The impact of wind power on power system operation - Evaluation with a stochastic optimisation model

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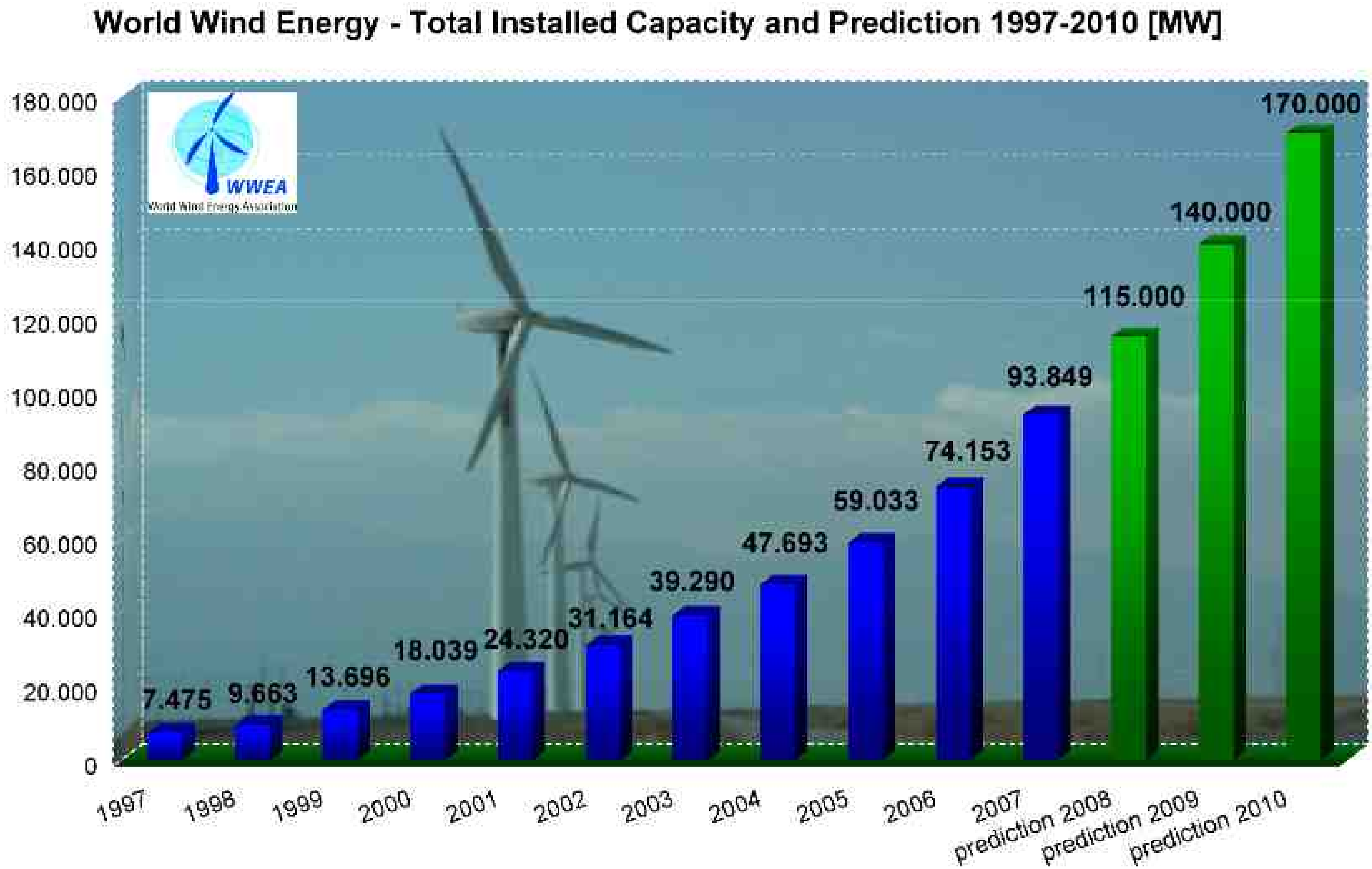
Overview of presentation

- Introduction and motivation
- Stochastic electricity market modelling
  i. Generation of wind power forecast scenarios
  ii. Stochastic optimisation of power plant operation
  iii. Results from optimisation
- Exemplary applications
- Summary and Outlook

Increasing wind power capacity worldwide



Source: World wind energy association

Characteristics of wind power

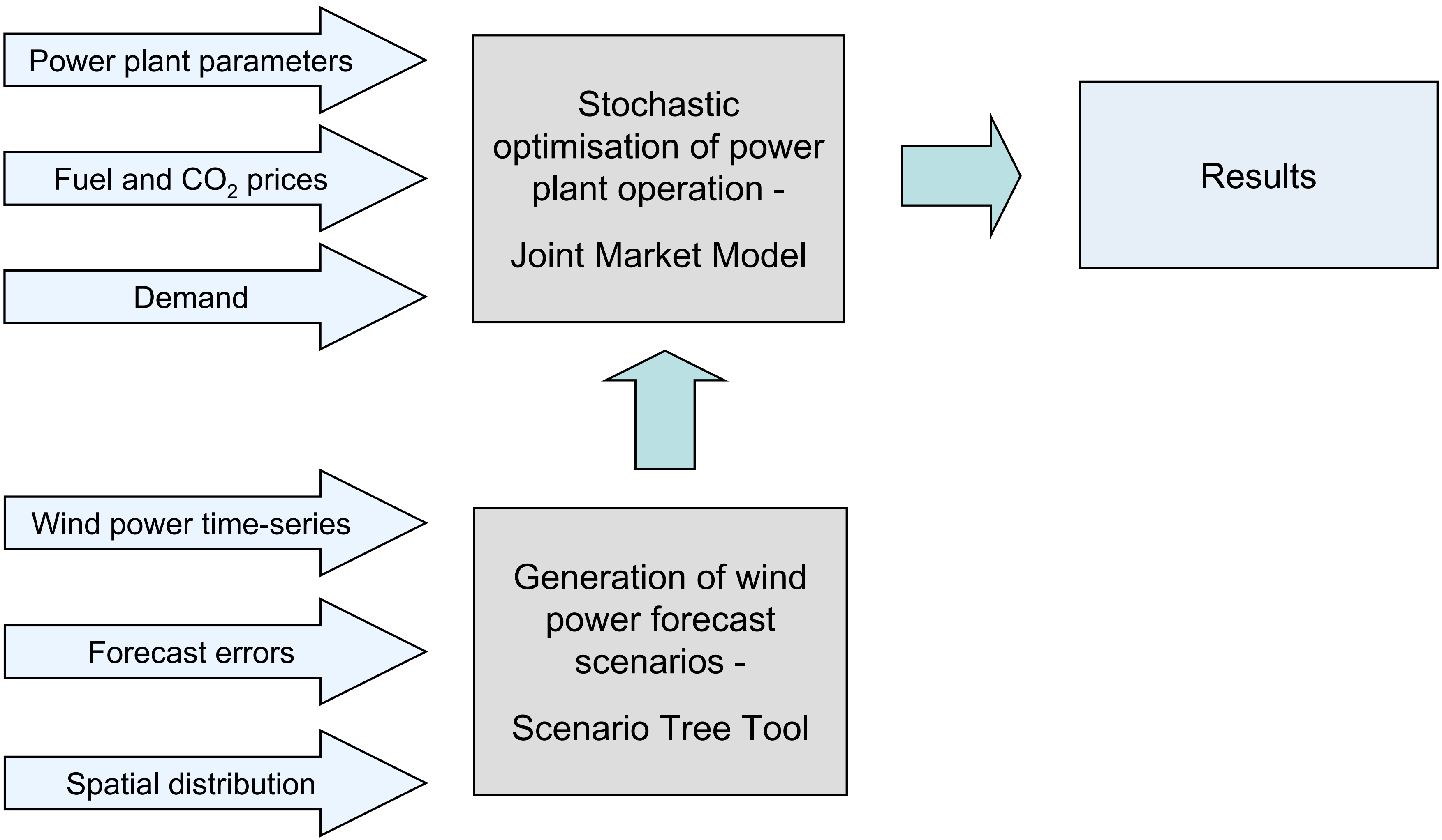
- Wind power production is
  i. strongly fluctuating
  ii. not perfect predictable
- No perfect correlation between wind power production and demand
- Capacity credit of wind power is low compared to installed capacity
- Concentration of wind power in regions with favourable wind conditions and remote from load centres can induce increased use of transmission networks

➢ Integration of wind power has impacts on power system operation and electricity markets

Evaluation of the impact of wind power

- Impacts of wind power production on the operation of power systems:
  i. Unit commitment and dispatch of conventional power plants
  ii. System operation costs and emissions
  iii. Electricity prices
  iv. Reliability of power systems
  v. Need for integration measures
- Aim to evaluate the impact of wind power on power system operation with stochastic electricity market models:
  i. Considering explicitly the intermittent nature of wind power production:
     1. Time-series of wind power production with high temporal resolution
     2. Scenarios of wind power forecasts with known error distribution
  ii. Covering different electricity markets and dispatch possibilities

Stochastic electricity market modelling - Overview



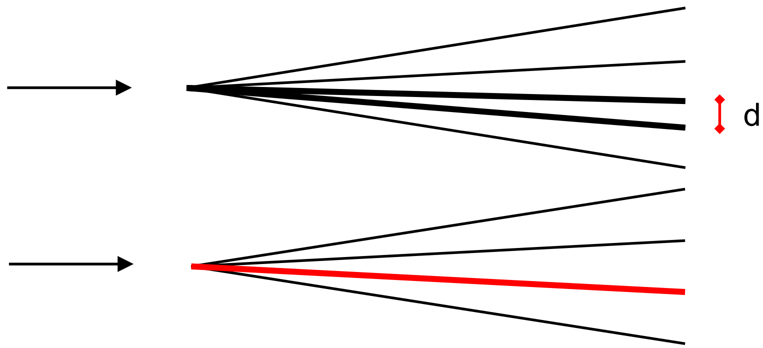
Generation of wind power forecast scenarios (I)

- Monte-Carlo-Simulation of wind forecasts based on ARMA time-series
- Simulation of forecast scenarios considers:
    i. Autocorrelation of the forecast errors over the forecast length
    ii. Correlations of the wind speed forecast errors between wind power regions for individual forecast hours
    iii. Spatial distribution of installed wind power capacity
- Generation of forecast scenarios:
    1. Uncertainty of forecast error represented by multiple drawings
    2. Scenario of forecast: Addition of forecast error to measured time-series

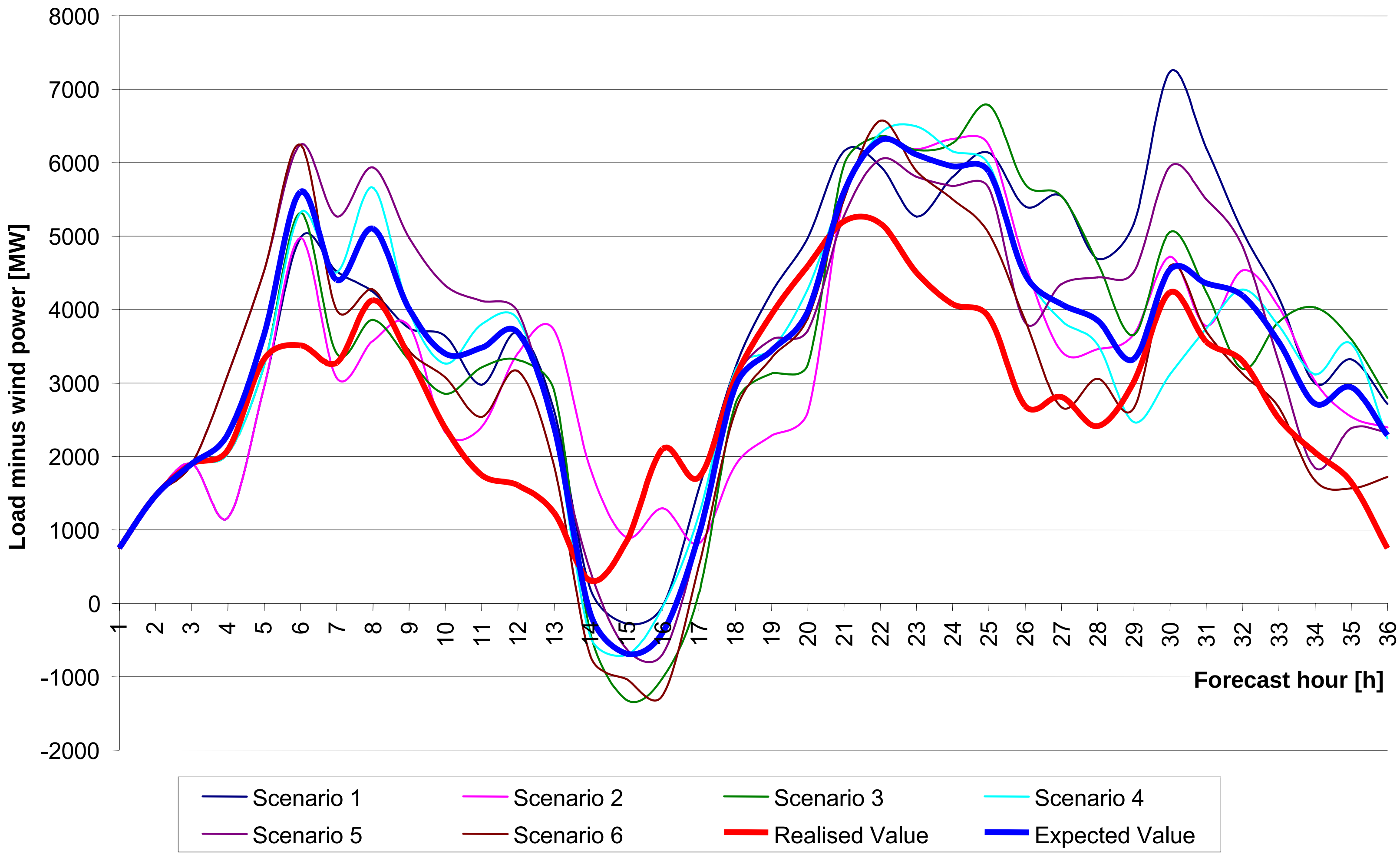
Generation of wind power forecast scenarios (II)

- Large number of forecast scenarios generated
- Reduction of resulting forecast scenarios to a specified number of scenarios required:

1. Determination of distances between individual scenarios
2. Representation of 2 most similar scenarios by one of them
3. Determination of probabilities of occurrence of the individual remaining scenarios
4. Creation of scenario tree



Resulting exemplary scenario tree



Stochastic optimisation of power plant operation (I)

- Stochastic linear mixed-integer optimisation model
- Coverage of electricity demand in hourly time resolution
- Objective: Minimisation of system operation costs
- Inclusion of balance equations describing following markets:
  1. Day-ahead market for physical delivery of power: Cleared at 12 o'clock for the following day taking into account scenarios of wind power forecasts
  2. Intra-day market for balancing deviations between power production expected at the day-ahead market and realised power production
  3. Markets for different kinds of reserve power
  4. Heat markets to consider the operation of CHP

Stochastic optimisation of power plant operation (II)

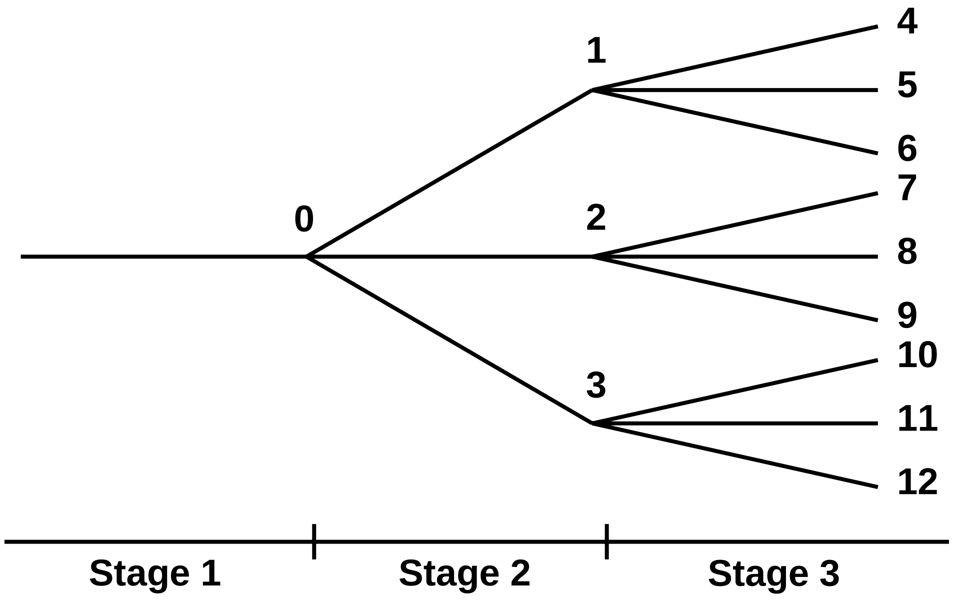
- Consideration of unit commitment and dispatch restrictions:
  i. Maximal and minimal operation capacities
  ii. Full and part load efficiencies
  iii. Start-up times and ramp rates
  iv. Minimum operation and shut down times
  v. CHP units: operating area
  vi. Abilities to provide different kinds of reserve power
  vii. Availabilities due to revisions and forced outages

Stochastic consideration of forecasts (I)

- Improve decision making by using information contained in stochastic short-term forecasts:
  i. Expected value of forecast, but also the distribution of forecast errors
- Sequence of decision making:
  i. Decisions with uncertain forecasts: Day-ahead scheduling
  ii. Decision after realization is known: Intraday down/up regulation of power plants
- Advantage: Model makes unit commitment and dispatch decisions being robust towards forecast errors

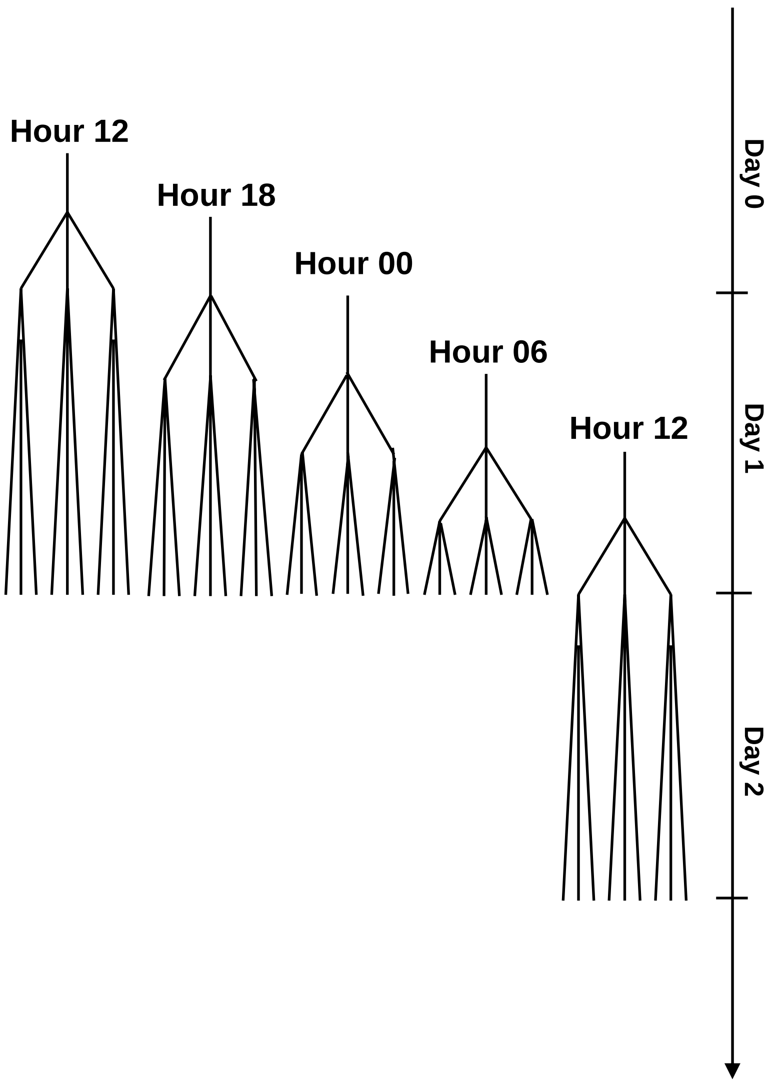
Stochastic consideration of forecasts (II)

- Distribution of stochastic short-term forecasts represented by scenario trees
- Optimization considers all possible scenarios with given probabilities of occurrence
- Consideration of longer time horizons with rolling planning



Rolling planning

- Sequence of successive scenario trees:
  i. Consideration of updated forecasts
  ii. Unit commitment and dispatch considers intertemporal restrictions between scenario trees
- First hours of root node of scenario tree correspond to realised power plant operation

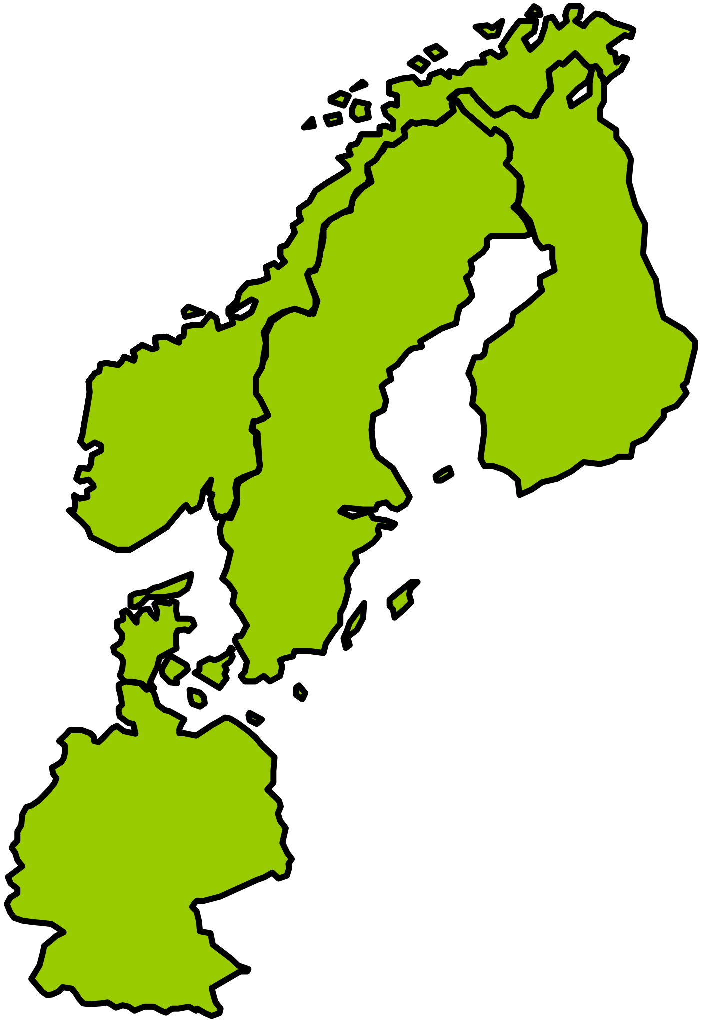


Results from optimisation

- Total system-wide operational costs due to:
  i. Fuel consumption, start-ups, further operation and maintenance costs, need for CO_2 emission permits
- Realised hourly unit commitment and dispatch of conventional units
- Realised distribution of reserve power categories on units
- Electricity prices (equal to marginal system operation costs)
- Fill level of storages
- Hourly power exchange between model regions
- CO_2-emissions

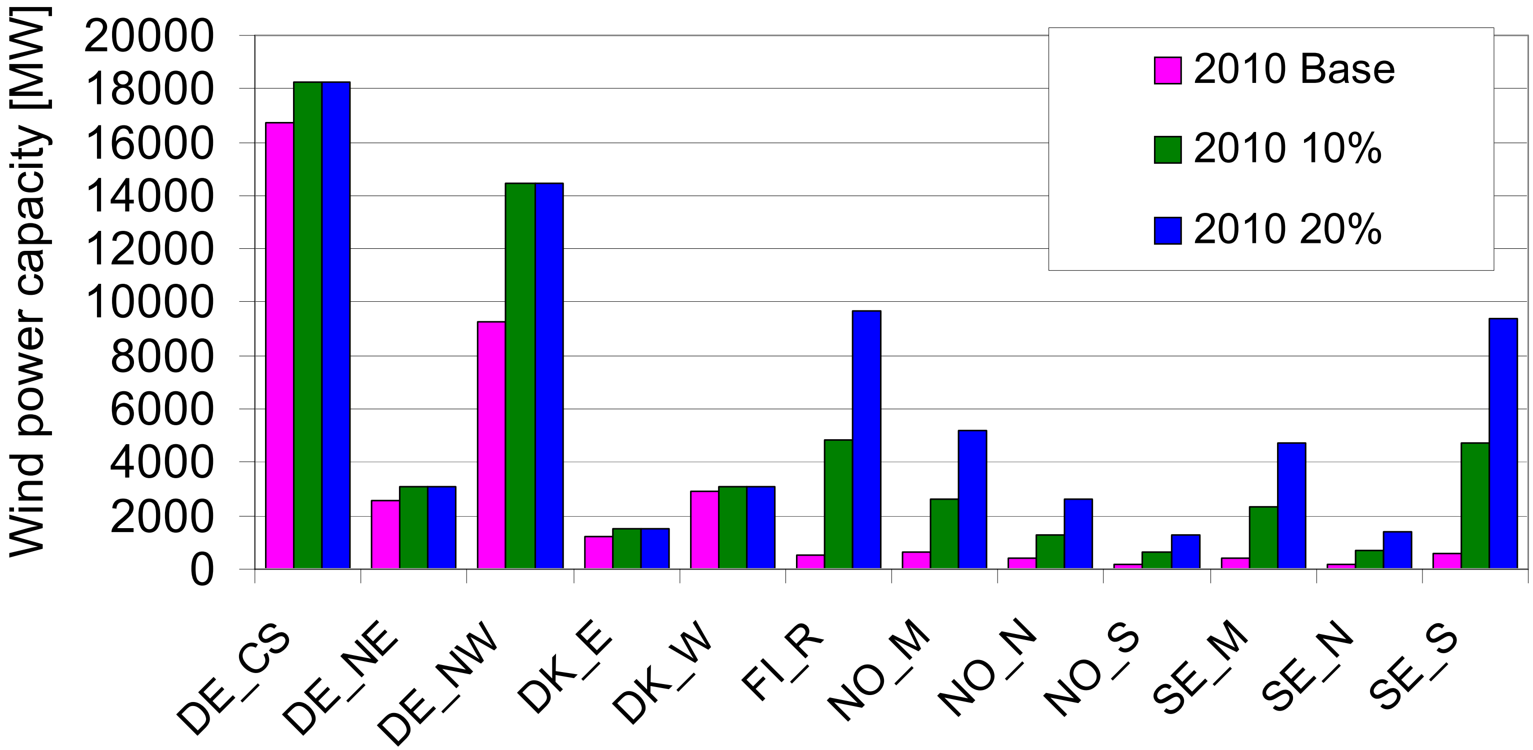
Application 1: Scandinavia and Germany

- Simultaneous consideration of Denmark, Finland, Germany, Norway and Sweden
- Subdivision of individual countries into further model regions
- Approx. 620.000 equations and 550.000 variables
- Further information: www.wilmar.risoe.dk/



Application 1: Case study

- Assumption on wind power capacity installed in 2010



- Share of total production: 2010 Base: 6 %; 2010 10%: 12 %; 2010 20%: 16 %

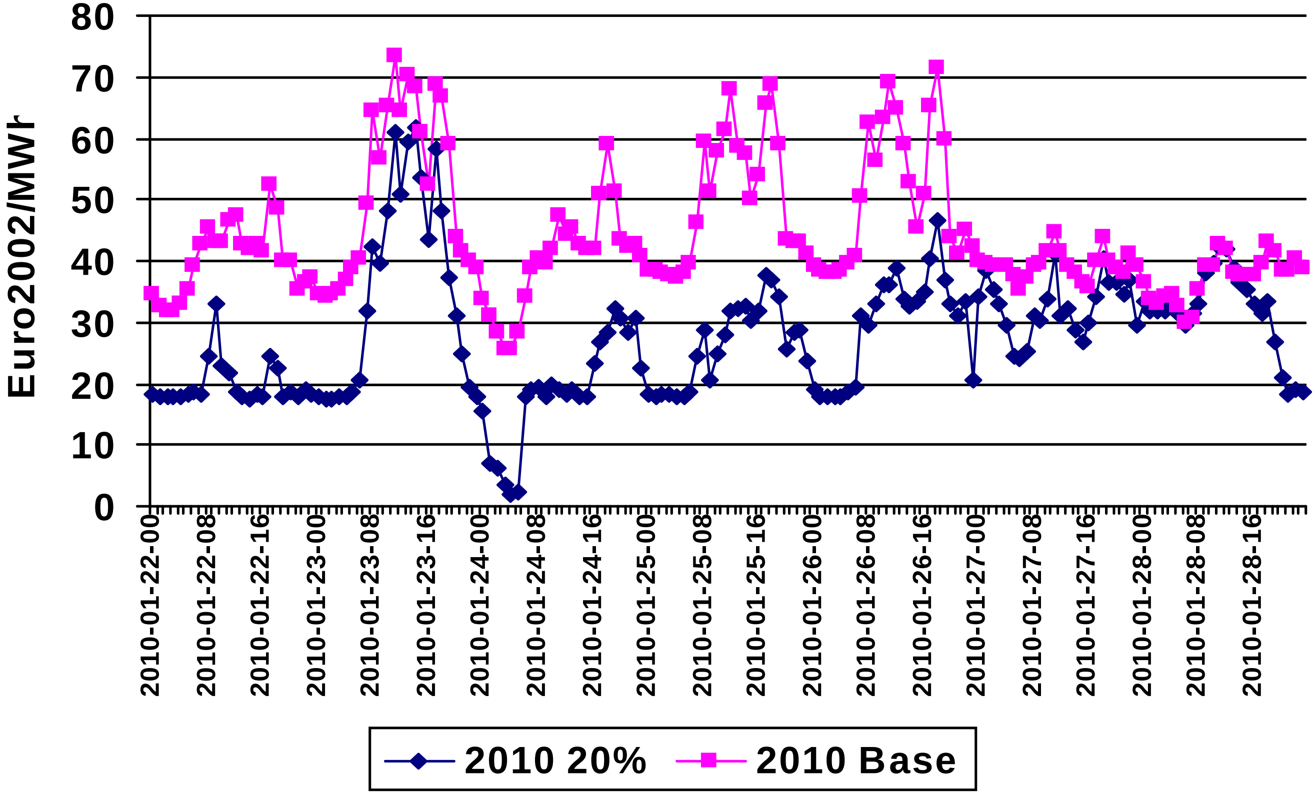
Application 1: Exemplary results (I)

Comparison of the total system operation costs with the wind power production during e.g. January and February:

Case Name	Total Costs [Mio. Euro]	Windpower Production [TWh]	Change in costs [Mio. Euro]
2010 Base	4929.6	10.4	-
2010 10%	4720.0	21.2	-209.7
2010 20%	4552.8	28.8	-376.9

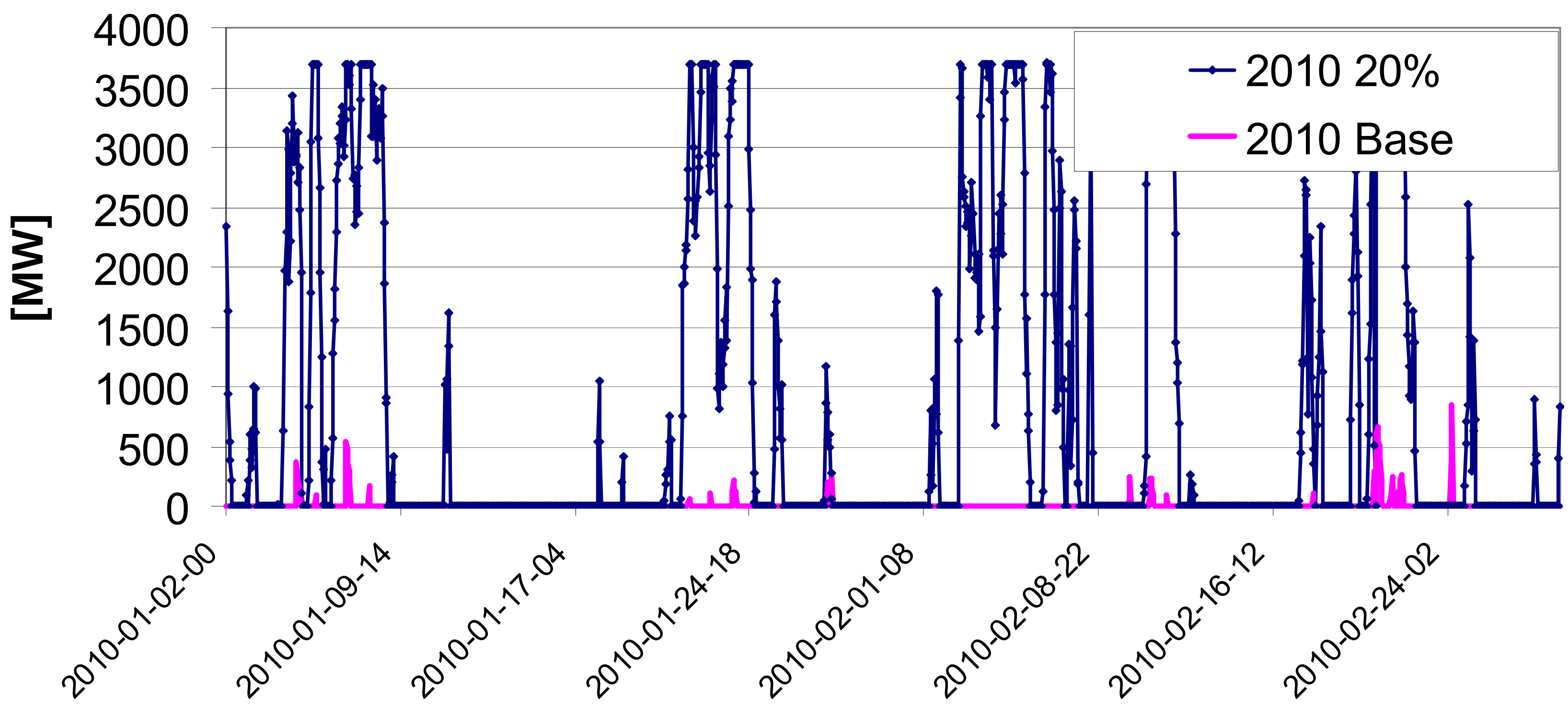
Application 1: Exemplary results (II)

Day-ahead prices in northern Germany during a January week for the cases 2010 Base and 2010 20%:



Application 1: Exemplary results (III)

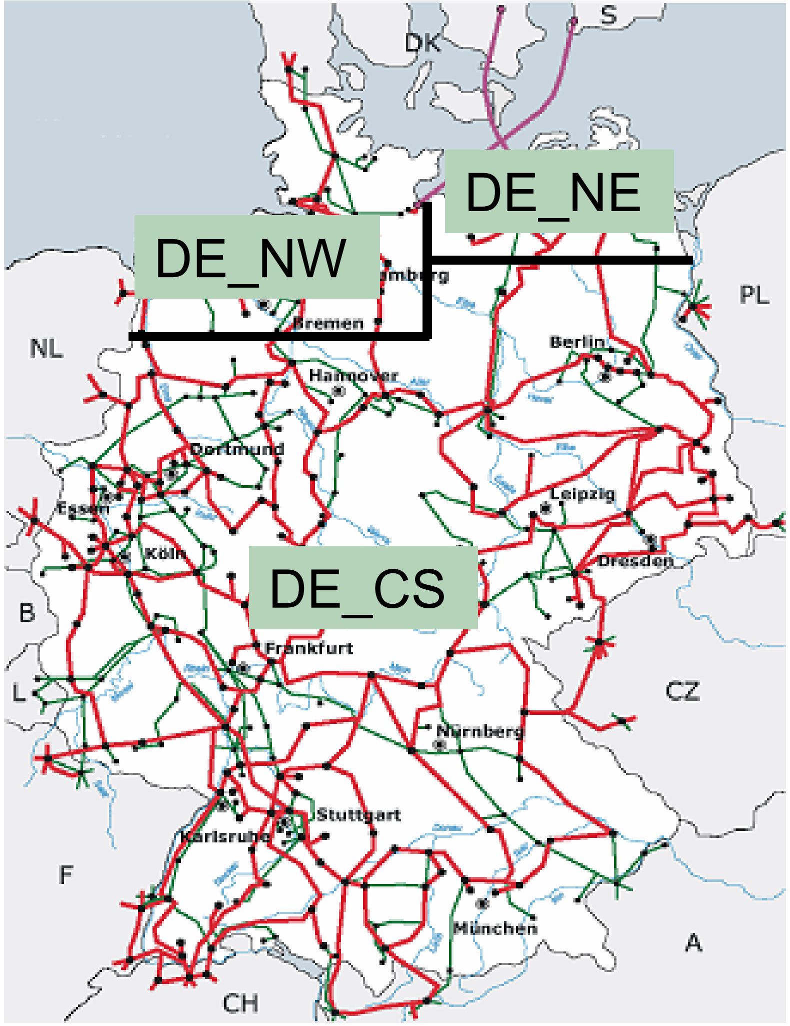
Electricity export from model region SE_S to SE_M e.g. during January and February for the cases 2010 Base and 2010 20%:



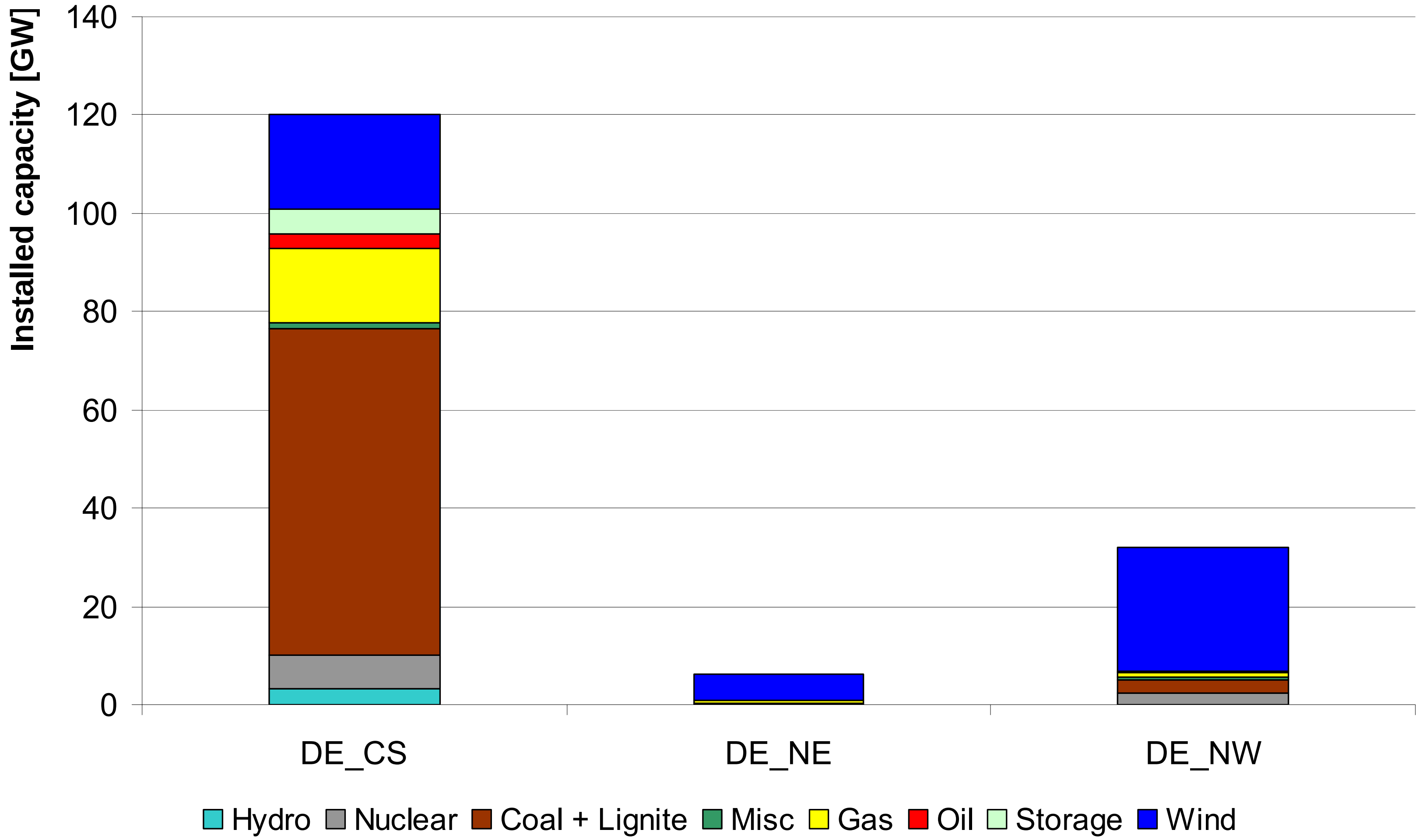
Application 2: Germany

- Subdivision of Germany allows to consider:
  i. Concentration of installed wind power capacity in coastal areas
  ii. Regions with low demand
  iii. Bottlenecks of the transmission system
- Case study for the year 2020:
  i. Resulting zonal electricity prices in individual model regions
  ii. Evaluation of integration measures like extension of transmission network and use of storages
- Further information:

  Barth et al.: Regional electricity price differences due to intermittent wind power in Germany: impact of extended transmission and storage capacities. Int. J. Global Energy Issues, Vol. 25 (2006), Issue 3/4, pp. 276 - 297

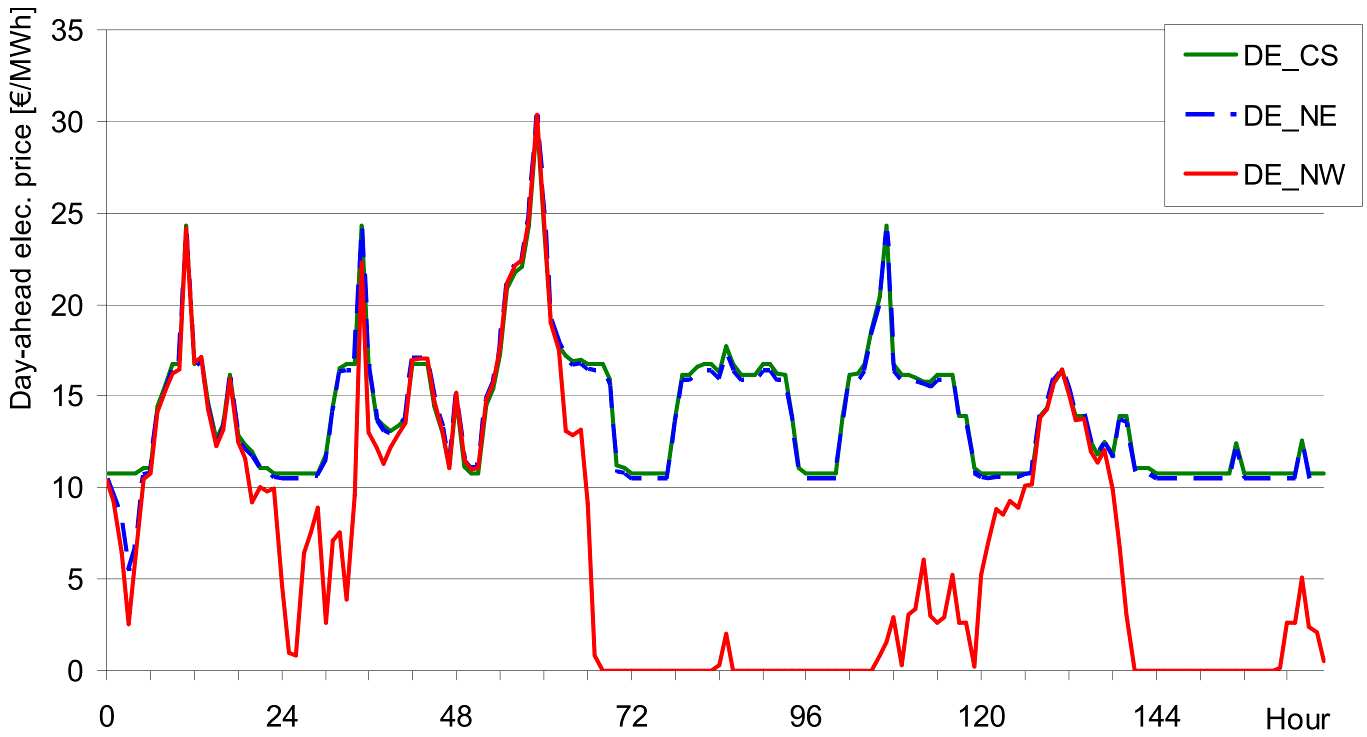


Application 2: Installed capacities



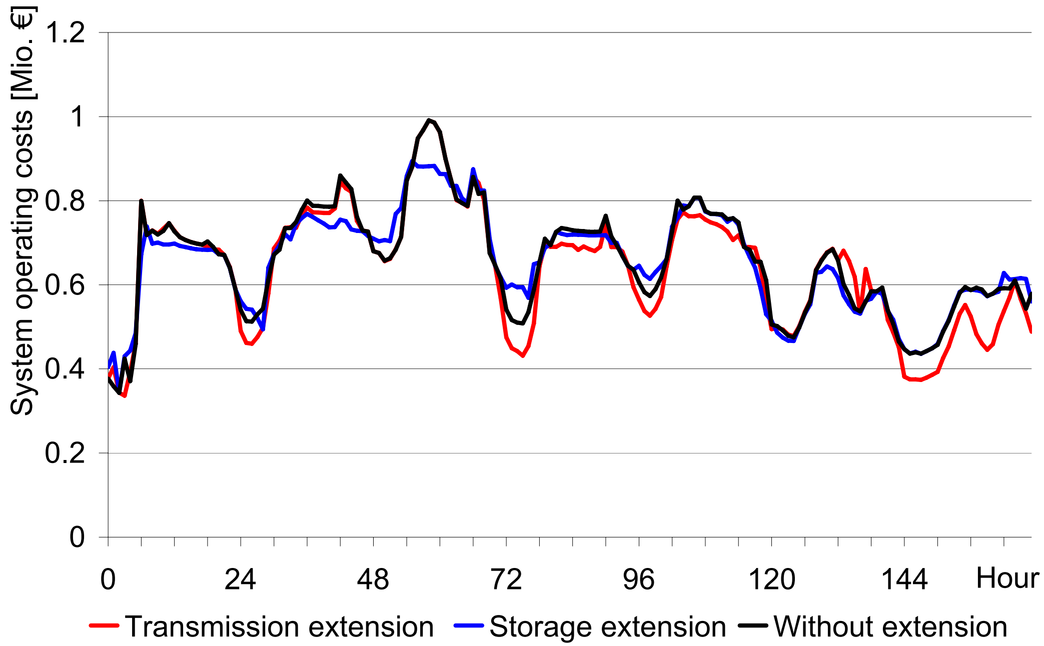
Application 2: Exemplary results (I)

- Day-ahead prices in exemplary week temporarily differ:
  i. Transmission lines are working at full load
  ii. Electricity prices equal to zero: Load is completely covered by wind



Application 2: Exemplary results (II)

- Consideration of integration measures:
  i. Extension of transmission network: Equalisation of electricity prices and maximal increased usage of wind power production
  ii. Use of storages: Electricity price differences remain
  iii. Lowest sum of system operation costs achieved with extension of transmission network



Application 3: Ireland and Northern Ireland (I)

- All Island Grid Study Work-stream 2(b):
  i. Investigation of the ability of the integration of renewables in the year 2020
  ii. Current Irish power system: Dominated by thermal power plants and only limited transmission possibilities to Great Britain
- Consideration of 4 penetration ratios of renewable power generation (estimated peak load 9619 MW):
  i. Wind energy: 2000 … 8000 MW
  ii. Tidal energy: 72 … 200 MW
  iii. Wave energy: 0 … 1400 MW
  iv. Biomass, biogas and further renewables: 182 … 392 MW
- Consideration of 6 scenarios of the future power plant portfolio:
  i. Different focus of expansion of conventional power plants:
     1. Hard coal power plants
     2. Combined cycle gas turbines (CCGT)
     3. Open cycle gas turbines (OCGT)
  ii. Determination of the impact of different power plant portfolios in combination with identical penetration ratio of renewable power generation
- Further information: www.dcenr.gov.ie and final report of All Island Grid Study Work-stream 2(b)

Application 3: Ireland and Northern Ireland (II)

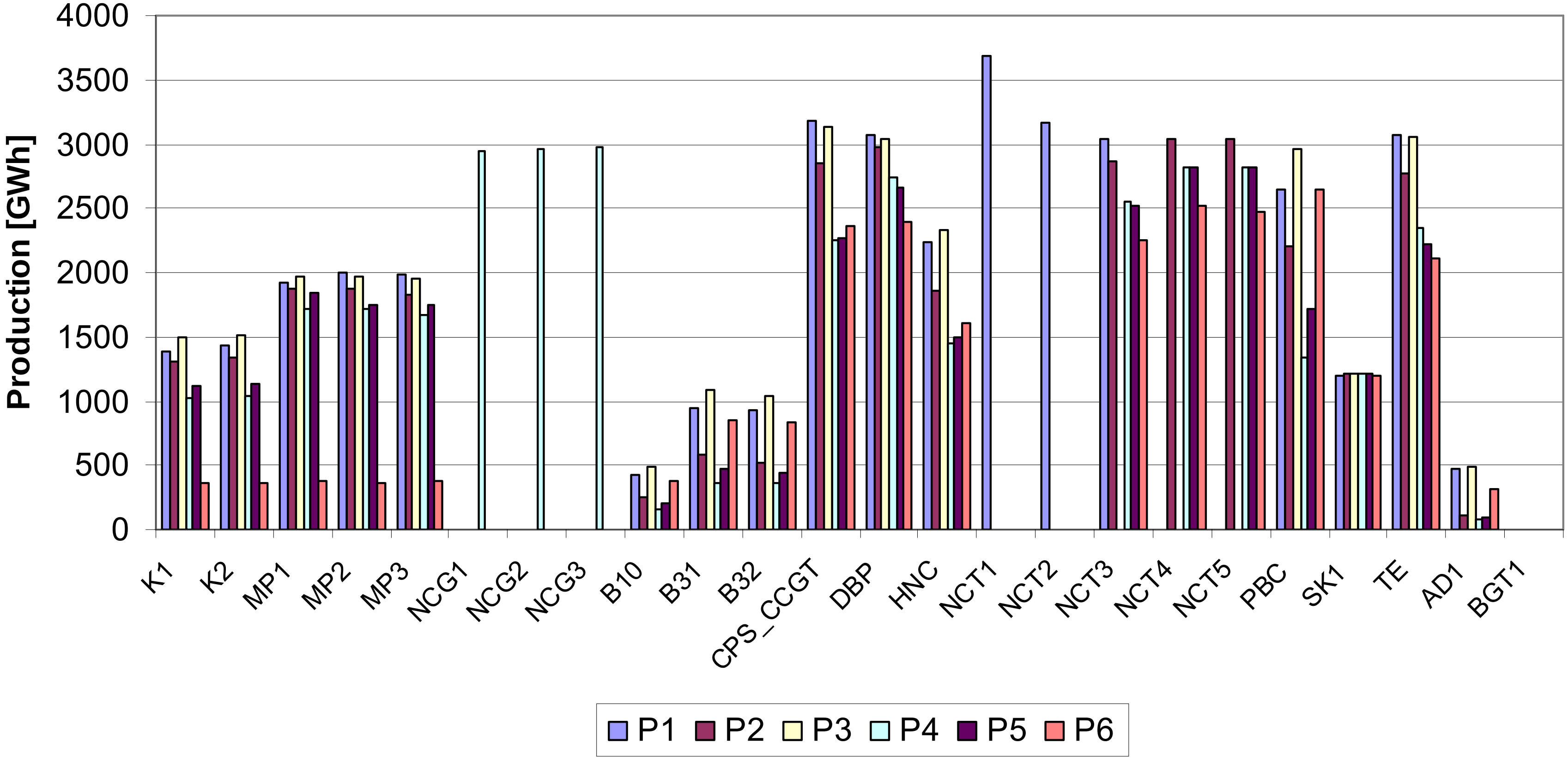
- Generation of results covering a whole year:
    1. Influence on system operation costs and emissions
    2. Reliability of power system to cover the load
    3. Detailed unit commitment and dispatch derived with mixed-integer programming
    4. Distribution of required reserve capacities on power plants
    5. Power exchange with Great Britain
- Additional model runs:
    1. Impact of improved wind power forecasting
    2. Impact of scenarios of fuel and CO_2 emission permit prices
    3. Impact of unit constraints

Application 3: Exemplary results (I)

- Increase of share of renewable electricity production of yearly demand from 16 to 59 %
- Decrease of system operation costs and CO_2 emission with increasing wind power production
- System operation costs: High share of base load units with low variable costs preferable
- CO_2 emissions: High share of gas-fired base-load units preferable
- Flexible OCGT have small contribution to electricity production
- Spinning reserves: Pumped hydro storage, coal fired units and CCGTs main sources
- Replacement reserves: OCGTs main sources
- Integration of wind power requires very flexible unit commitment and dispatch with high number of start-ups
- Decrease of import from Great Britain with increasing wind power production

Application 3: Exemplary results (II)

- Resulting annual electricity production per unit (excerpt)



Summary

- Evaluation of the impact of wind power on power system operation and electricity markets requires:
  i. Detailed consideration of conventional power plant portfolio and unit commitment and dispatch restrictions
  ii. Representation of design of electricity markets
  iii. High temporal resolution of time-series of wind power production and load
  iv. Use of stochastic programming to consider both variability and not perfect predictability of wind power
- Various applications in case studies and investigations for stakeholders evaluating the impact of integration of wind power into electricity markets regarding:
  i. System operation costs and electricity prices
  ii. Reliability of load coverage
  iii. Optimal unit commitment and dispatch
  iv. Suitable structure of conventional power plant portfolios to integrate wind power
  v. Use of integration measures like transmission network extension and use of storages

Outlook

- Ongoing development and enhancements:
  i. Improved consideration of electrical load flows within transmission networks by
     - detailed description of complex load flow
     - approximative description for consideration of large areas like several countries

  ii. Extension of power plant database to cover the whole of Europe
- Further application for the whole of Europe and for selected single countries
- …

Thank you for your attention!

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