Norsk vannkraft i det europeiske kraftmarkedet

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CEDREN-Hydrobalance (2013-2017)

WP 1 Roadmaps for balancing from Norwegian hydropower

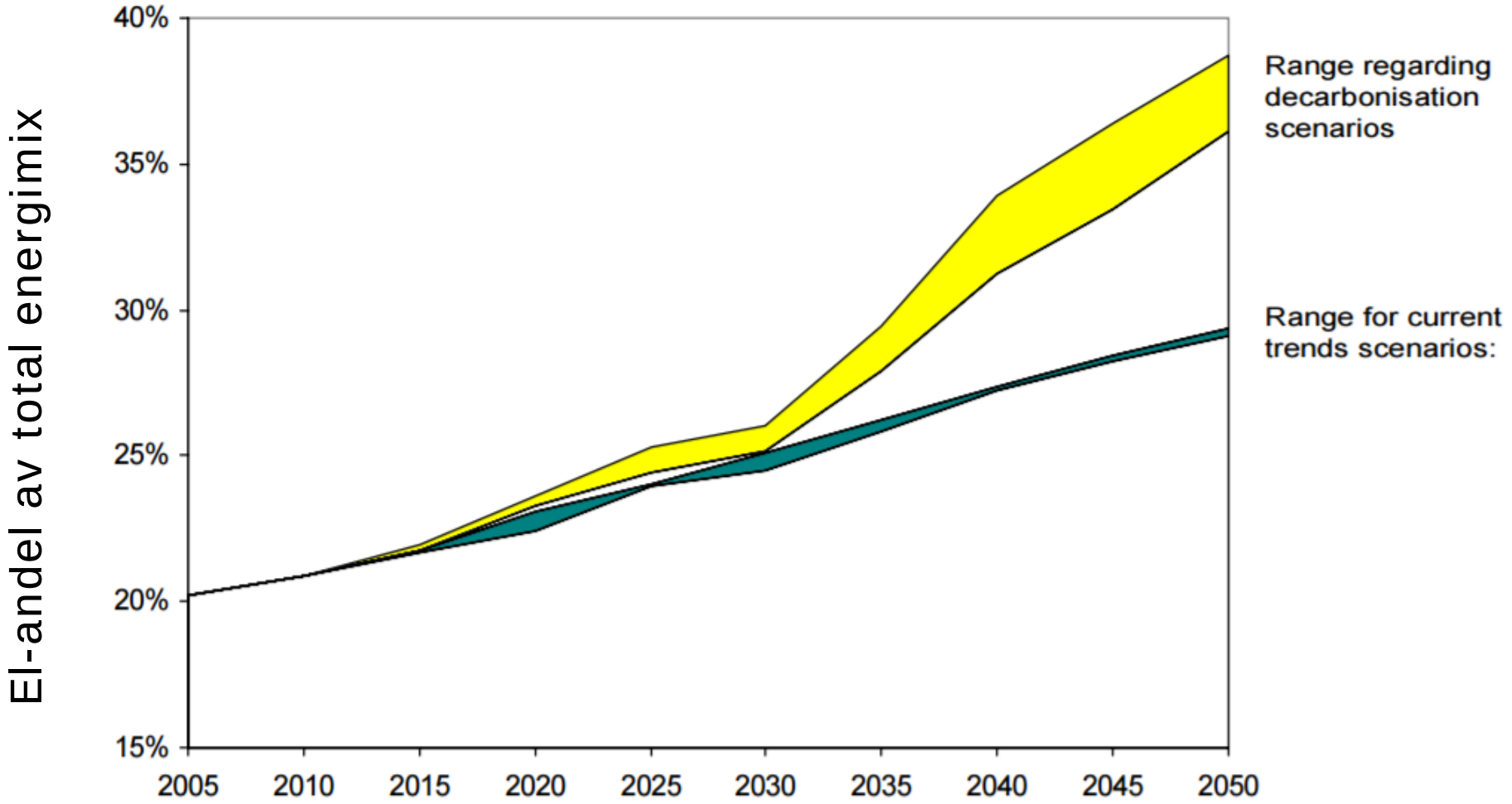
WP 2 Demand for balancing in Europe

WP 3 Business models

WP 4 Environmental impact

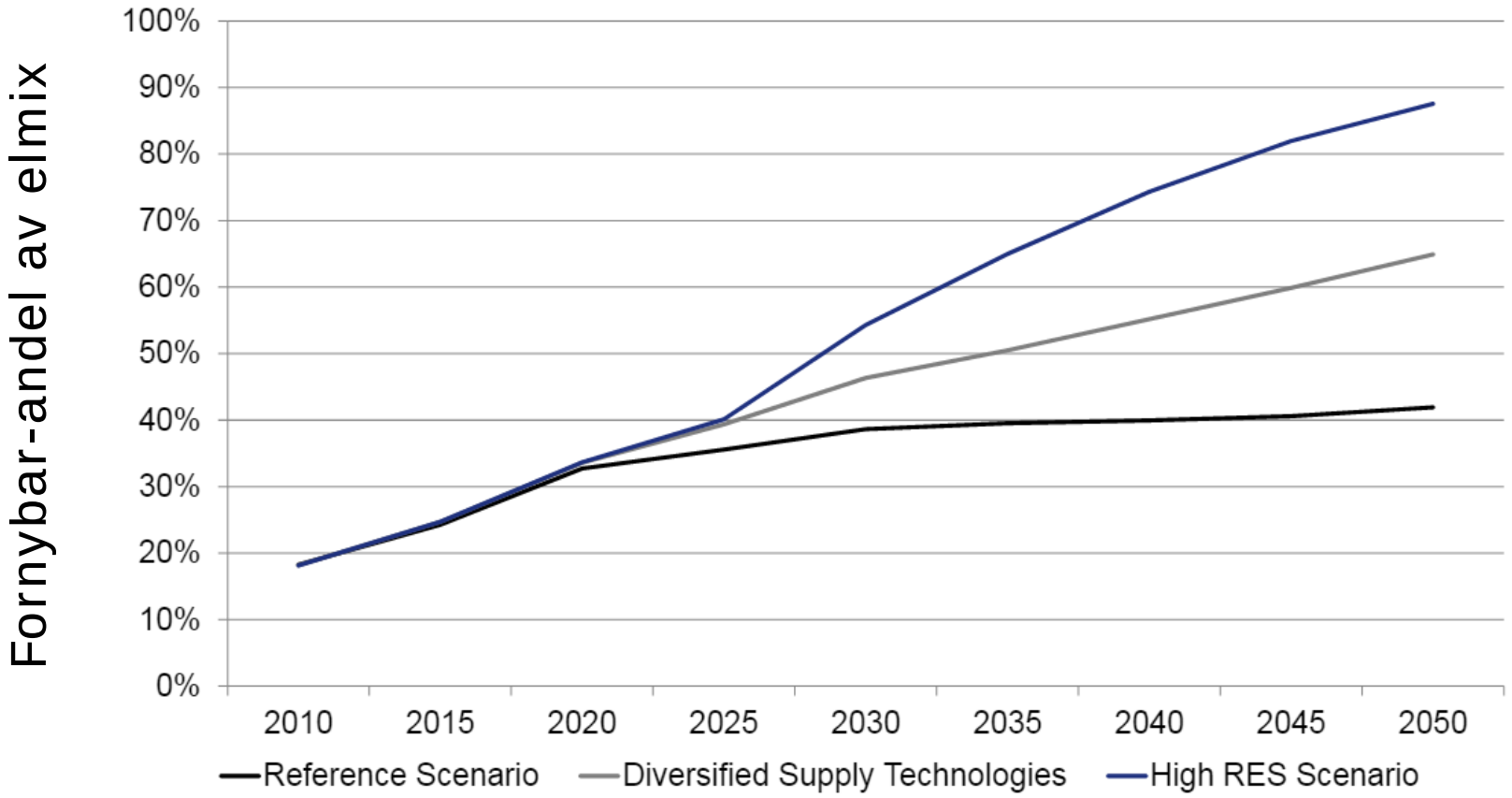
WP 5 Social acceptance and regulatory framework

Europa skal avkarboniseres og elektrifiseres…



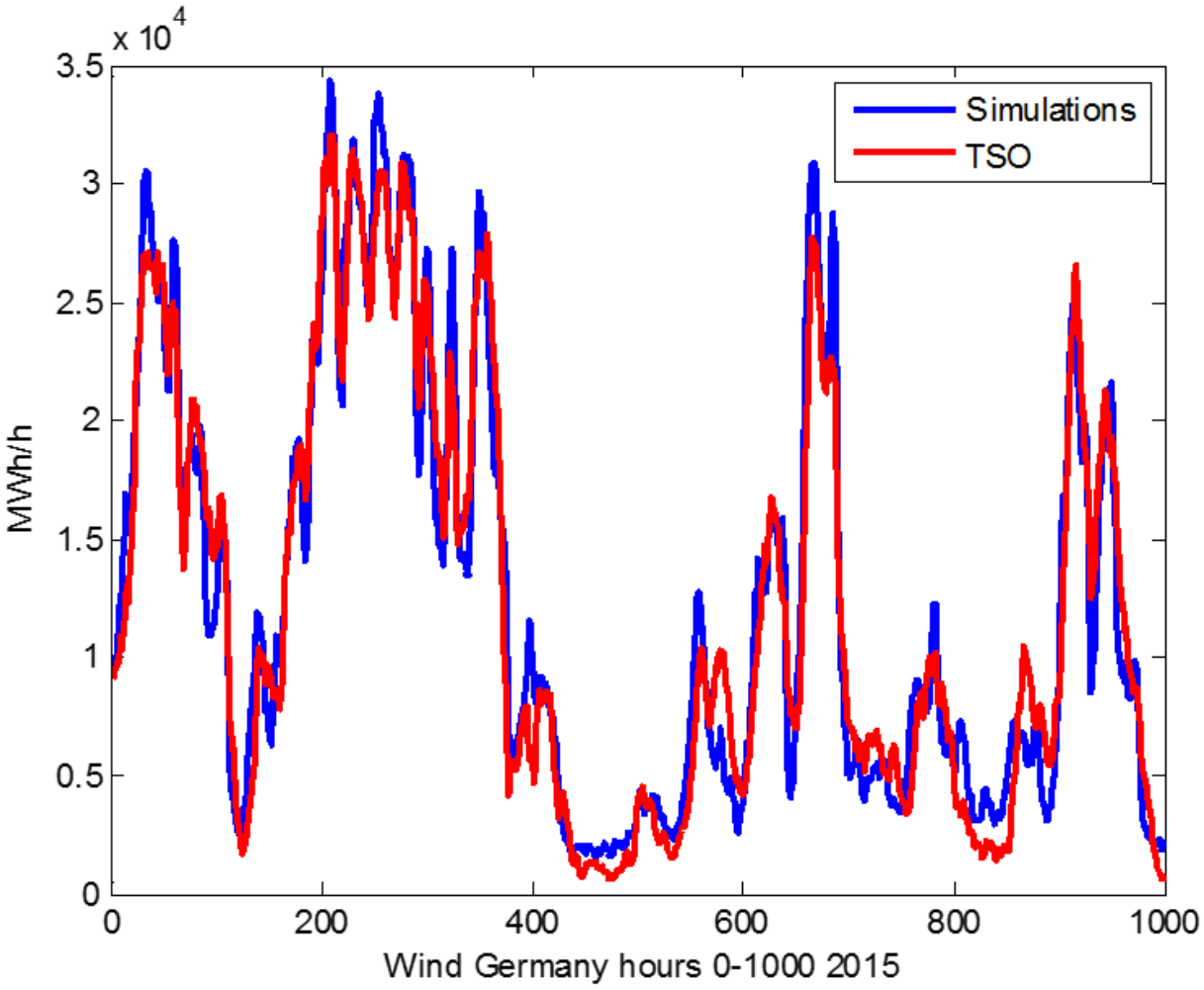
Kilde: EU Energy Roadmap 2050

… ved storskala omlegging til fornybar energi



Kilde: EU Energy Roadmap 2050

Vind-og solvariasjoner er en økende utfordring for systemet



Betydelig samvariasjon av vind i Nordsjøområdet

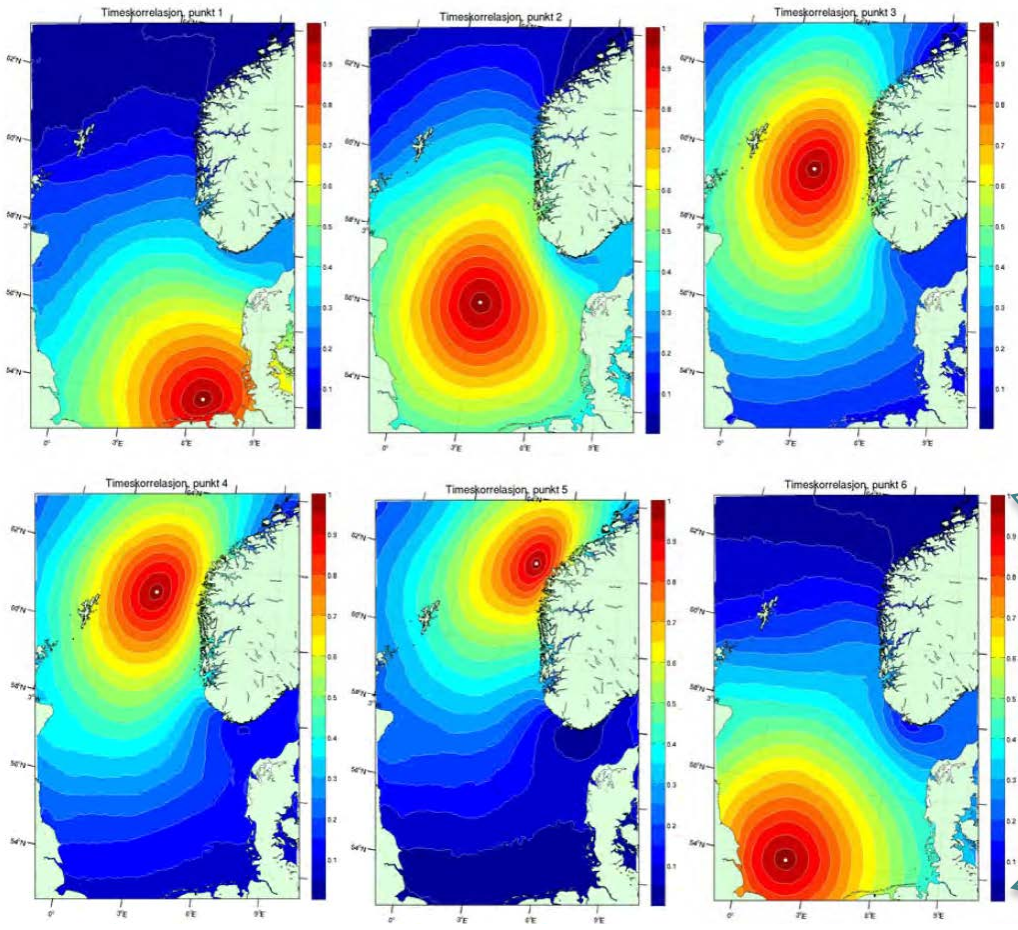
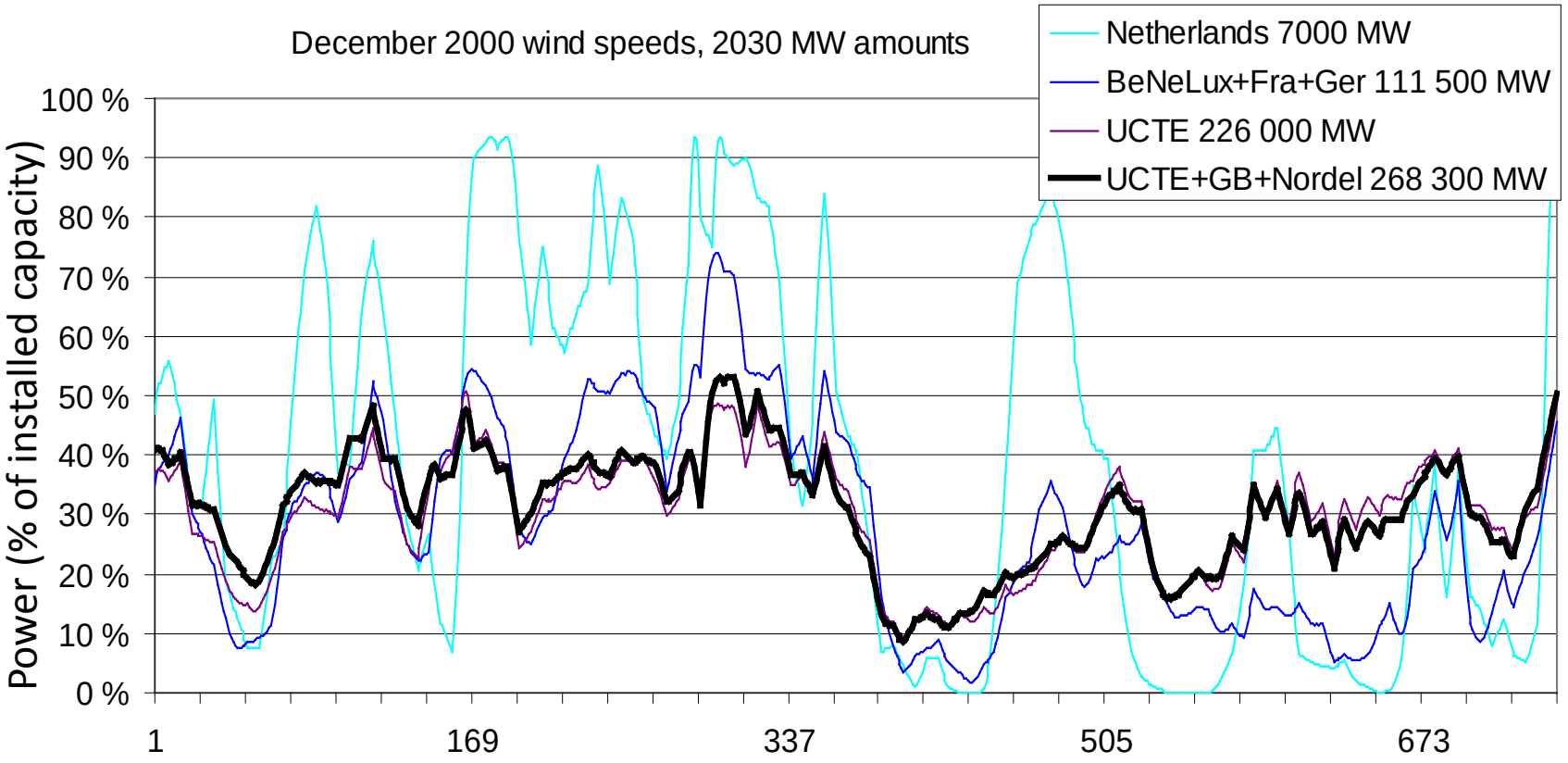


Figure shows correlation for hourly wind velocity in the North Sea.

Source: Kjeller Vindteknikk

Et velutbygd kraftnett hjelper på å glatte ut lokale variasjoner



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

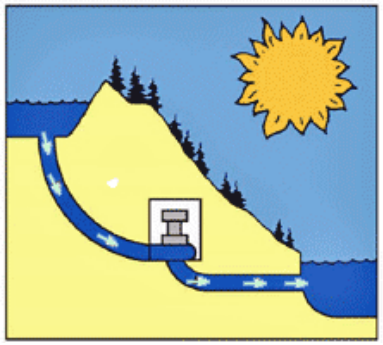
Source: Fraunhofer IWES

TradeWind

Nordisk vannkraft har unike kvaliteter..

- Hurtig reguleringskapasitet for levering av effekt
- Store vannmagasiner for lagring av energi
- Store effekt- og pumpeutvidelser mulig i eksisterende vannkraftsystem

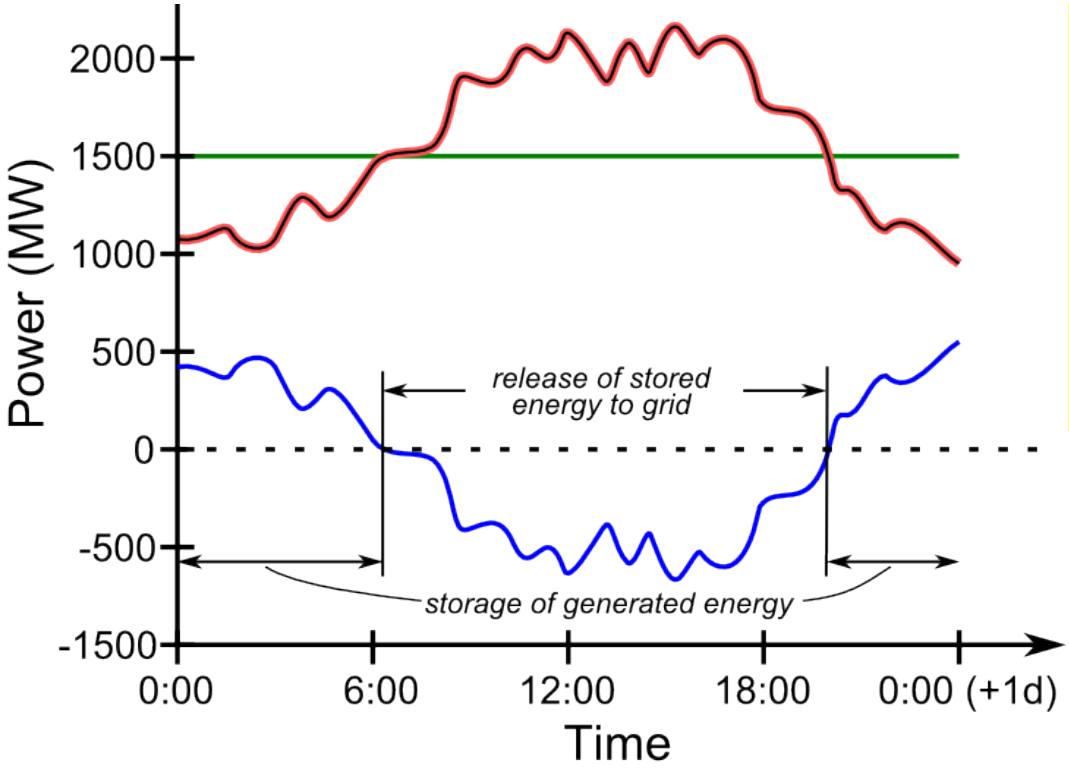
- Det er et sterkt økende behov for fleksibel kraft i Europa. Hva slags rolle kan nordisk vannkraft spille?



Energilagring

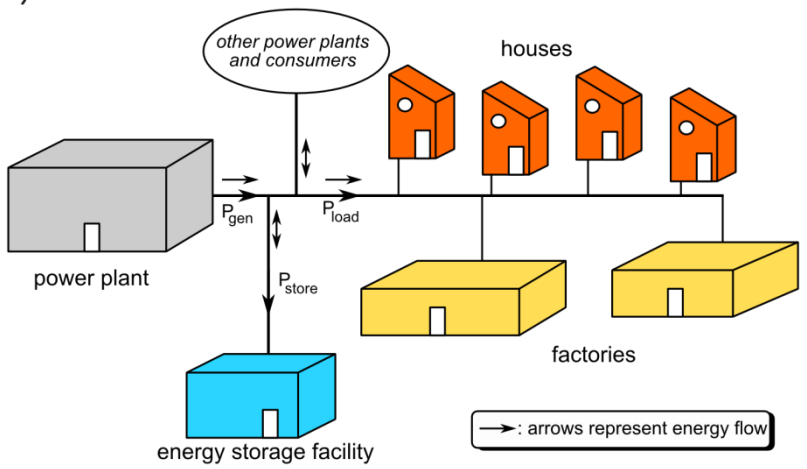
- Sikre samsvar mellom forbruk og produksjon av el
- Tradisjonelt har vi sett behov innen to hovedområder
  - *Balansering av el-produksjon i varmekraftverk over døgnet*
  - *Sesonglagring av vannkraft fra vår og sommer til vinter*
- Nå økende fokus på integrasjon av sol og vind
- Behov for energilagring på mange tidsskalaer
- Nødvendig for å sikre framtidig fornybar-satsing
- Ikke alltid lett å se behovet i dag – hvorfor?

Balansering over døgnet i et termisk system (variasjon i forbruk)



Termiske kraftverk er mest effektive når de kjøres med jevn last. Endringer i forbruk i løpet av døgnet kan med fordel håndteres av andre typer kraftverk, for eksempel pumpekraftverk eller gasskraftverk

Tradisjonelt er pumpekraft brukt for å supplere kraftproduksjon i høylast-perioder om dagen, mens pumping har skjedd om natta. Dette har endret seg for eksempel i Tyskland på grunn av mye PV-produksjon om dagen



Sesongvariasjon i tilsig og forbruk i Norge (2007)

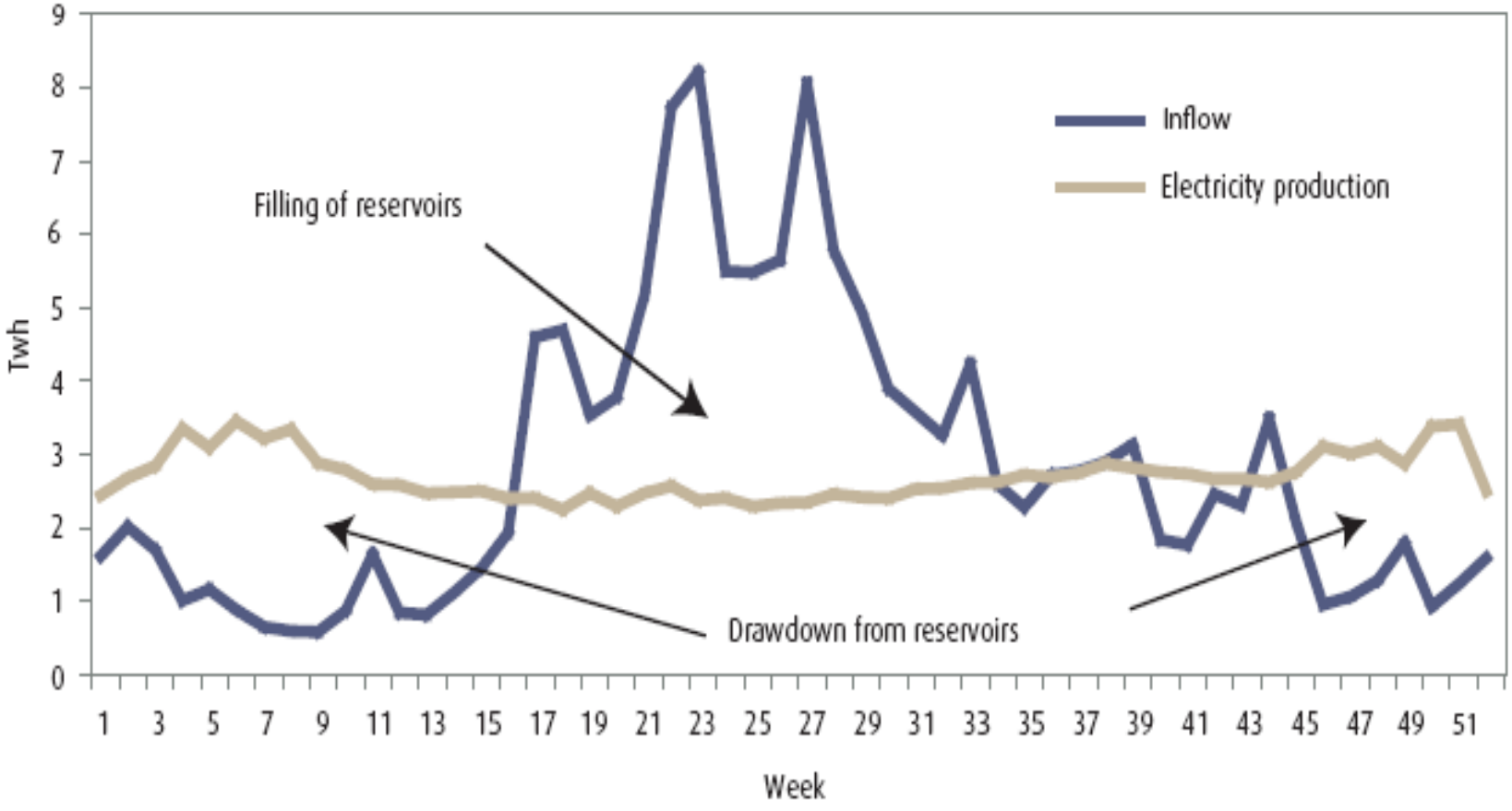
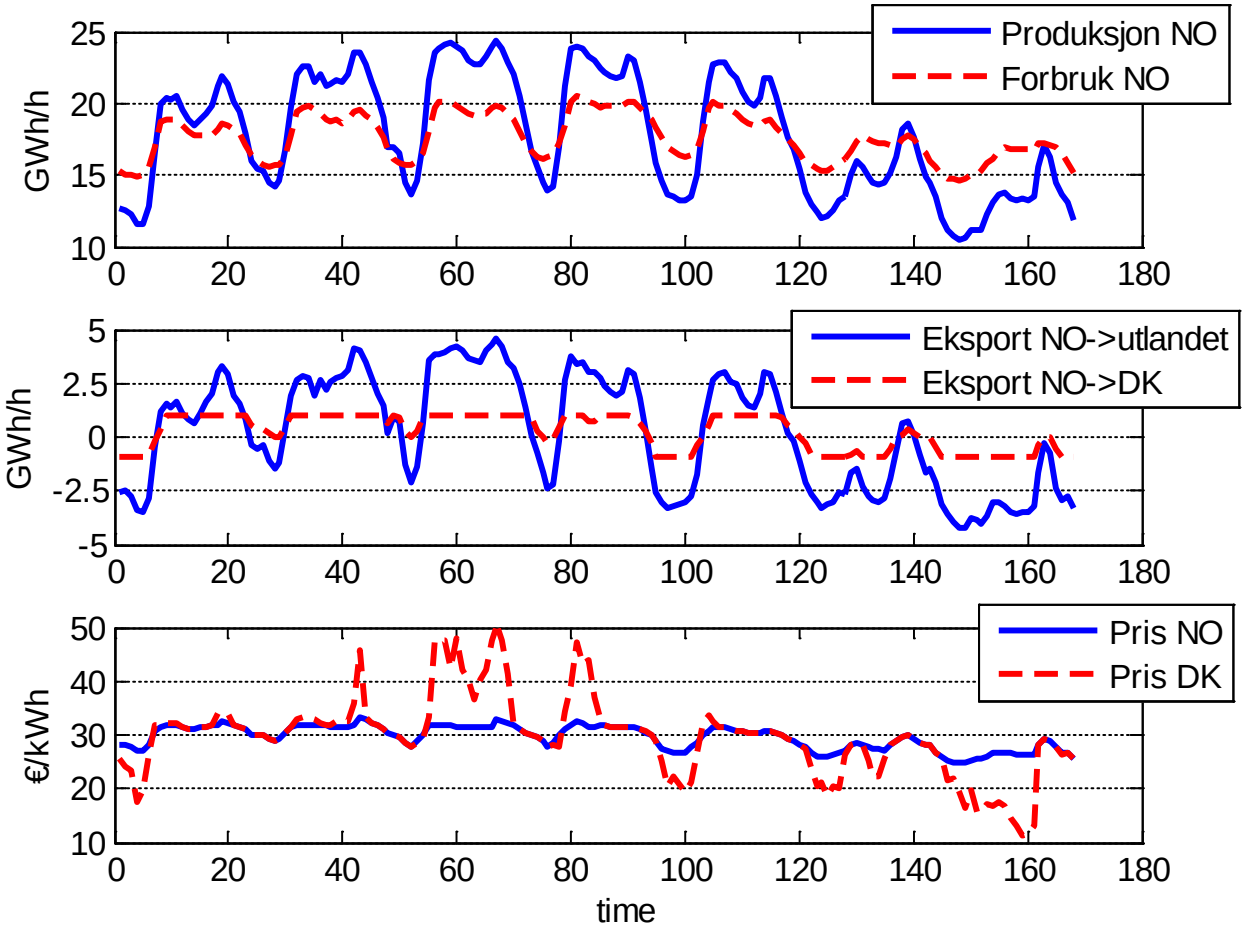
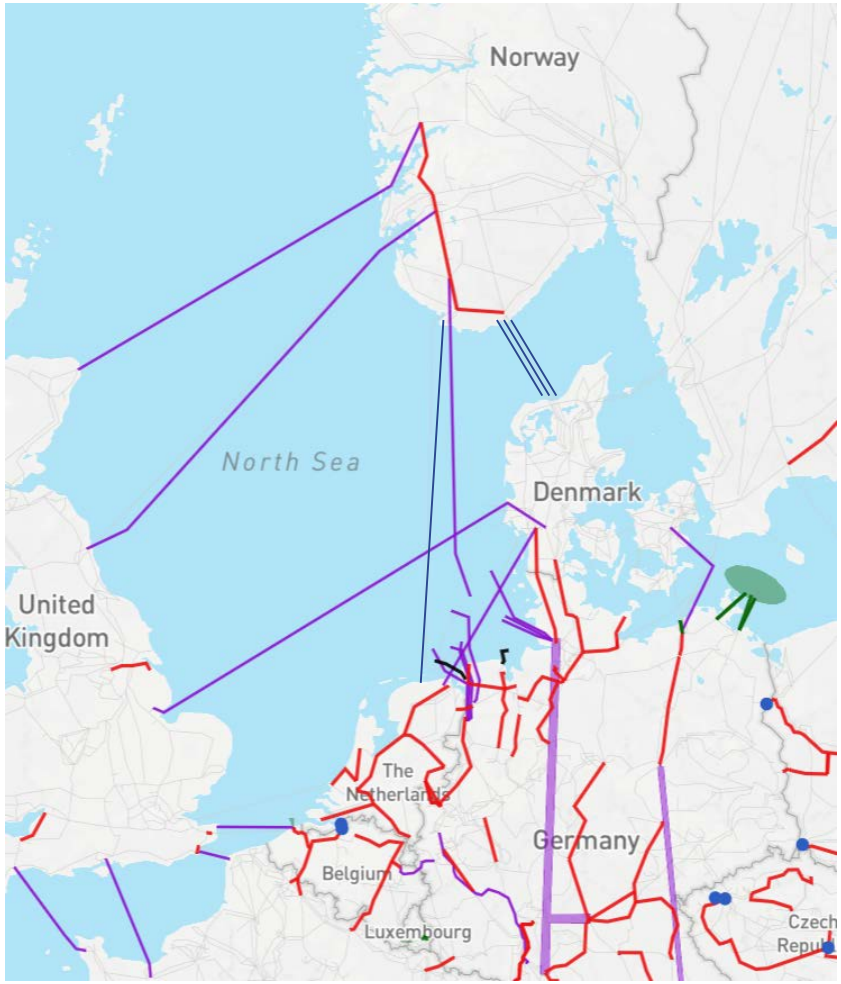


Figure 2.2 Variations in water inflow and electricity output in 2007.
Source: Nord Pool

Dagens utvekslingsmønster (timer-uke)



Nettutvikling rundt Nordsjøen



Source: ENTSO-E

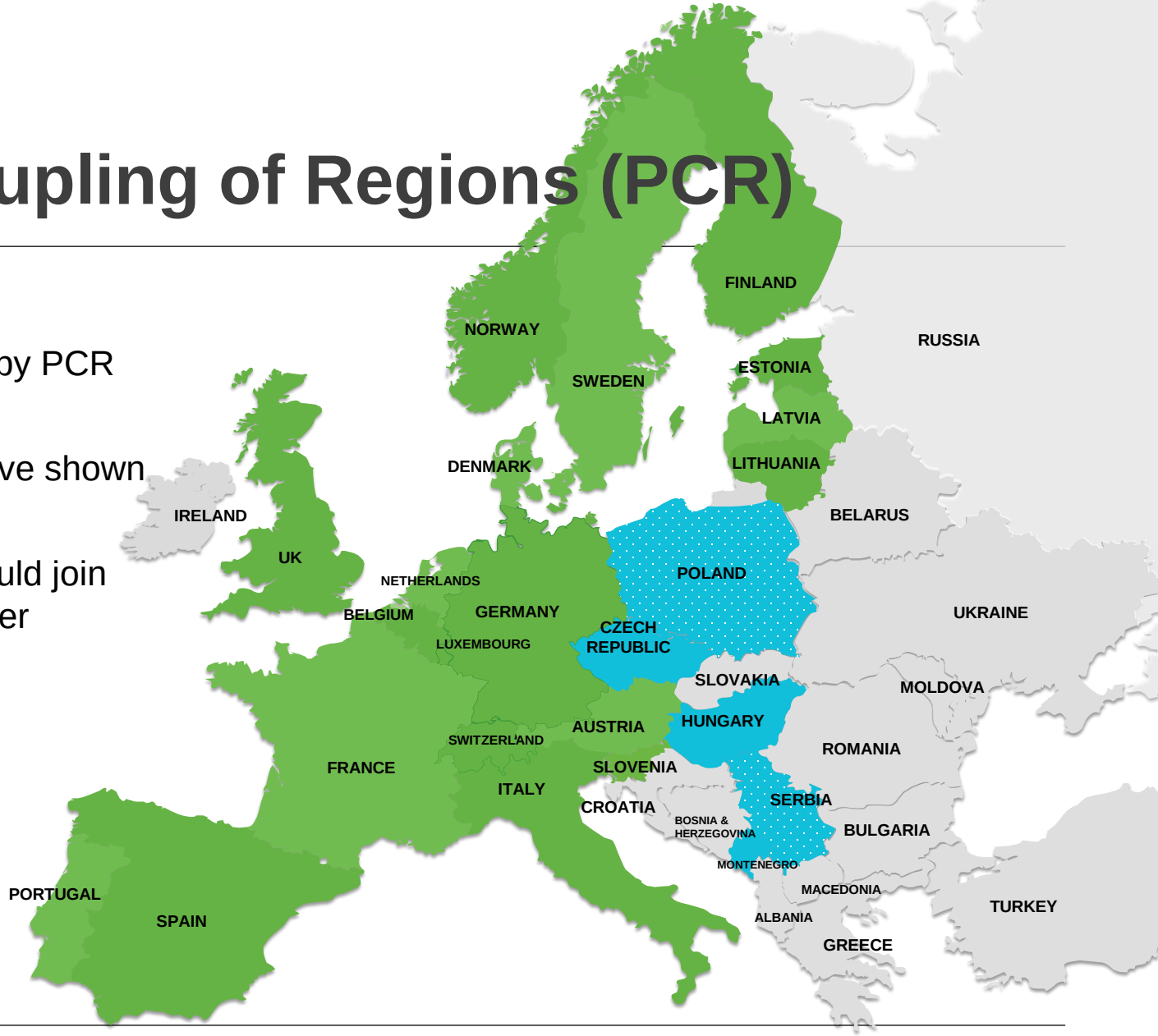
Egenskaper til et kraftmarked som er tilrettelagt for fleksibilitet

- Felles markeder for spot, balanse og systemtjenester over landegrensene
- Produksjonsplaner oppdateres hyppigere
- Markedsklarering tettere på driftstimen
- Forbrukssiden deltar aktivt

- Tillate ekstrempriser på spot eller innføre kapasitetsmarkeder
  - «Merit order effect»

Price Coupling of Regions (PCR)

- Markets covered by PCR (2860 TWh)
- Markets which have shown interest to join
- Markets which could join as a part of a larger European plan



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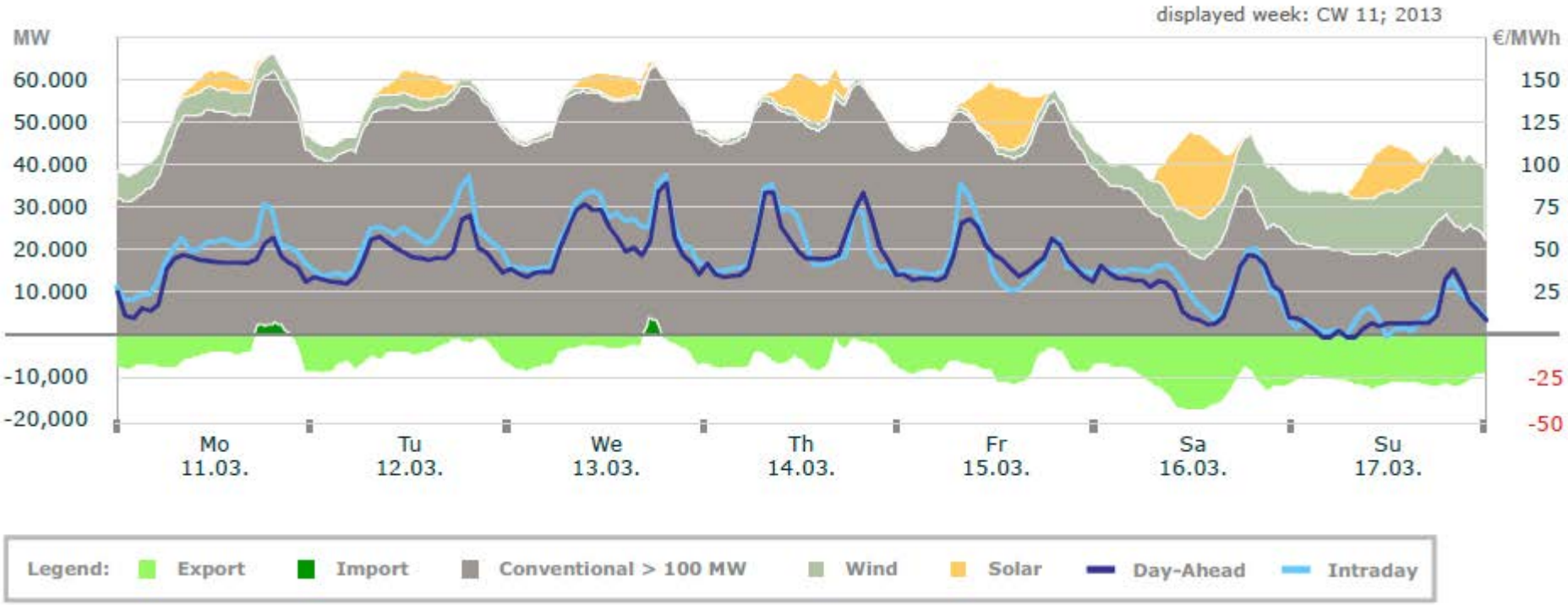
Sammenhengen mellom vind/sol og pris

Eksempel fra Tyskland



Source: J. Mayer, Fraunhofer ISE

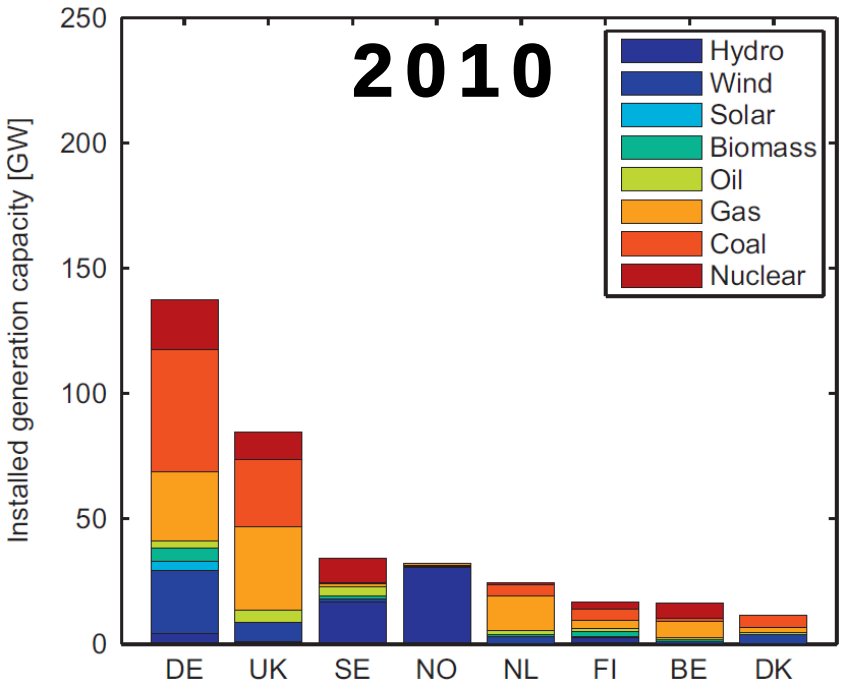
North-European Power market model

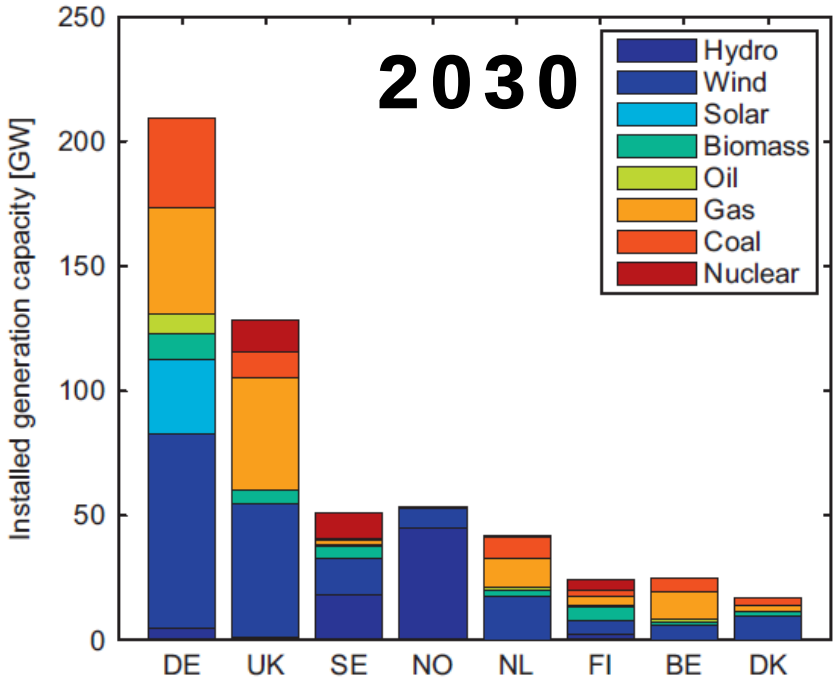
- 75 climatic years (wind, solar, inflow, temperature)
- 2 hours resolution
- 52 areas
- about 1500 power plants
- 80 transmission corridors
- Stochastic optimisation
- Unit commitment and dispatch

Source: Jaehnert, Korpås, Doorman (NTNU)

Scenarios for generation capacity

- Phase-out of nuclear in Germany
- Much more wind power in Europe (and solar in Germany)
- +11 GW hydro generation capacity in Norway (+5 GW pumpinig)
- Consumption increases with 5-15 %, depending on country

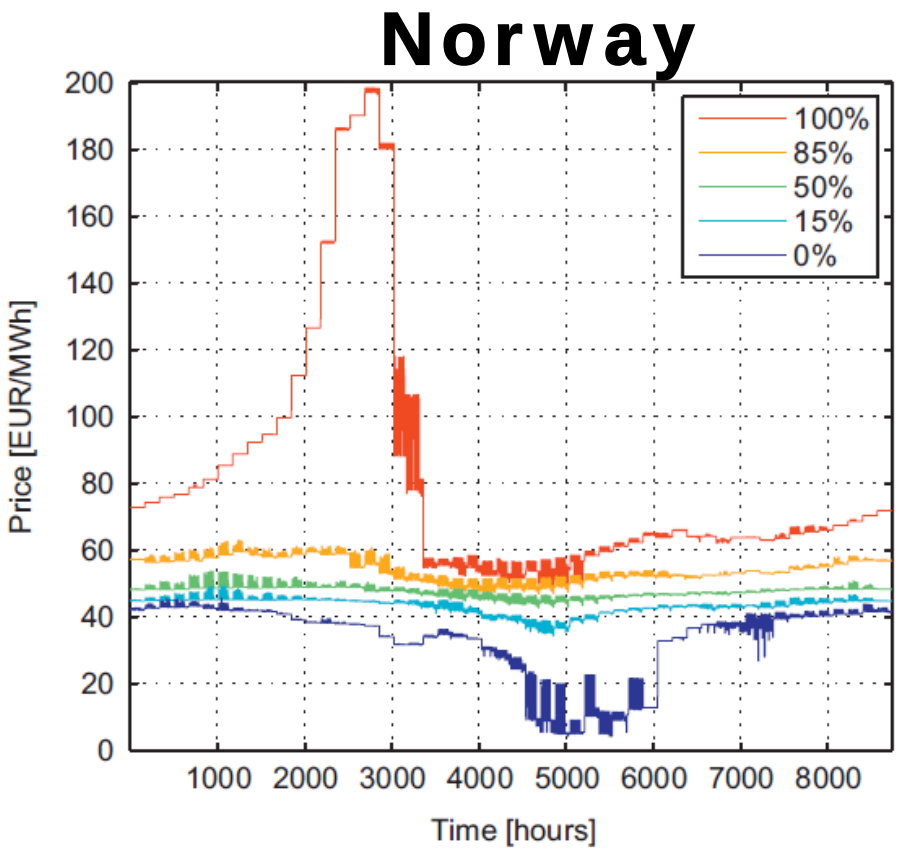


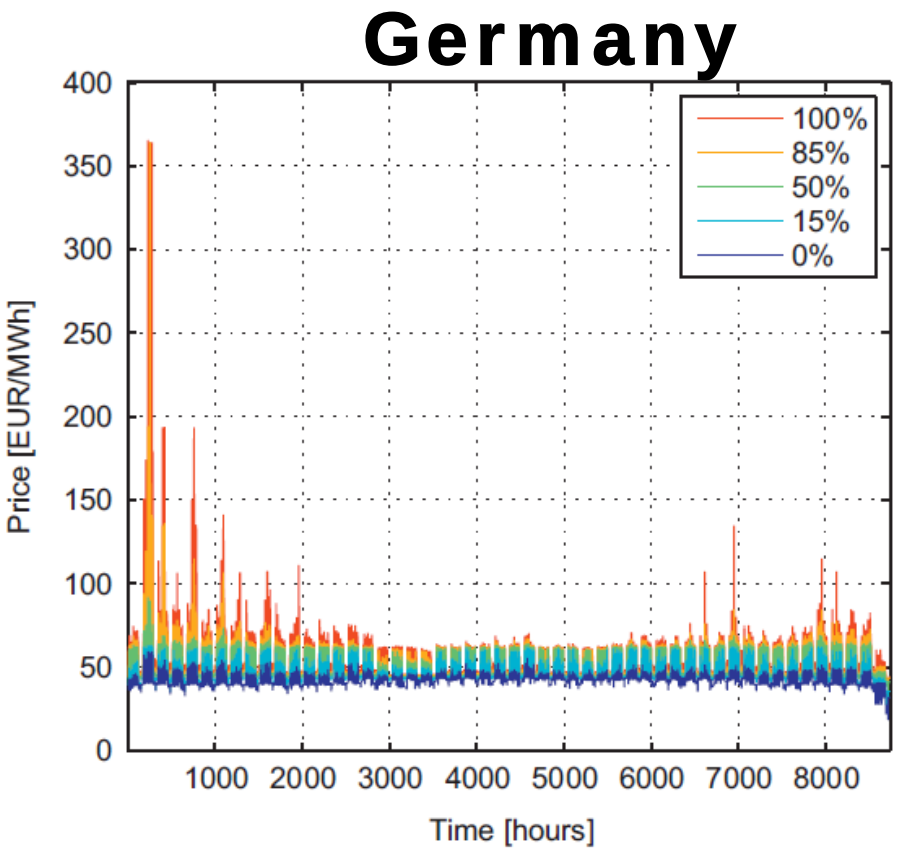


Source: Jaehnert, Korpås, Doorman (NTNU)

Simulated electricity prices in 2010

- Daily prices in Germany reflects the costs of thermal power
- Seasonal prices in Norway depends on the available water



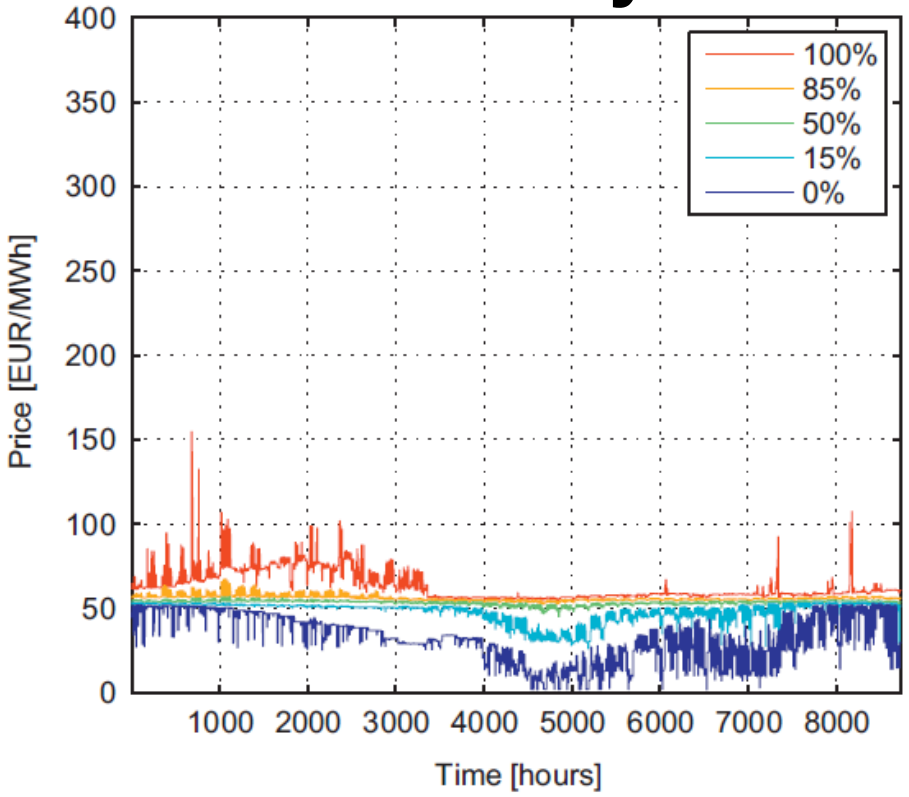


Source: Jaehnert, Korpås, Doorman (NTNU)

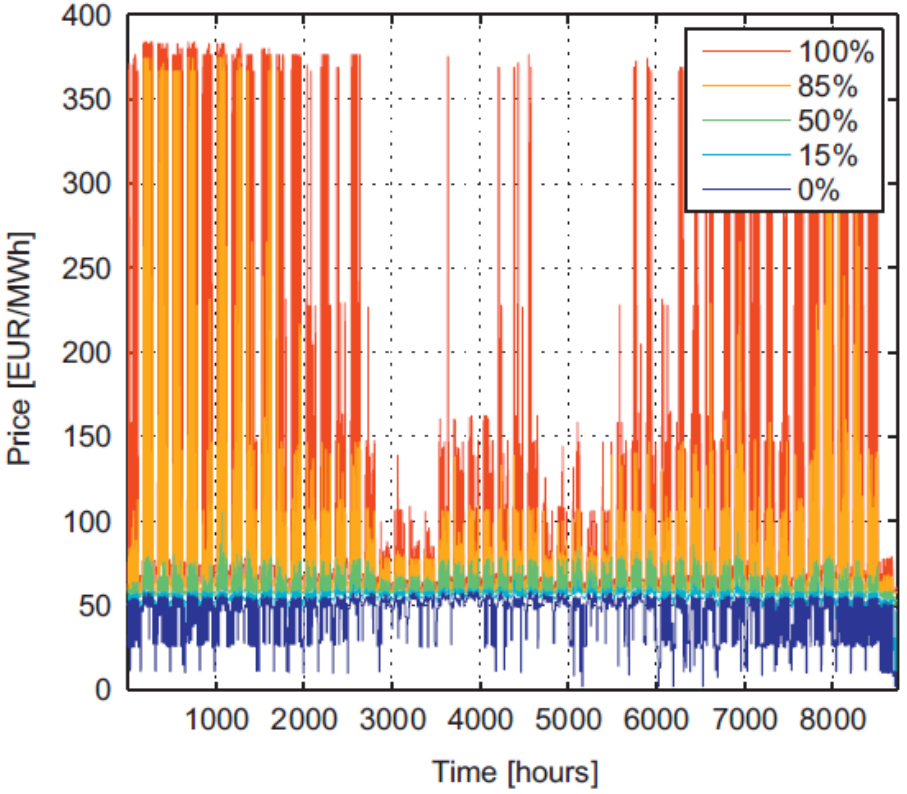
Simulated electricity prices in 2030

- Higher short-term price variability in Germany
- Lower short-term price variability in Norway

Norway



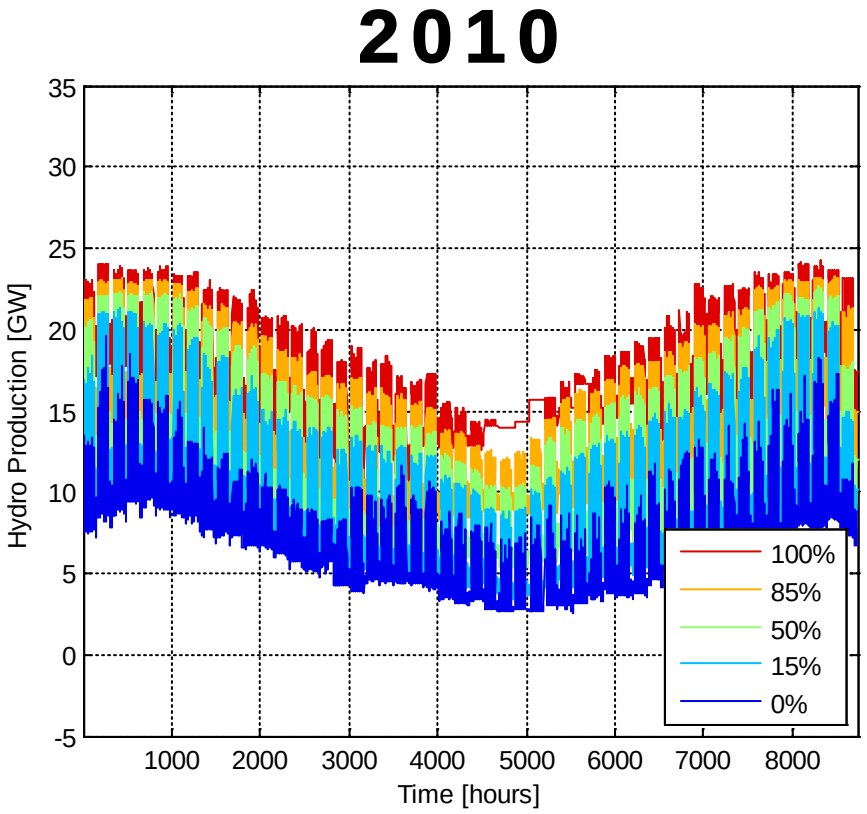
Germany

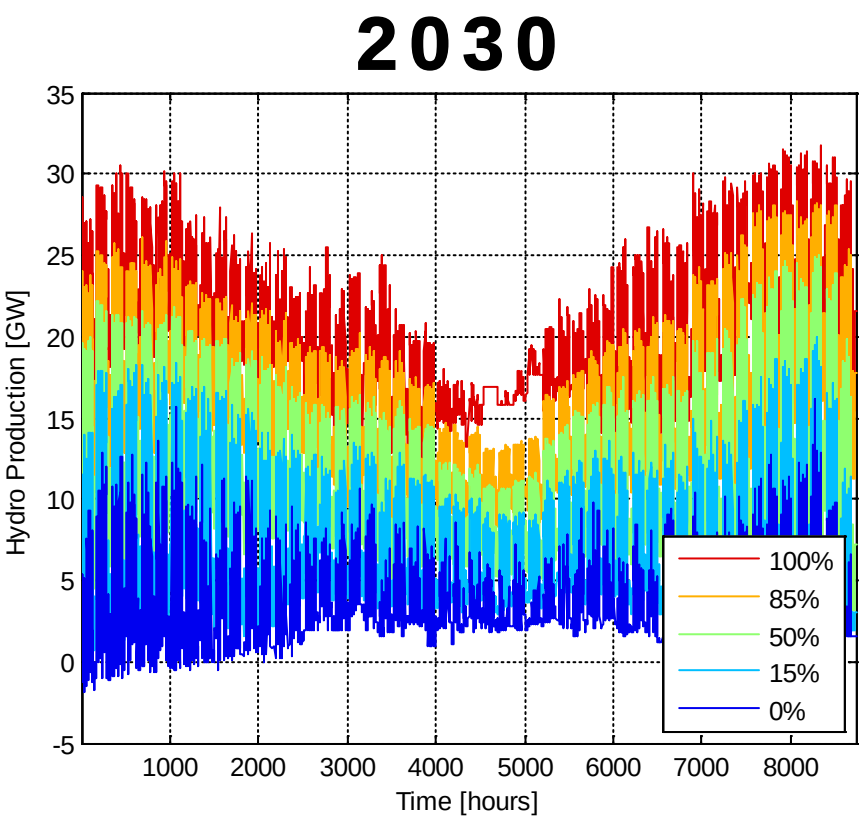


Source: Jaehnert, Korpås, Doorman (NTNU)

Norwegian hydro production

- Increased production variability due to balancing of WPP

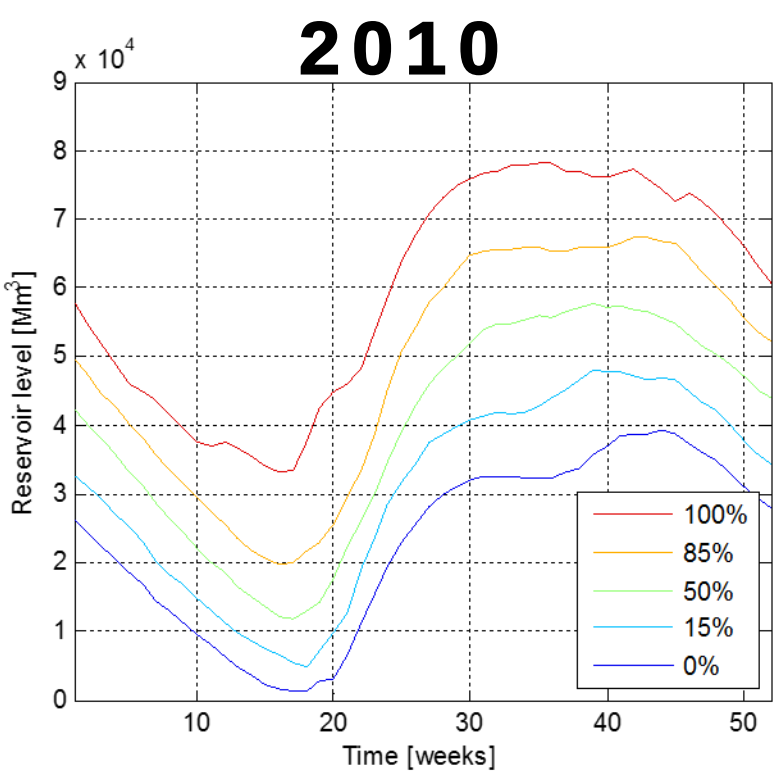


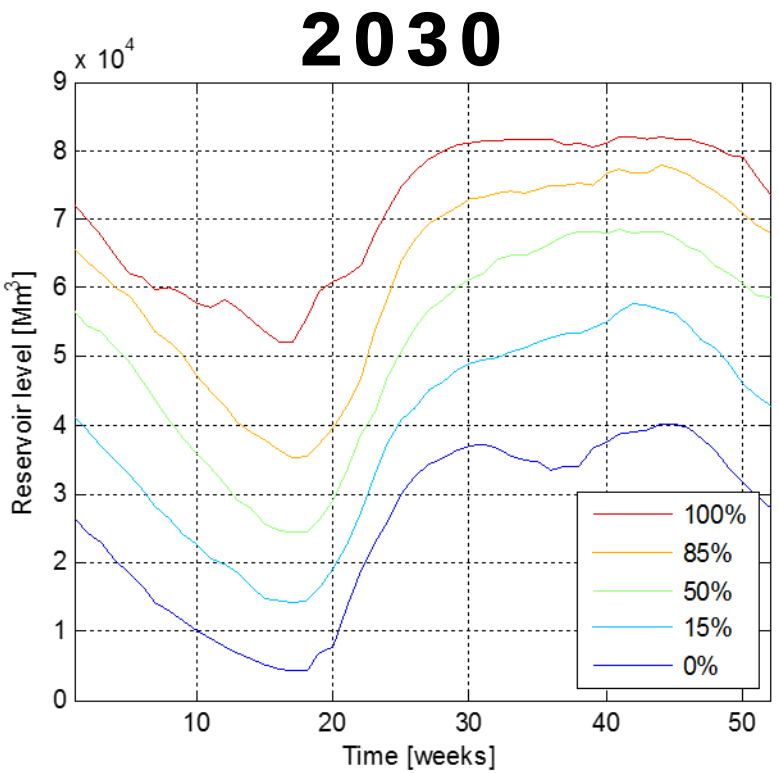


Source: Jaehnert, Korpås, Doorman (NTNU)

Norwegian reservoir handling

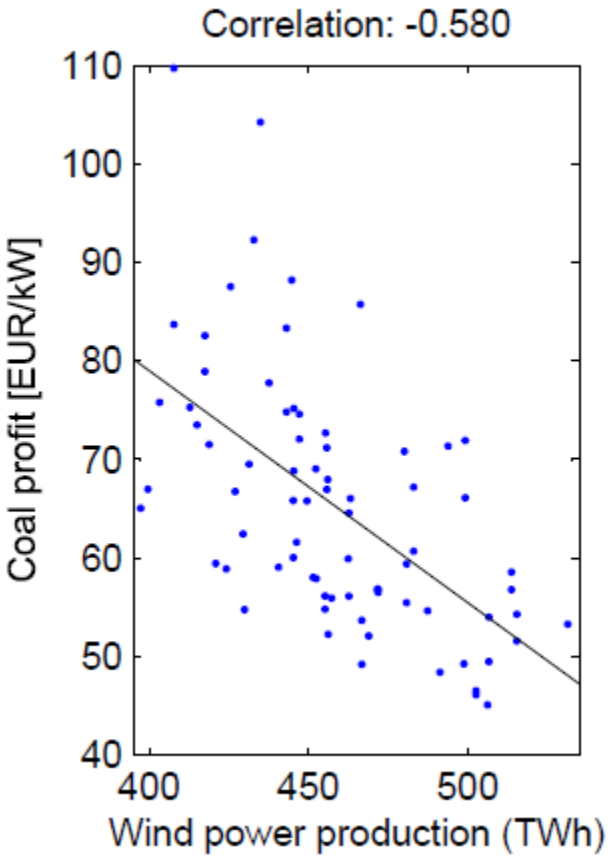
- Almost similar pattern: Still unused storage potential
- Higher levels due to increased inflow

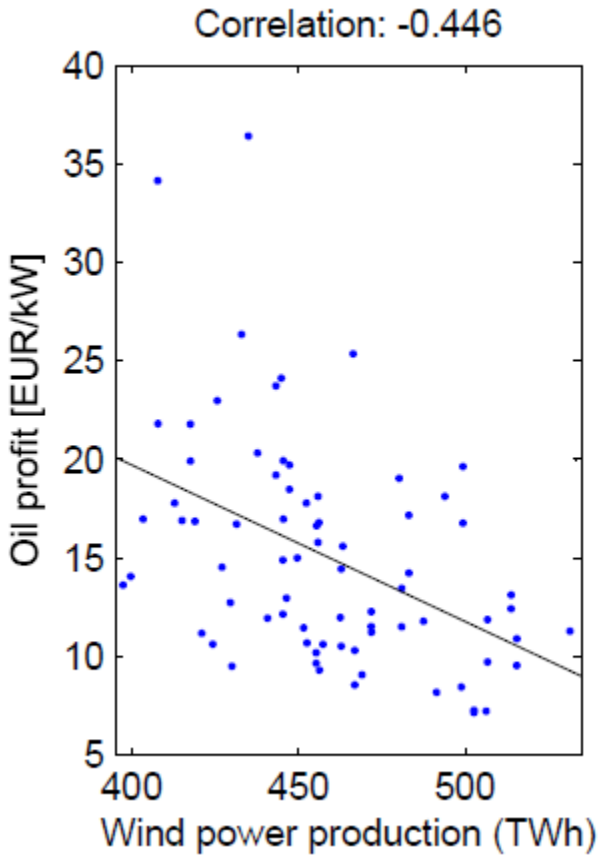




Source: Jaehnert, Korpås, Doorman (NTNU)

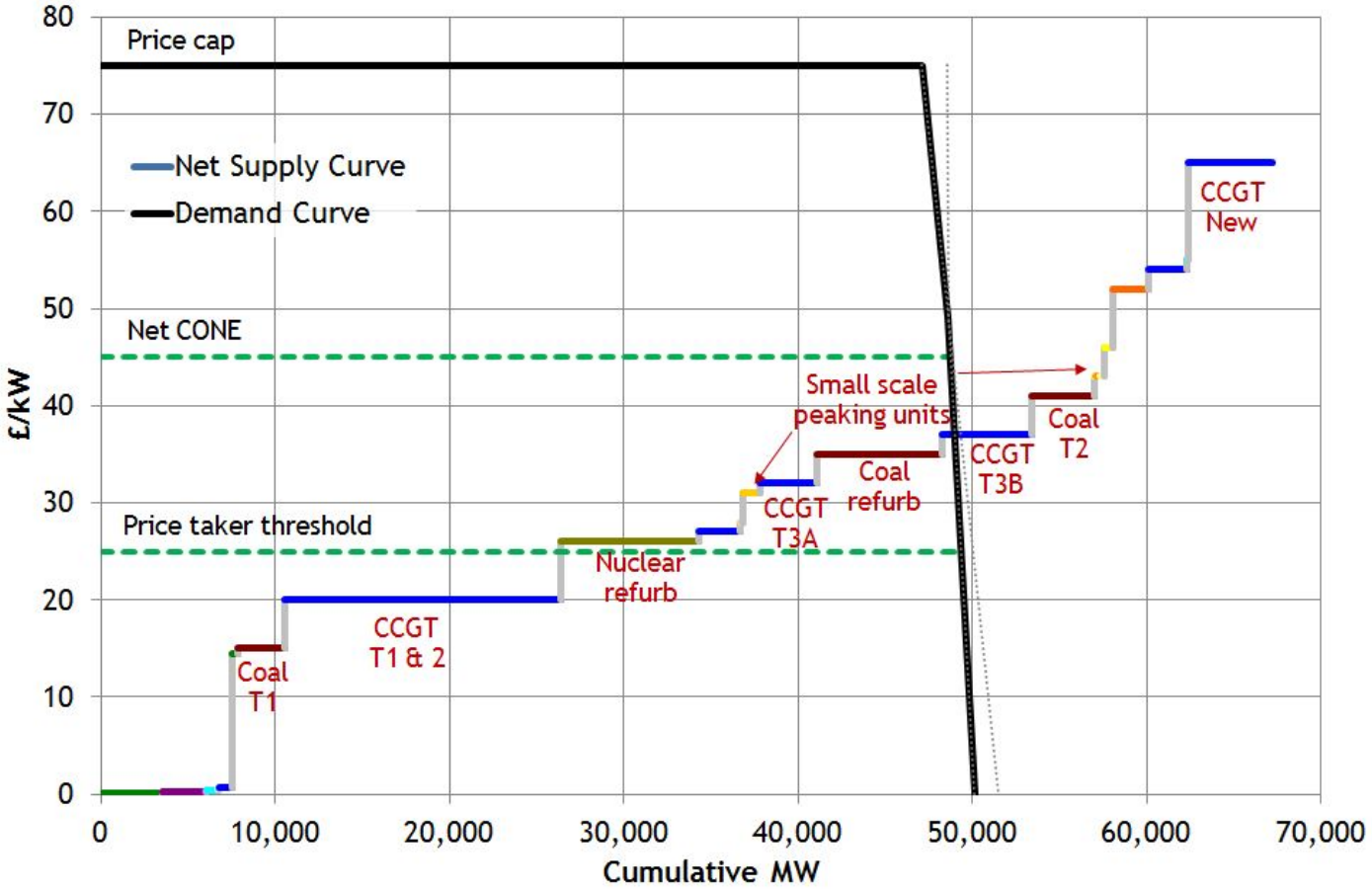
Wind and solar pushes fossils out of the spot market…





Source: Jaehnert, Korpås, Doorman (NTNU)

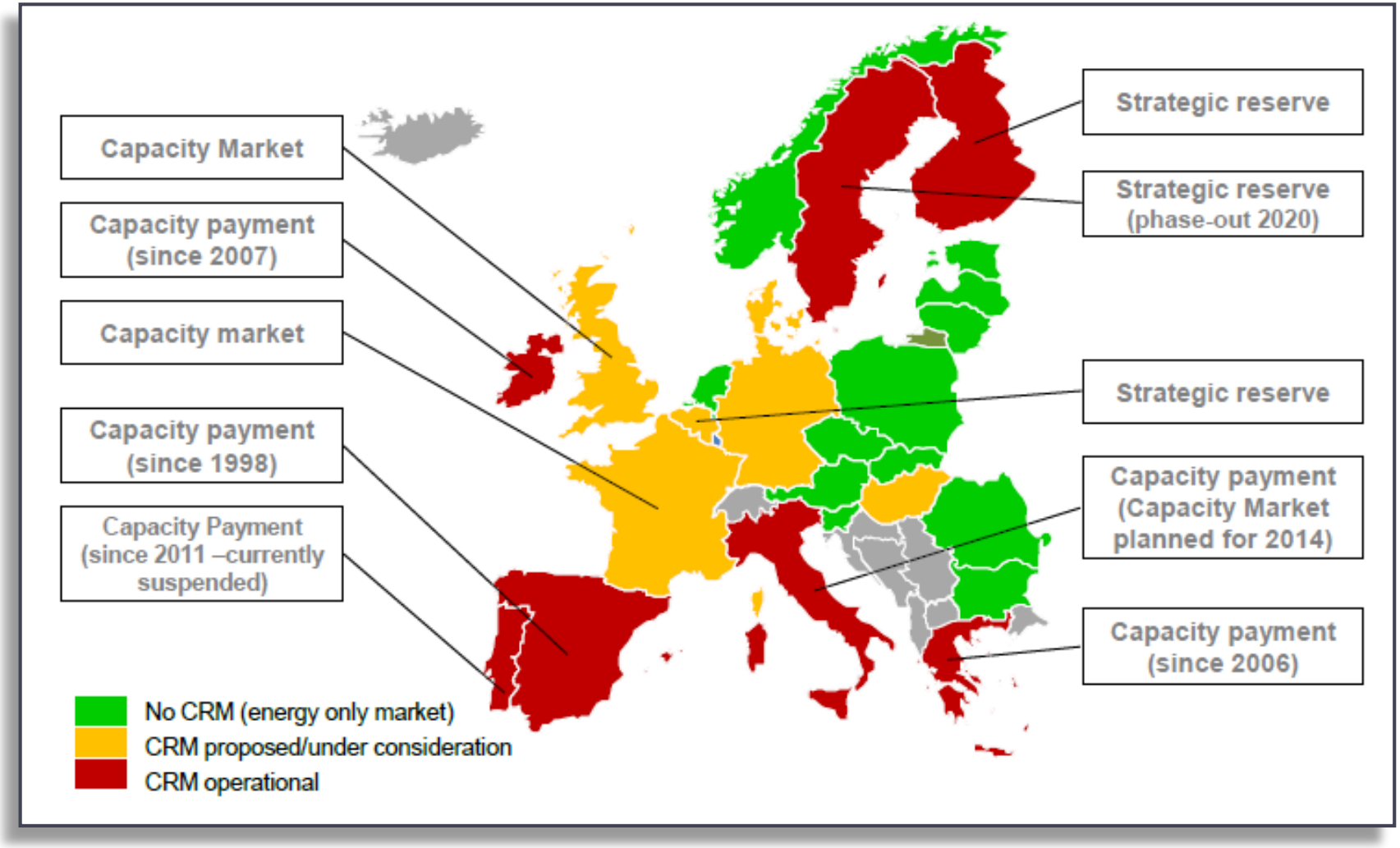
...and into the (emerging) capacity markets



Source: Timera Energy (UK)

Capacity remuneration mechanisms

throughout Europe



- Source: ACER, "Report: CAPACITY REMUNERATION MECHANISMS AND THE INTERNAL MARKET FOR ELECTRICITY", 2013

Generation Adequacy Study

- **Given:** Scenarios for large-scale RES in Europe and demand for electricty
- **Modelling challenge:** Find the optimal mix of the other energy sources
  - Investment costs
  - Operational characterstics and costs
- **Goal of study:** Analyze how energy storage affects the need for thermal power
  - Distributed batteries
  - Pumped storage from Norway

Generation Mix study

High RES scenario of the northern European power system: ENTSO-E Vision 4.

41 % RES-share

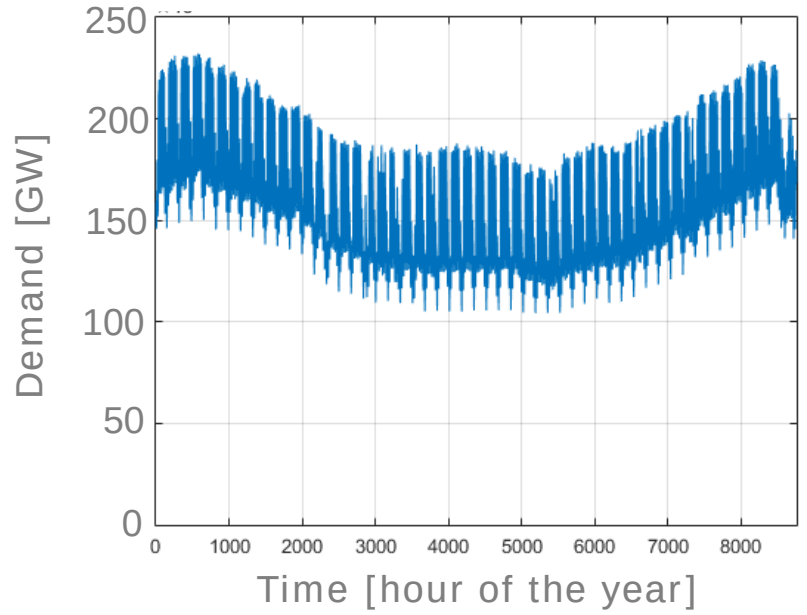
Four thermal technologies

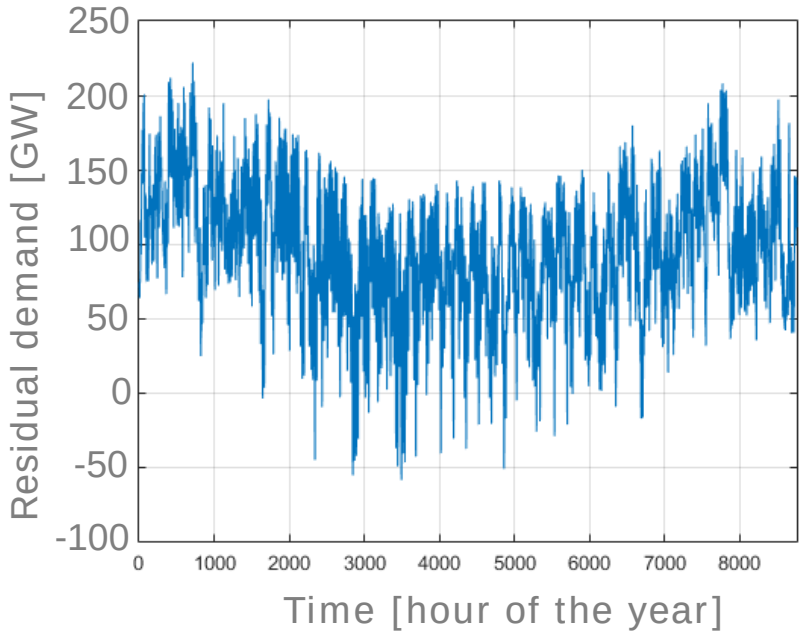
Nuclear, Coal, CCGT and OCGT.

Two storage technologies with fixed costs and efficiencies:

Norwegian PHES and batteries. PHES includes cost of HVDC cables

Optimal installed capacities and operation each hour is determined by the model



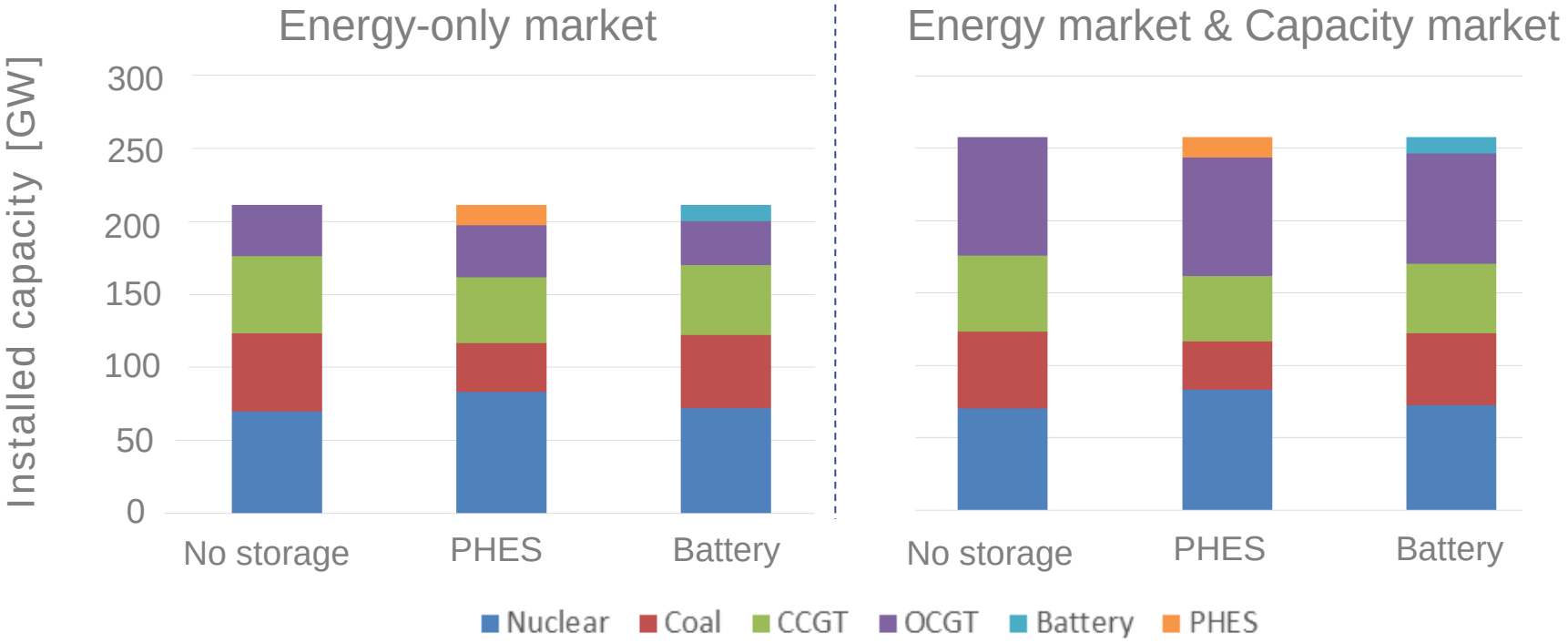


Results: Installed Capacity

Introduction of Norwegian PHES decrease coal power

Battery reduces the OCGT capacity

The additional capacity with a capacity market is OCGT



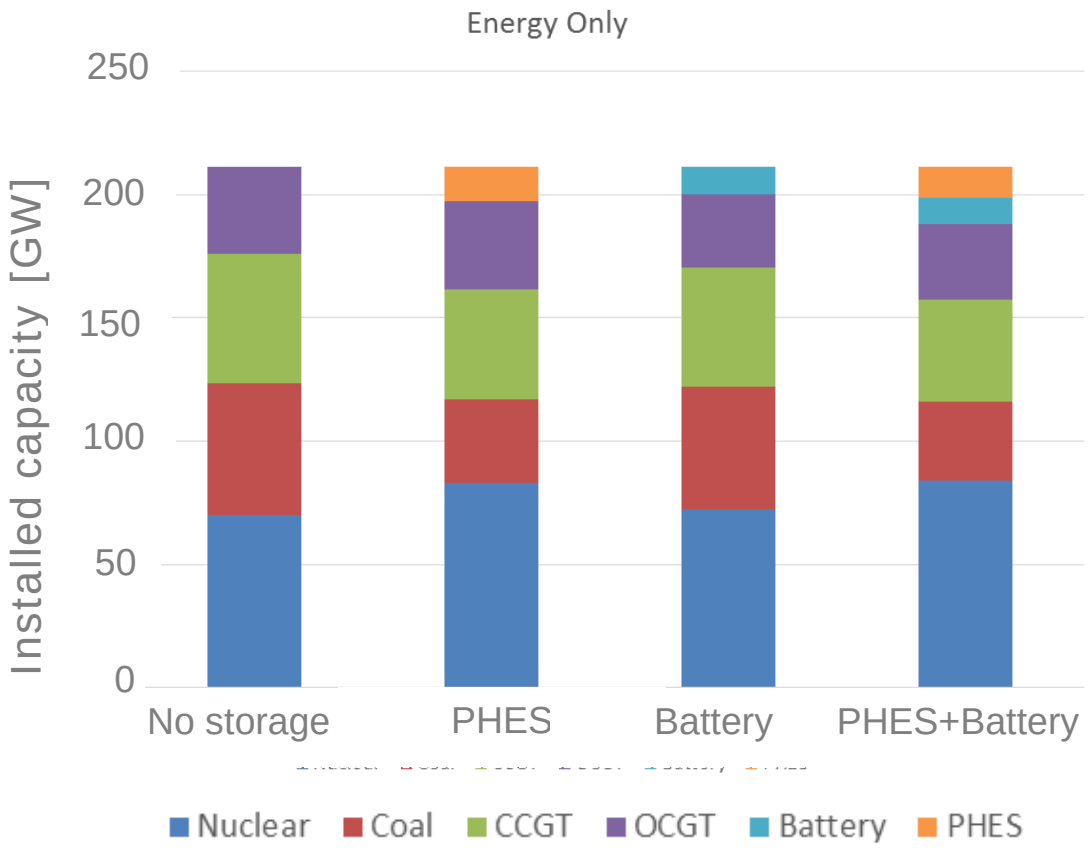
Results: Installed Capacity

PHES + Batteries in the same system: Nearly the same installed capacity.

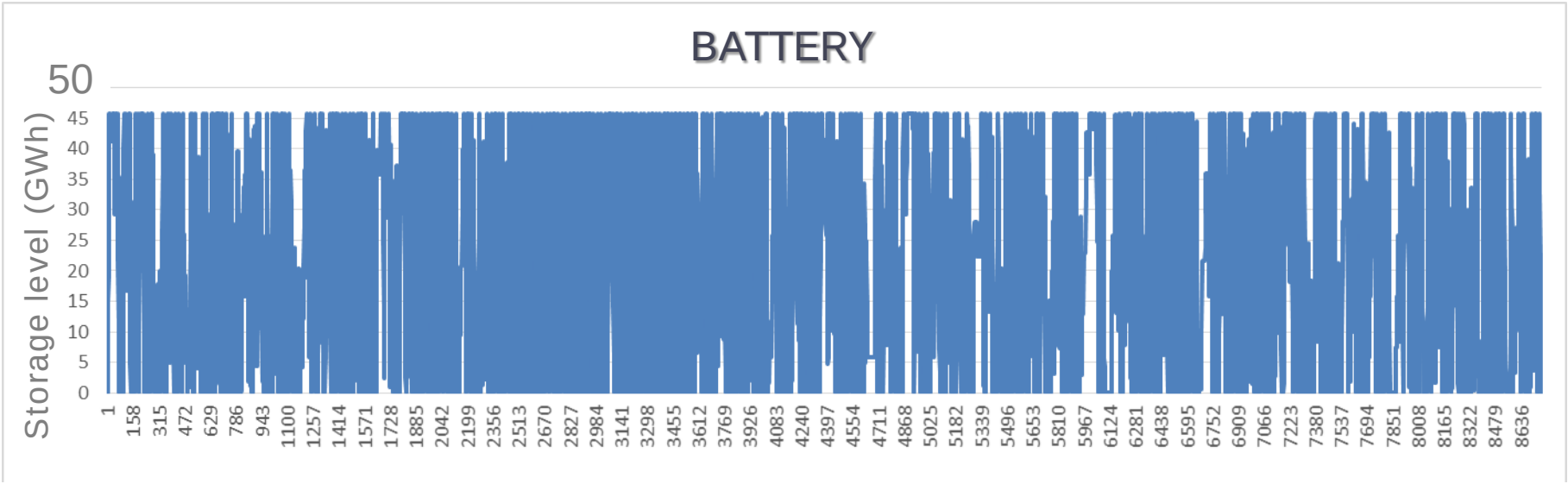
Increased base load capacity.

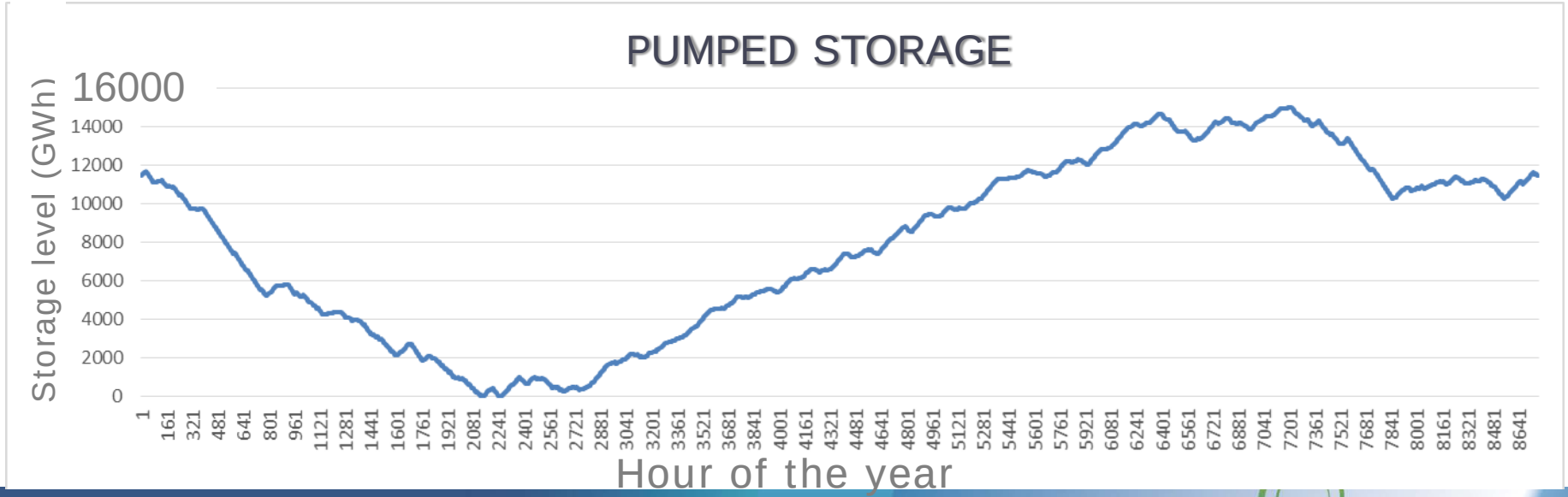
Decreased mid-merit capacity.

This suggests that both technologies are needed in the system.



Which storage technology?

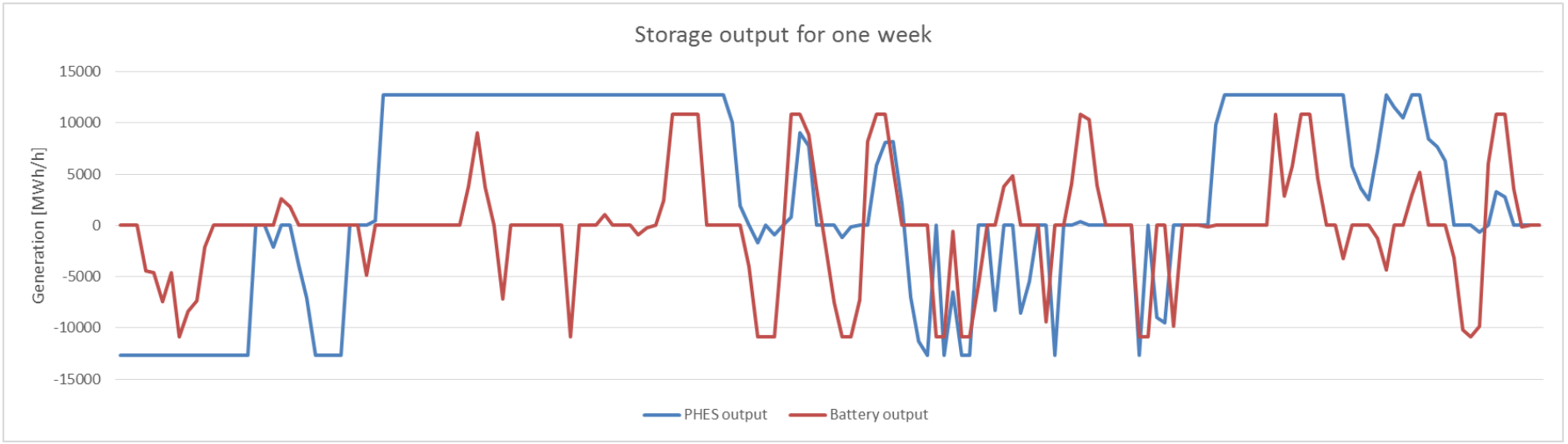




Which storage technology?

PHES need a bigger price difference due to higher losses

PHES can store much more due to abuntant reservoir capacity



Sensitivity: Battery costs

Optimisitc reference investment cost

Converter cost:

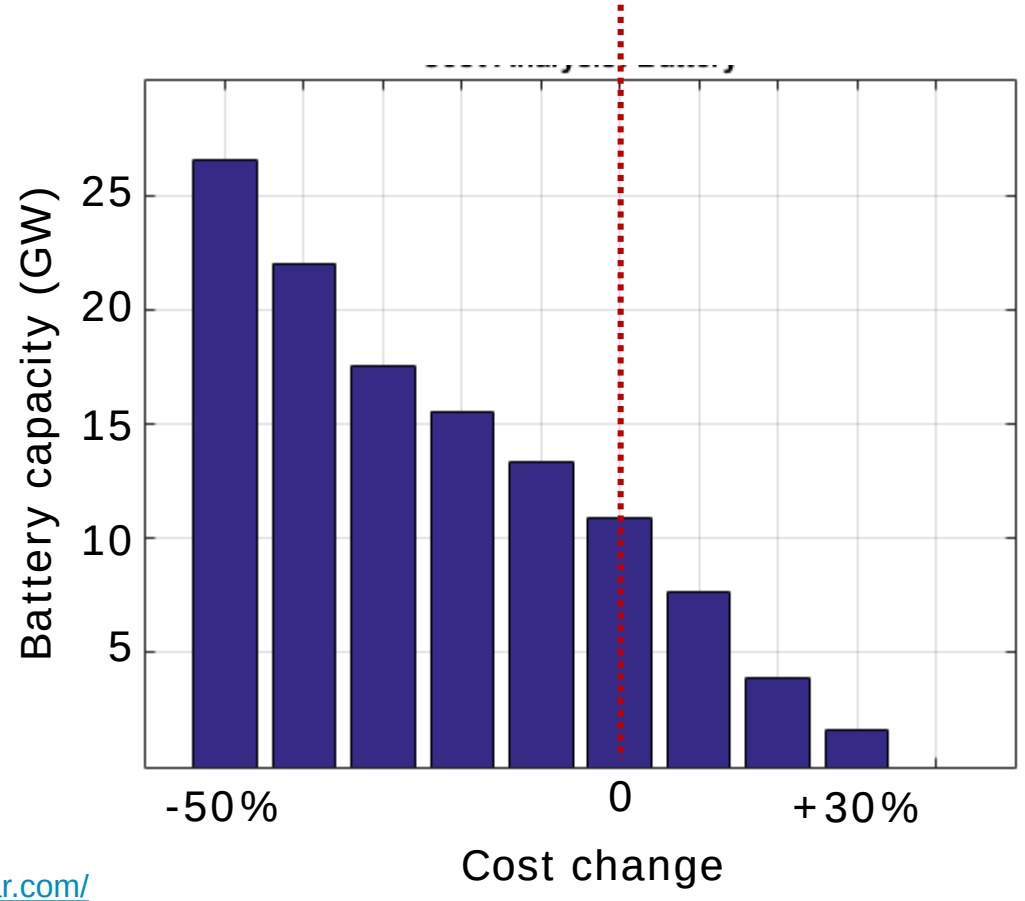
200 EUR/kW

Storage size cost:

50 EUR/kWh

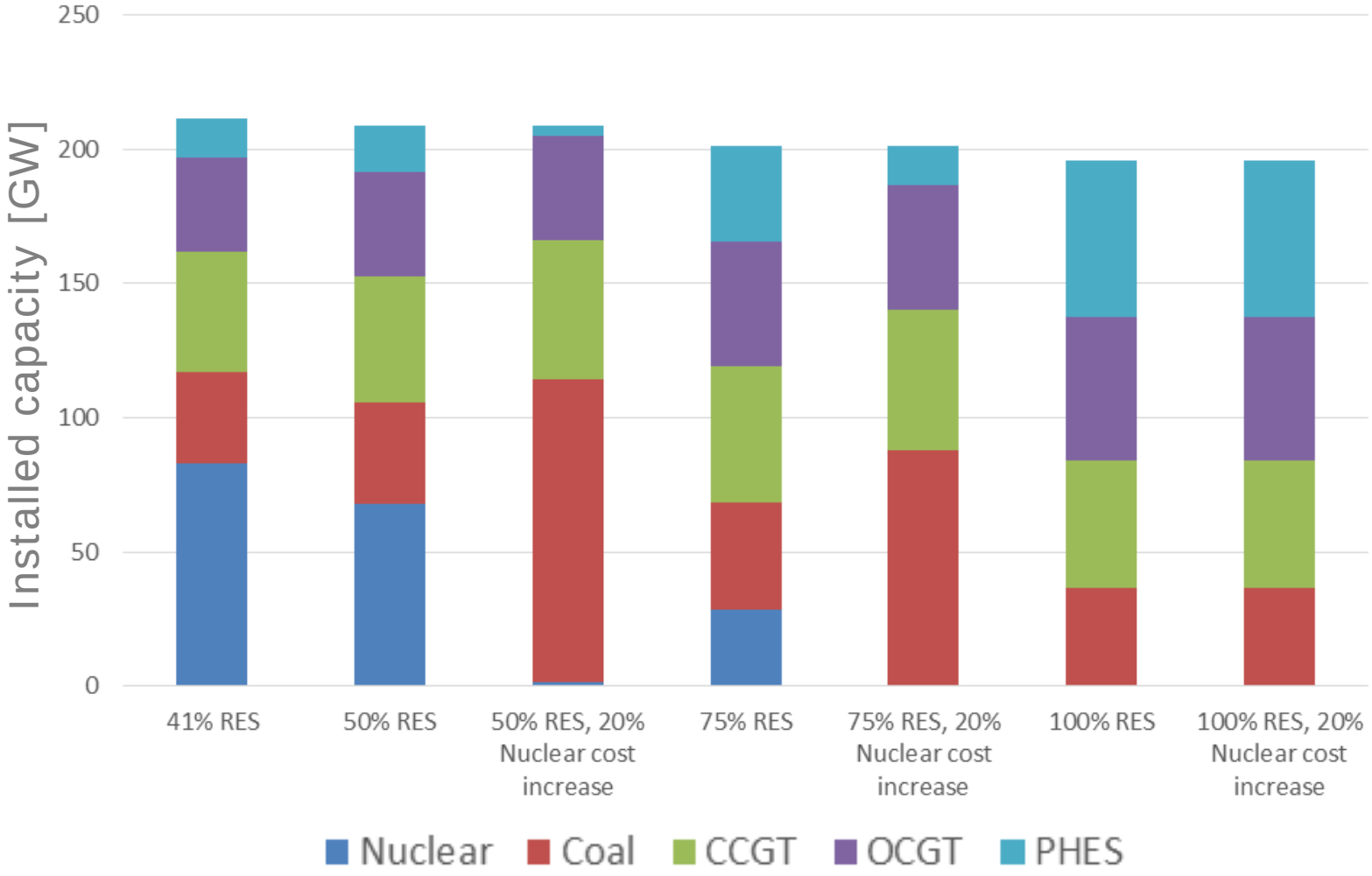
With ~4,5 hour storage capacity, this corresponds to 100 €/kWh (converter included)

Tesla Powerwall (6,4 kWh without converter) presently costs ~3000 $*



* http://www.wholesalesolar.com/

Sensitivity: Increased renewable share and nuclear costs



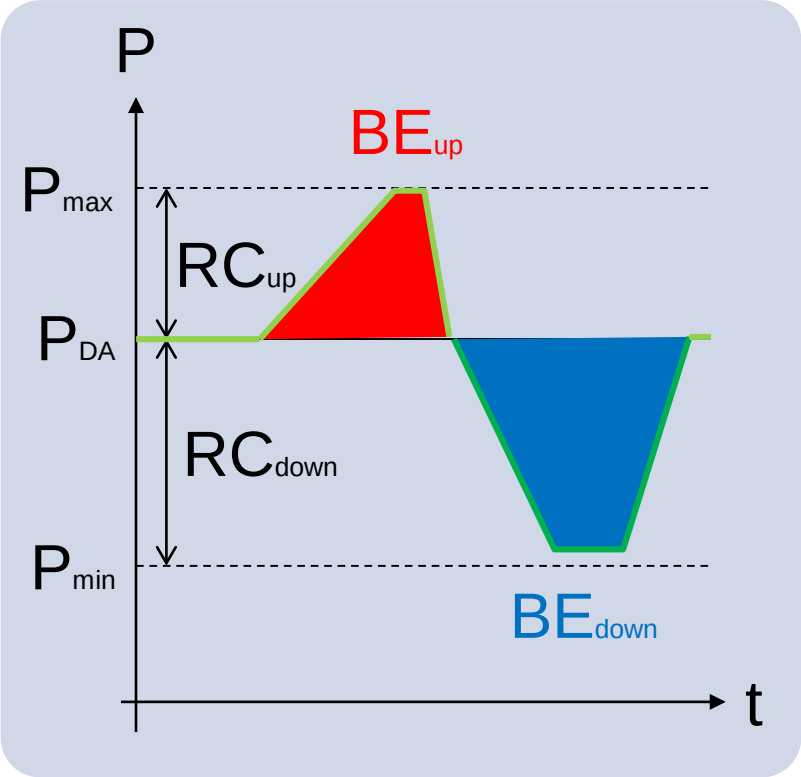
Balancing Reserve Capacity vs Energy

Reserve procurement

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

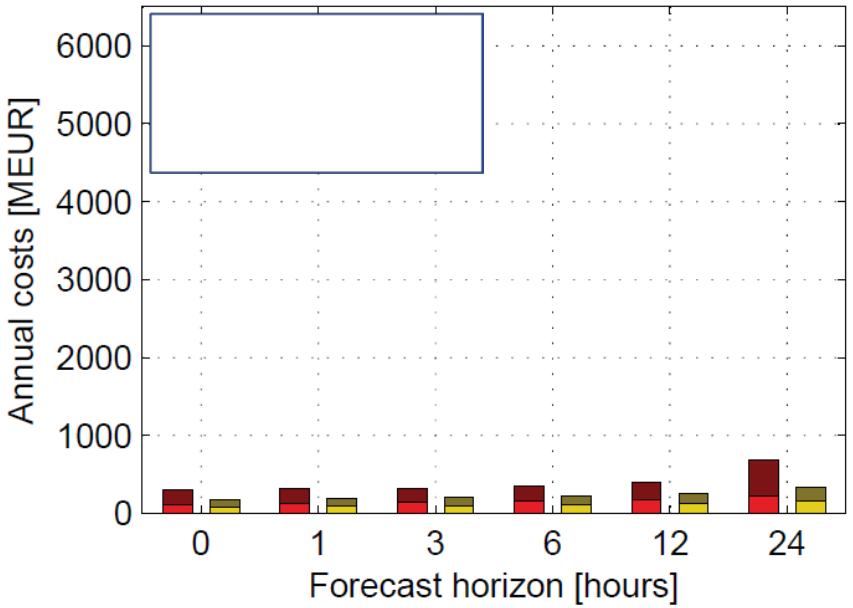
System balancing

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

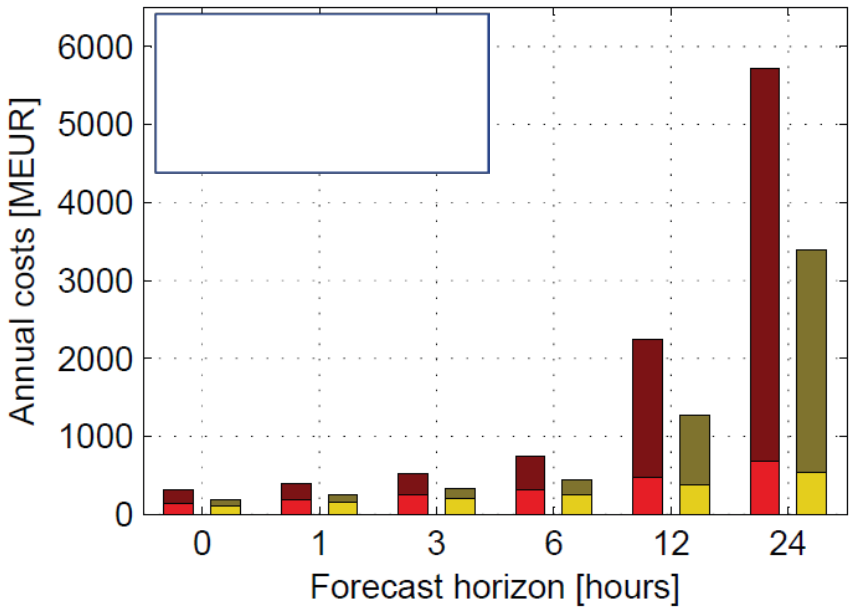


Source: Doorman (NTNU)

Total balancing market costs for different wind forecast horizons



(a) 2010

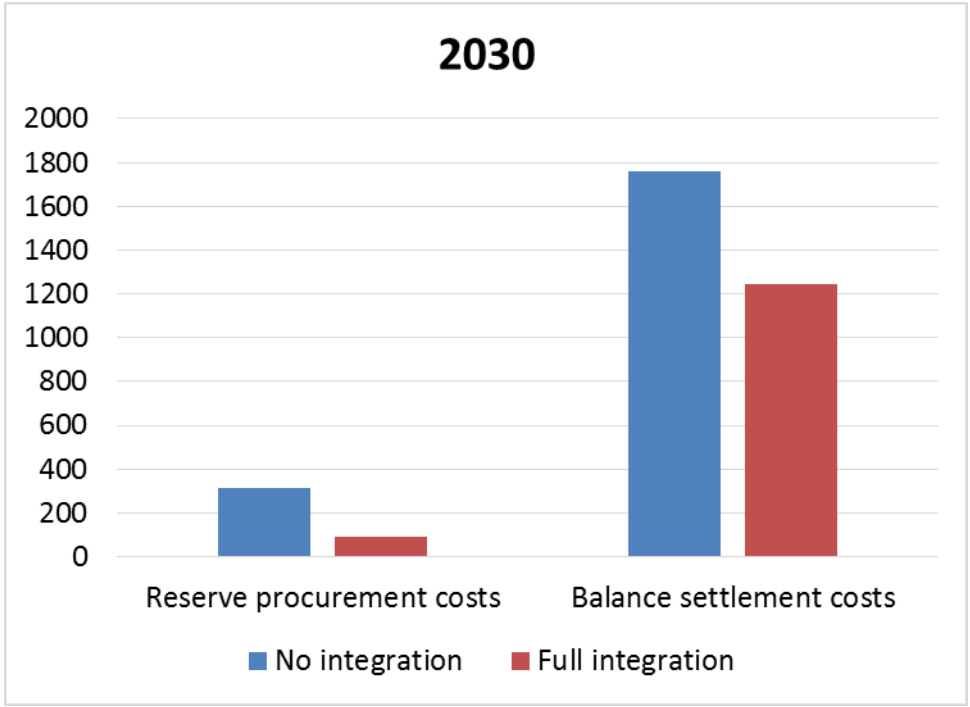


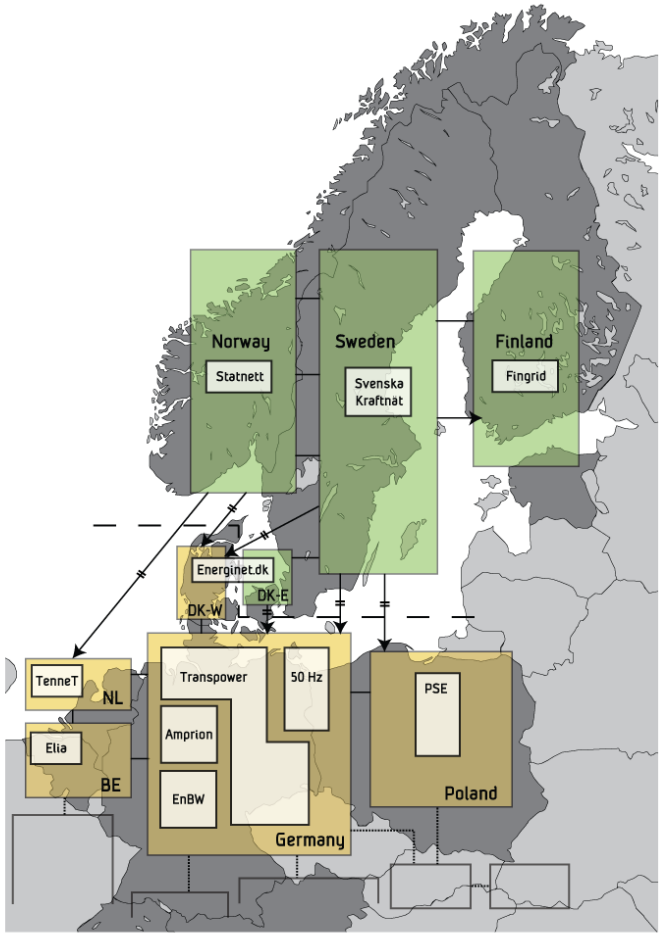
(b) 2020

No integration : Reserve procurement
No integration : System balancing
Full integration: Reserve procurement
Full integration: System balancing

Large benefits of integrating the Northern and continental balancing markets

Total annual balancing costs (Mill.EURO)

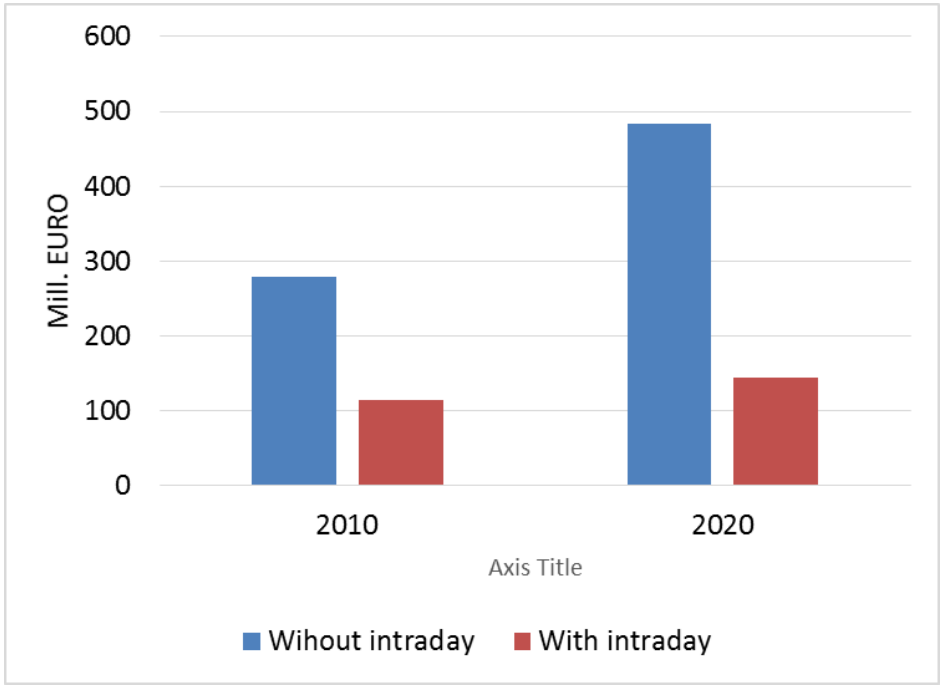




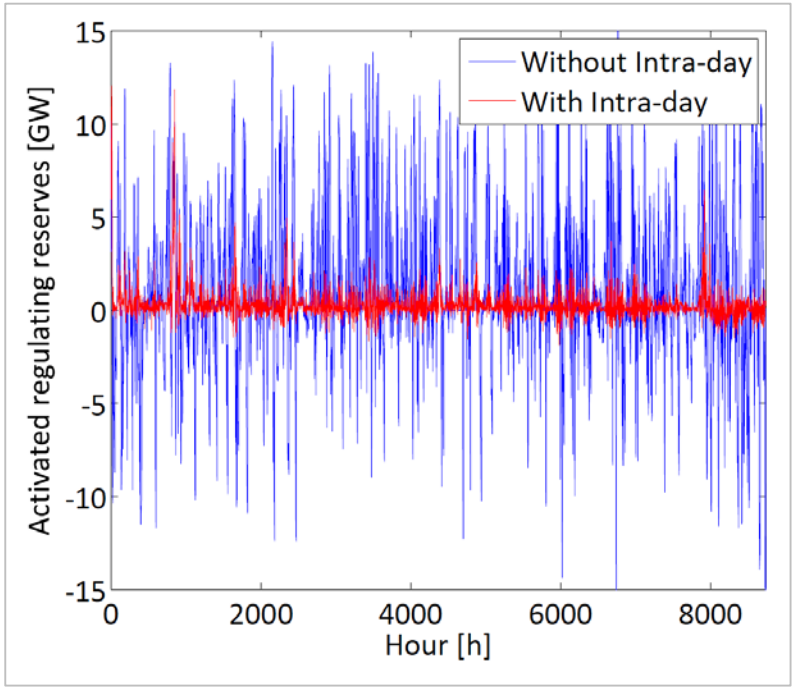
Source: Farahmand (NTNU/SINTEF)

Significant savings are achieved with integrated intra-day markets

Total annual balancing costs



Activated reserves

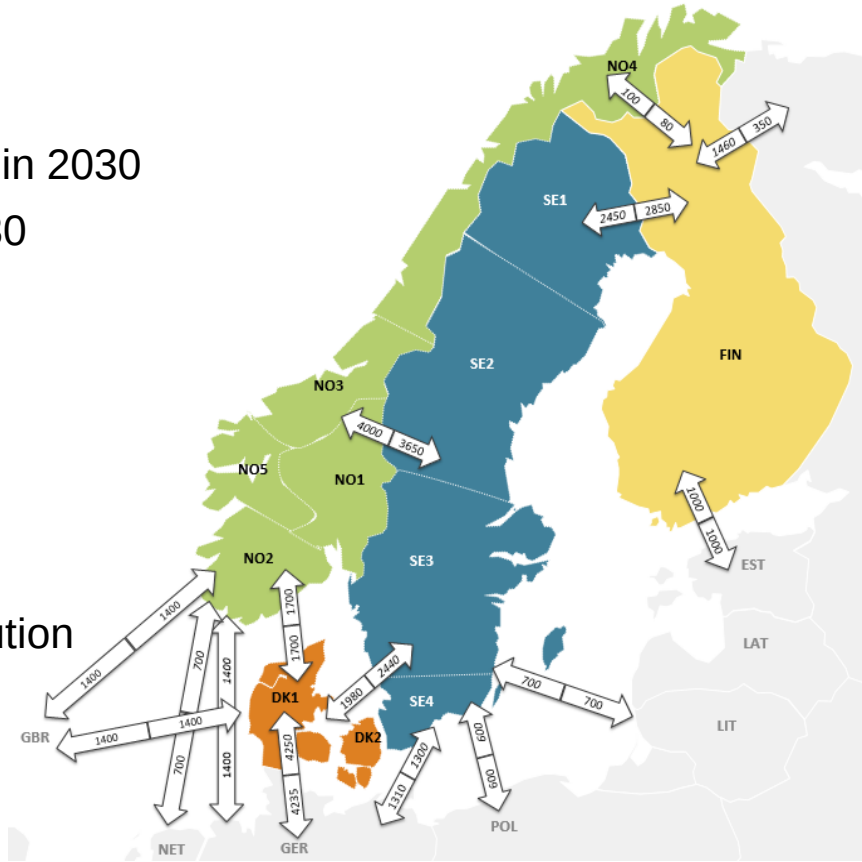


Source: Aigner (NTNU)

Slide made by Karen Byskov Lindberg

Impact of ZEBs on the Nordic Power System

- Assumptions on ZEBs
  - 50 % of Norwegian building stock is ZEB in 2030
  - PV generation 17 TWh/a (20 GW) in 2030
- EMPS model 2030
  - Minimises total system cost
  - Stochastic optimisation
  - 30 scenario years (climatic)
  - Time horison: 1 year, with 3hr time resolution
  - Unit commitment and dispatch



CenSES
Centre for Sustainable Energy Studies

ZEB

NTNU

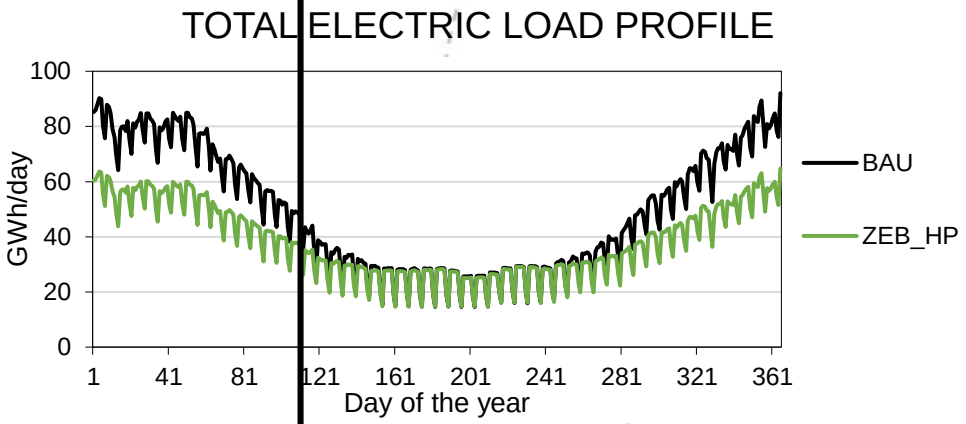
Slide made by Karen Byskov Lindberg

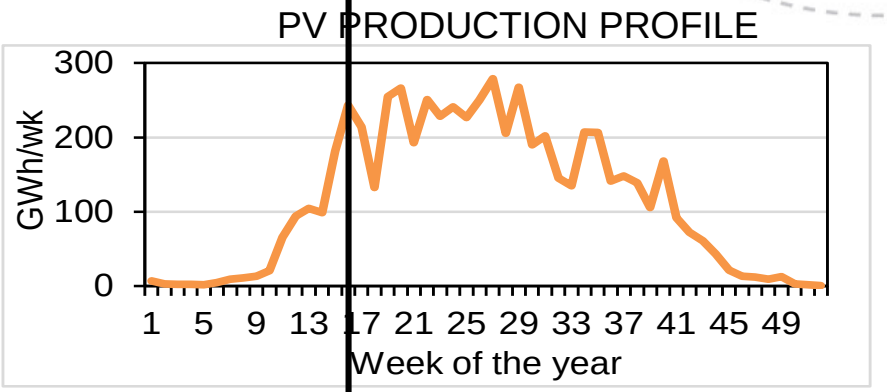
- Energy efficiency
  - Brings more energy in the system
- PV production
  - Brings more energy in the system
  - «Deterministic» on a monthly scale
- Reservoir levels
  - Hydro power producers adapts to the changes
  - «Known» PV production soaring in spring

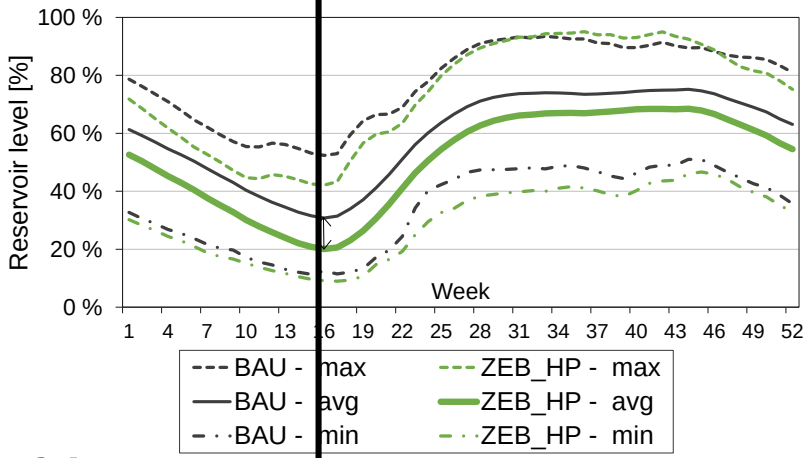
    → Seasonal storage of water less critical

    → Decreased spillage of water

    → Increased power production







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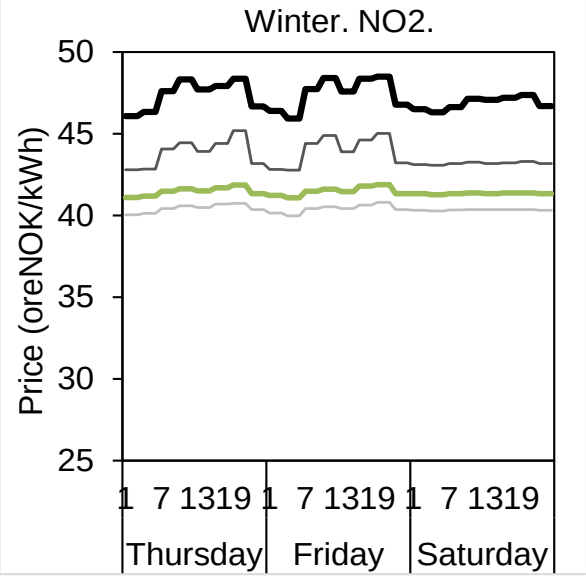
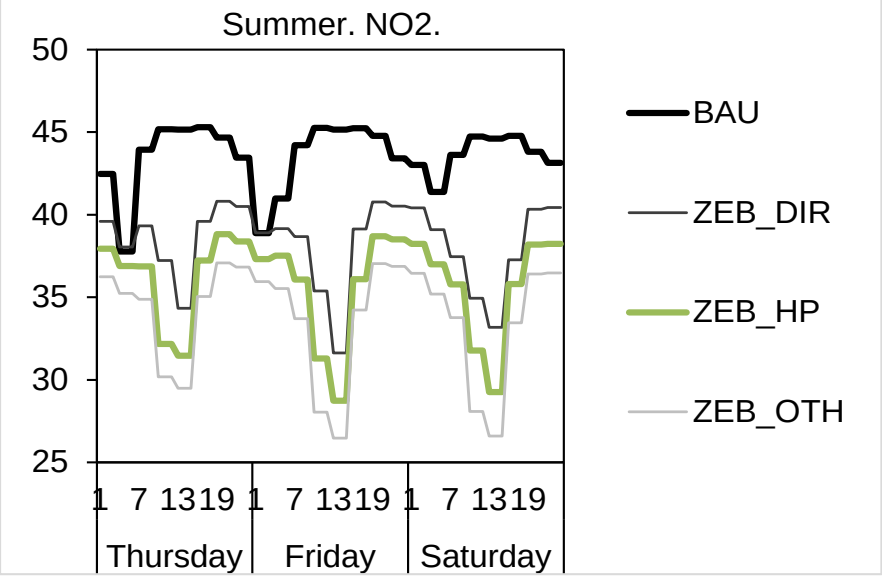
Power Prices

- Average power prices
  - Annual average price: -9 to -15 %
  - Profile in summer is turned upside-down





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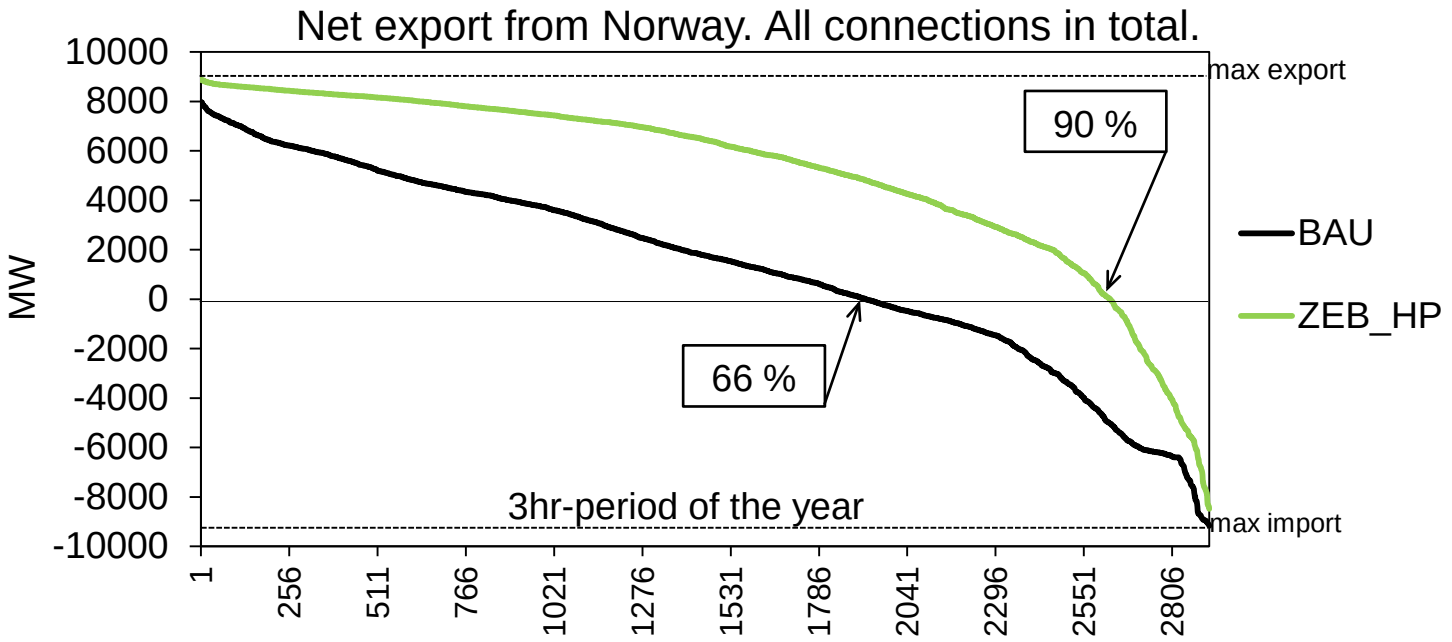
Power Exchange

- Average Nordic power balance
  - Increasing from +36 TWh (BAU) to +60 TWh (ZEB_HP)
  - Massive export to UK, NL, DE & Baltikum



Summary of research findings

- Distributed Batteries and Norwegian Pumped Hydro complements each other
  - Batteries balances short-term variations and replaces open-cycle gas
  - Pumped hydro balacances short-term AND long-term variation and replaces coal + some combined cycles gas
- Large system-benefits of sharing balancing markets across borders and across cables in the North Sea
  - Market design and grid access are critical factors
- The hydro reservoirs can handle more connections to the continent and more wind+PV in the Nordic area
  - Norwegian hydro is a cost-efficient and reliable partner to wind and solar power