Impact of high penetration renewable energy sources (RES) on the electricity generation system operation

Feasibility, security, costs and market design

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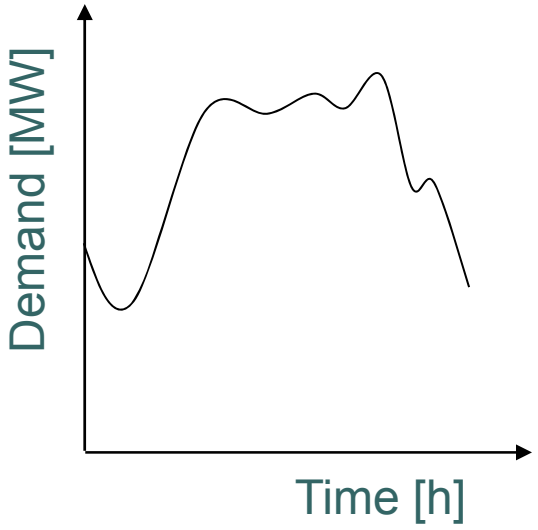
Impact of high penetration RES on electricity system

- Power system fundamentals
  - Electricity system
    - Generation
    - Grid
  - Electricity market
- RES intermittency
  - Variability
  - Unpredictability
- Challenges
  - Electricity system
    - Generation
    - Grid
  - Electricity market

Power system fundamentals
Electricity system

- Electric power
  - Travels at speed of light
  - Is difficult to store

    → Supply must meet demand instantaneously
  - Requires network for transport
    - High voltage – Transmission
    - Low voltage – Distribution
  - Energy versus Power
    - Power: Flux or flow [MW]
    - Energy: Amount (over time) [MWh]
  - Regarding RES, focus on fluxes



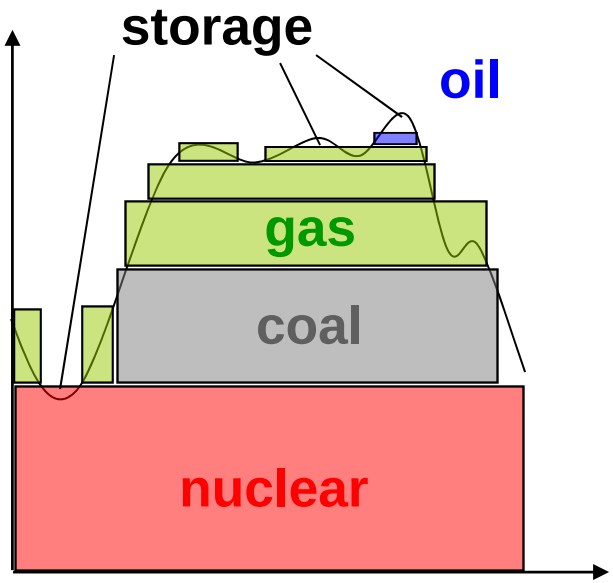
Power system fundamentals
Electricity system: generation

- Electricity generation system is mix of
  - Centralized well dispatchable units
  - Centralized intermittent units
    - Poorly or not dispatchable
      - E.g. large wind farms
  - Distributed generation
    - Dispatchable
      - E.g. CHP
    - Non-dispatchable
      - E.g. solar PV, wind turbine
  - Storage
    - Centralized
      - PHS

➔ All have to play in harmony

Power system fundamentals
Electricity system: generation

- Unit Commitment

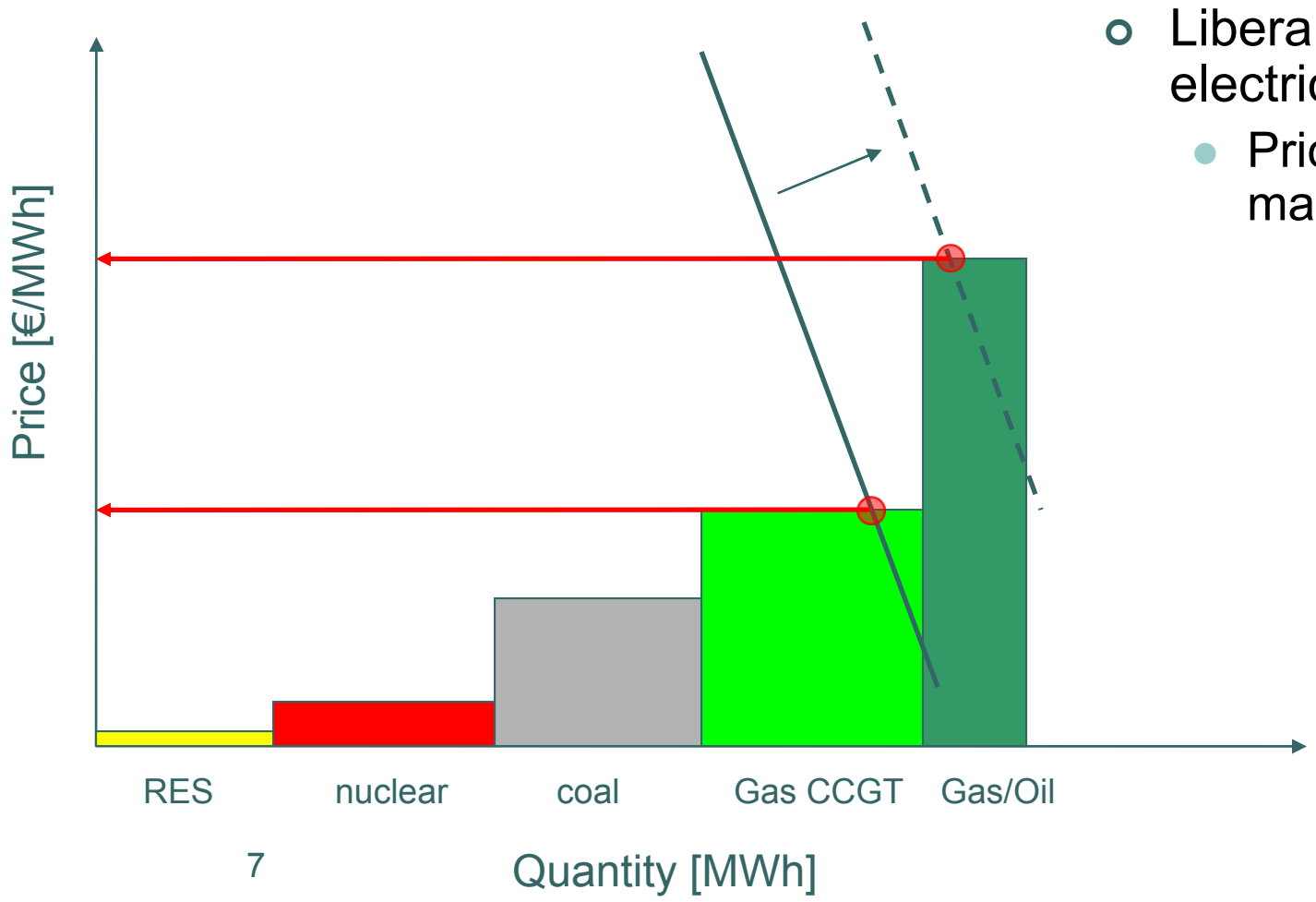


Power system fundamentals

Electricity system: grid

- Electricity grid is key to matching demand and supply
- Different control areas
  - Responsibility of Transmission System Operator (TSO)
- Cross-border interconnections
  - Security reasons
  - Trading purposes
- Cross-border interconnections are relatively weak
  - No real European grid

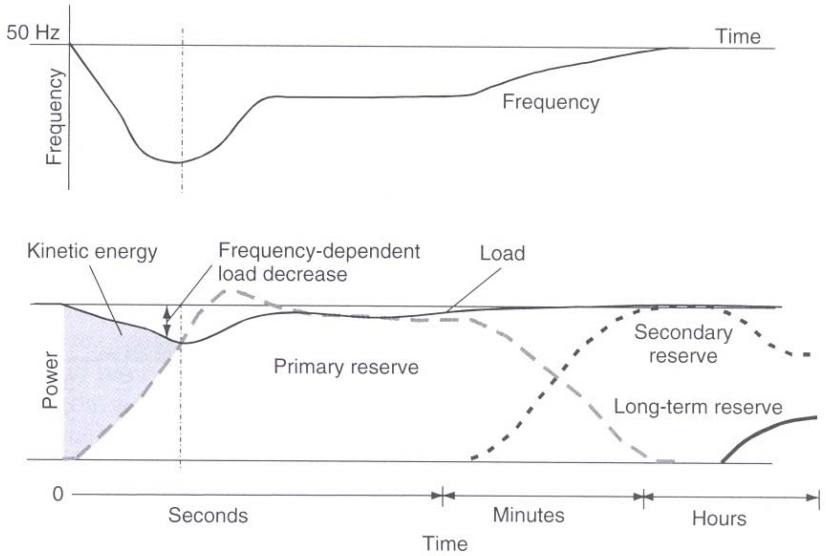
Power system fundamentals
Wholesale market



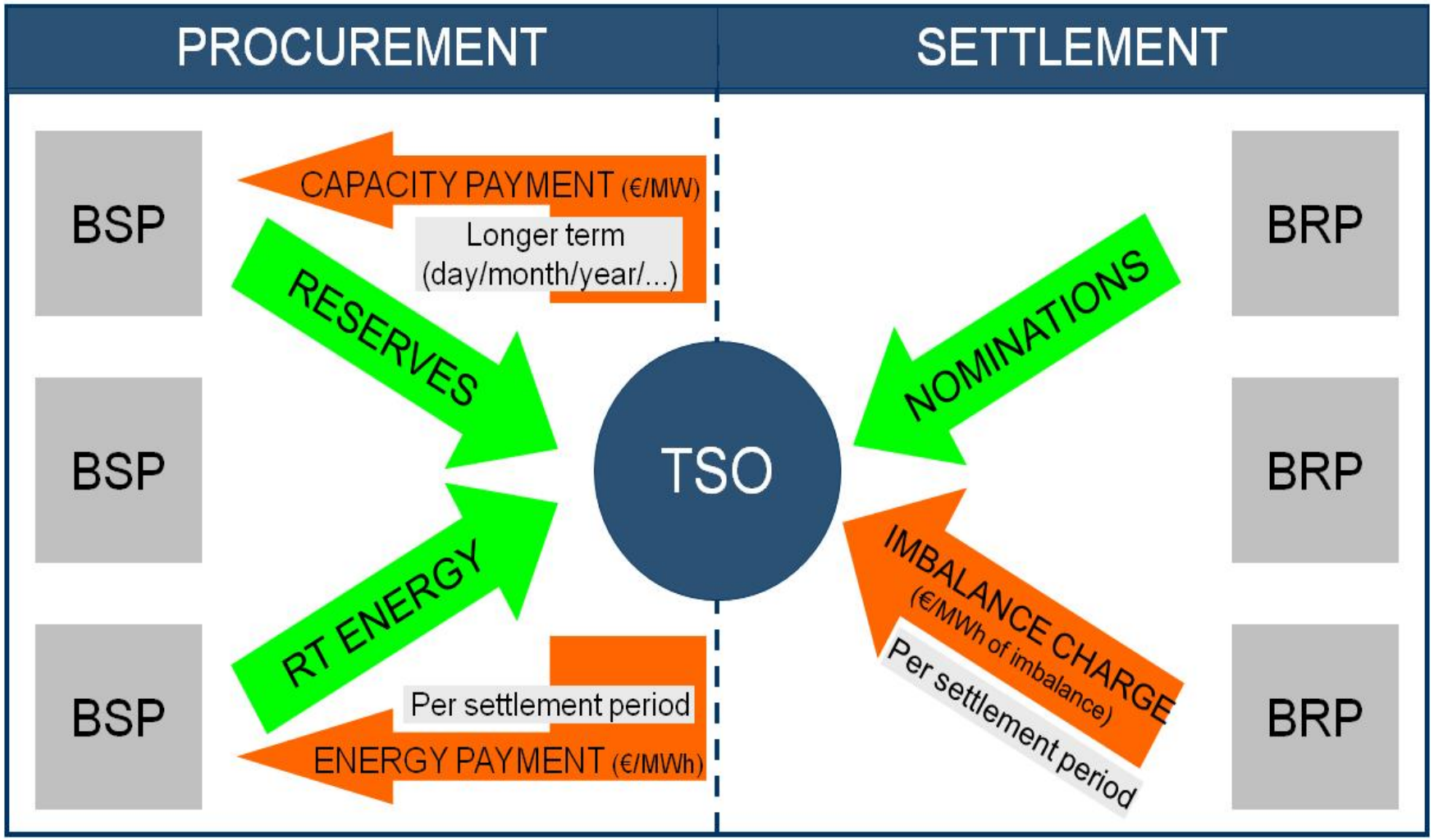
- Liberalized electricity market
  - Price set by marginal unit

Power system fundamentals
Balancing market

- TSO responsible for ensuring demand-supply balance at all times and secure operation
  - Has contracted reserves available
  - Different kinds of reserves
    - Primary reserves
    - Secondary reserves
    - Tertiary reserves



Power system fundamentals
Balancing market

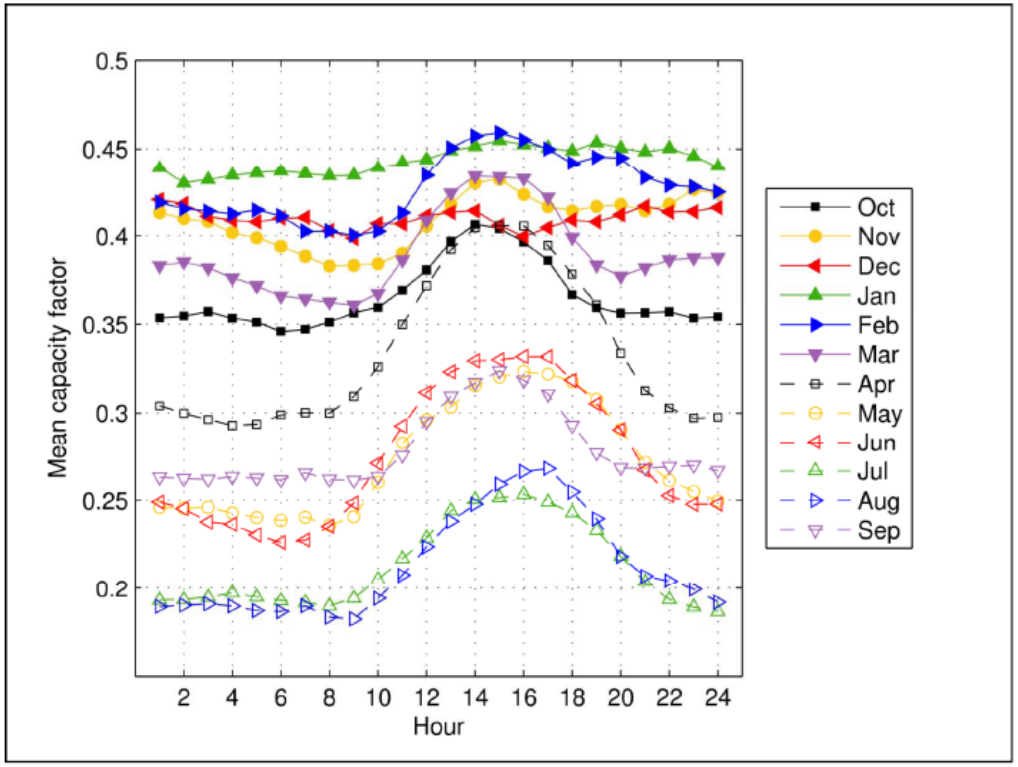


RES intermittency

- RES can be intermittent (e.g., wind, solar)
  - Variable
  - Unpredictable (to some extent)
- To deal with this
  - Appropriate system required
    - Generation
    - Grid
  - Appropriate market required

RES intermittency
Variability

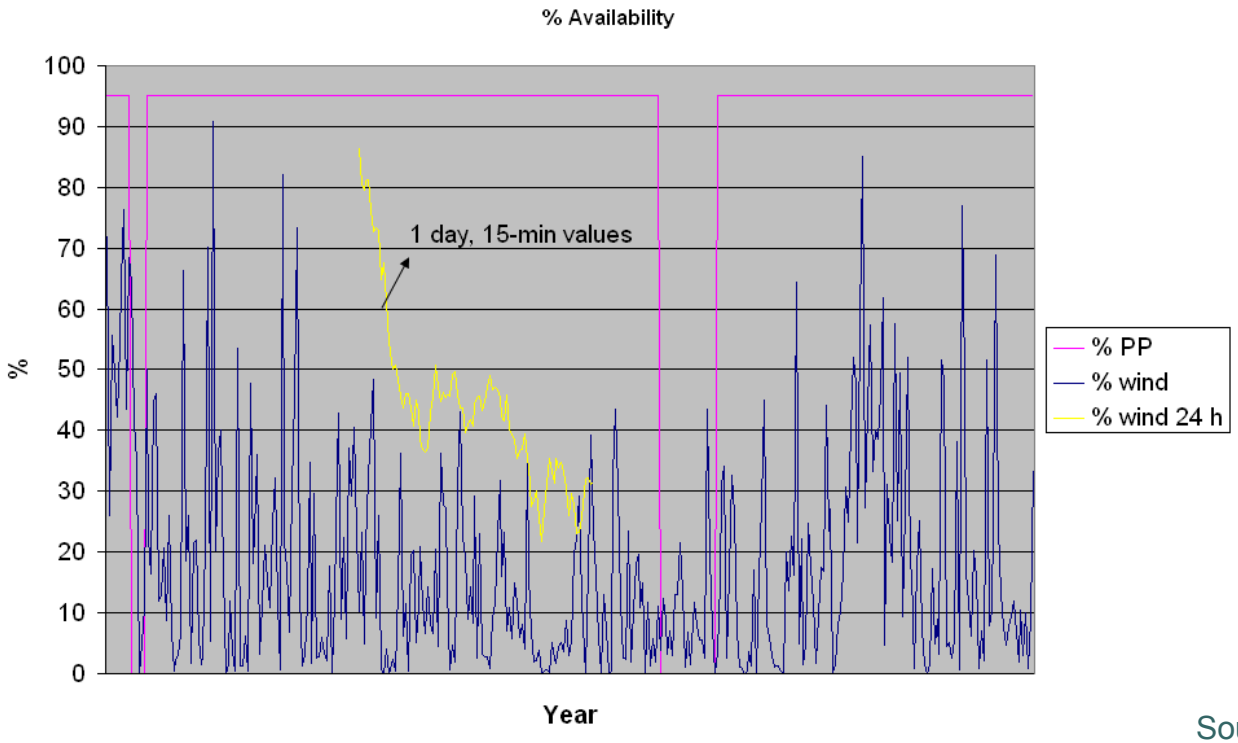
- Wind power averaged hourly/monthly fluctuations



Source: O'Malley, 2010

RES intermittency
Variability

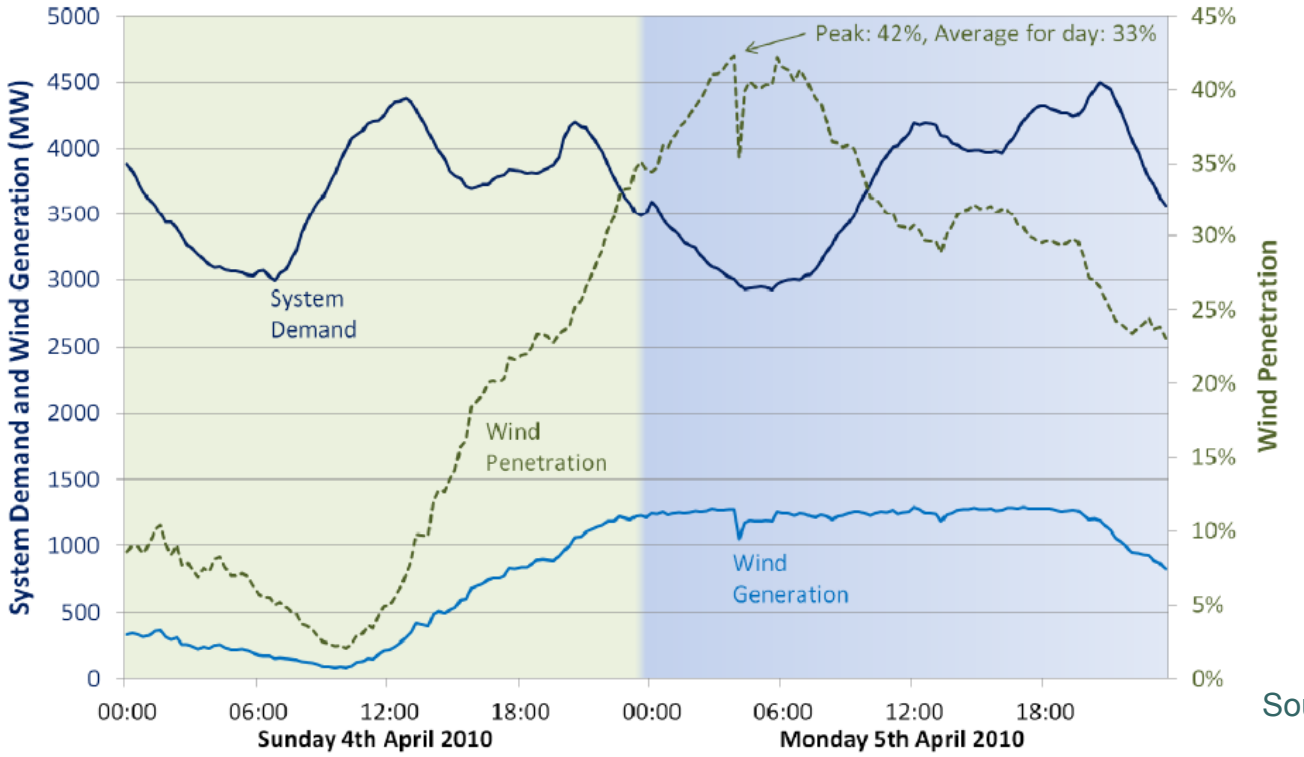
- Wind power daily average versus 15 min values



Source: Van Roy

RES intermittency
Variability

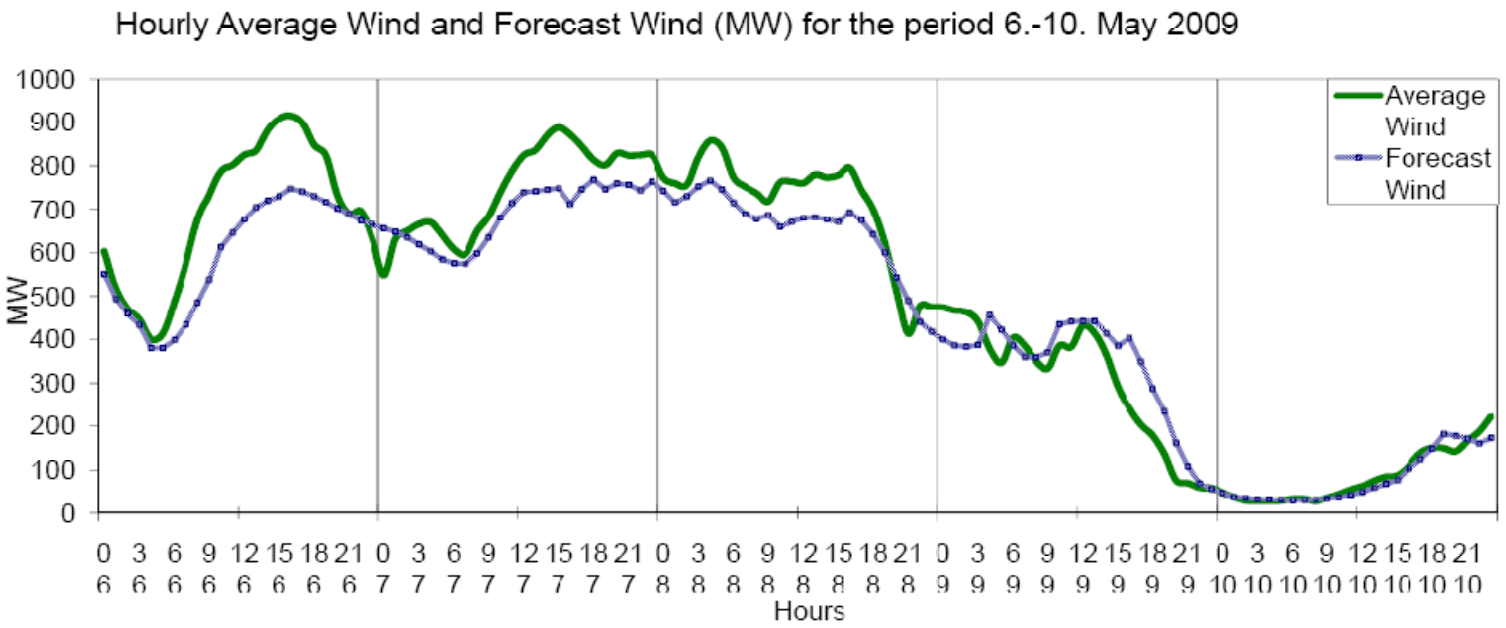
- Example of high wind power variability: Ireland, April 2010
  - 1.2 GW change in 18 hours
  - 2% to 42% of generation



Source: O'Malley, 2010

RES intermittency
Unpredictability

- E.g. wind power forecast

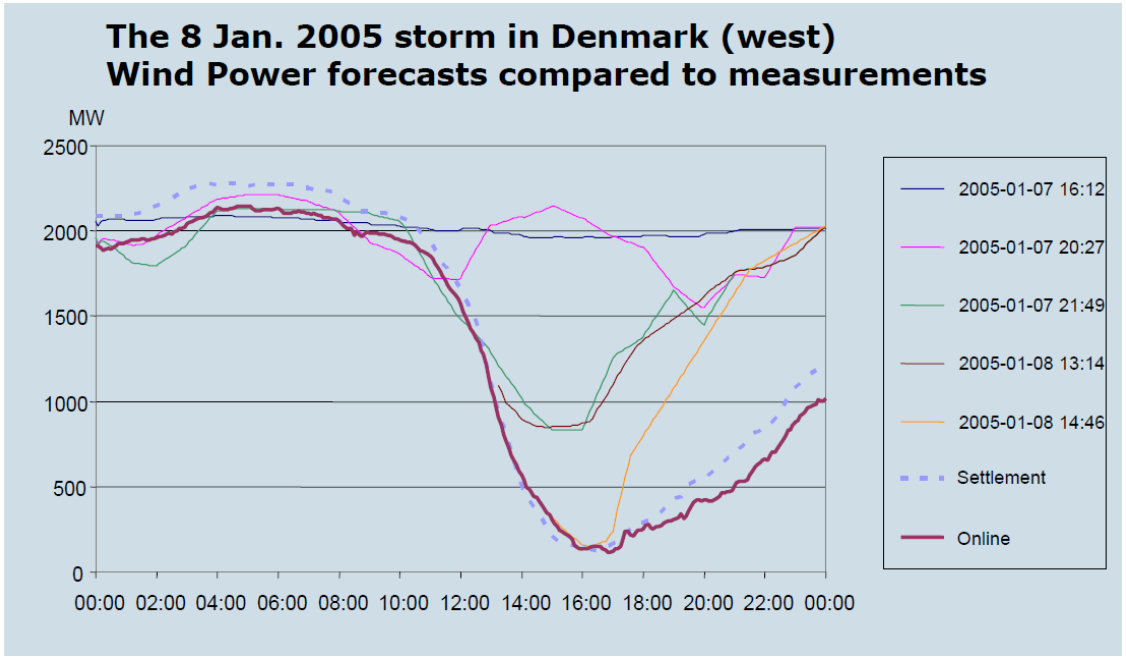


Source: O'Malley, 2010

RES intermittency
Unpredictability

- Error decreases with geographical dispersion
- Error decreases with shorter horizon

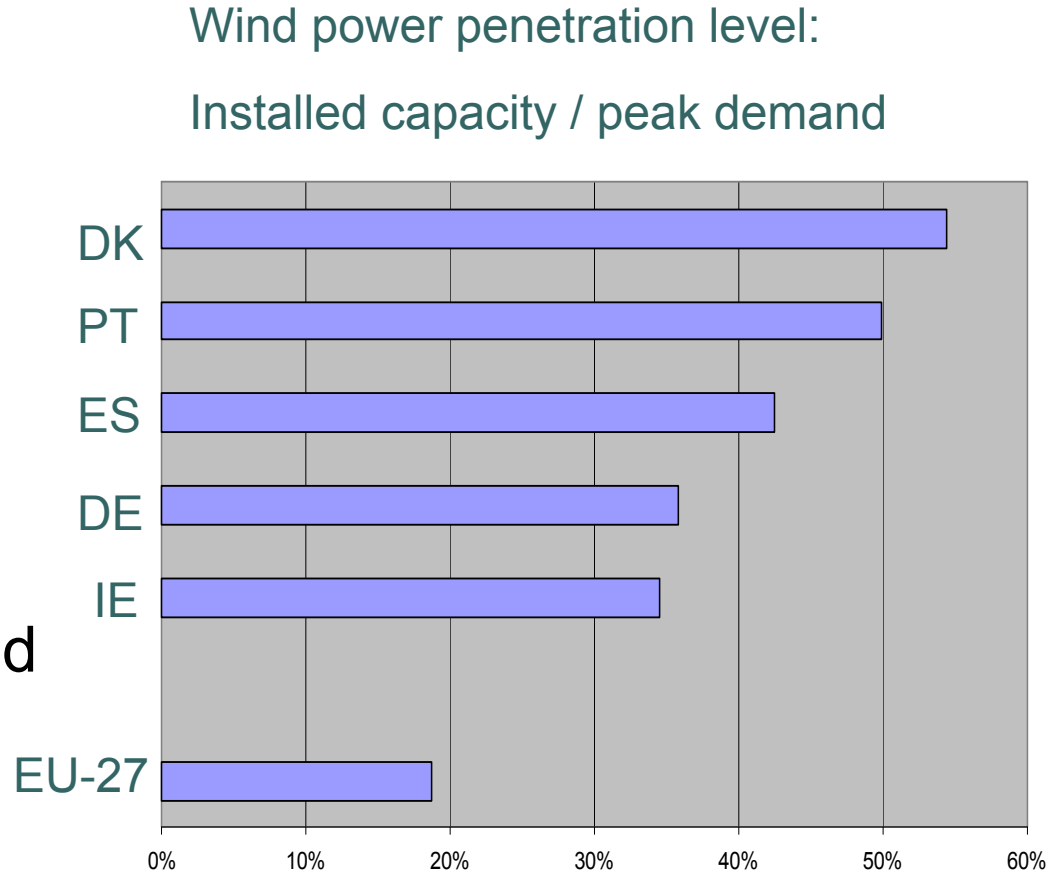
Wind power forecasting



Source: Energinet.dk

Challenges
EU Situation

- So far, system has been able to absorb RES
- In future, RES penetration will only increase
  - E.g., 30% of energy demand by wind → means installed capacity of about 80% of peak demand



Challenges
EU Targets

- 35% renewable electricity is needed to reach the 20% target for renewable energy
- Today RES produces about 20% of EU electricity (11% hydro, 5% wind, 4% other)
- Excluding large hydro the share of RES must increase from 9% to approximately 25%
- EC ‘expects’ contribution of wind power to be 12% of electricity demand in 2020
- EC recently issued its "Roadmap for moving to a competitive low-carbon economy in 2050”
  - Moving towards a nearly fully decarbonized power sector

Challenges

- Integration efforts
  - Technical
  - Economical
  - Regulatory

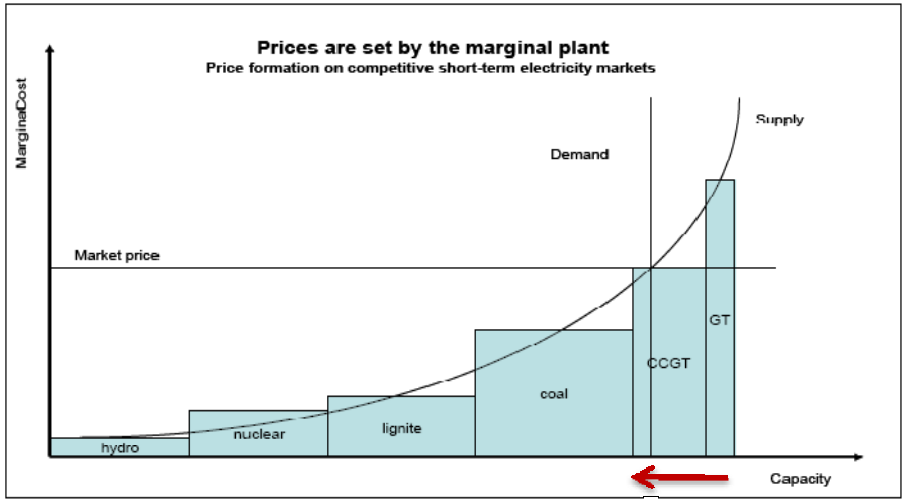
→Electricity system

  - Generation
  - Grid

→Market design

Challenges
Electricity system: Generation

- RES generation reduces “net demand”
  - Power generation from classic units can be reduced
  - RES generation is variable



?

→ Can the installed capacity be reduced?

Challenges
Electricity system: Generation

- Capacity Credit (CC) of RES
  - What is amount of firm capacity required to back-up RES?
  - Keeping same level of reliability
  - CC = amount of conventional power replaced by RES
    - E.g., if 1000 MW wind allows 200 MW of conventional power to be decommissioned

      → CC = 20%

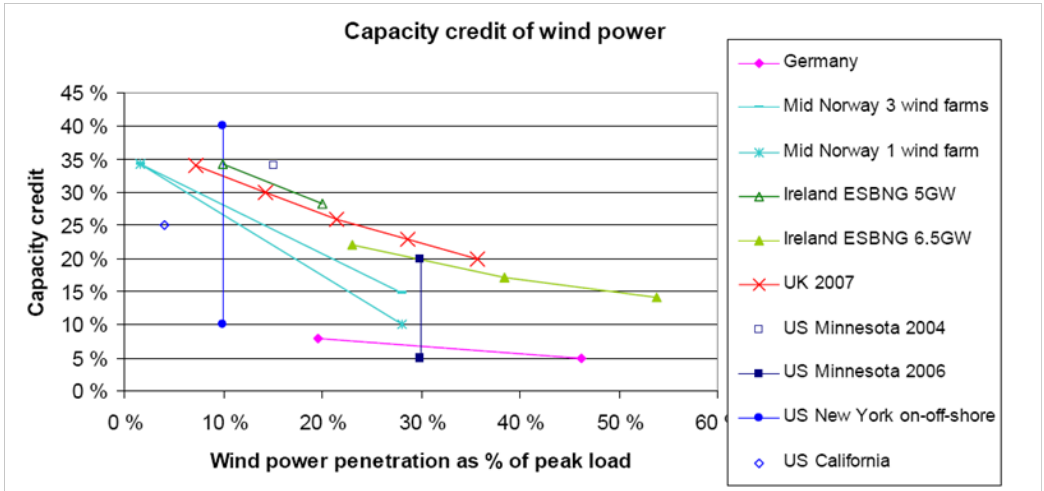
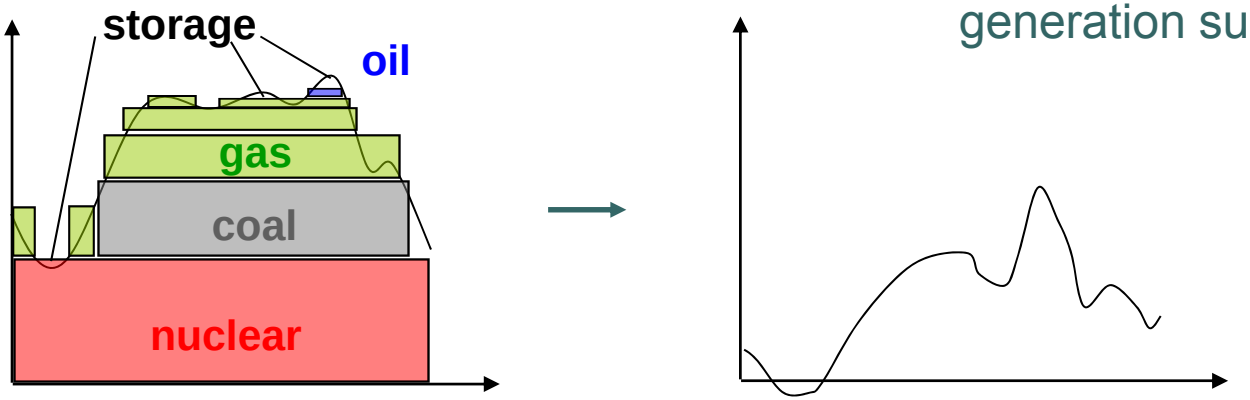


Fig 59. Capacity credit of wind power, results from eight studies. The Ireland estimates were made for two power system configurations, with 5 GW and 6.5 GW peak load.

Challenges
Electricity system: generation

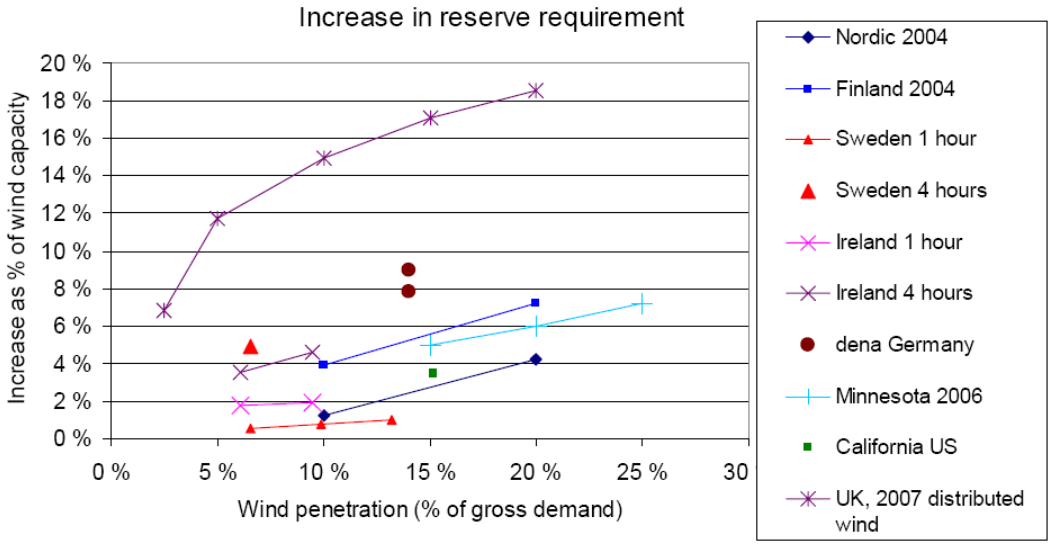
- Unit Commitment



- Flexibility
  - Flexible back-up power plants
  - Storage
  - Demand response

Challenges
Electricity system: Generation

- Unpredictability → increase in reserve requirement



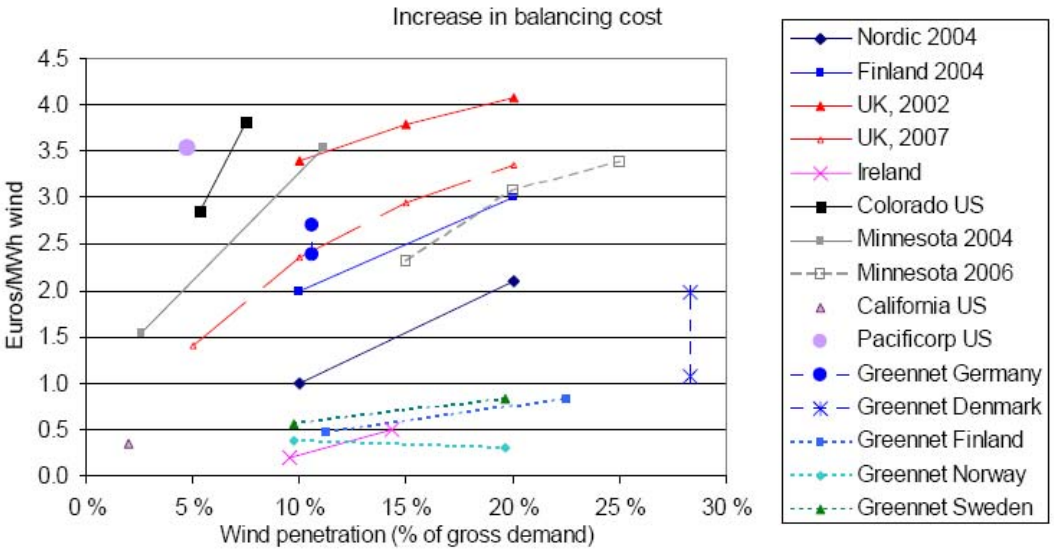
Dependent on

- power system
- time scales
- size of control (balancing) area
- methodology/assumptions
- …

Fig 56. Results for the increase in reserve requirement due to wind power. German Dena estimates are taking into account the day-ahead uncertainty (for up and down reserves separately) and UK the variability of wind 4 hours ahead. In Minnesota and California, day ahead uncertainty has been included in the estimate. For the others the effect of variations during the operating hour is considered For Ireland and Sweden the 4 hour-ahead uncertainty has been evaluated separately.

Challenges
Electricity system: Generation

- Increase in balancing costs



Dependent on

- power system
- time scales
- size of control (balancing) area
- methodology/assumptions
- …

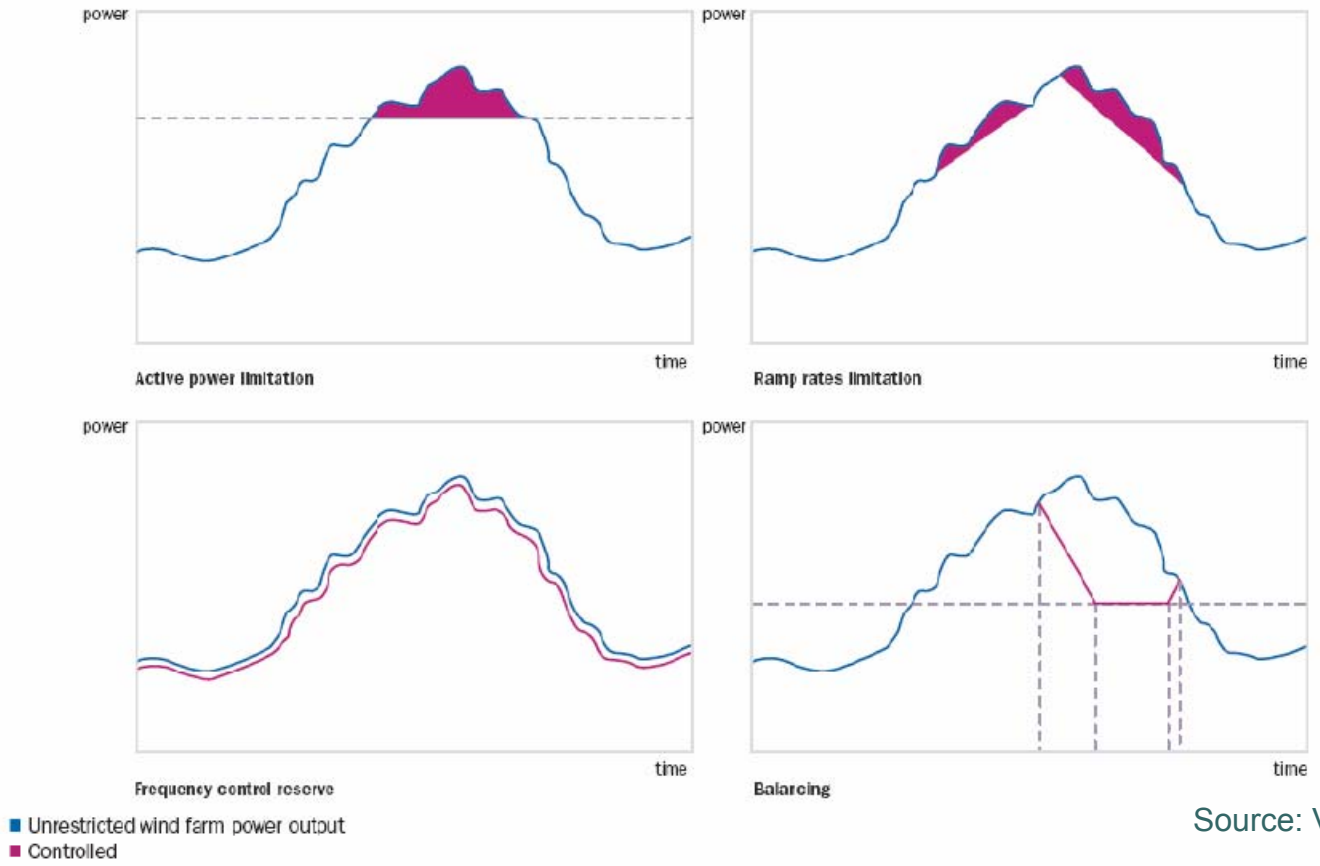
Fig 57. Results from estimates for the increase in balancing and operating costs due to wind power. The currency conversion used here is 1 € = 0.7 £ and 1 € = 1.3 US$. For UK, 2007 study the average cost is presented here, the range in the last point for 20 % penetration level is from 2.6 to 4.7 €/MWh.

Challenges
Electricity system: Generation

- Wind power contribution to reserves?
  - Secondary reserve
    - Activated within seconds – minutes
    - Permanently reduced output, e.g. 5% margin, to offer up-regulation
      - Loss of revenue
    - Or only down-regulation
  - Wind power cluster management?
    - Profile based generation with wind power plants

Challenges
Electricity system: Generation

- Controlling wind power output



Source: Van Hulle, 2008

Challenges
Electricity system: Grid

- Grid building involves very long lead times
  - Difficult licensing and permitting
- Investment incentives?
- Need for trans-national coordinated approach
- EC: “Blueprint for an integrated European energy network”
  - Identification of priority corridors
  - Set up of modular development plan
  - Creation of faster and more transparent permit granting procedures
  - Stable framework for financing

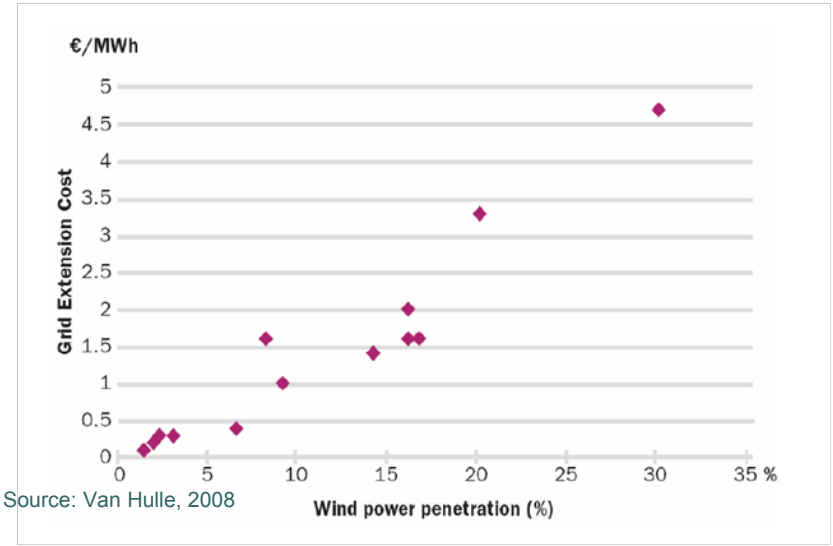
Challenges
Electricity system: Grid

- N-1 security
  - Grid reinforcements with new connections
  - Phase shifters
  - Other elements of a solution
    - Determine higher overhead line transport capacity when high wind
    - Real-time monitoring of lines
    - Reduced wind power output during line outages
    - Move from deterministic to probabilistic approach
      - Offshore wind
        - Intermittent, average P much lower
        - Full grid expansion (to remote area) not economically justified cf. MWh transported
        - N-1: grid must be able to transport 60-50-40% of P_{inst}, depending on season
        - Allows more wind turbines to be connected
      - Necessary condition: power reduction possibility

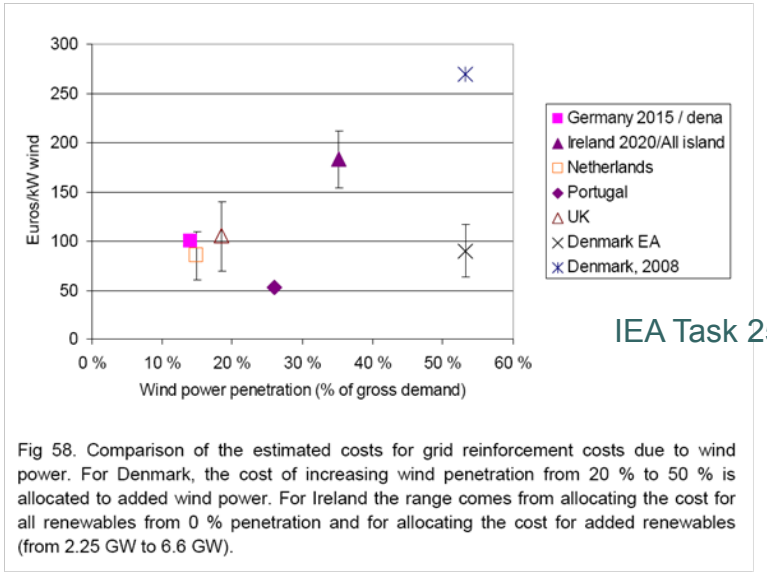
Source: Van Roy

Challenges
Electricity system: Grid

- Estimated additional grid extension cost



Source: Van Hulle, 2008



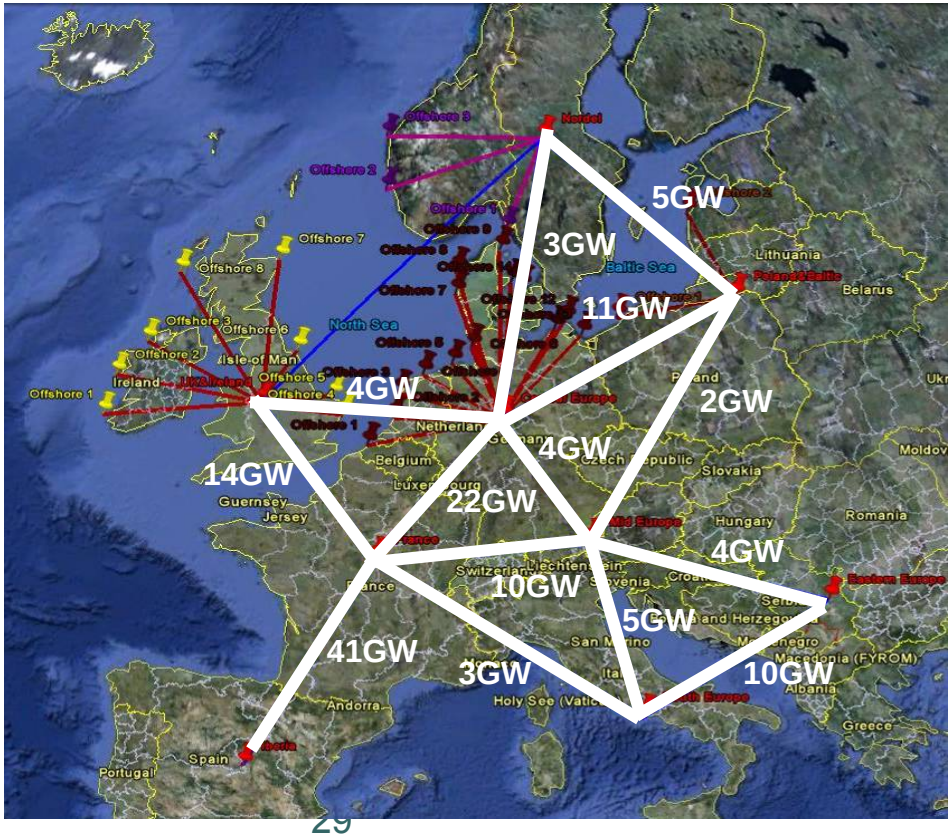
IEA Task 25

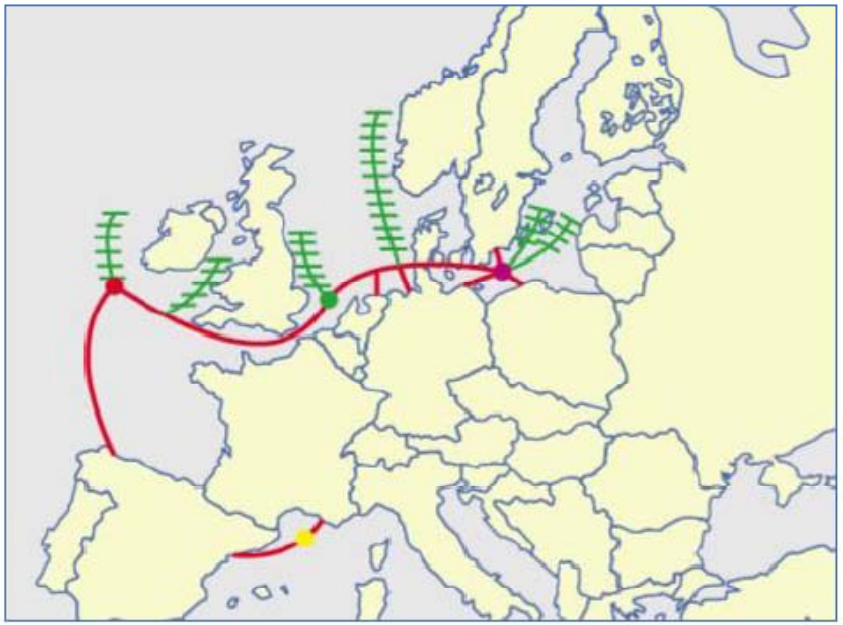
Fig 58. Comparison of the estimated costs for grid reinforcement costs due to wind power. For Denmark, the cost of increasing wind penetration from 20 % to 50 % is allocated to added wind power. For Ireland the range comes from allocating the cost for all renewables from 0 % penetration and for allocating the cost for added renewables (from 2.25 GW to 6.6 GW).

- Wide range in costs is reported
  - E.g. ECF 2050 versus Power Choices

Challenges
Electricity system: Grid

- Future “Supergrids”?



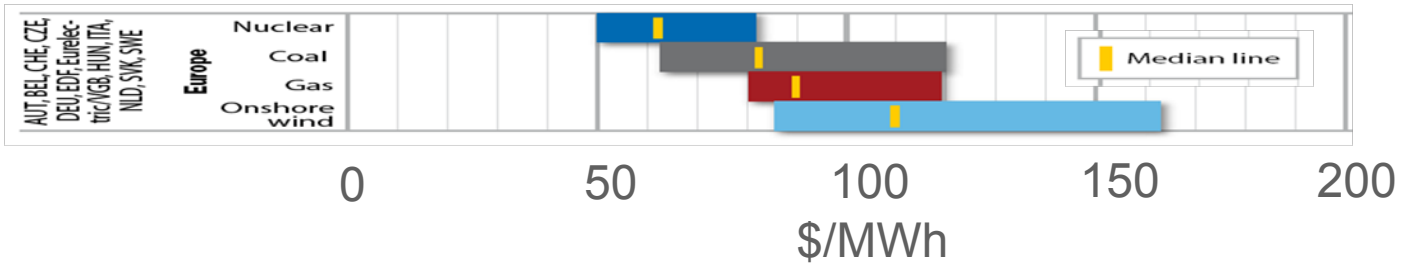


ECF, Roadmap 2050

Airtricity

Challenges
Market design

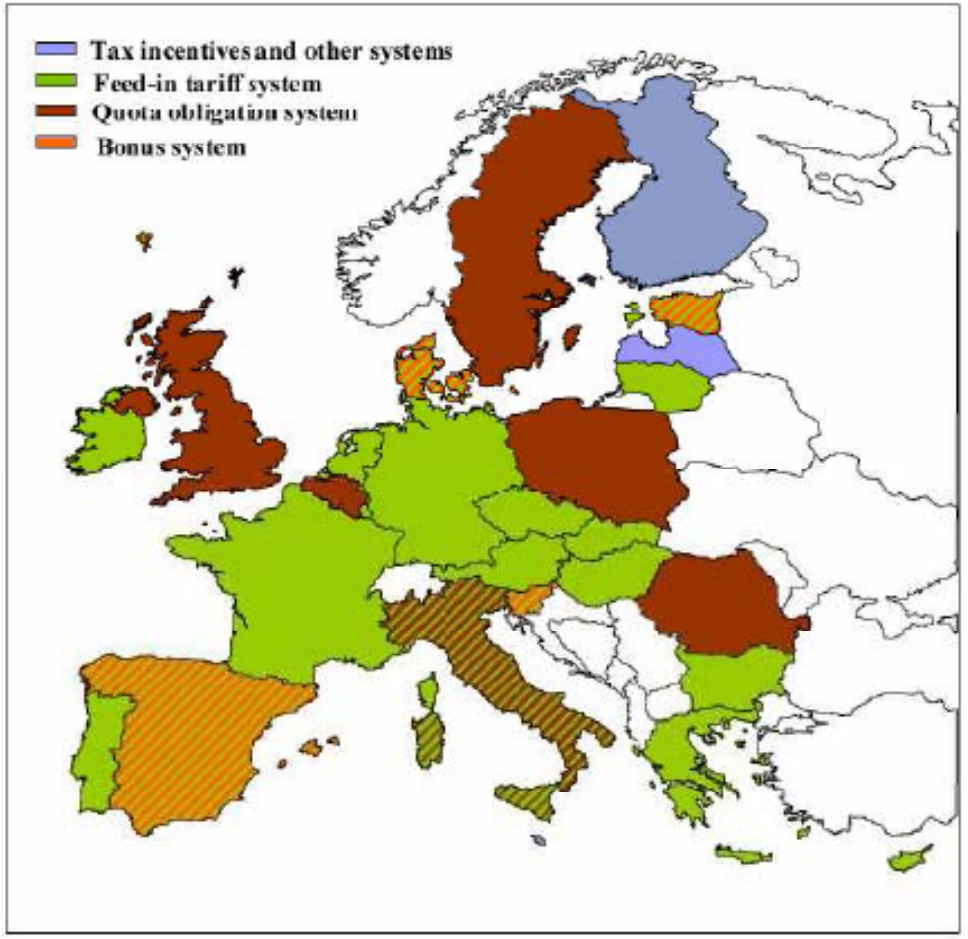
- Impact of RES energy on electricity costs depends on regulation
  - Main effect on costs: subsidies
  - Cost of RES currently still higher than classical generation



- Market design adequate for RES integration?
  - Does the market provide signals for the “right” implementation of wind energy?

Challenges
Market design

- Support mechanisms
  - Price based
    - Feed-in
    - Premium
  - Quantity based
    - Green certificates
  - Other
    - Tender
    - Investment subsidies
    - Tax incentives



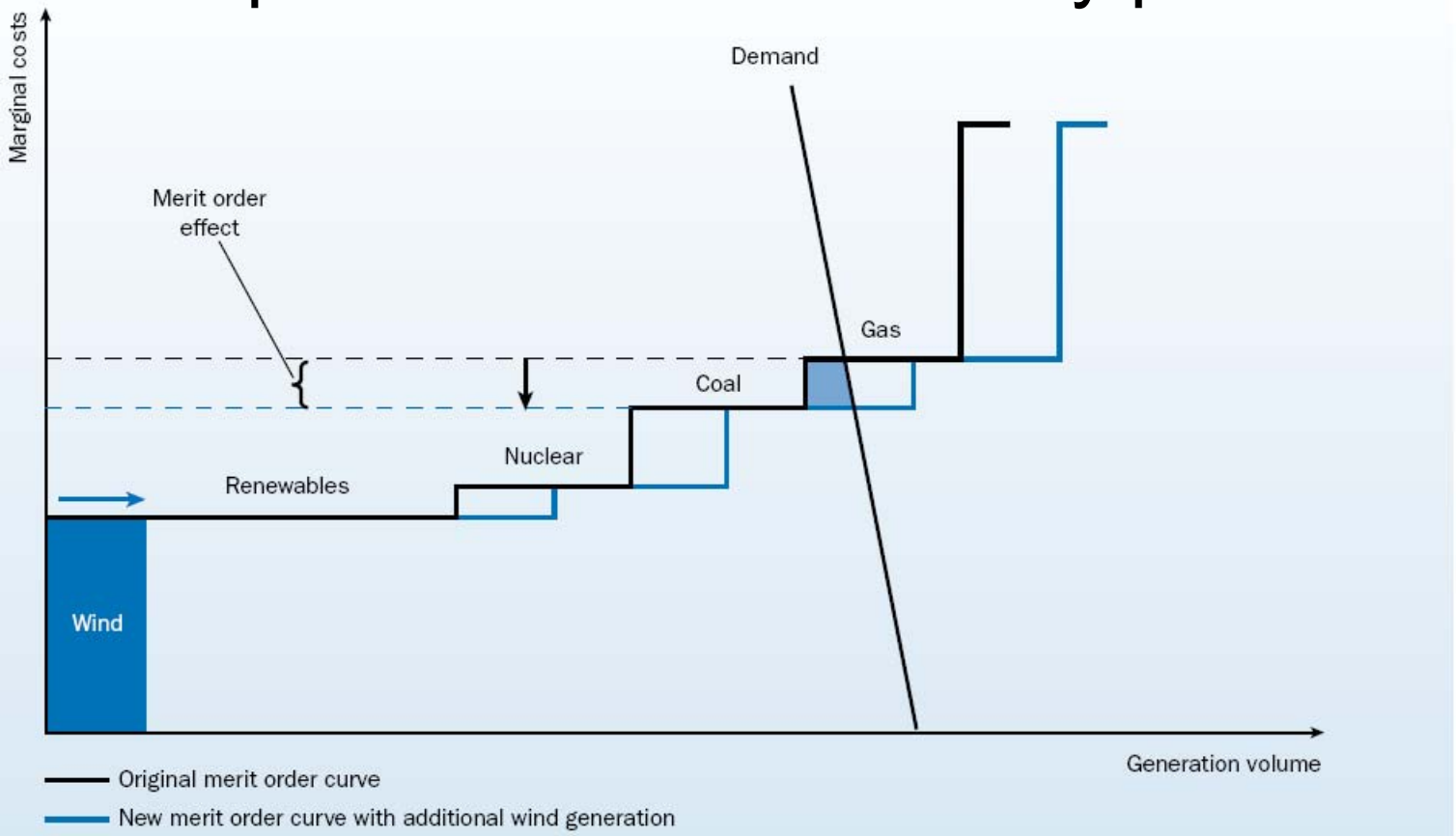
Source: Nicolosi, 2009

Challenges
Market design

- Are current markets well suited to function with a large penetration of RES?
  - Short term effect of RES on prices
    - Lower prices due to push-down of net demand
    - Increase in price volatility
- Stick to marginal cost based electricity markets?
  - Insufficient investment incentives?
  - Capacity markets/payments?

Challenges
Market design

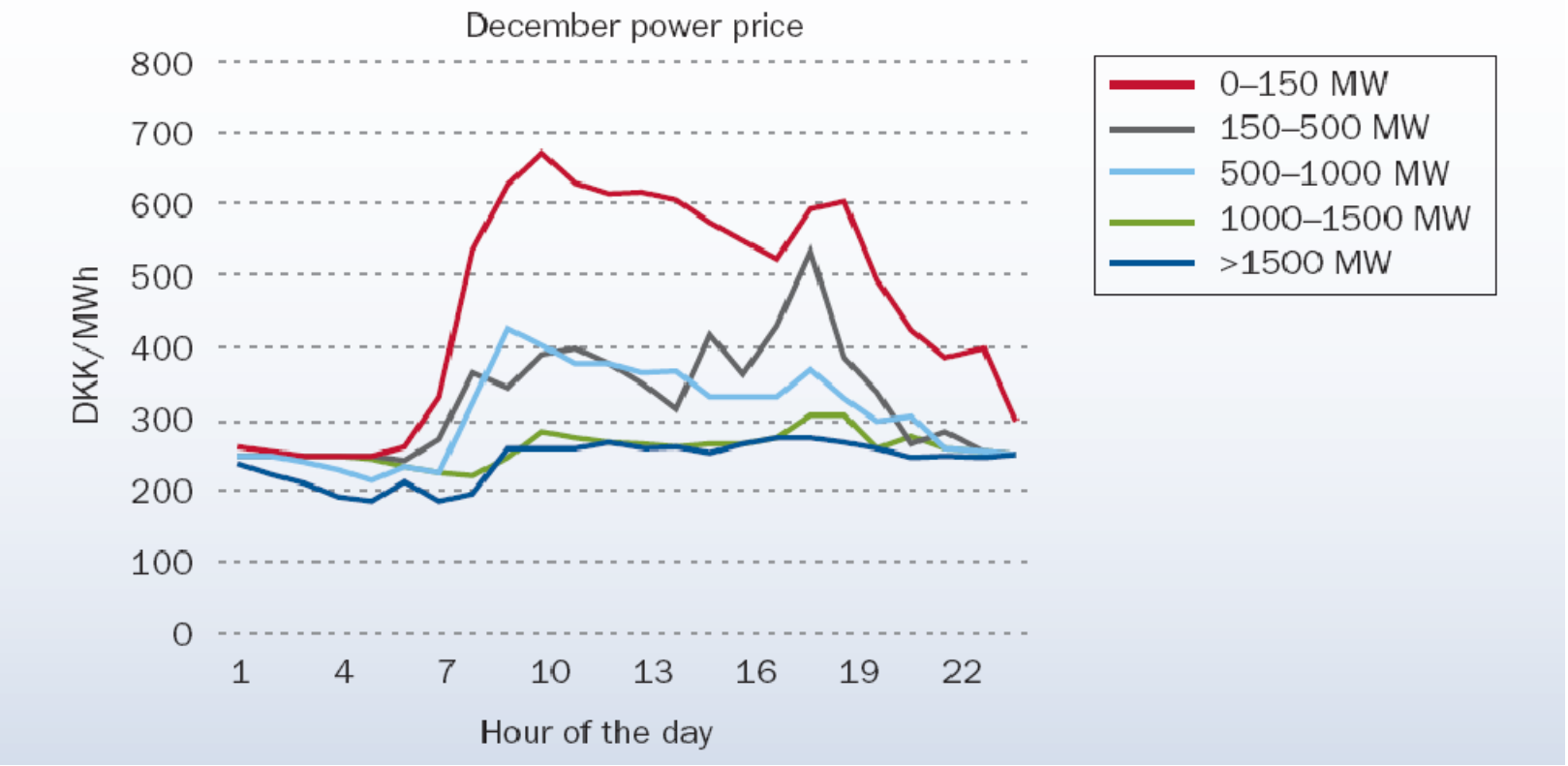
- Impact of RES on electricity price



Source: EWEA

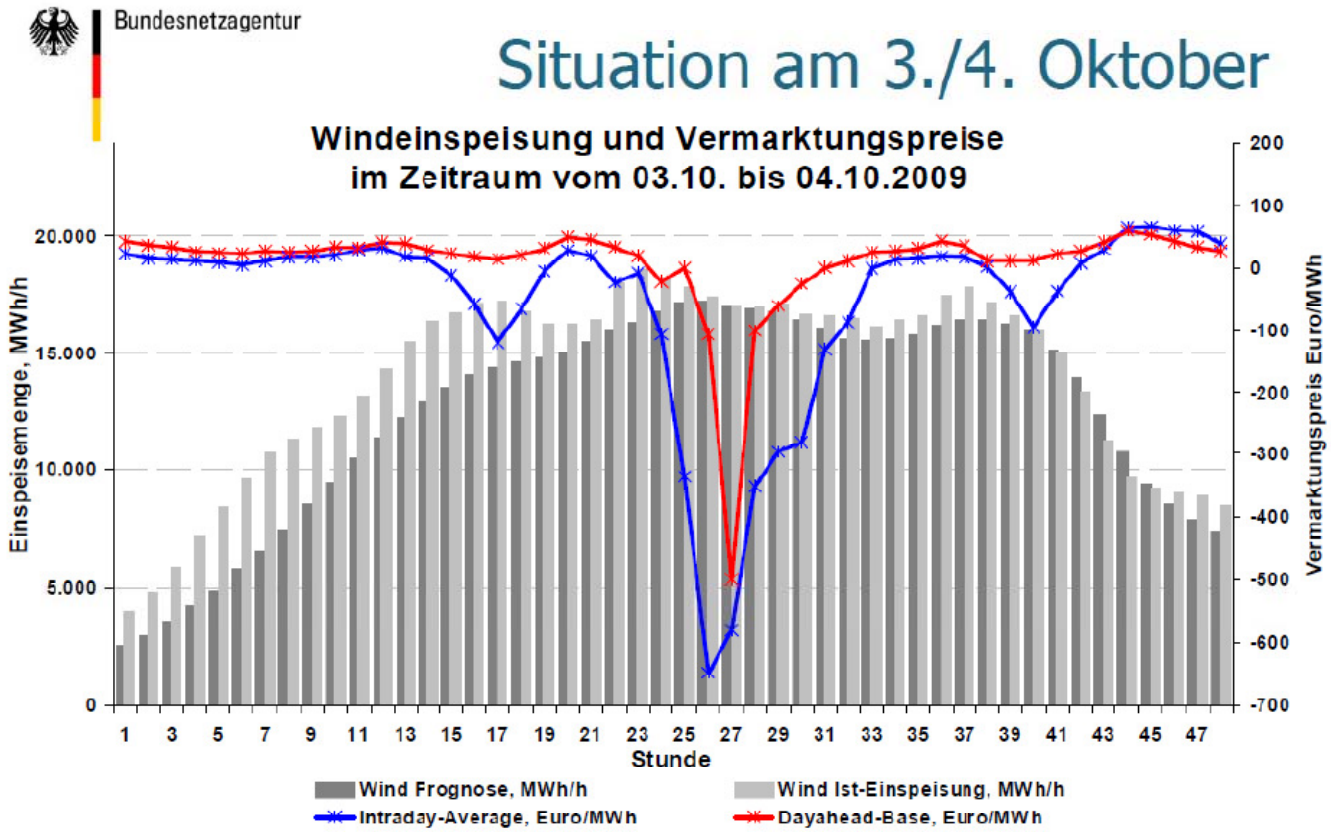
Challenges
Market design

- Impact of wind on electricity price
  - Denmark



Challenges
Market design

- Negative prices

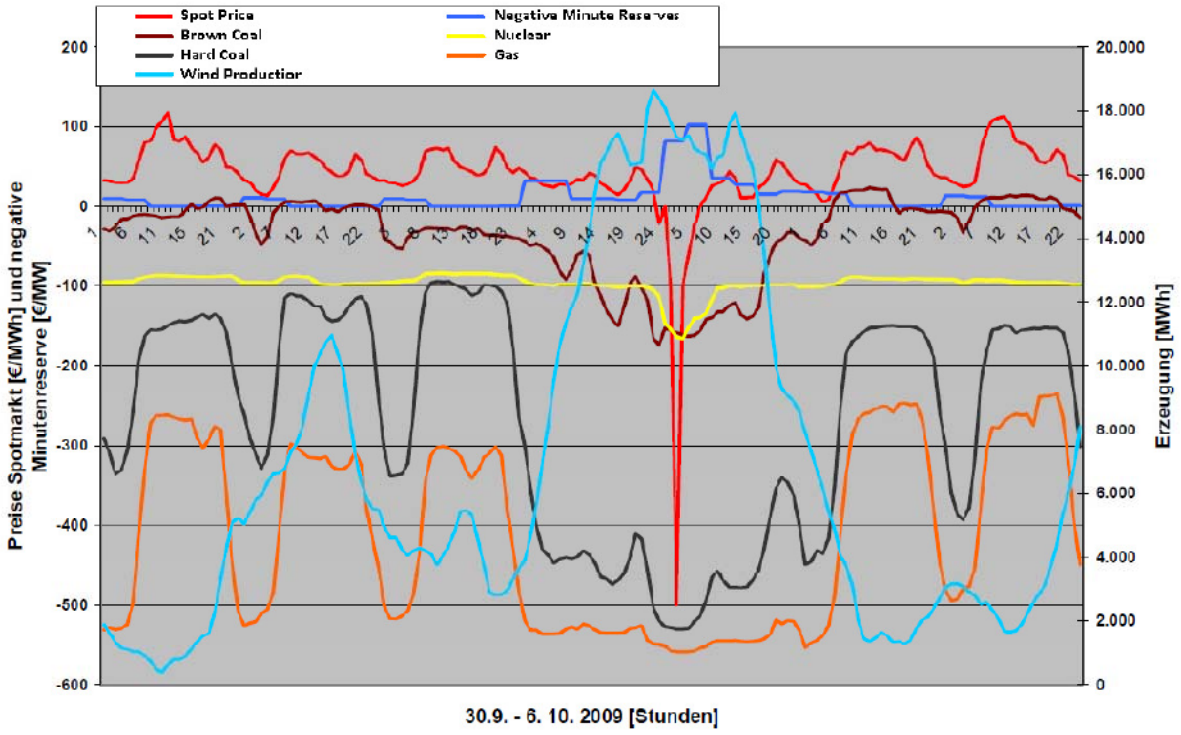


Source: Neeser, 2010

Challenges
Market design

- Negative prices

Abbildung 20: Die Marktsituation am 4. Oktober 2009



Quelle: EWI auf Basis von EEX, BDEW und Regelleistung.net Daten.

Source: Neeser, 2010

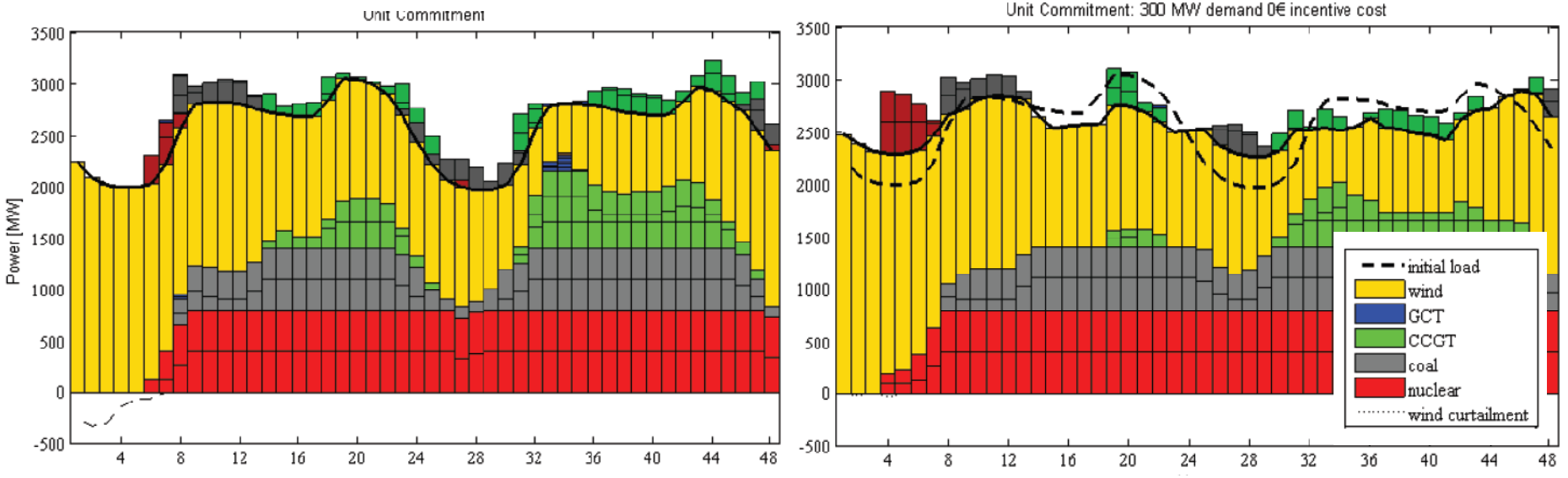
Challenges
Market design

- Balancing: possible solutions?
  - Shorter time horizon
    - Intraday trading
  - Larger control areas, or common reserve markets
    - Better balancing
    - More 1°-2°-3° reserve power available
    - Market rules that pay for reserve power availability
    - But: higher need for transmission capacity
  - New demand markets to use wind power overflow at large penetrations
    - Smart load management + storage

Source: Van Roy

Challenges
Market design

- Example demand response



Conclusions

- Power rather than aggregated energy is relevant
  - As electricity can not (yet) be stored (economically)
- Is there an upper limit for RES penetration?
  - Technical
  - Economic
  - Regulatory

Conclusions

- Challenges due to fast growth and high penetration
  - Need for appropriate system
    - Flexible generation (back-up)
    - Sufficient network capacity
      - Coordinated approach
    - Storage
    - Demand side participation
  - Need for appropriate market framework
    - Harmonization of day-ahead markets
    - Development and improvement of intraday markets
    - Common reserve market
    - Capacity markets?