THE ROLE OF CHP IN A HIGHLY RENEWABLE ELECTRICITY SYSTEM IN GERMANY

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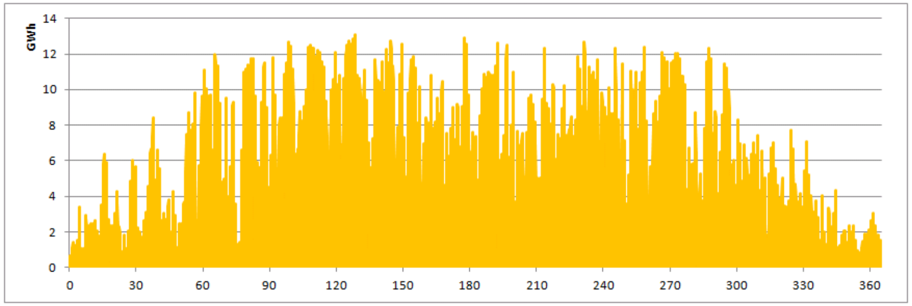

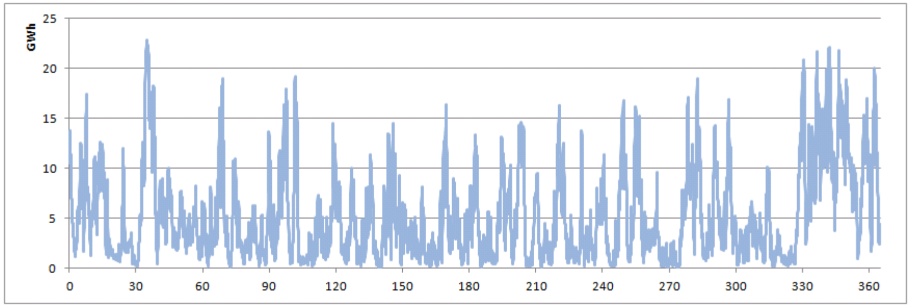

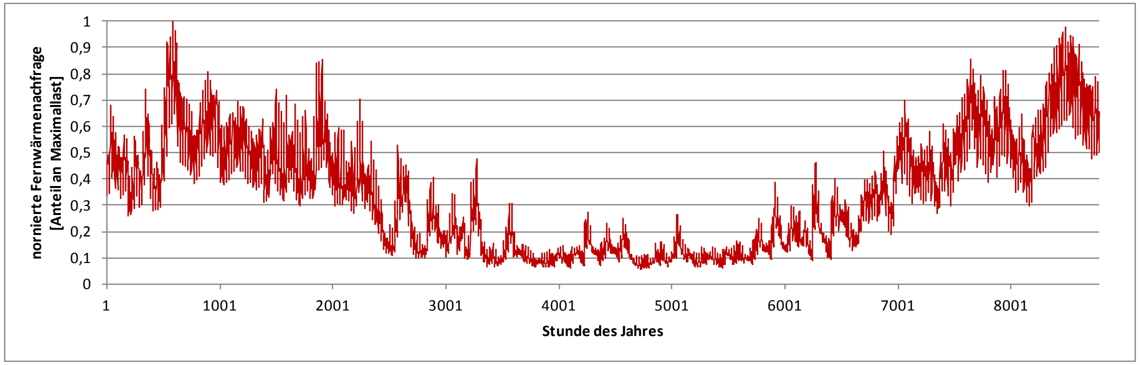

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Framework

- There are different goals on the way to convert the German energy system
  - Long term:
    - Up to 80% renewable electricity until 2050
    - 450 ppm CO_2
  - Short term:
    - 35% renewable electricity until 2020 (coalition agreement)
    - 25% combined heat and power production until 2020 (KWKG 2012)
- This leads to changes in the electricity system
  - Fluctuating RES → cause flexibility needs
  - CHP plants , that need to cover heat load → must run units → cause flexibility needs
  - Electric boilers can provide flexibility
- Questions
  - What is the role of CHP in a highly renewable electricity system in Germany?
    - What role play electric boilers?
    - How does the picture change, when the European electricity system is taken into consideration?

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Methodology
Heat grid integration

- Investment, fixed and variable operation and maintenance costs are included in the objective function

$$\min_{X,x} \sum_{a} \left(\begin{array}{l} \sum_{i} \left(d_{i,a} \left(C_{i}^{fix} X_{i} \right) + \sum_{h} C_{i,a}^{var} x_{i,a,h} \right) + \\ \sum_{hg} \sum_{ht} \left(\underbrace{d_{ht,a} \left(C_{ht}^{fix} \dot{Q}_{ht} \right)}_{\text{new capacities}} + \underbrace{\sum_{h} C_{ht,a}^{var} q_{ht,a,h}}_{\text{dispatch of heat production}} + \underbrace{\sum_{h} C_{ht,a}^{var} x_{ht,a,h}}_{\text{dispatch of electricity production}} \right) \end{array} \right)$$

- Heat demand included as a heat demand supply constraint and storage constraint

$$\left[DS_{hg} \right] \forall a, hg, h : \sum_{ht} q_{a,ht,h} + q_{a,hg,h}^{s_{In}} - q_{a,hg,h}^{s_{Out}} \geq D_{a,hg,h}^{Q}$$

- Electricity consumption of the electric boilers is included in the electricity demand supply equation of the fundamental electricity model

$$\left[DS_{el} \right] \forall a, hg, h : \sum_{i} x_{i,a,h} + \sum_{ht} x_{a,h,ht}^{chp} - x_{a,h}^{eb} \geq D_{a,h}$$

  - Electricity demand has to be delivered by the electricity system
  - Electricity supply of chp plants has to be used in the electricity system
  - Flexibility can be used by the electricity system

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Methodology
Analyzed Scenarios

- Cost optimized scenario of the electricity system for Germany
  - Existing plants are taken into consideration with their lifetime
  - Endogenous optimization of fossil and renewable generation
  - Hourly resolution for one year

- Main input parameters:

	2020	2030	2040	2050	Source
Heat demand in district heating [TWh]	110	114	104	92	Own assumption [1]
Heat demand in industry (100-500°C) [TWh]	136	126	121	123	Own assumption [1]
Fuel price gas [€/MWh]	37,78	39,64	39,77	38,70	EC 2014[2]
Fuel price hardcoal [€/MWh]	13,86	14,73	16,55	19,14	EC 2014[2]
Fuel price lignite [€/MWh]	3,80	3,80	3,80	3,80	EC 2014[2]
Fuel price nuclear [€/MWh]	3,10	3,10	3,10	3,10	EC 2014[2]
Fuel price oil [€/MWh]	54,38	57,20	63,00	67,62	EC 2014[2]
CO_2 price [€/t]	10	35	65	100	Own assumption

- Sensitivities on flexibility in district heating grids

[1] based on Data derived by the FORECAST model
[2] EC, 2014, Trends to 2050 Reference Scenario 2013

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Results

1. Hourly operation for one winter week with high wind speeds
2. Yearly installed capacity and generation
3. RES-, chp- and power-to-heat shares
4. CO_2-emissions and considered system costs
5. How the picture changes, when Europe is taken into consideration

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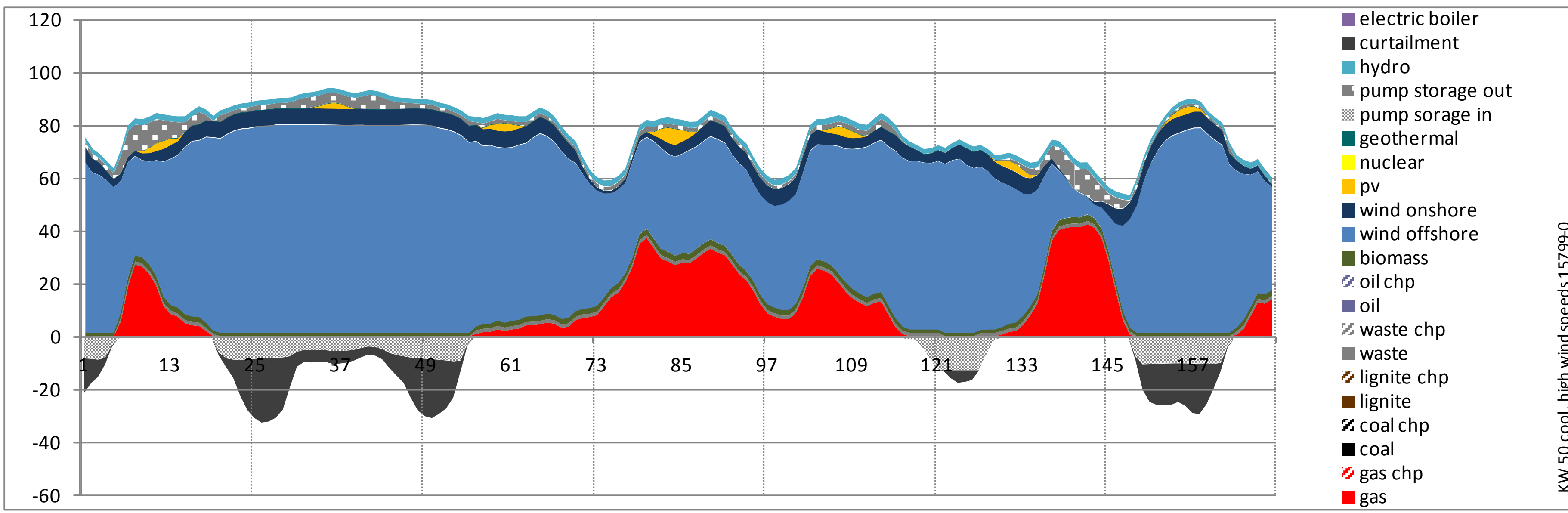
Hourly operation without heat grids 2050 isolated

- Reference Scenario without linkage to the heating system
  - Electricity production is mainly based on wind and gas
  - Significant times of surplus electricity production and curtailment



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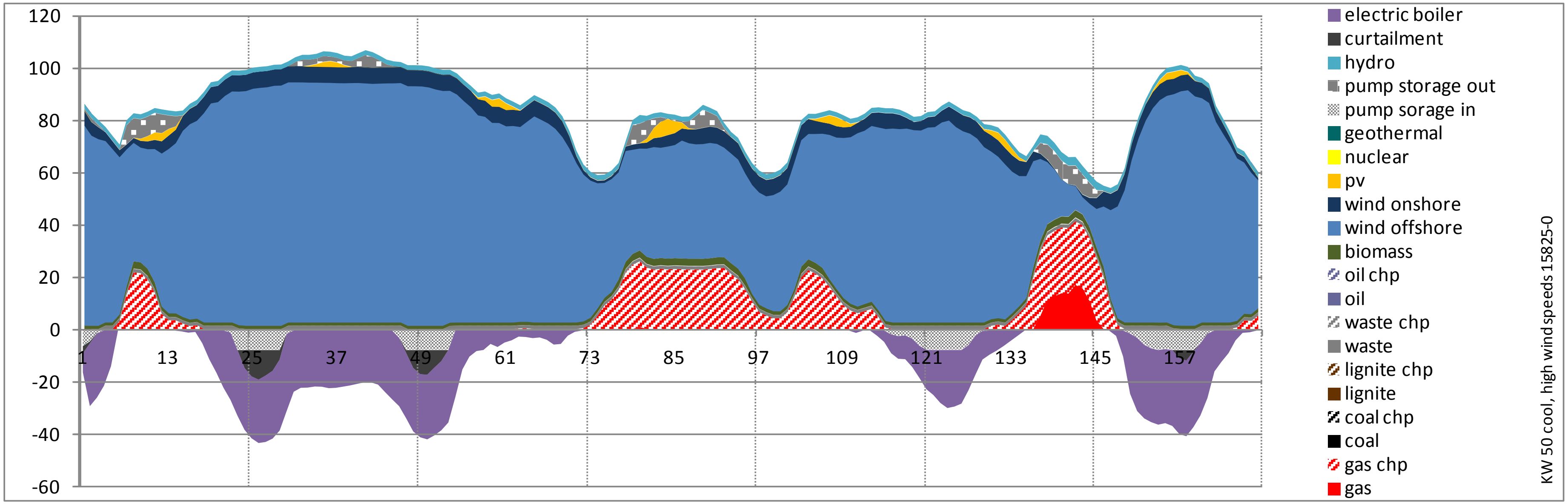
Hourly operation with heat grids

- Scenario with consideration of heat grids
  - Gas is replaced by gas chp
  - Installed wind capacity increases
  - Surplus electricity production is used in electric boilers



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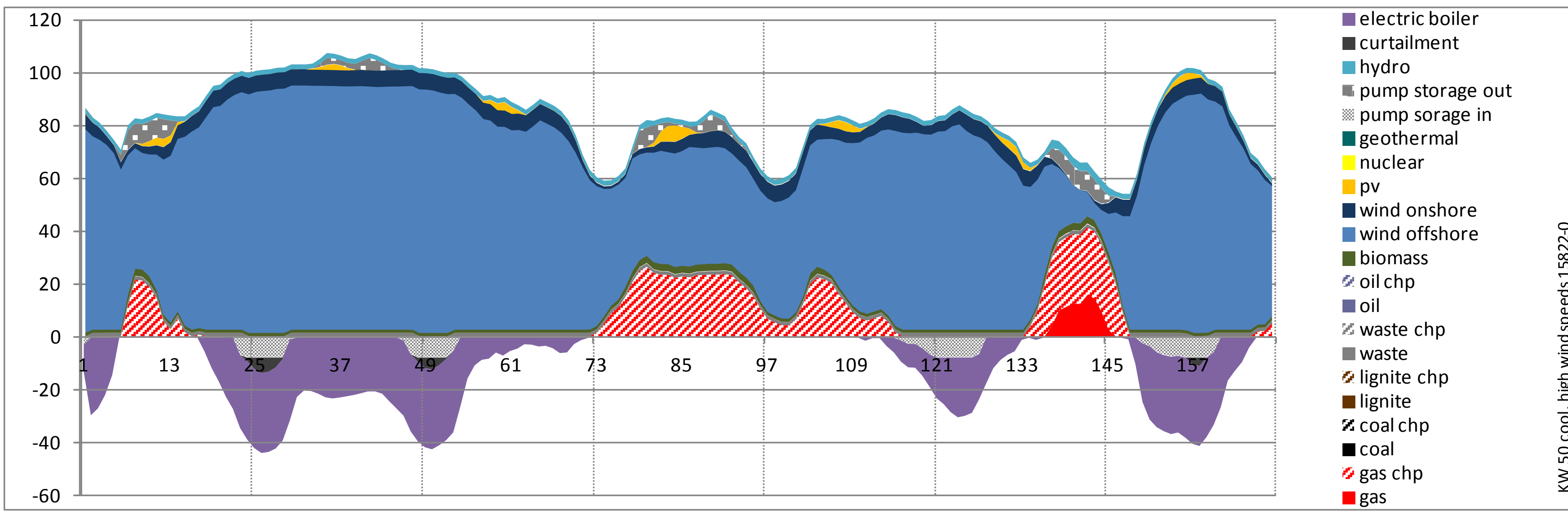
Hourly operation with flexible heat grids

- Scenario with consideration of heat grids including heat storages in district heat grids
  - Installed wind capacity is further increased
  - Curtailment decreases, while heat production in electric boilers increases



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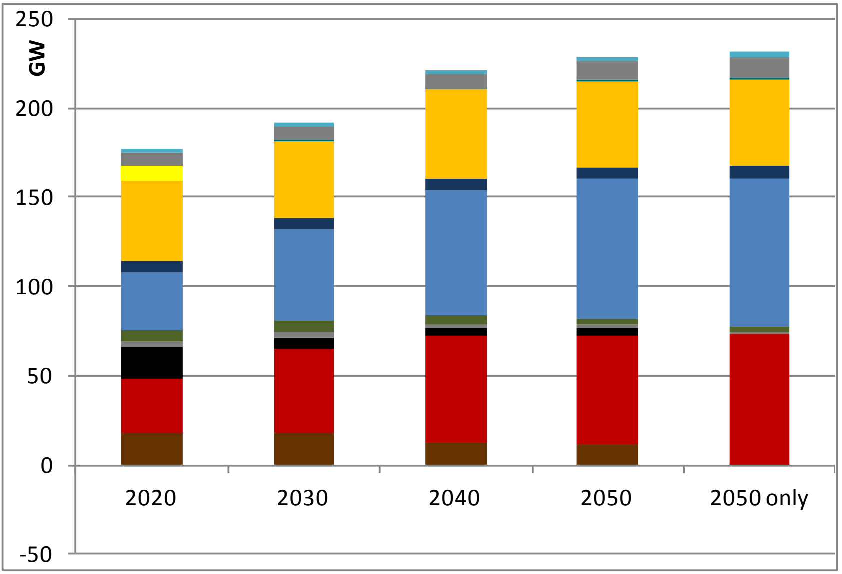
Results
Reference Scenario without heat grids

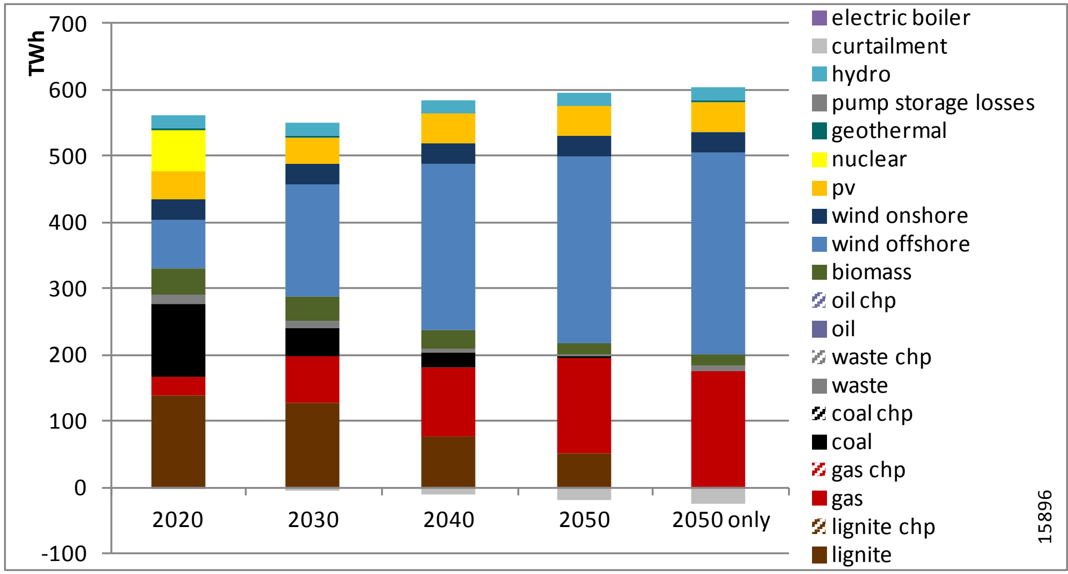
Installed Capacity

- phase out of lignite and coal power plants
- no lignite and coal in isolated optimization of 2050, but in the trajectory

Generation

- increasing shares of wind energy
- curtailment as of 2040





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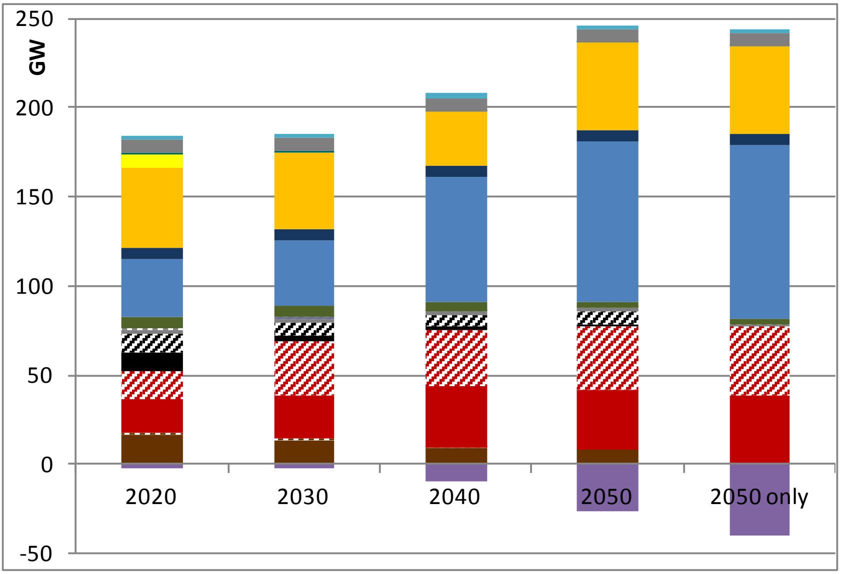
Results
Scenario with flexible heat grids

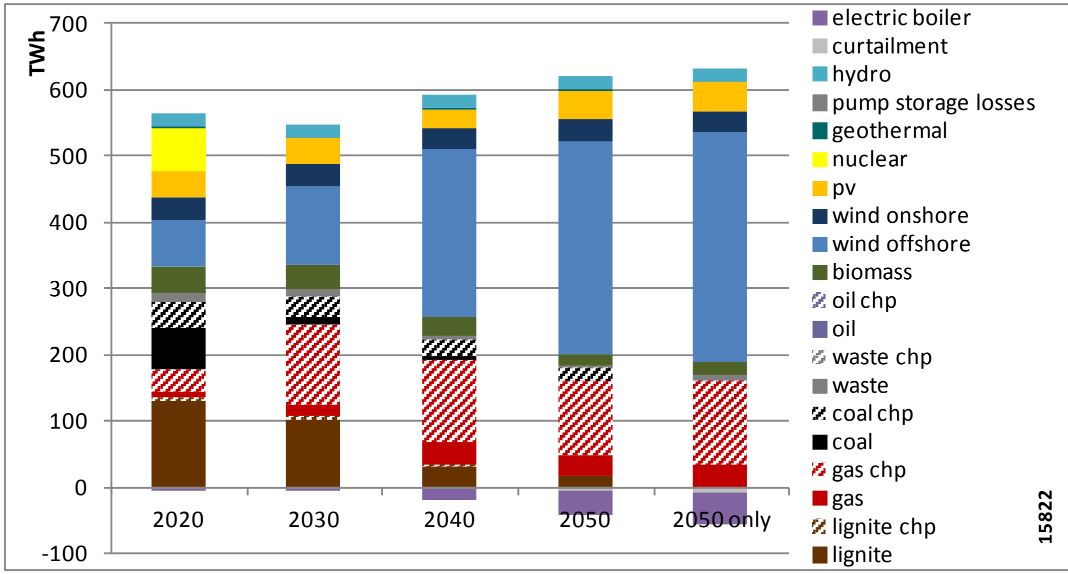
Installed Capacity

- chp instead of condensing plants
- less wind energy in 2030
- more wind energy in 2050

Generation

- less lignite
- electric boiler as curtailment as of 2040





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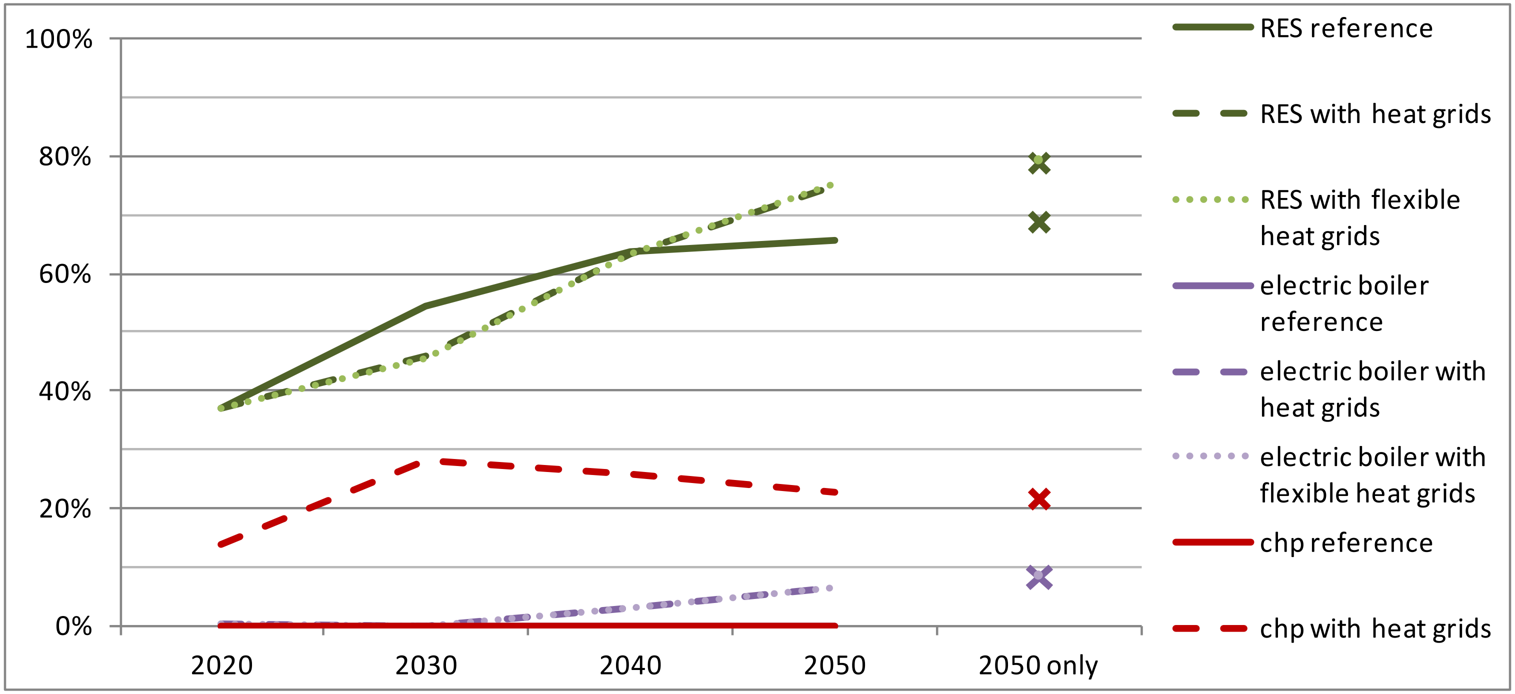
Differences
in RES-, chp- and power-to-heat shares

- Chp shares increase with increasing CO_2-prices and phase out of existing power plants
- Chp slows down RES capacity increase in 2030
- In the long run, chp is partly replaced by electric boilers



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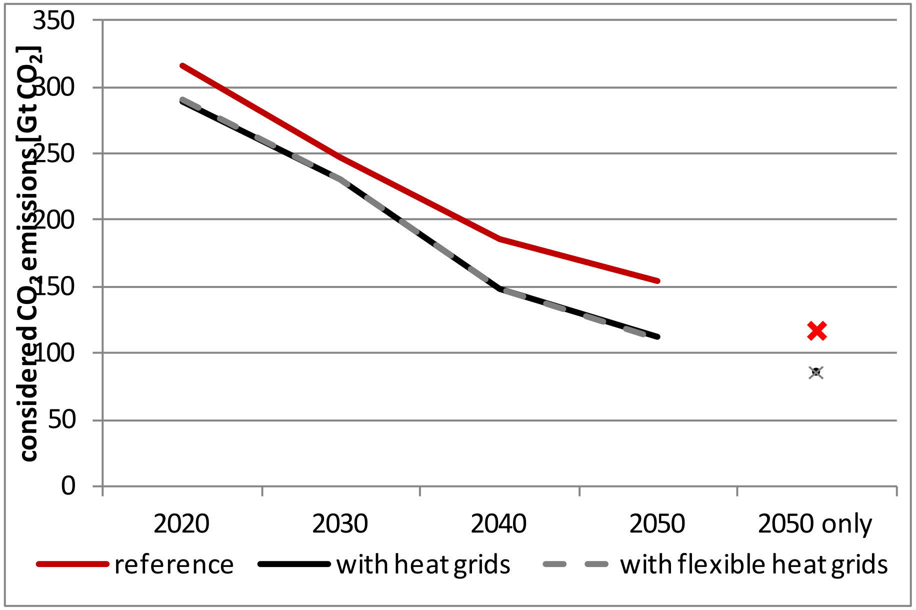
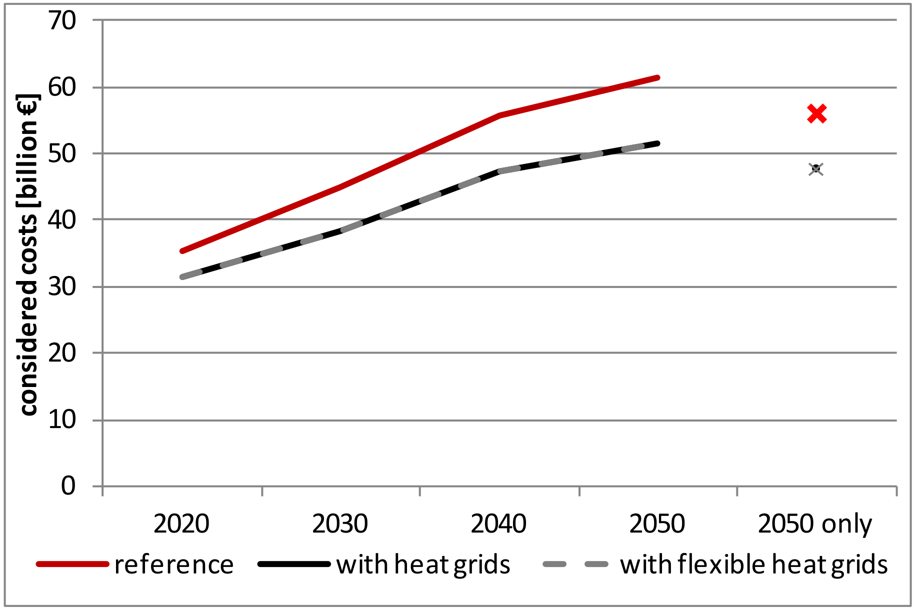
Differences in CO_2 emissions and considered system costs

- CO_2- emissions of the electricity and considered heating sector are 7%-27% lower with chp and electric boilers compared to uncoupled heat and electricity generation
- Costs are reduced by 11% to 16%
- Additional flexibility does not significantly reduce emissions or costs





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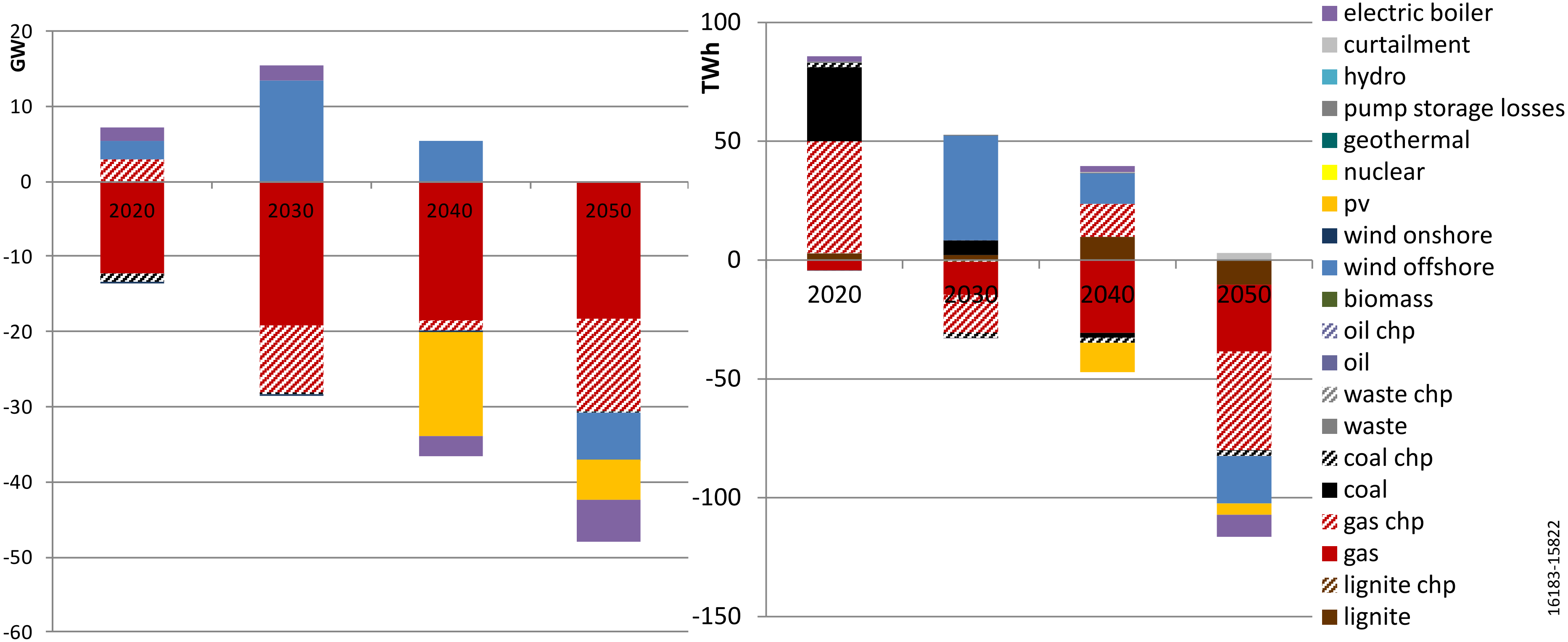
Results
Changes in an European Context

- Decrease in gas capacities
- Change from an exporting to an importing country



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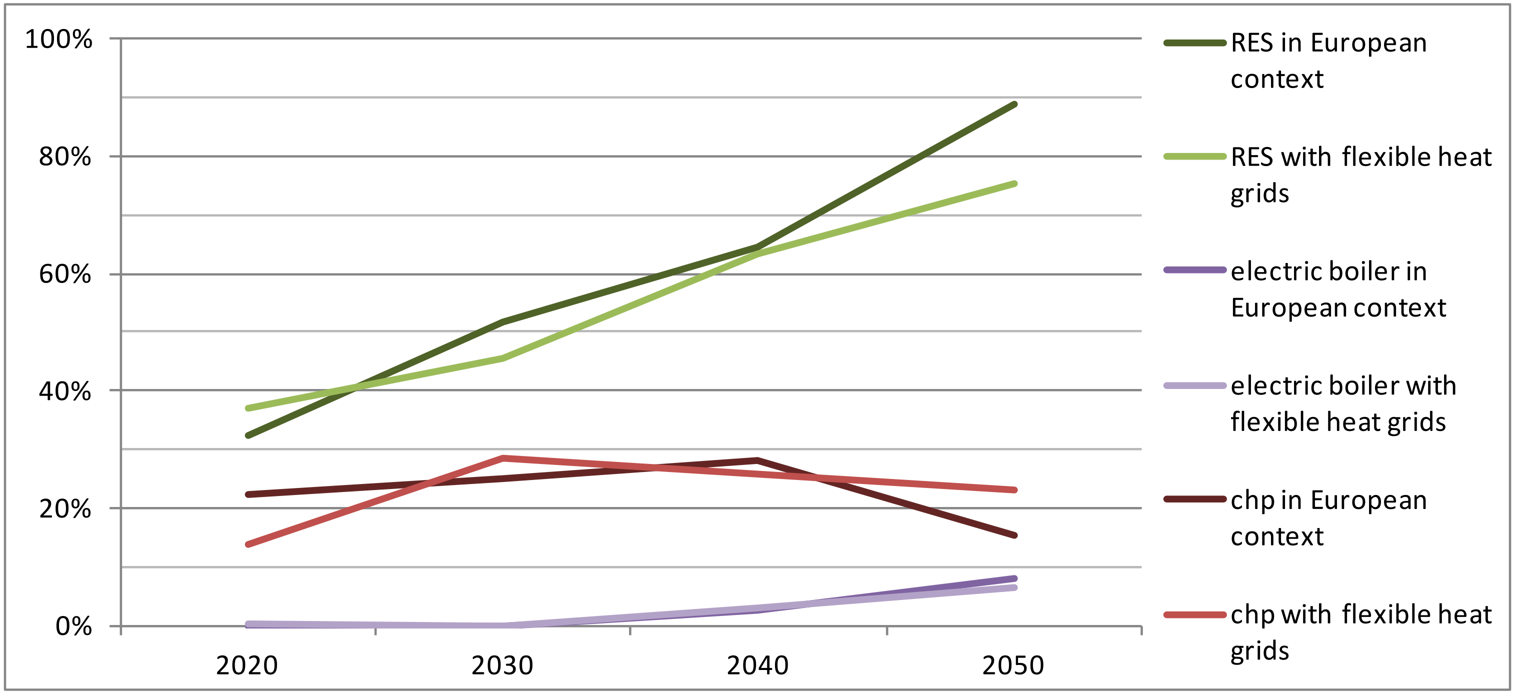
Differences in RES-, CHP- and power-to-heat shares

- Im- and export at the European market lead to higher RES and power-to-heat shares in 2050 due to less electricity production in Germany
- Chp shares are lower in 2050 as they compete with renewable electricity imports



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Conclusions

- What is the role of CHP in a highly renewable electricity system in Germany?
  - Condensing power plants, chp plants and RES compete at the electricity market
  - Rising CO_2-prices increase competitiveness of chp plants and RES
  - Moderate CO_2-Prices lead to high chp shares with lowered RES-shares
  - High CO_2-prices lead to high RES-shares with lower chp-shares and significant electricity consumption in electric boilers
- RES-Integration and flexibility
  - Electric boilers as well as chp can contribute to integrate fluctuating RES generation if they are integrated in a bivalent heat grid
- CO_2 emission and costs savings
  - A strong link between heat and electricity market can reduce CO_2 emissions while reducing considered system costs

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Remarks? Questions?

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