Institute of Power Systems and Power Economics
RWTH Aachen University
Univ.-Prof. Dr.-Ing. H.-J. Haubrich

Economic Evaluation of the Impact of Integrating Wind Turbines in the Generation System

- Introduction
- Considered system
- Methodical approach
- Input data
- Results
- Conclusion

Dipl.-Ing. Tobias Mirbach

Bejing, 19 Nov 2008

Motivation and aim of this approach

Situation

Change in fuel mix expected

- Shortage of fossil energy carriers expected in the near future
- High potential of renewable energy sources, esp. wind power
- Installed capacity of wind turbines (onshore) continuously increasing in Europe
- Offshore projects are planned, esp. in Germany

Complication

New generation technologies mainly non-steerable

- Generation of wind power plants depends on weather conditions
- Feed-in of wind power plants influences operation of generation pool

Aim of this approach

Investigation of the influence of high wind energy feed-in on

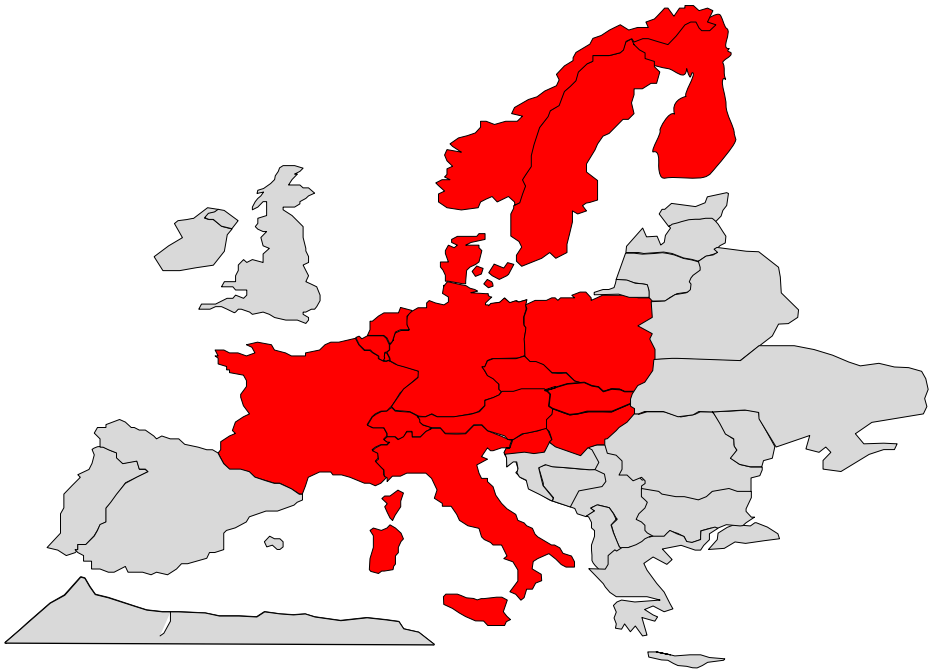
- Operation of power plants
- Total generation costs
- CO_2 emissions

in

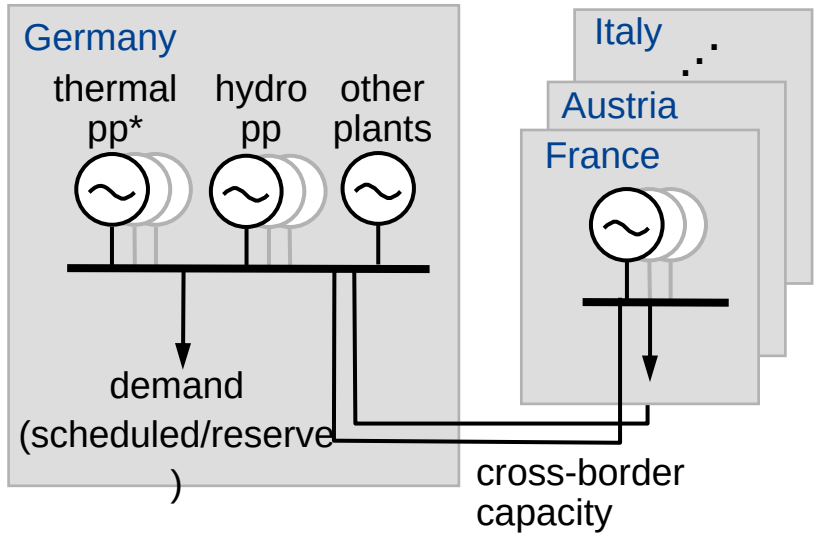
- Central Europe with focus on Germany

System under consideration

- Time horizon
  - Investigations for the year 2015 (hourly time pattern)
- Geographical focus
  - Central Europe including Nordel-states
  - Countries at the system boundaries (e.g. spain): simplified consideration by historical profiles of cross-border power exchange



system components



* pp = power plant

Method overview

Input data

Generation system 2015 Central Europe

- hydrothermal generation system
- prices for primary energy and CO_2 certificates
- generation of wind turbines
- generation of other must run units
- cross-border capacities

System constraints

- load
- reserve demand

Optimization method

Generation and Trading Planning Tool*

Economic optimization of the generation system

- Objective function: minimal (economic) generation costs
- Constraints:
  - fulfillment of load and reserve demand
  - power plant specific parameters
  - cross-border capacities

Results

System results

- total generation costs

Unit results

- power plant specific generation schedule
- CO_2 emissions

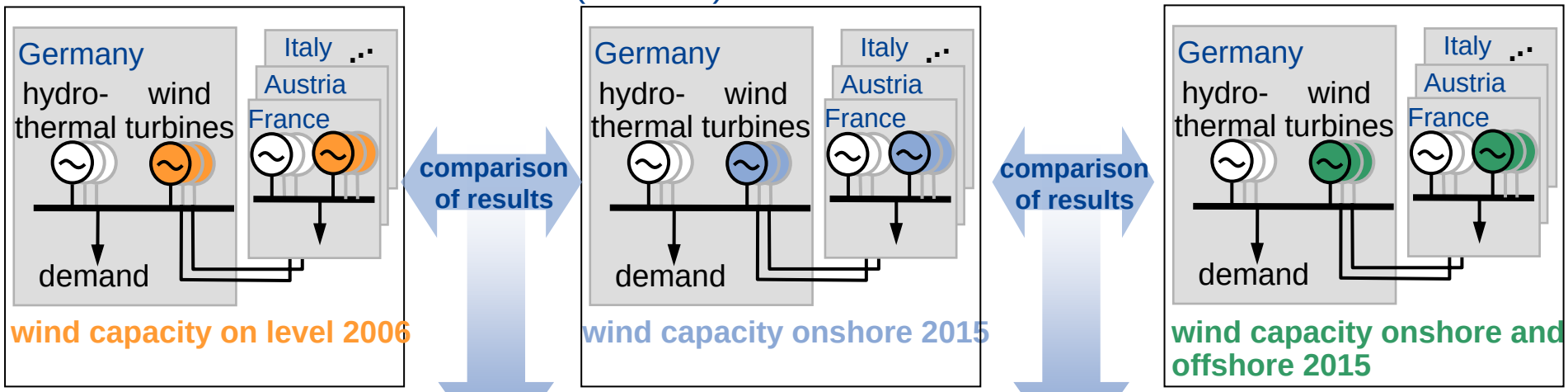
* developed at IAEW

Investigated systems for 2015

I. European system 2015 with installed wind capacity based on level 2006

II. European system 2015 with installed wind capacity based on prognoses for 2015 (onshore)

III. European system 2015 with installed wind capacity based on prognoses for 2015 (onshore and offshore)



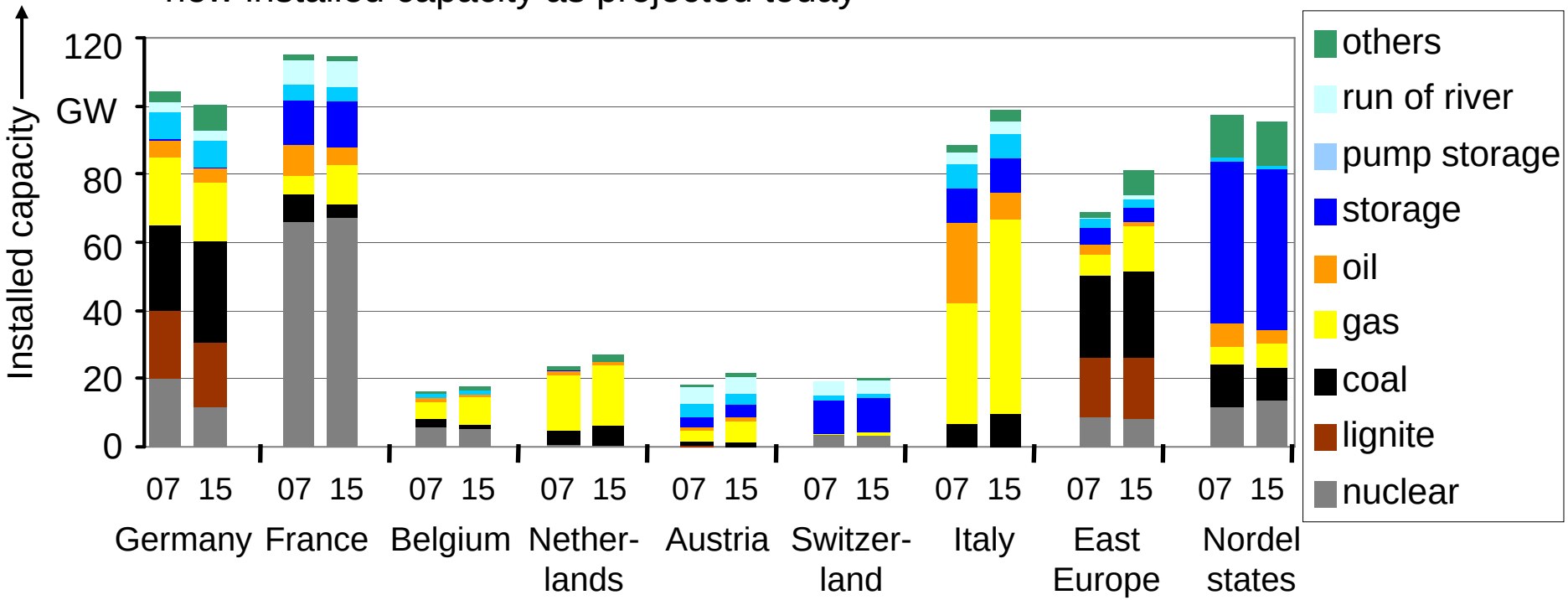
Comparison of the simulation results (I. to III.) to evaluate the benefit of additional wind capacity

System results:
- Total generation costs
- Hourly system marginal costs

Unit results: schedule
- Power plant specific generation
- CO_2 emissions

Power generation mix (hydro-thermal)

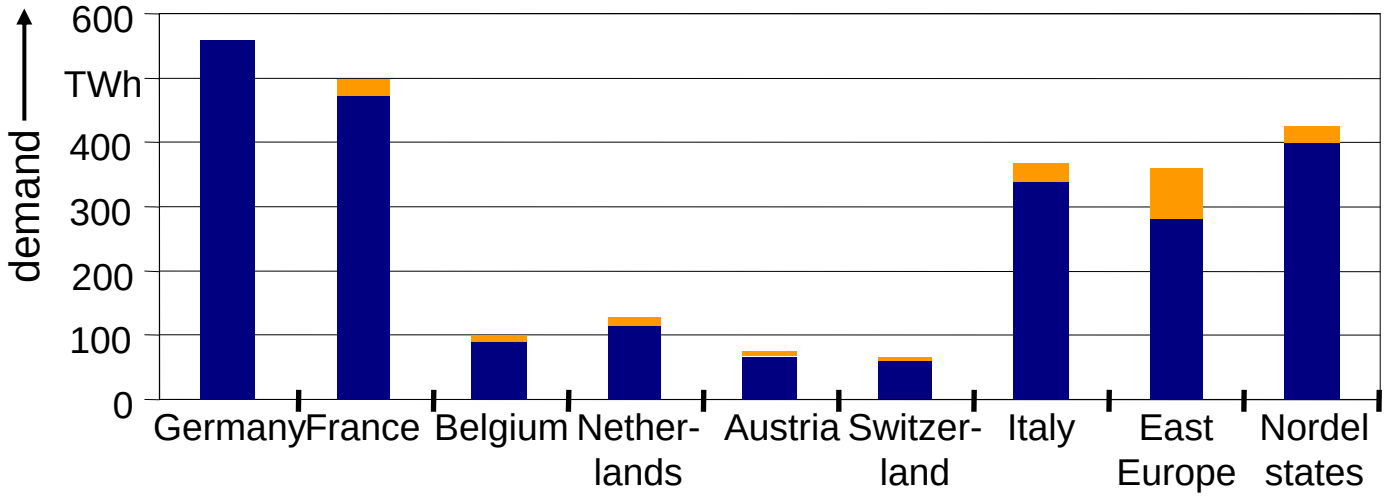
- Current (2007) and estimated (2015) power generation mix
  - blockwise modeling of thermal system
  - phasing out of nuclear generation in Germany
  - new installed capacity as projected today



sources: European Union, EUROPROG
Deutsche Energie Agentur,
Nordel, IAEW-database

Primary energy prices and power demand

- Primary energy prices (including transport)
  - Uranium 1.0 €/GJ
  - Lignite 1.6 €/GJ
  - Hard coal 2.2 €/GJ (±0.8 €/GJ)
  - Natural gas 7.1 €/GJ (±0.4 €/GJ)
  - Oil 11.0 €/GJ (±0.2 €/GJ)
- CO_2-emission price estimated to 30 €/t CO_2
- Current (2007) and estimated (2015) power demand

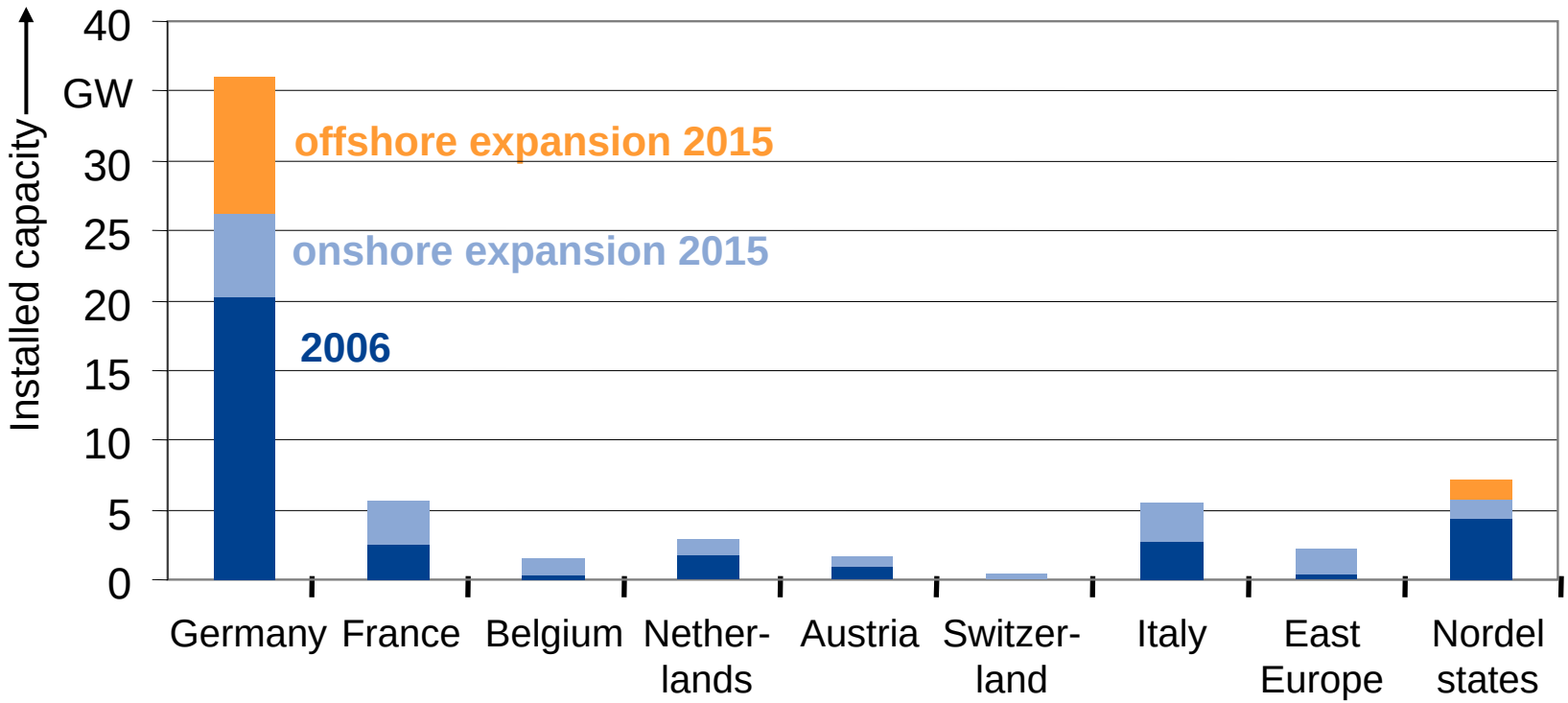


sources: European Union, Deutsche Energie Agentur, UCTE

- Additional reserve demand in 2015 estimated to ~2 GW in Central Europe (source: UCTE)

Installed capacity in wind turbines

- Current (2006) and estimated (2015) installed capacity in wind turbines



sources: European Union,
European Wind Energy Association

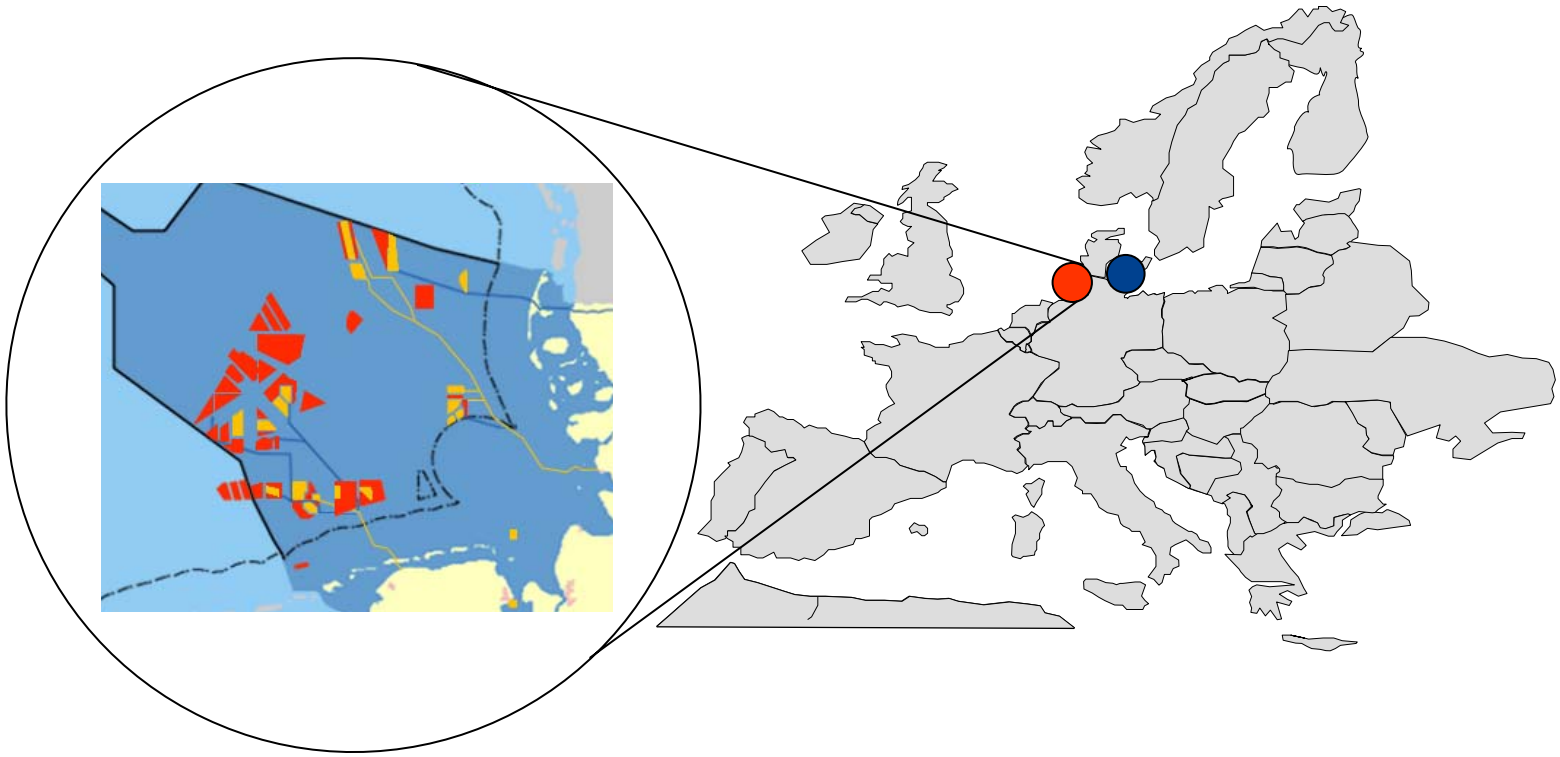
Wind power generation

- Feed-in of wind turbines separated in onshore and offshore
  - Onshore
    - Typical full load hours between 1500 and 2000 hours per year in central Europe
    - Historical time series of feed-in is partly available (1/4-hourly data e.g. for Germany and Denmark)
    - Time series for 2015 based on historical time series, scaled to installed wind power in 2015
  - Offshore
    - Typical full load hours between 3500 and 4500 hours per year (Northern Sea), but historical time series not available

    → Method for the construction of synthetic time series for 2015 needed
    - Feed-in of wind turbines mainly depends on
      - wind speed
      - power generation curve of wind turbines

Wind power generation – offshore (I)

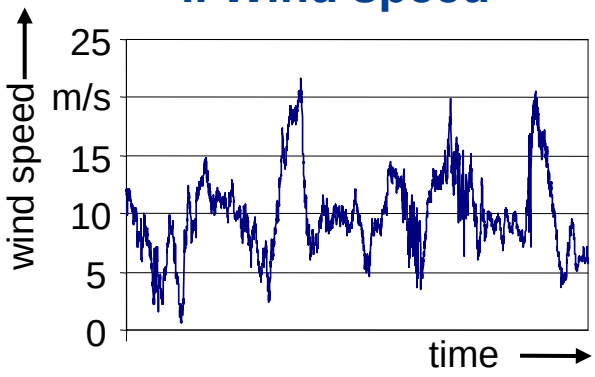
- Locations of offshore-projects
  - Current offshore-projects located in the Northern and Baltic Sea
  - Forecast of the installed capacity (offshore) in Germany in 2015
    - Northern Sea ~8.4 GW
    - Baltic Sea ~1.4 GW



Wind power generation – offshore (II)

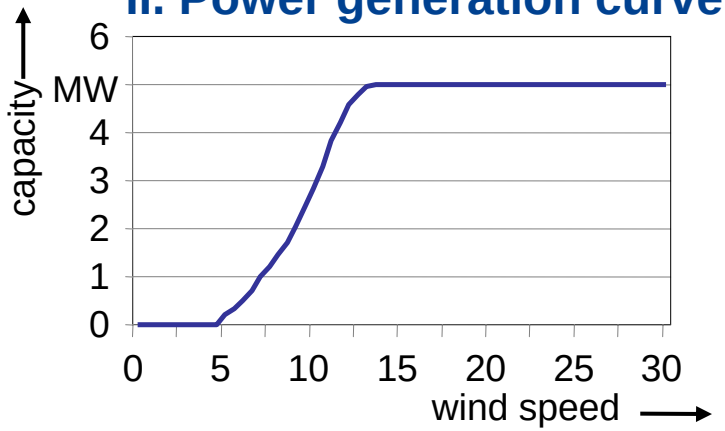
- Construction of synthetic time series based on
  - I. Hourly Wind speed (Northern Sea: offshore weather station, height 95 metres)
  - II. Power generation curve of wind turbines offshore (typical capacity 5 MW, e.g. REPOWER 5M, MULTIBIRD M5000)

I. Wind speed

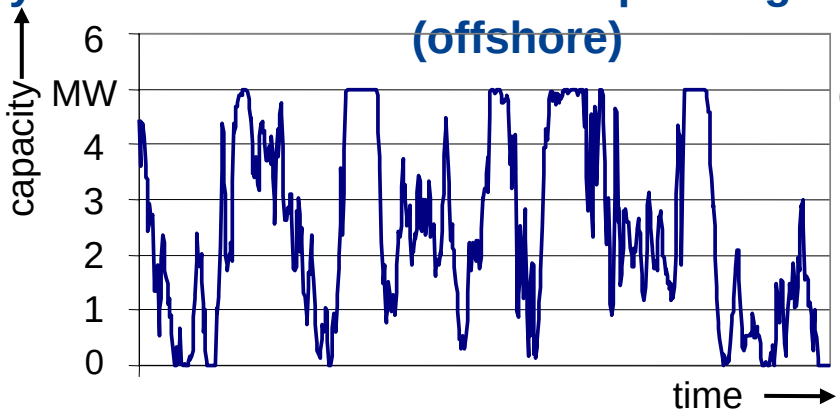


synthesis of wind speed/ generation curve

II. Power generation curve



Synthetic time series of wind power generation (offshore)



Characteristics of time series (2015):

- full load hour: ~4000 h/a
- power generation: ~40 TWh/a (9.8 GW in Germany 2015)

Results can be split in operational values and cost values

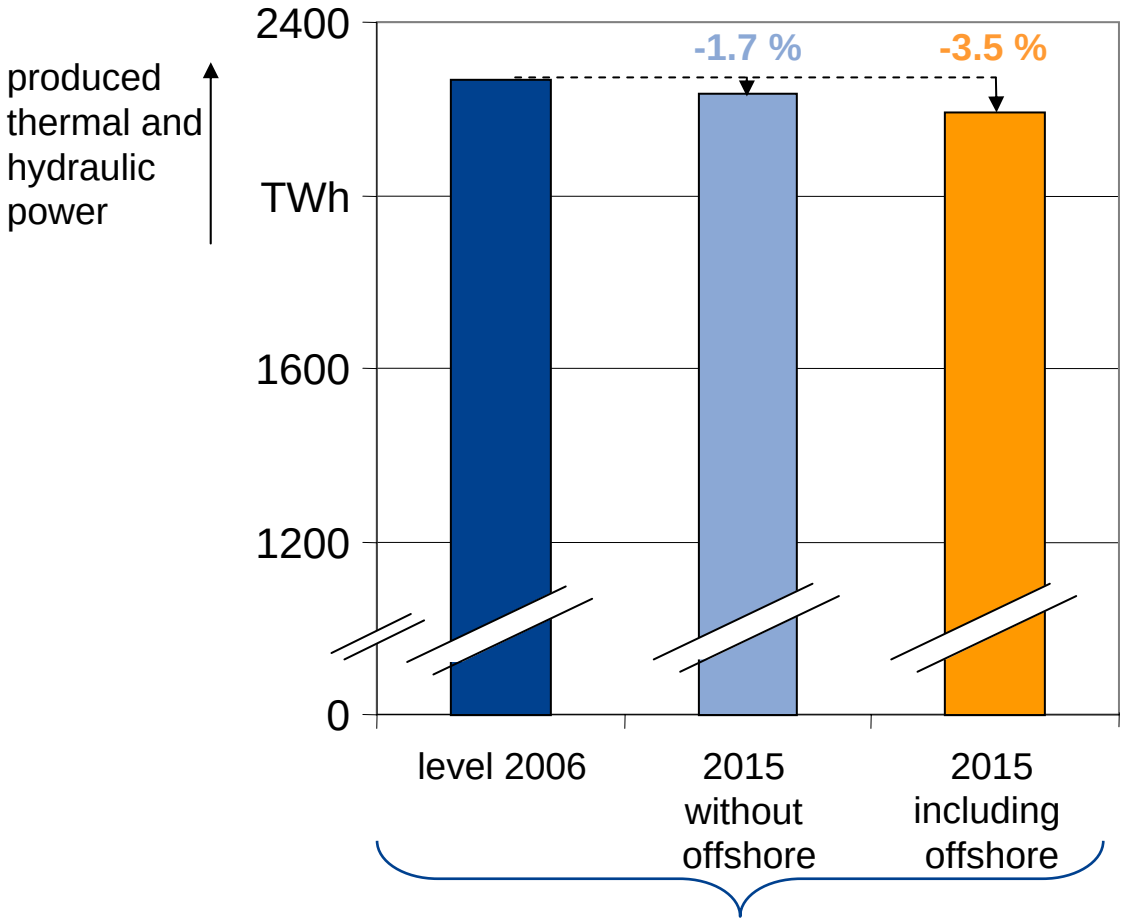
Operation

- Power plant specific generation schedule
- Generated thermal energy
- Generated hydraulic energy
- CO_2 emissions

Costs

- Total generation costs

Impact of additional capacity of wind turbines on the hydro-thermal power generation (2015)

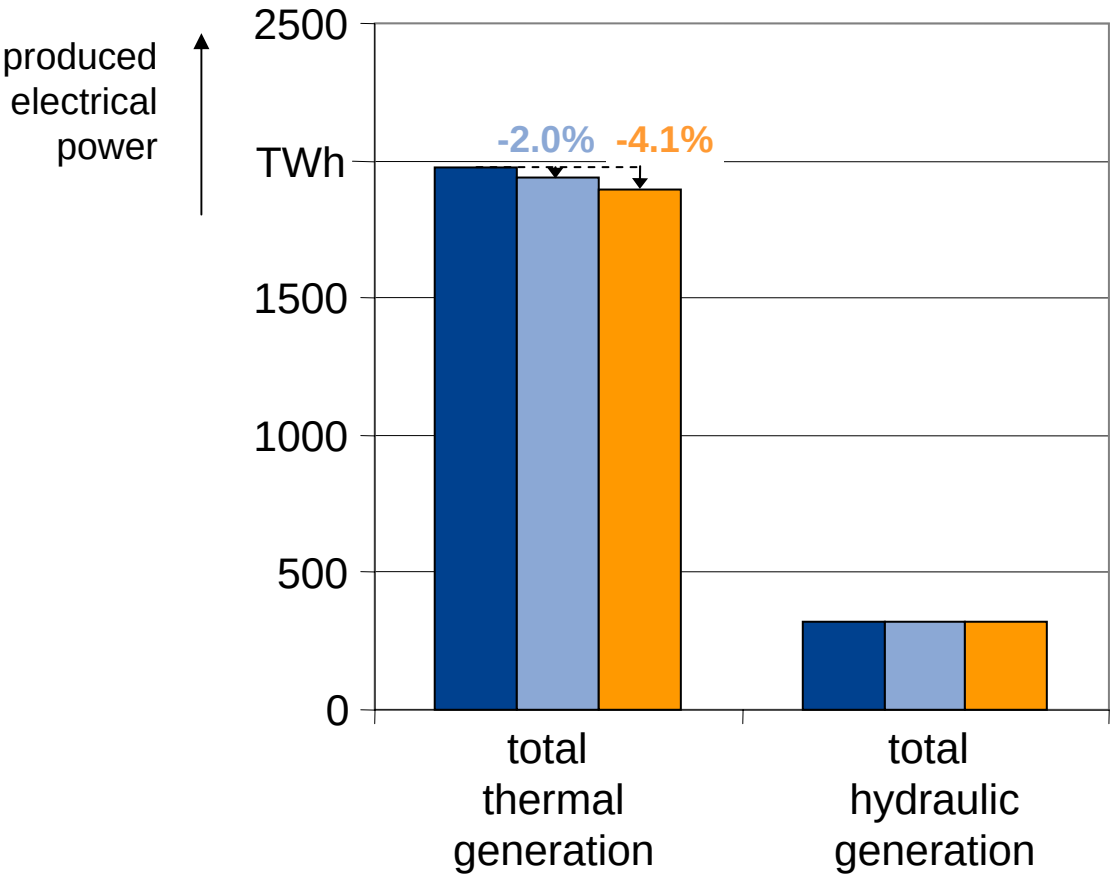


Installed capacity of wind turbines

- 31.7 GW (level 2006)
- 52.8 GW (2015 without offshore)
- 62.6 GW (2015 including offshore)

- → Reduction due to declining usage of thermal and hydro power plants
- → Additional wind power generation in 2015:
  - onshore:
    21.1 GW/1887 full load hours
    → 39.8 TWh
  - offshore:
    9.8 GW/4093 full load hours
    → 40.1 TWh

Wind power generation substitutes mainly thermal and marginally hydraulic generation

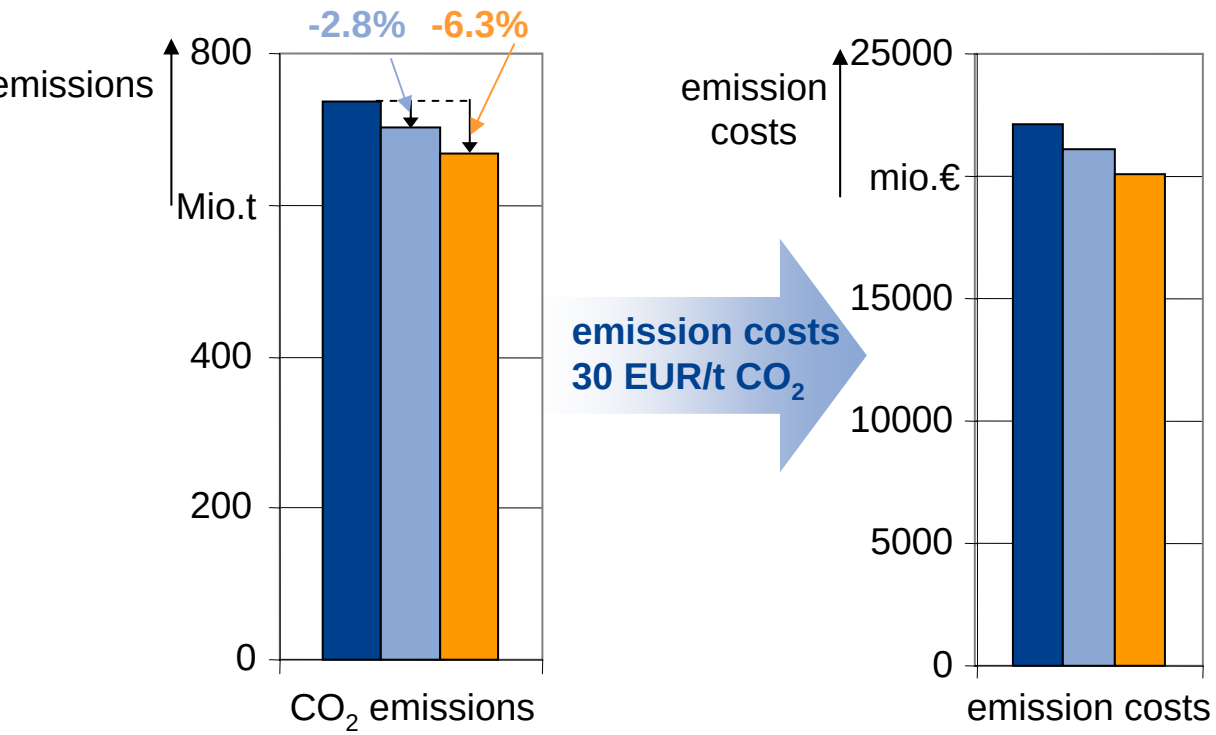


Installed capacity of wind turbines

- 31.7 GW (level 2006)
- 52.8 GW (2015 without offshore)
- 62.6 GW (2015 including offshore)

- ➔ Lower percentage of hydraulic generation
- ➔ Substitution of thermal power plants by wind power
- ➔ Impact of additional wind power on total hydraulic generation negligible

CO_2-emissions reduced in case of additional wind power generation



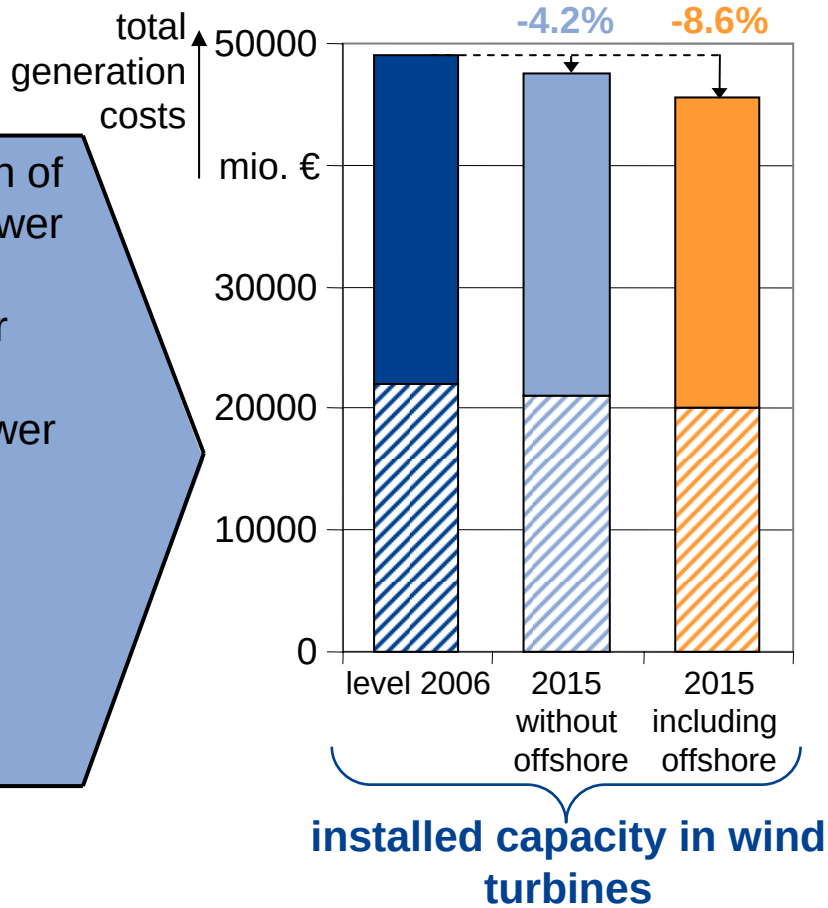
Installed capacity of wind turbines

- 31.7 GW (level 2006)
- 52.8 GW (2015 without offshore)
- 62.6 GW (2015 including offshore)

➔ Less usage of thermal power plants leads to reduction of CO_2 emissions and emission costs

Additional installed capacity in wind turbines reduces the total generation costs by up to 8.6%

- Substitution of thermal power plants by wind power generation leads to lower variable generation costs



Installed capacity of wind turbines

- 31.7 GW (level 2006)
- 52.8 GW (2015 without offshore)
- 62.6 GW (2015 including offshore)

- costs for fuels, operational costs start-up
- emission costs

➔ Reduction of up to 8.6% results in cost difference of rounded 4 billion € caused by less use of primary energies and reduced CO_2 emission costs

Macroeconomic benefits of wind power generation (onshore)

Reduced costs

- Reduction in generation costs: **2 billion €/a** for 21 GW capacity in wind turbines onshore

—

Costs for wind power generation

- Assumptions for the costs for wind power generation

  Investment costs: 1 Mio. €/MW

  depreciation time: 20 a

  interest rate: 6 %

- Total investment costs for 21 GW installed capacity: **21 billion €**
- Annuity of the total costs (β_{20} = 11.5): **1.8 billion €/a**

+

- Operation costs (1% of investment costs/a): **0.2 billion €/a**

=

Total costs: **2 billion €/a**

=

Conclusion

➔ Investment costs for installed wind capacity is compensated by reduced generation costs

➔ Macroeconomic breakeven reached for 1 Mio. €/MW investment costs (onshore)

IAEW RWTH AACHEN

Macroeconomic benefits of wind power generation (offshore)

Reduced costs

- Reduction in generation costs: **2 billion €/a** for 9.8 GW capacity in wind turbines offshore

–

Costs for wind power generation

- Assumptions for the costs for wind power generation

  Investment costs: 4 Mio. €/MW (+ 2 billion € for network access)

  depreciation time: 20 a

  interest rate: 6 %

- Total investment costs for 9.8 GW installed capacity: **41.2 billion €**
- Annuity of the total costs (β_{20} = 11.5): **3.6 billion €/a**

+

- Operation costs (1% of investment costs/a): **0.4 billion €/a**

=

Total costs: **4 billion €/a**

=

Conclusion

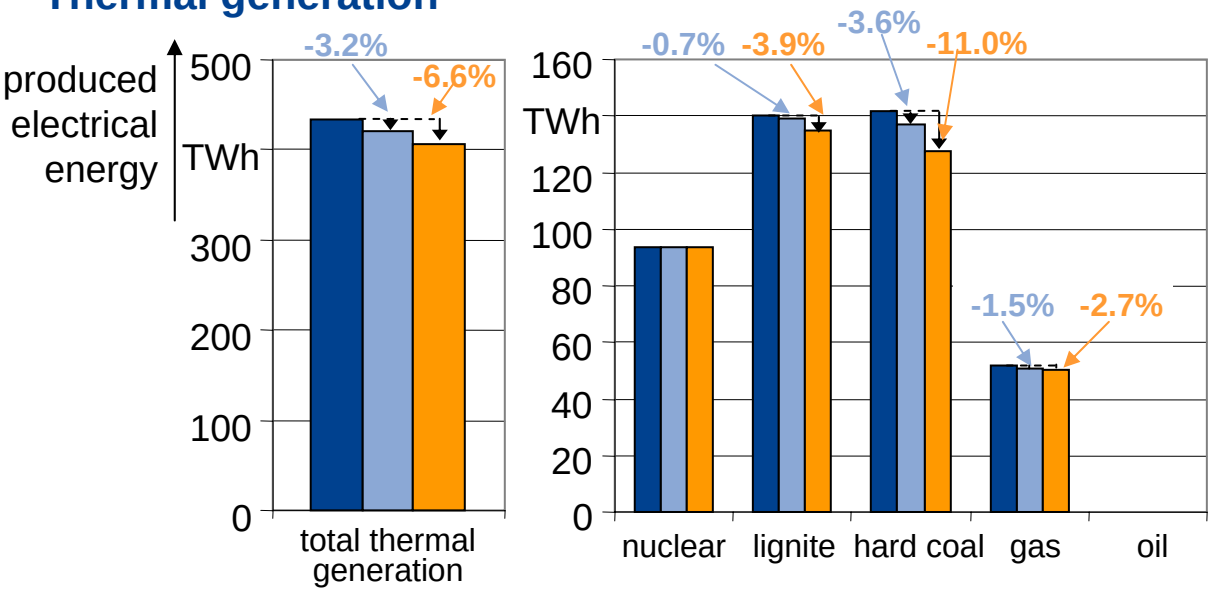
- ➔ Total benefits of **-2 billion €/a**
- ➔ Under the described assumptions wind energy (offshore) is macroeconomically not beneficial due to the currently high investment costs
- ➔ Macroeconomic breakeven reached for 2.1 Mio. €/MW investment costs (offshore)

Conclusion

- Aim of the approach
  - Economic evaluation of the impact of integrating wind turbines in the generation system
- Comparison of the central European system in 2015 by investigating the generation system with installed capacity in wind turbines based on
  I. Level 2006 in Central Europe
  II. Analogue I. with additional installed capacity in wind turbines onshore 2015
  III. Analogue II. with additional installed capacity in wind turbines offshore 2015
- Results for central Europe
  - Less usage of thermal power plants leads to reduction of CO_2 emissions under consideration of expansion of the installed wind capacity
  - System wide cost reduction potential of 2 billion €/a for onshore (21 GW), 2 billion €/a for offshore (9,8 GW)
  - Macroeconomic breakeven for wind turbines (onshore) reached for 1 Mio. €/MW investment costs, which is comparable with current investment costs
  - Macroeconomic breakeven for wind turbines (offshore) reached for 2.1 Mio. €/MW investment costs (current investment costs 3 - 5 Mio. €/MW)

High impact of additional capacity of wind turbines on the German generation system

Thermal generation

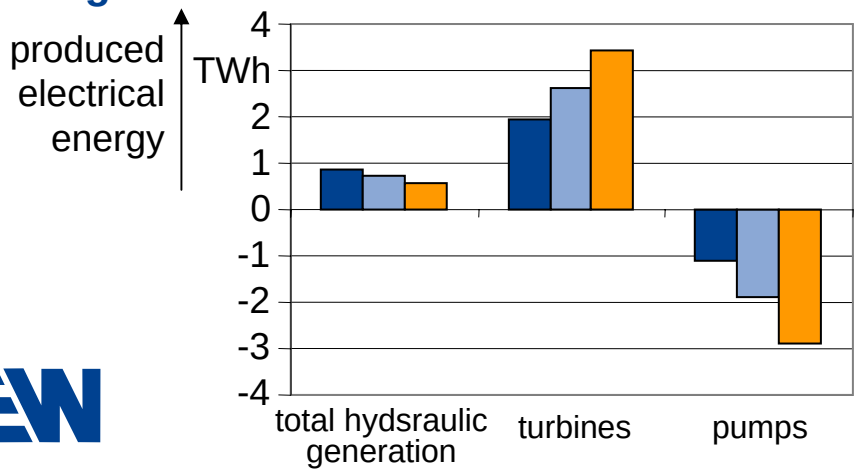


Installed capacity of wind turbines

- 31.7 GW (level 2006)
- 52.8 GW (2015 without offshore)
- 62.6 GW (2015 including offshore)

➔ Reduction esp. in hard coal generation, caused by
- higher generation costs vs. lignite
- gas generation mainly in combined heat power plants → must run units

Hydraulic generation



➔ Increasing usage of pumps to storage wind power generation

IAEW

RWTH AACHEN