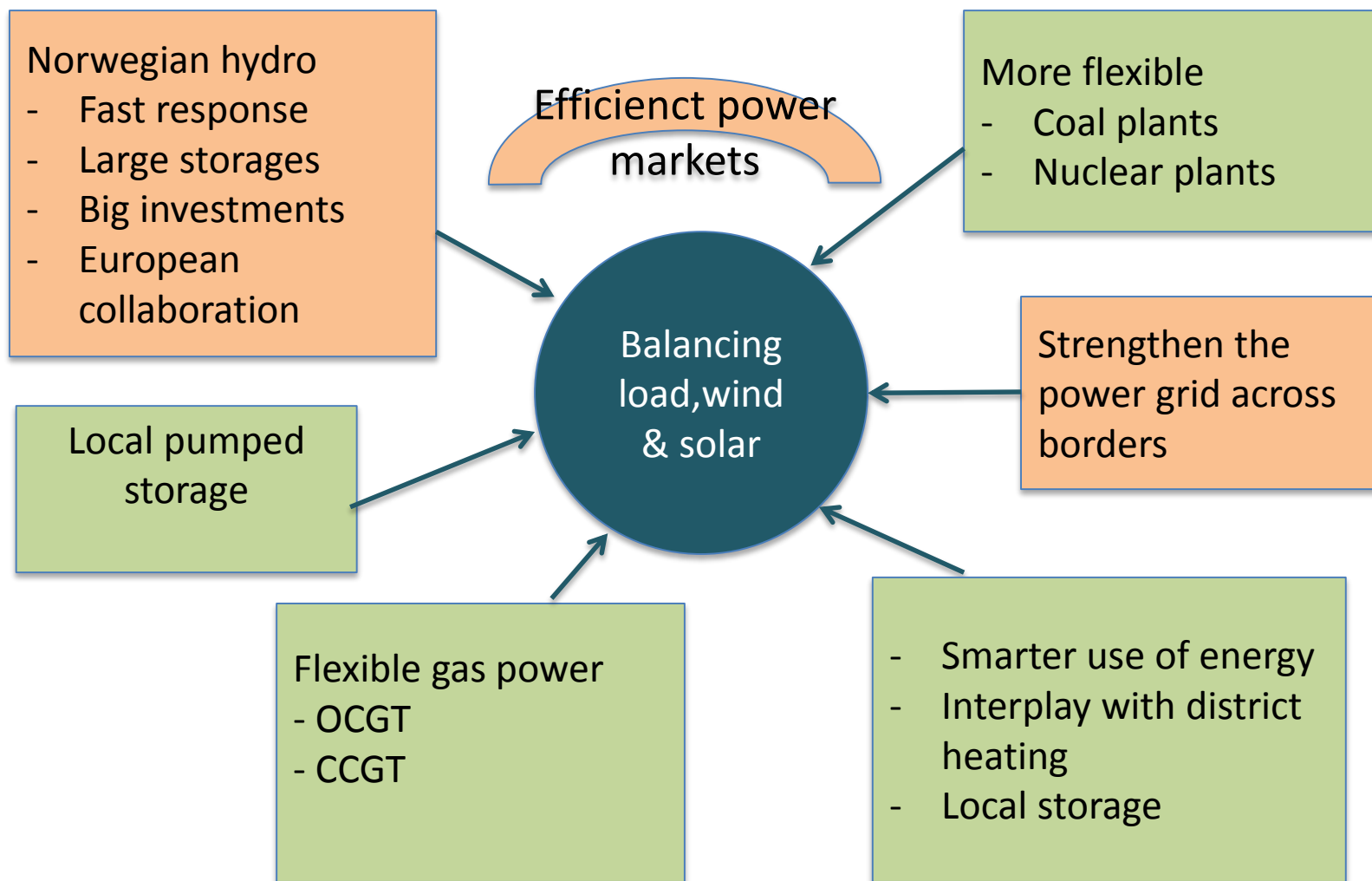
CEDREN Balancing potential study 2030



- 20 000 MW new pumping capacity in southern Norway
- Export of balancing services
- Integration of grids & markets



Balancing of renewables in Europe



Electricity Markets



Balancing Market

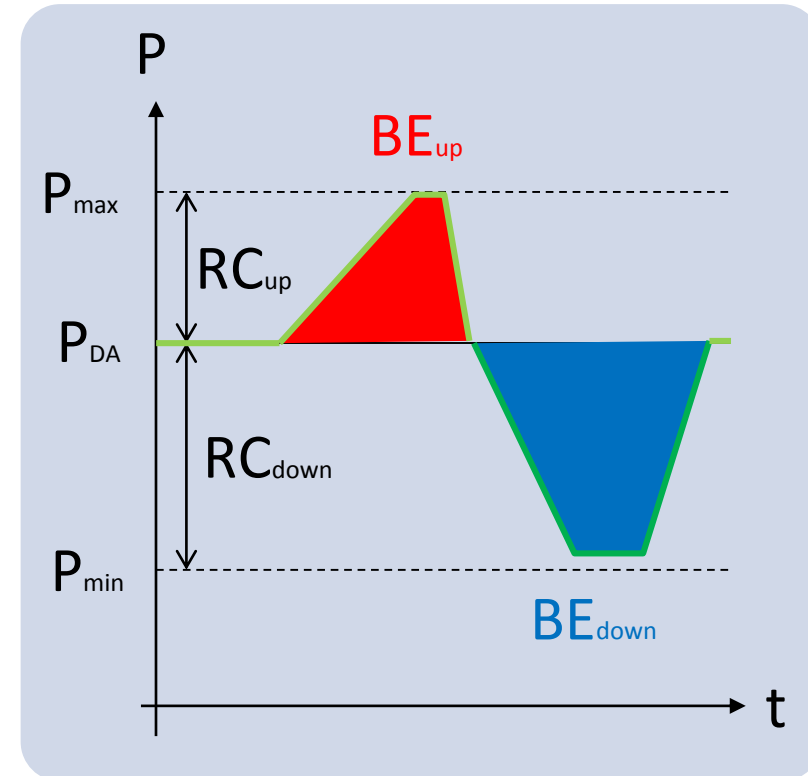
Balancing Reserve Capacity vs Energy

Reserve procurement

- Reserve capacity (RC) [EUR/MW]
- TSOs ensure sufficient reserves in the system during operation

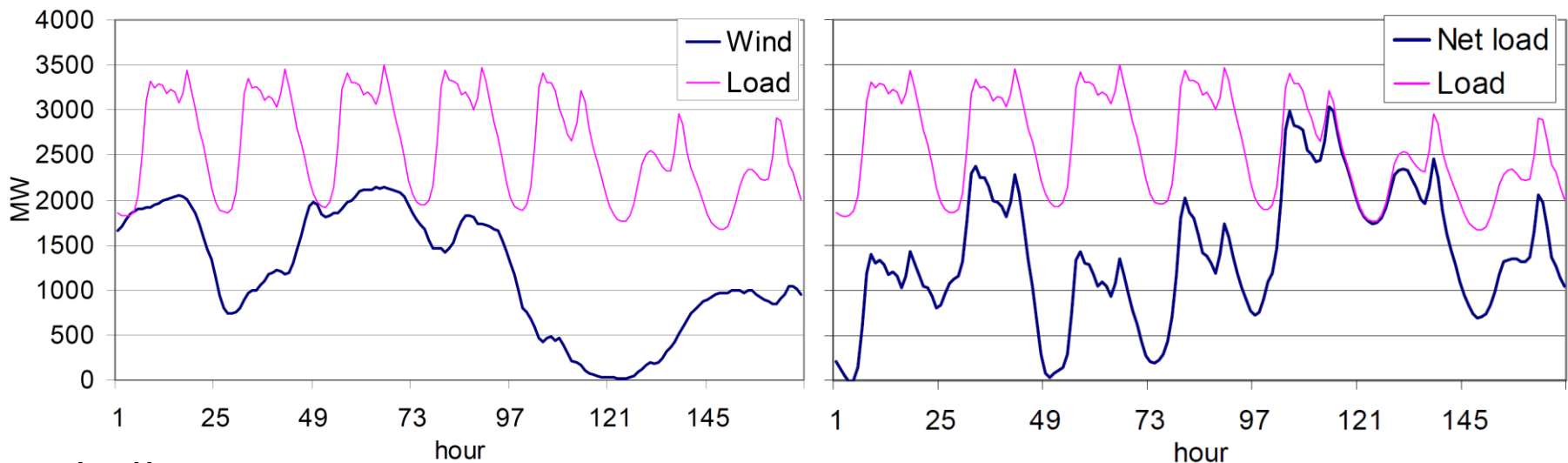
System balancing

- Balancing energy (BE) [EUR/MWh]
- TSOs activate reserves to counteract system imbalances



It is the Net Load that matters

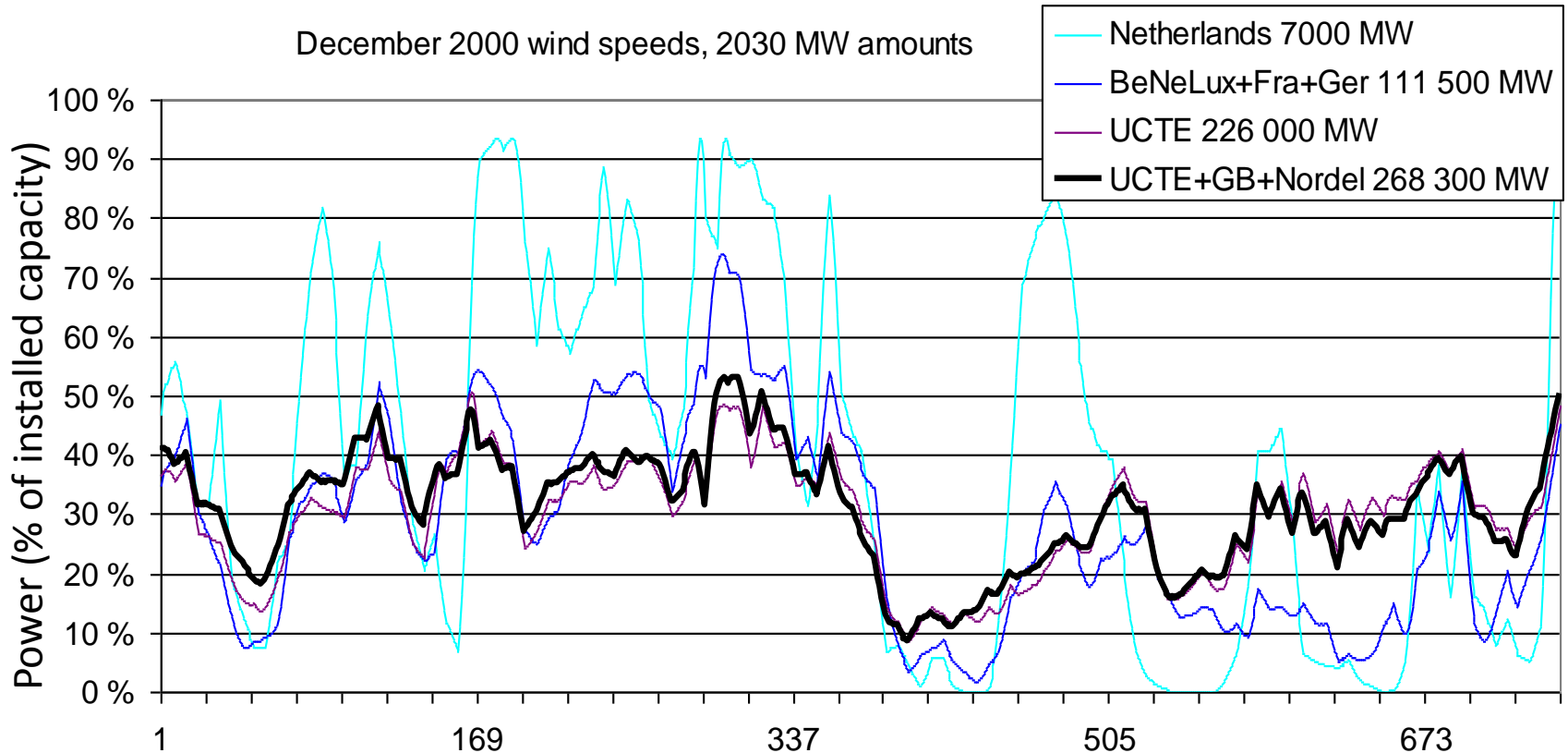
- The system will see the aggregated net imbalance
 - Unforeseen variations in load, wind and solar
 - $\text{Net load} = \text{Load} - \text{Wind} - \text{Solar}$



Challenges:

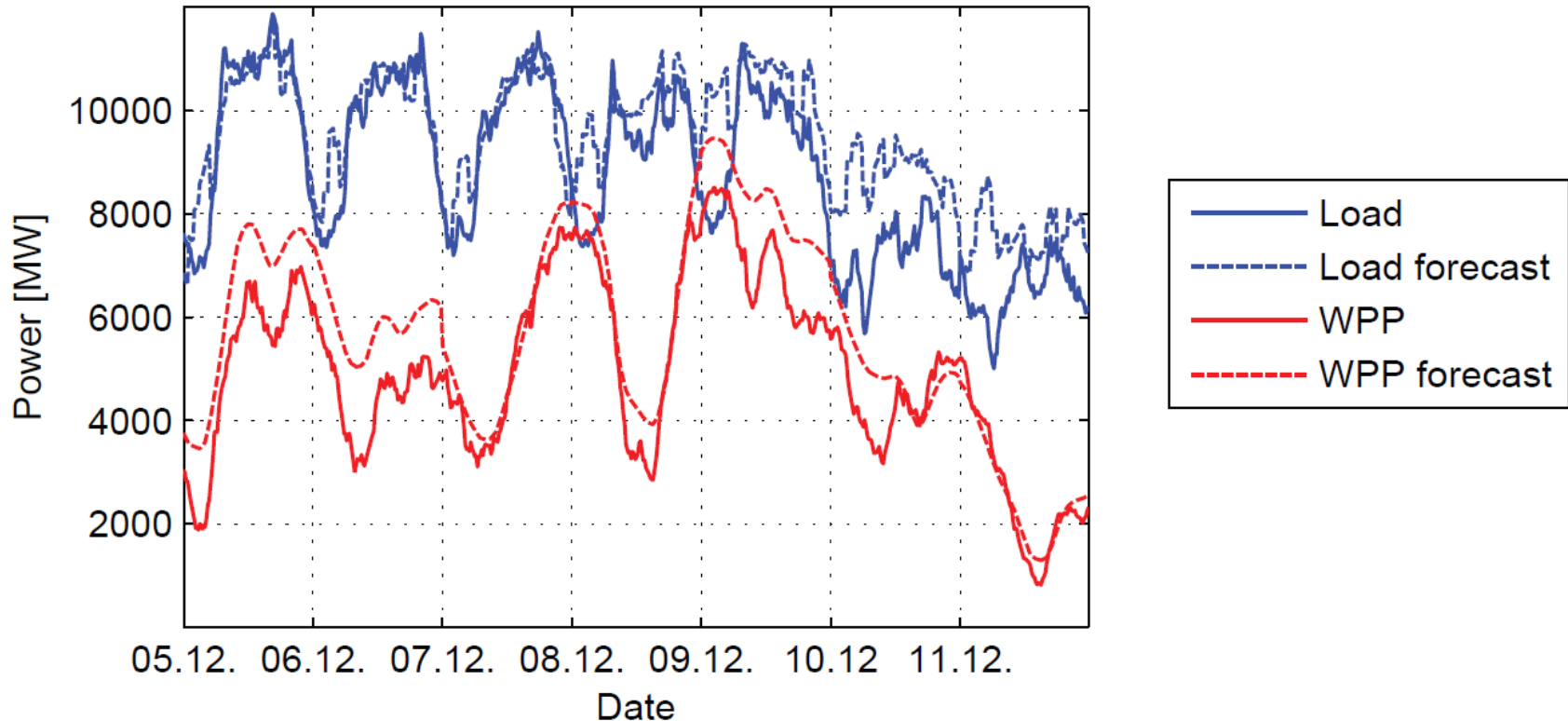
- Flexibility of thermal power plants (ramp rates, start/ stop operation)
- With very high RE share, thermal plants can be pushed out of the market – security of supply has to be fulfilled

Smoothing effect of variability



Pan-European balancing can reduce storage needs of wind+PV by a factor of 11 compared with regional storage

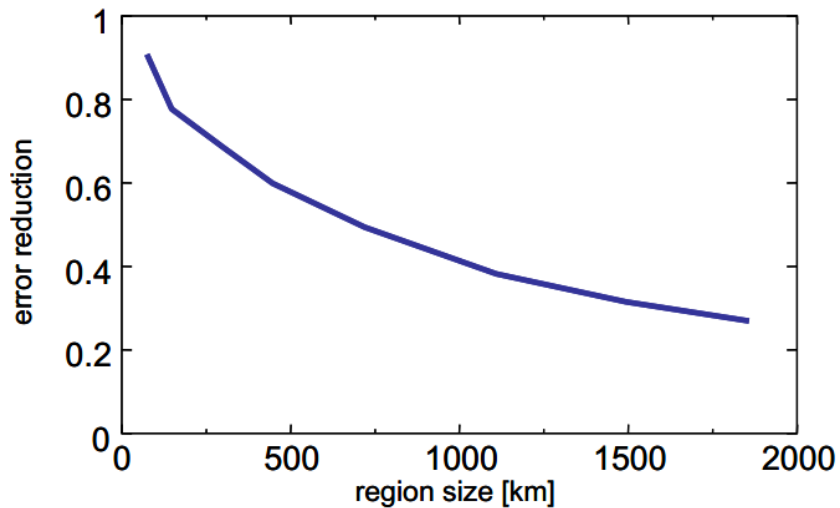
Wind forecasts are not that bad...



- Actual and predicted load and wind power forecasts in the 50Hertz area in Dec. 2011

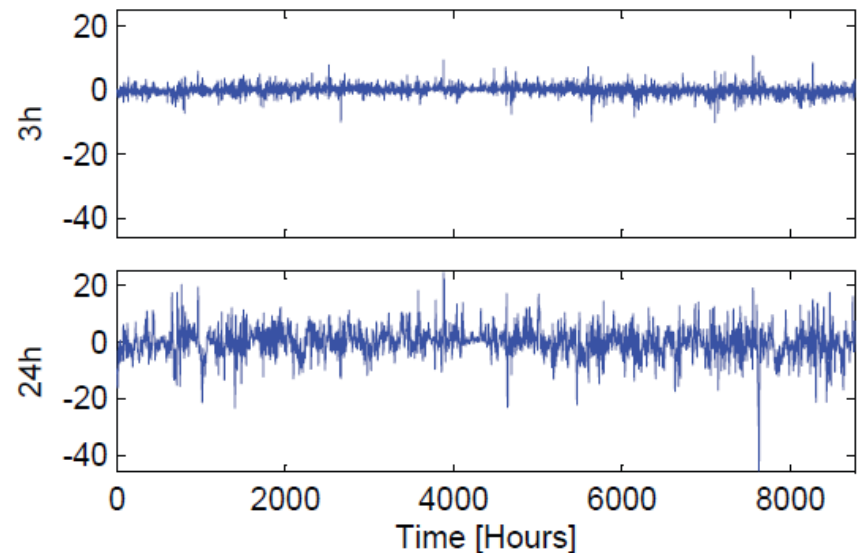
..but forecast horizon and geographical spread are essential

Geographical smoothing of forecast errors based on 40 German wind farms



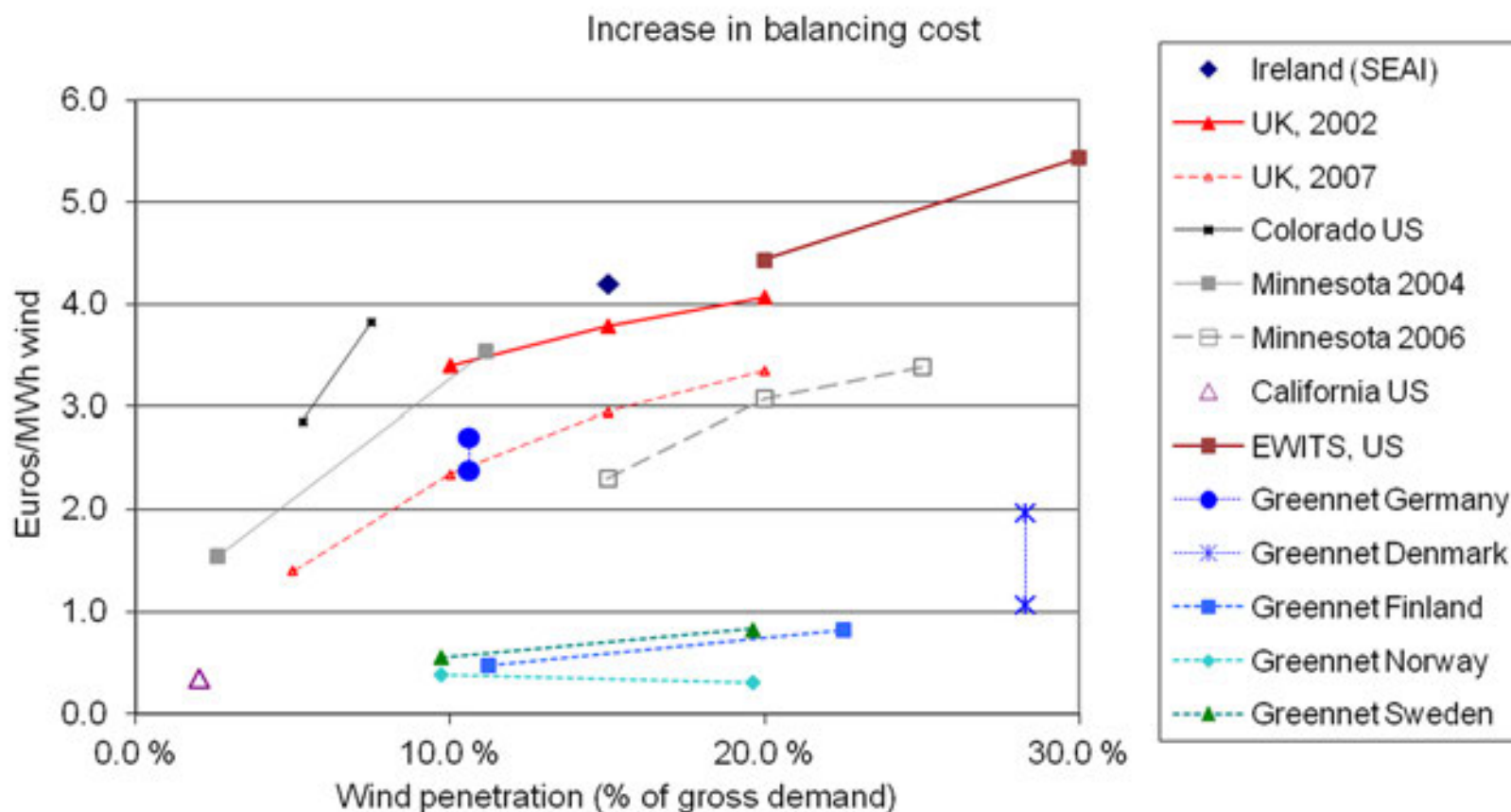
Source: energy & meteo systems, IEA Wind

Simulated forecast error [GW] in Northern Europe in 2020

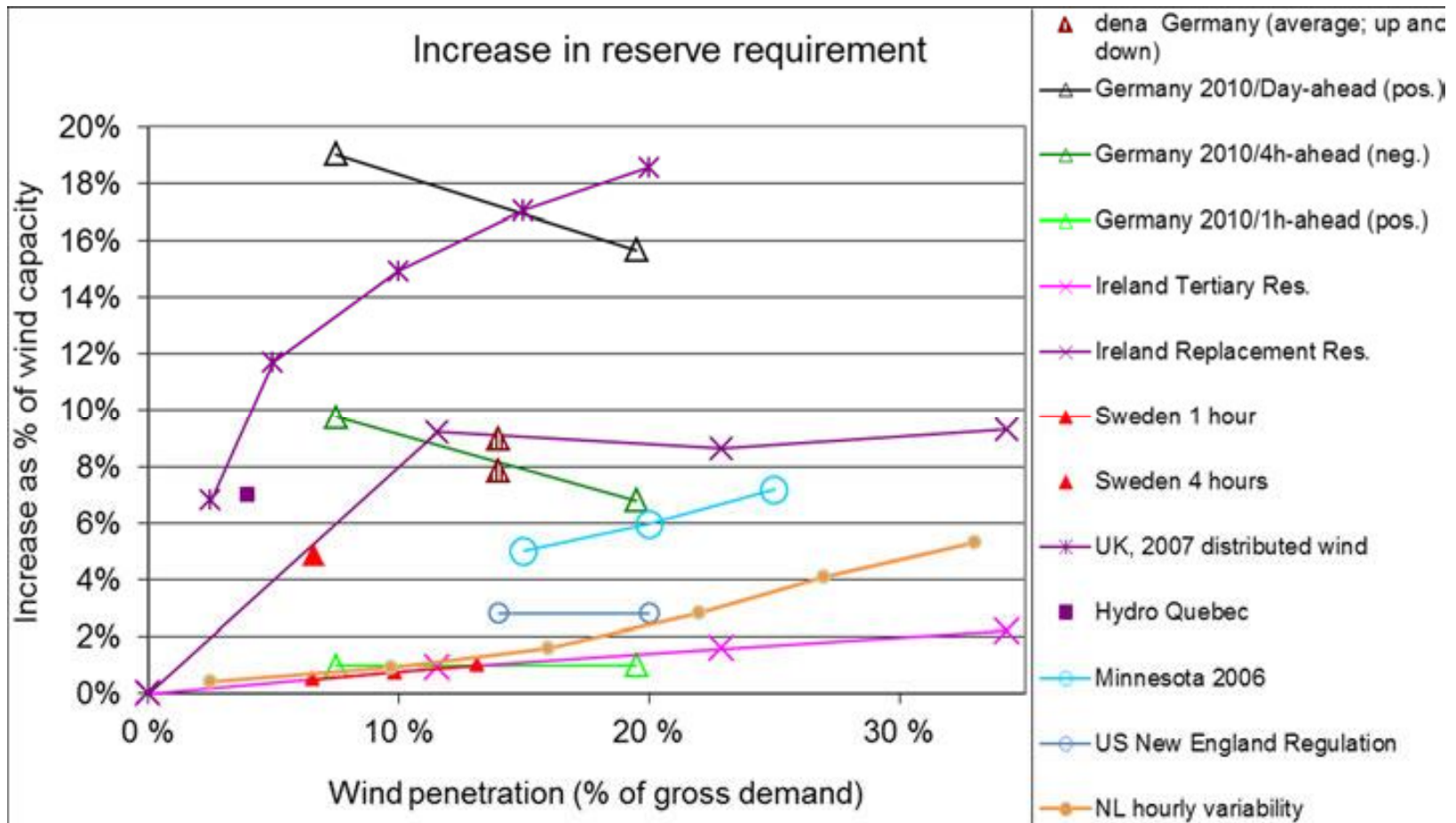


Source: Jaehnert (NTNU)

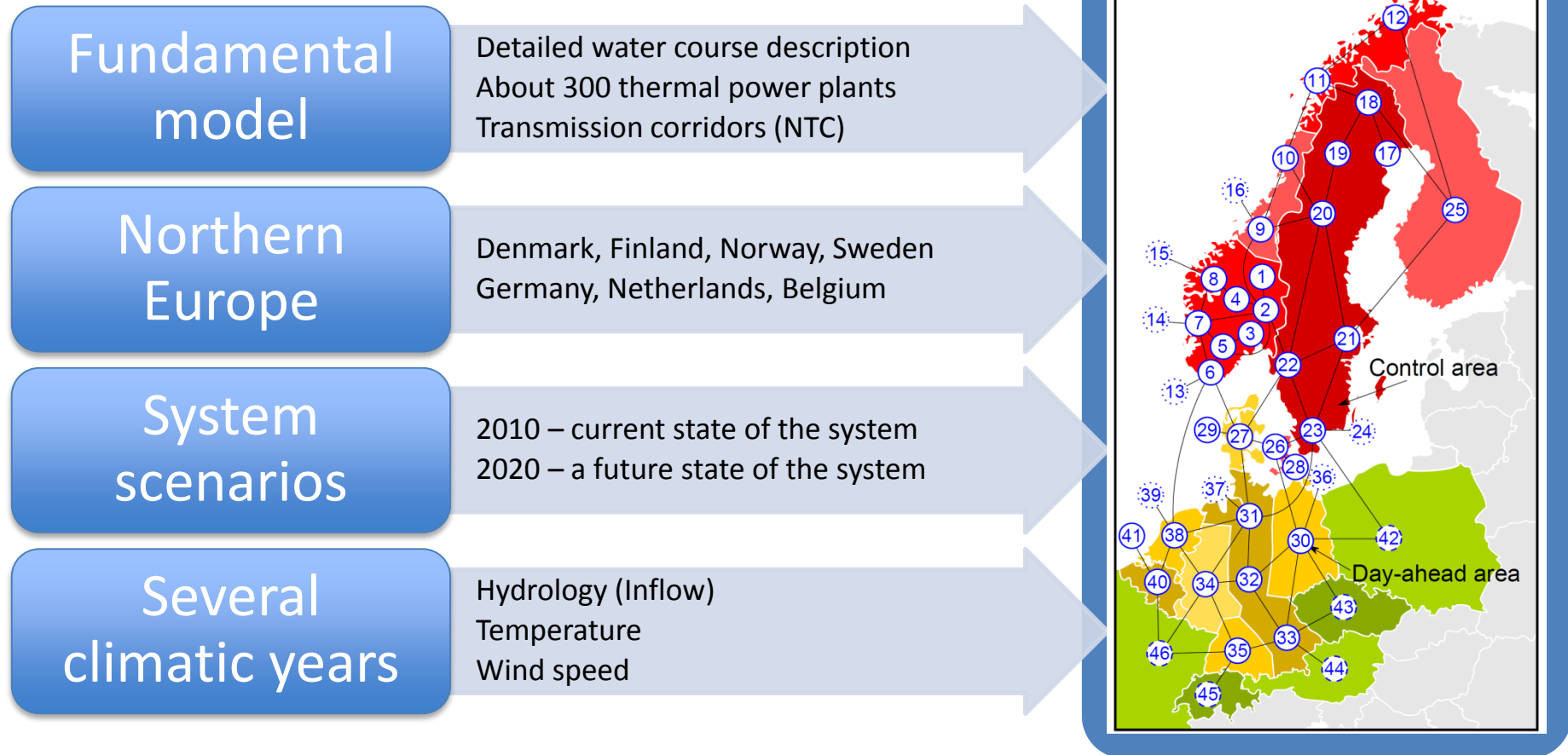
Increase in balancing costs due to wind



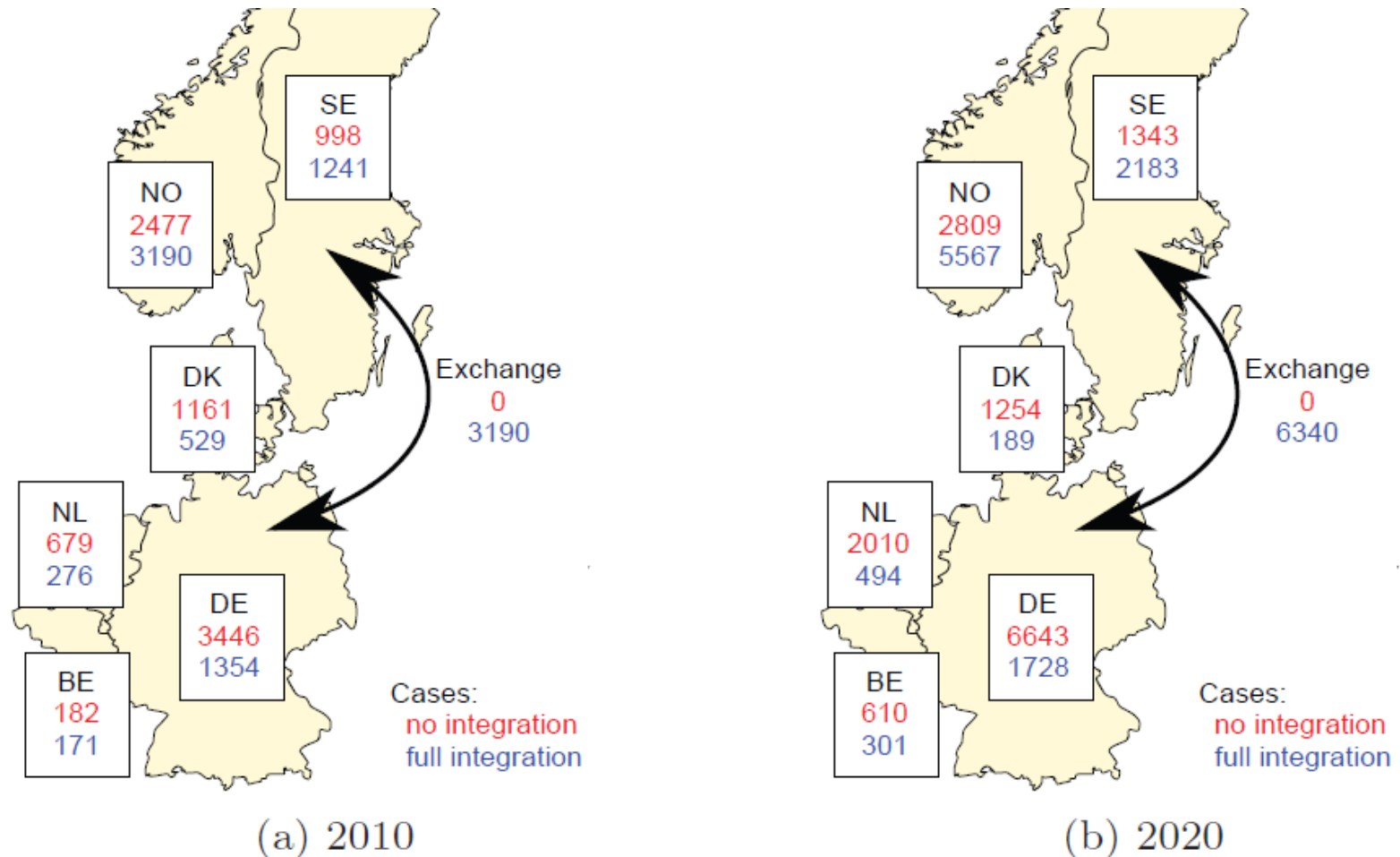
Increase in reserve requirement due to wind



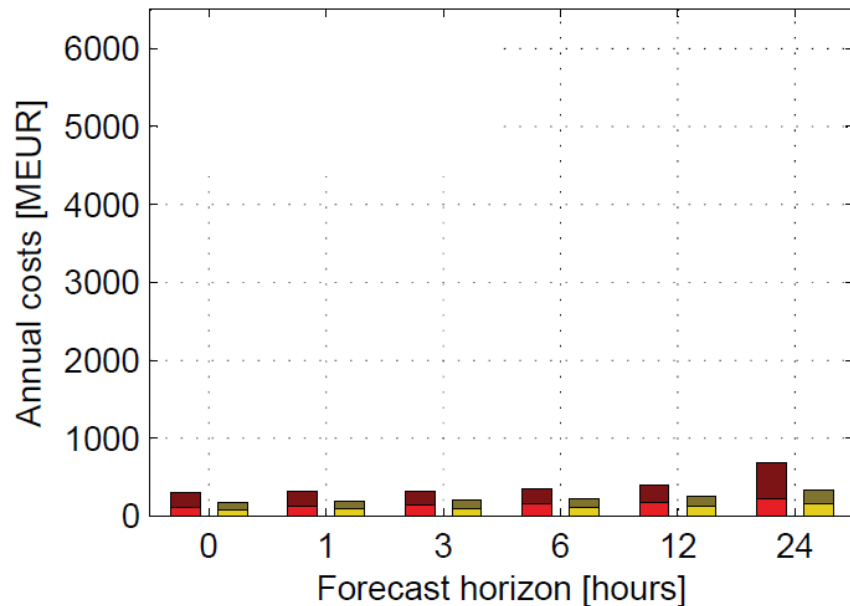
Study model 1 – Integration of balancing markets



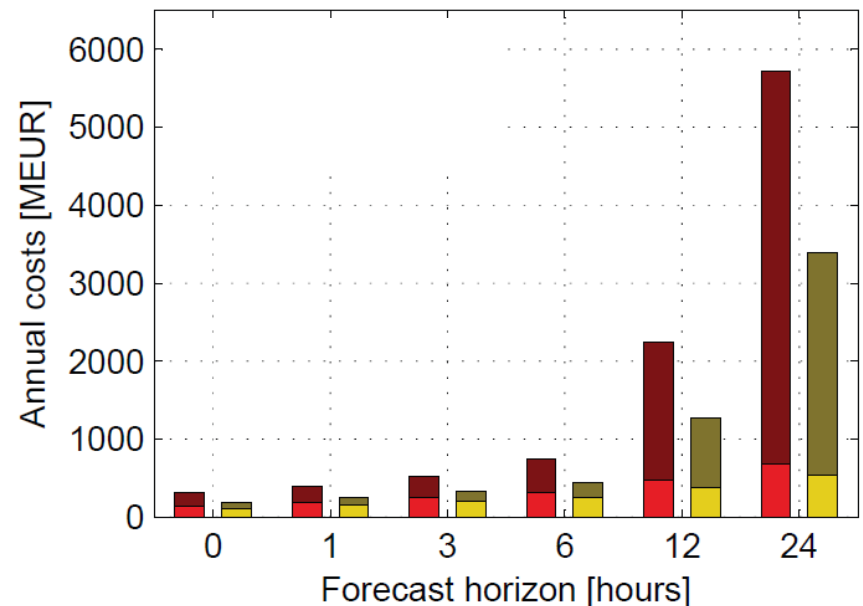
Country wise annual balancing reserve allocation (GWh/yr)



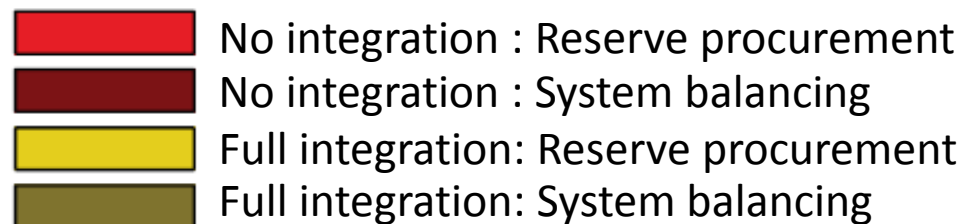
Total balancing market costs for different wind forecast horizons



(a) 2010

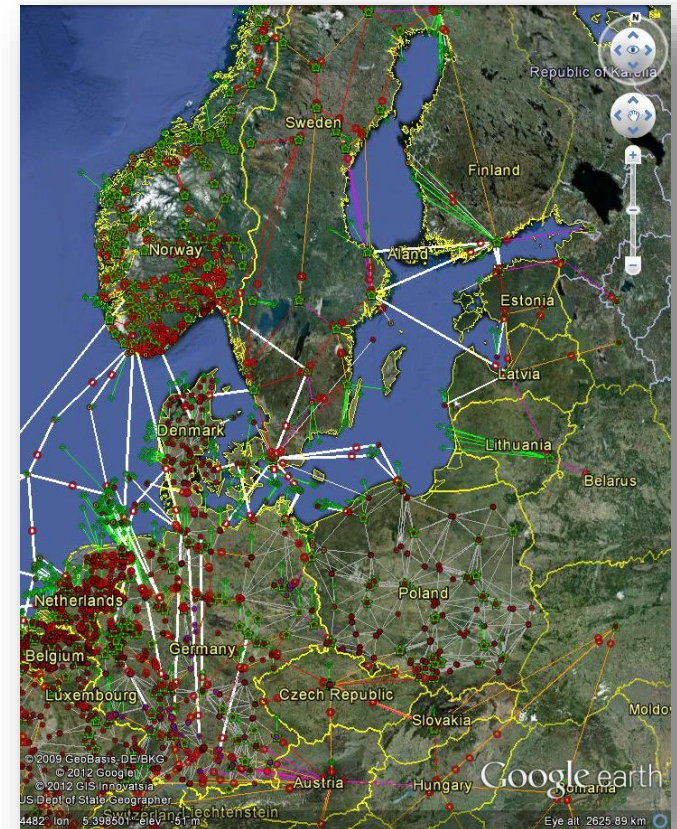


(b) 2020



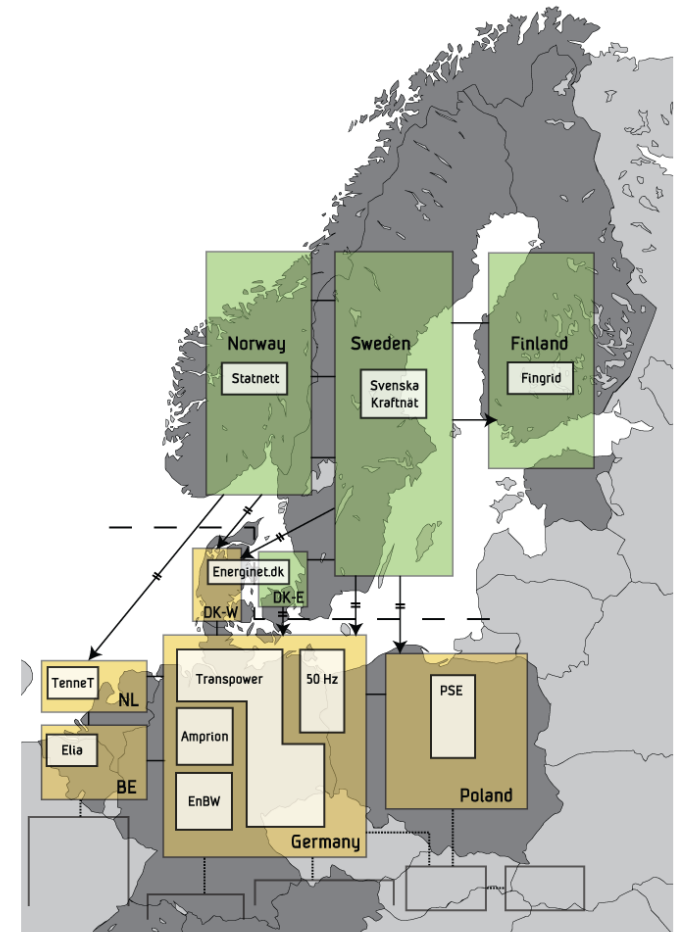
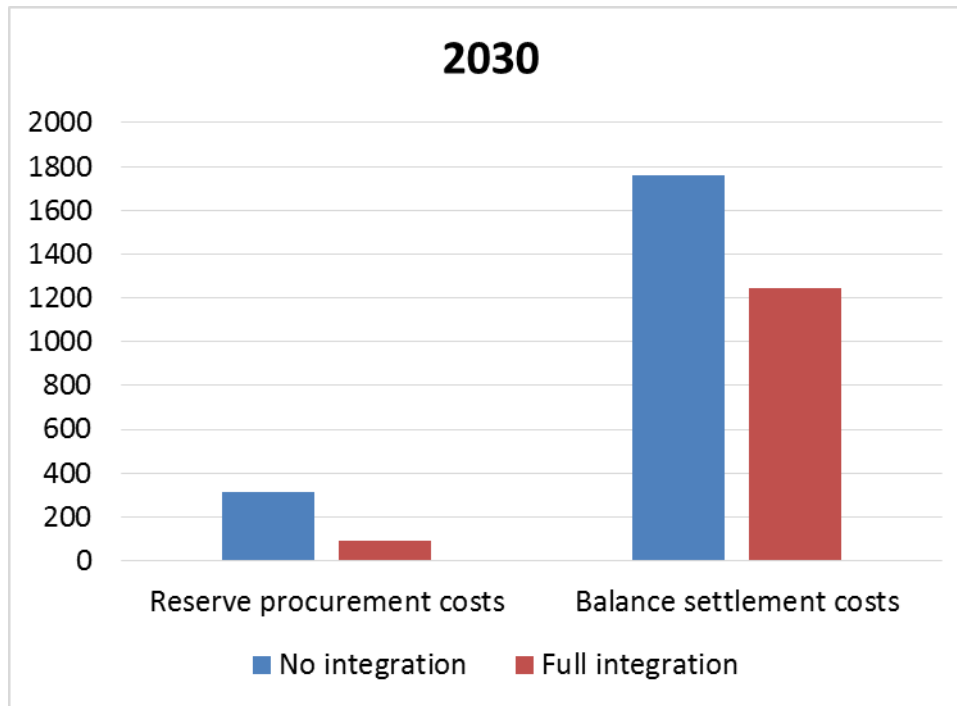
Study model 2 – Integration of balancing markets

- Detailed European grid model based on DC power flow
- Representation of day-ahead, intra-day and balancing markets
- Co-optimizing day-ahead schedules and reserve procurements based on forecasts
- Scenarios for load, generation and grid capacity year 2020 and 2030



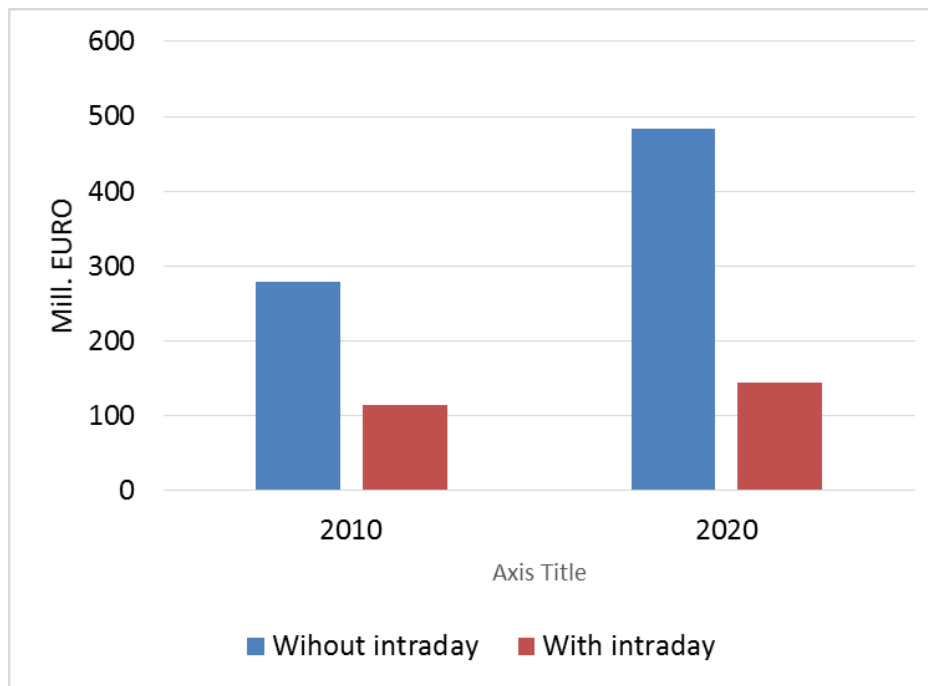
Large benefits of integrating the Northern and continental balancing markets

Total annual balancing cost savings (Mill.EURO)

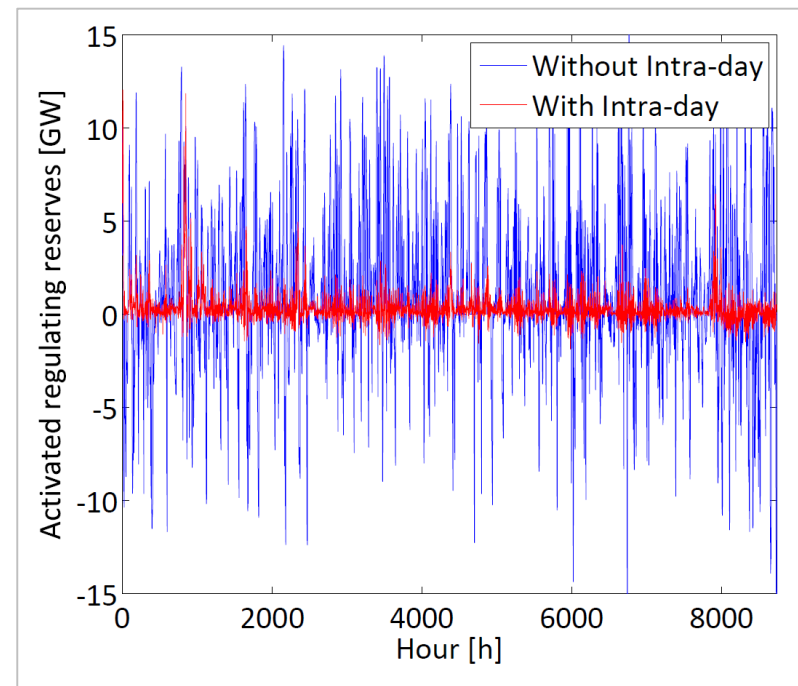


Significant additional savings are achieved with intra-day markets

Total annual balancing cost savings



Activated reserves



Summary

- It is the net load variations that matters
 - Load – Wind - PV
 - Geographical smoothing of RE variability
 - Geographical smoothing of RE predictability
- An efficient and integrated power market is an enabler for high RE penetration
 - Reduces the need for expensive storage
 - Reduces the need for expensive reserves
- Comprehensive studies of balancing markets in Northern Europe
 - Huge benefits of integrated markets for balancing resources
 - Huge benefits of integrated markets for intra-day trading