Comprehensive Modelling and Analysis of a Future German Energy System with a Dominant Supply from Renewable Energies

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Outline

- Targets of the German climate protection policy
- Analysis of a possible German energy system in 2050
  - Methodology
  - Results
    - Sensitivity analysis
    - Analysis of a selected system
    - Needed investments
- Conclusions & outlook

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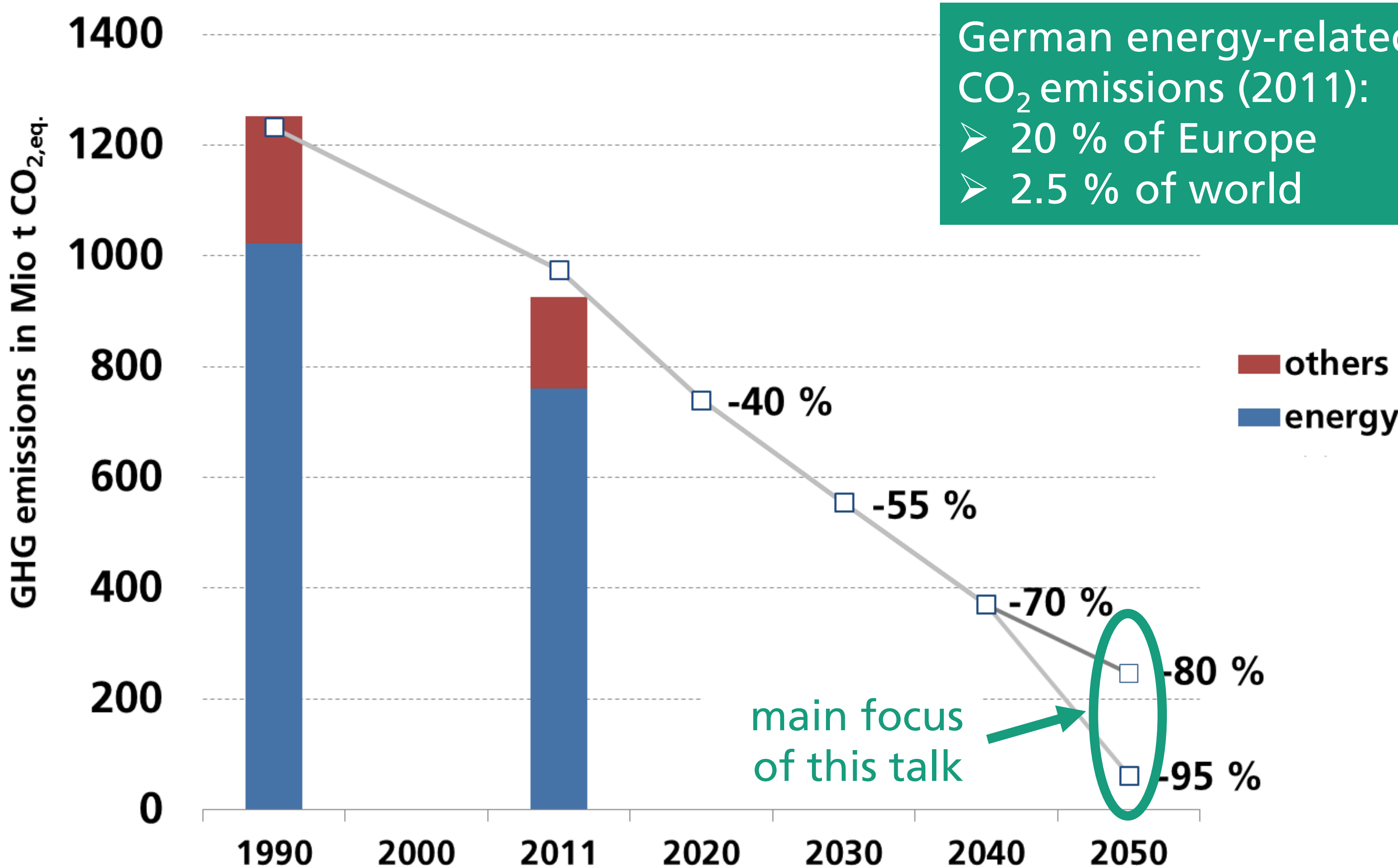
German greenhouse gas emissions – history and targets



German energy-related CO_2 emissions (2011):

- 20 % of Europe
- 2.5 % of world

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Motivation
Inter-sectorial overall energy system analysis

Guiding questions

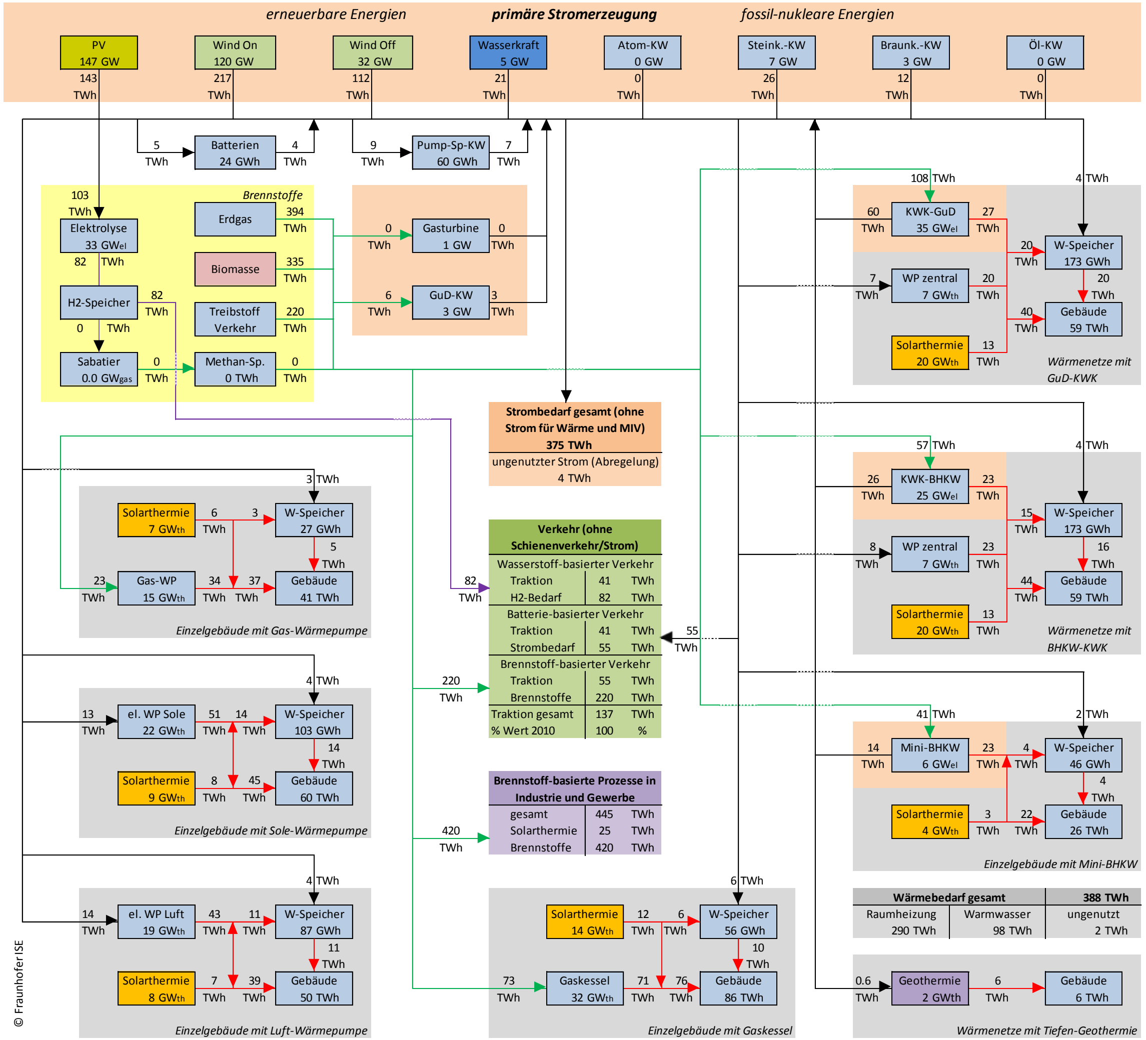
- Is it possible to achieve Germany's CO_2 emission reduction targets by using large shares of renewable energies?
- If yes: what is the „best“ composition of such energy system?
- And what is its cost?

➔ Long term perspective on macro-economic level

Approach

- Model of overall energy system based on hourly energy balance
- Generic optimizer ➔ optimum composition and sizing of all components
- Goal function: minimum of total annual cost (re-investment, maintenance, operation, financing)

Optimization of the German future energy system based on hourly modeling



REMod-D

Renewable Energy Model – Deutschland

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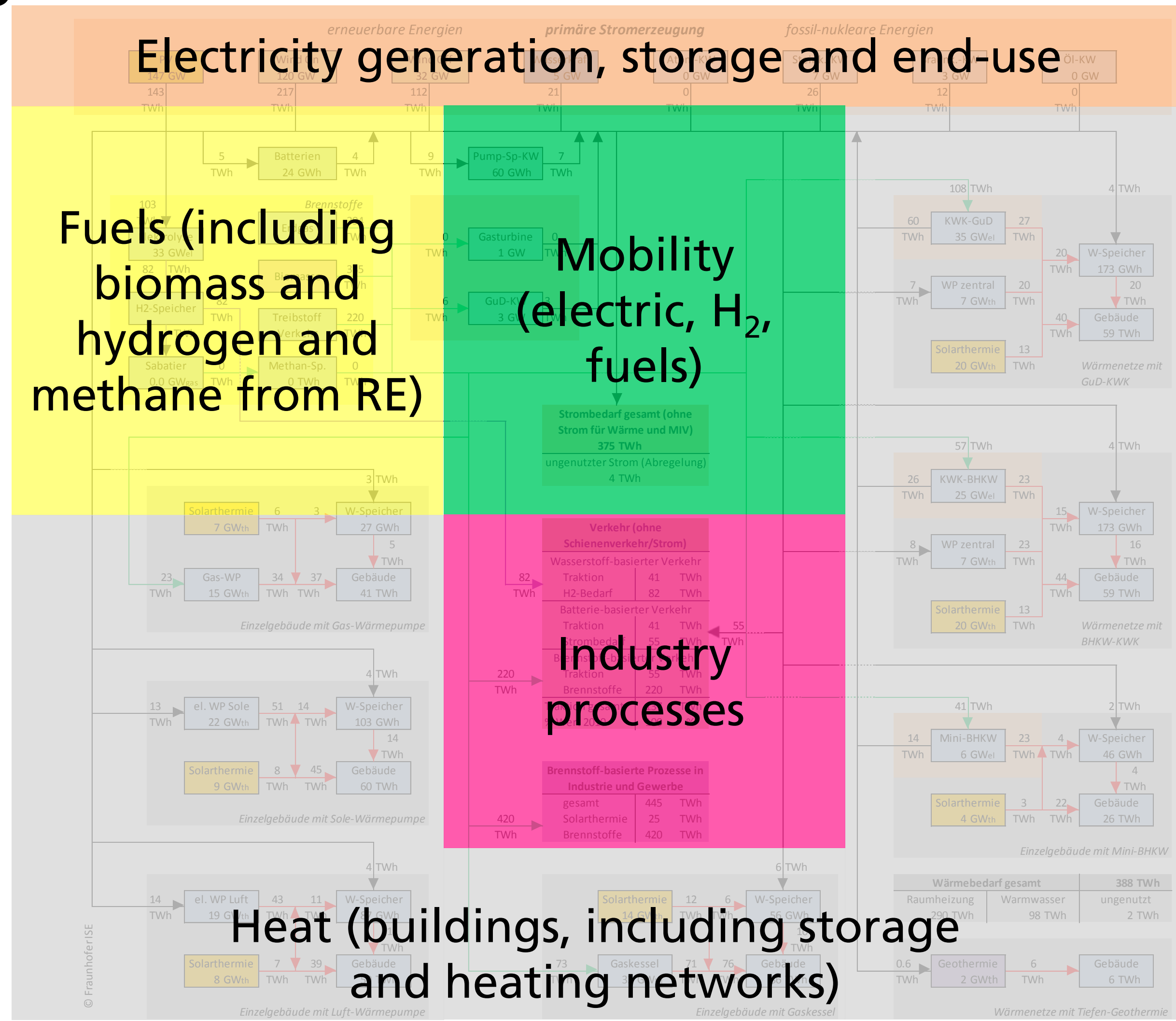
Optimization of the German future energy system based on hourly modeling



REMod-D

Renewable Energy Model – Deutschland

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Optimization approach

Assumptions

CO_2 emissions → available amount of fossil energy sources

Basic electricity demand

Process energy in industry

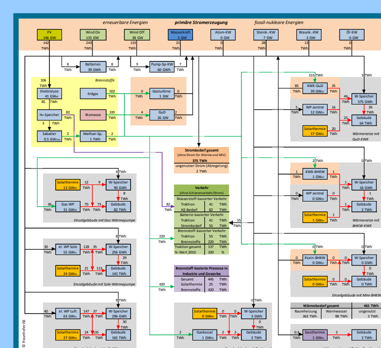
Total energy demand for mobility; composition of technologies for vehicles

Available biomass

Installed capacity of conventional power plants

Optimizer

minimize total annual cost



Results

Installed capacity of energy converters

Size of storages

Range of building energy retrofit

Heating technology mix (including district heating networks)

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Sensitivity analysis

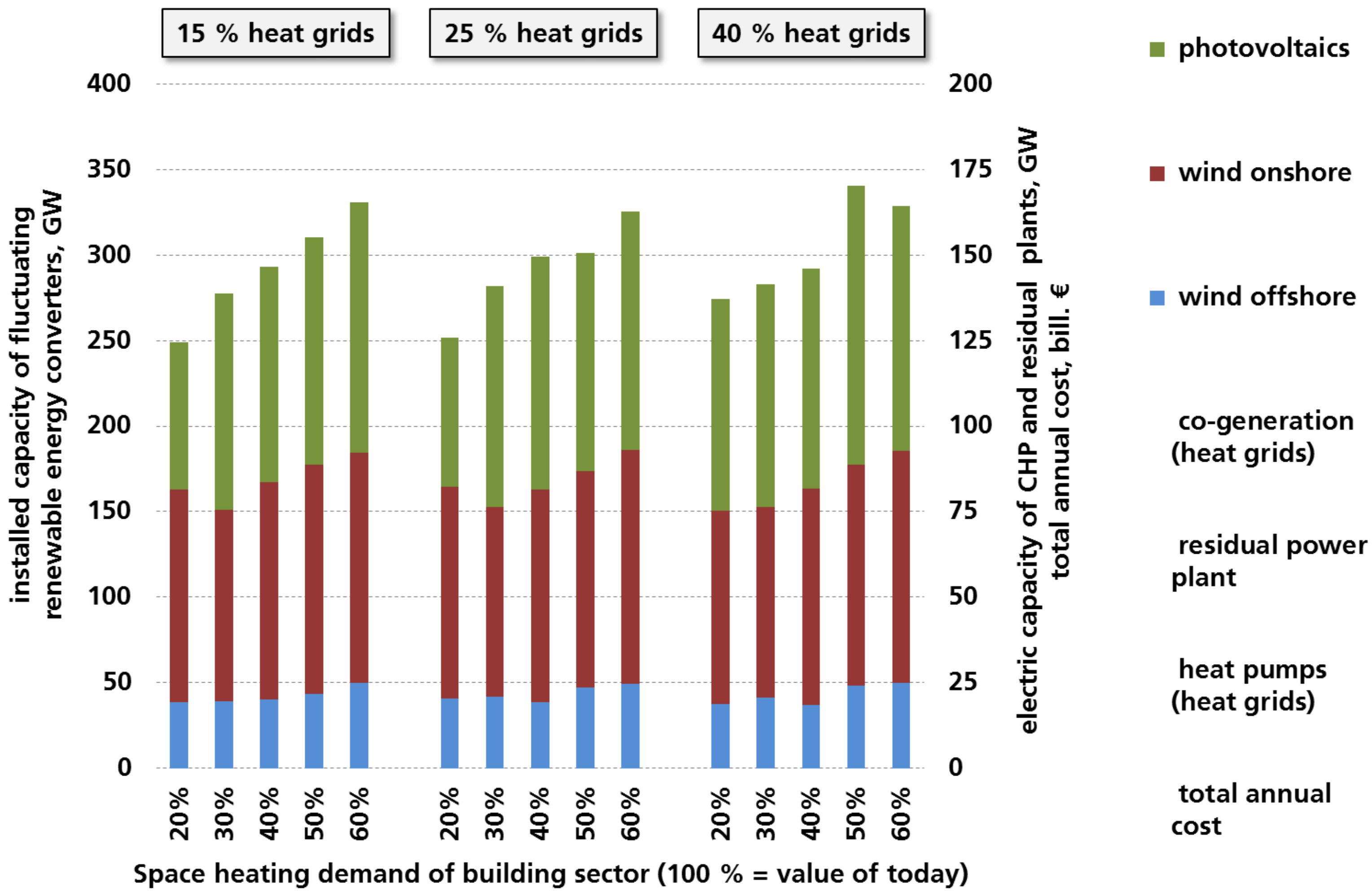
Variation of

- Space heating demand of building sector (building energy retrofit)
- Fraction of heat demand in building sector covered by district heating systems

Studying the impact of these parameters on

- Installed capacity of fluctuating renewable energies (PV, wind onshore, wind offshore)
- Overall cost
- Capacity of CHP plants, centralized heat pumps and residual power plants
- Composition of heating technologies in single buildings

Fluctuating renewable energy sources
Installed capacity in GW



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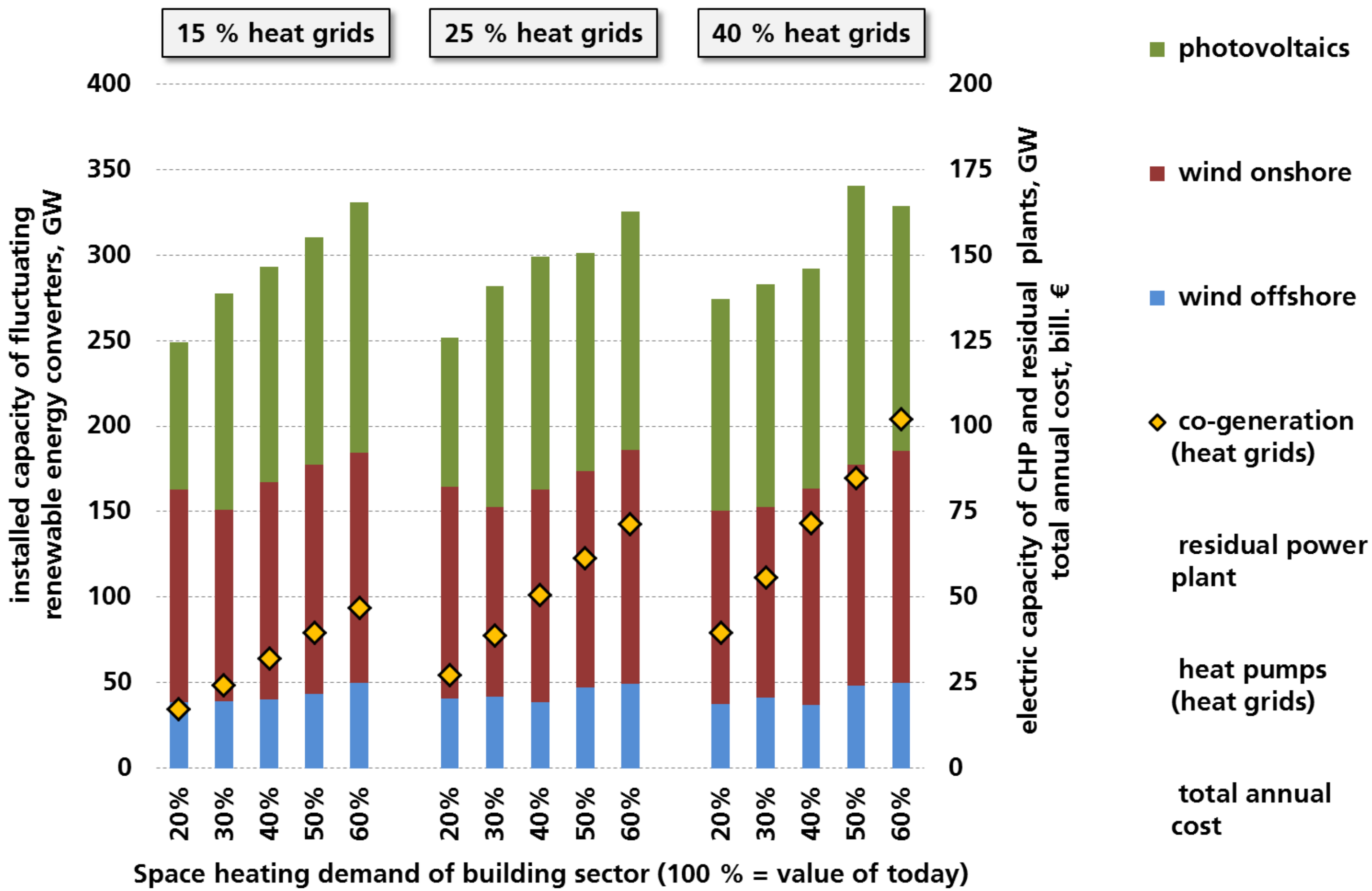
Medium and large scale CHP systems (district heating)

Installed capacity in GW_{el}



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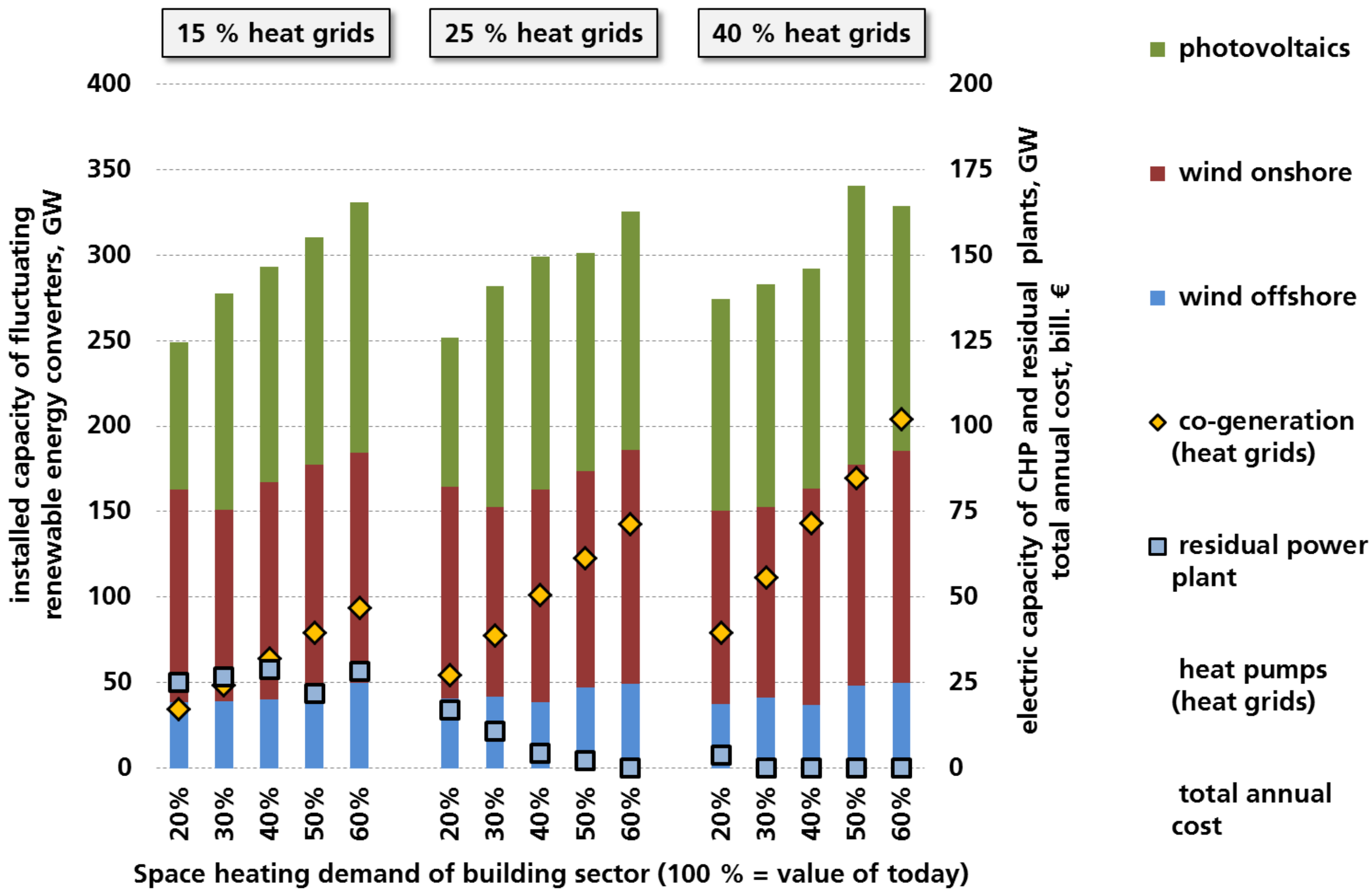
Backup power plants

Installed capacity in GW_{el}



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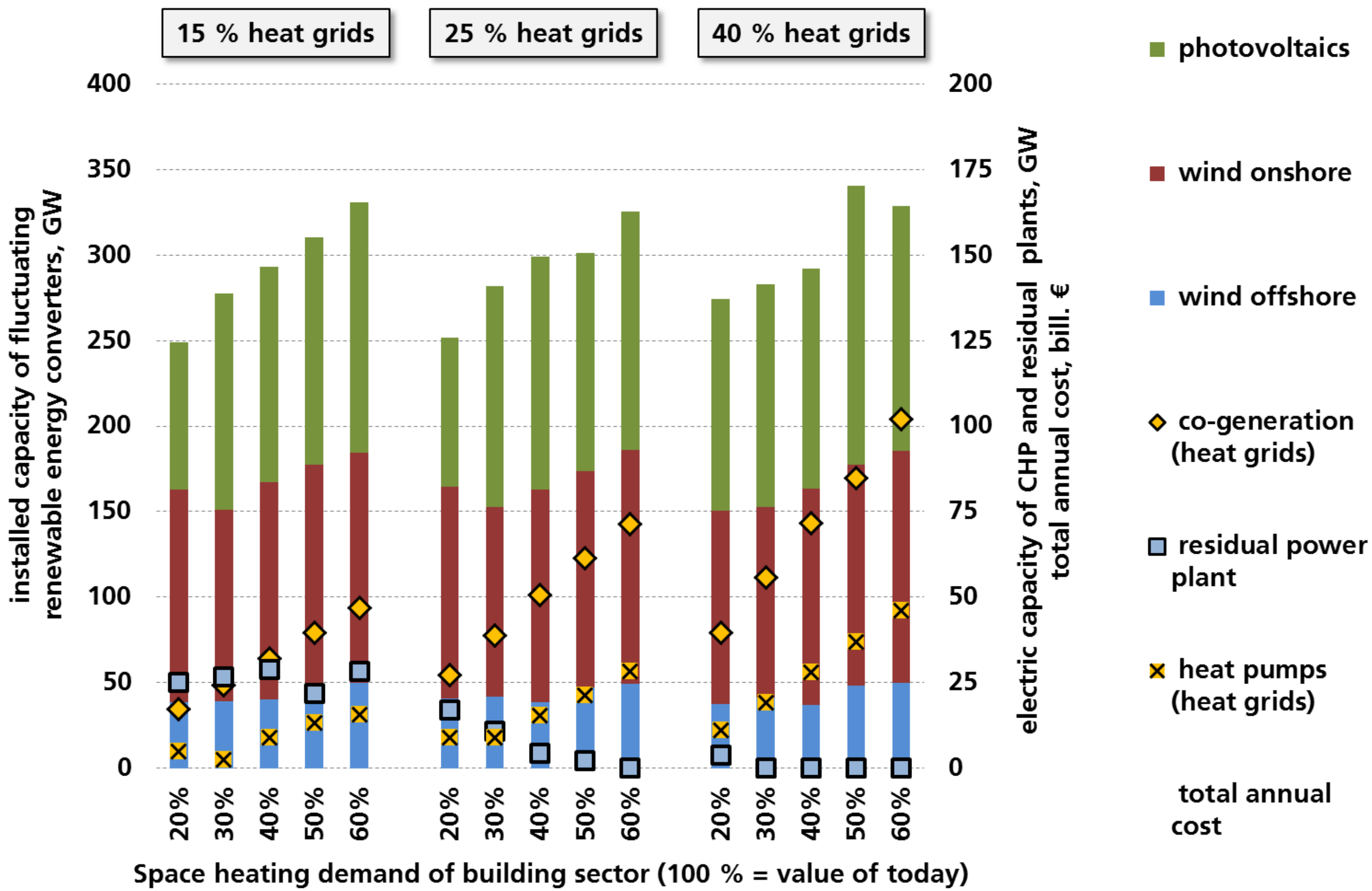
Centralized heat pumps (district heating)

Installed capacity in GW_{th}



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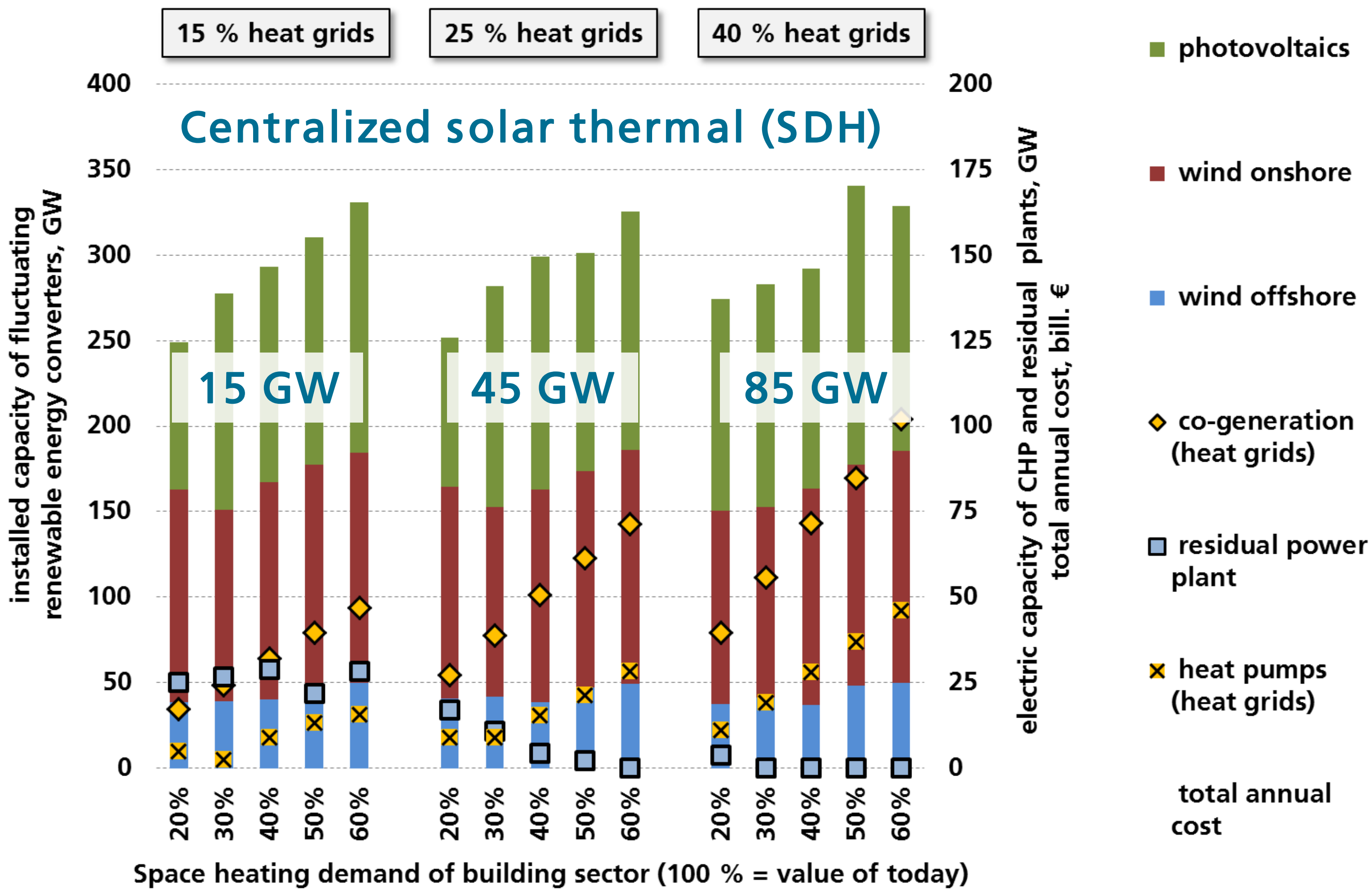
Centralized solar thermal (SDH)

Installed capacity in GW_{th}



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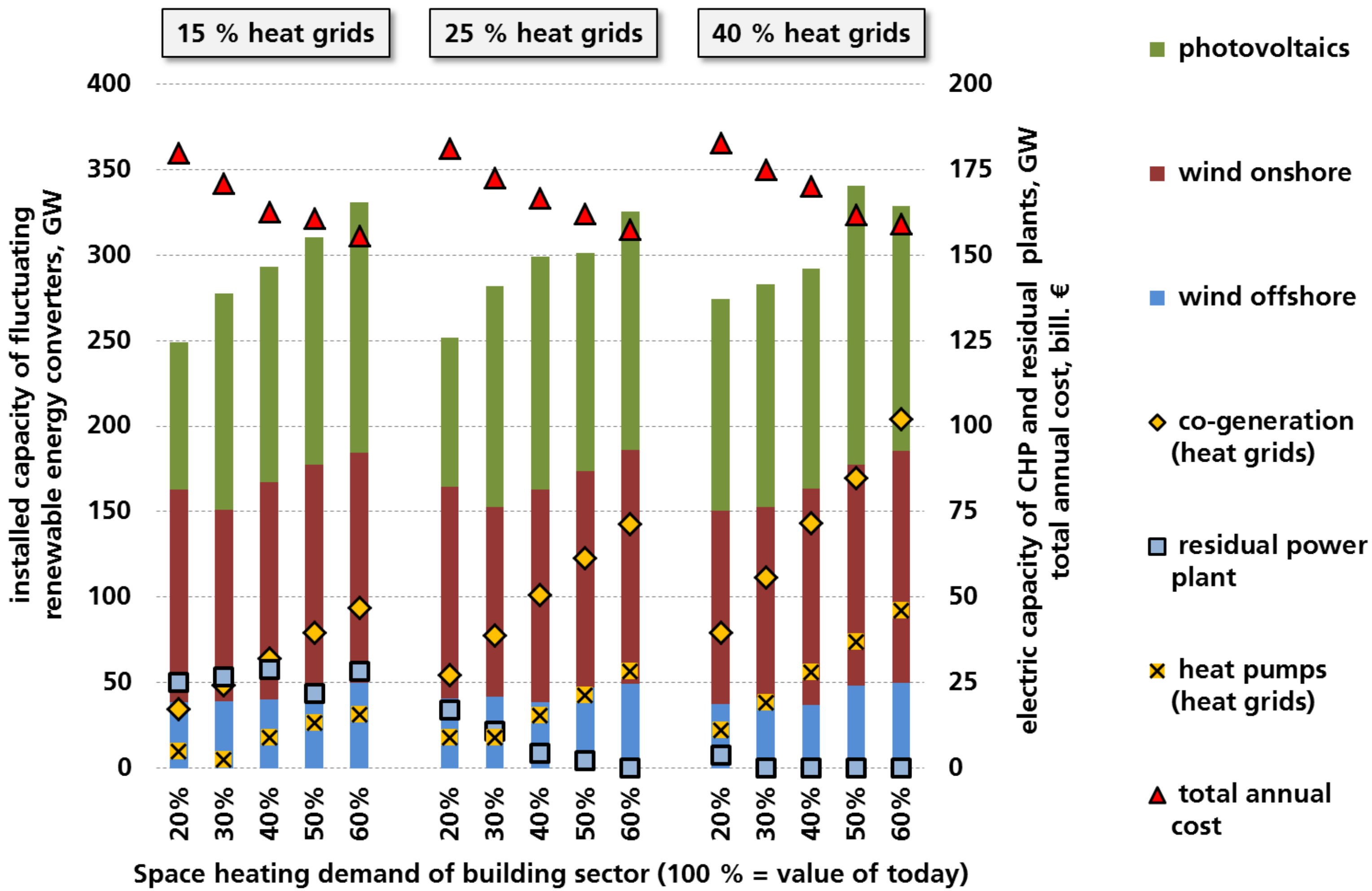
Total annual cost
Bill. €



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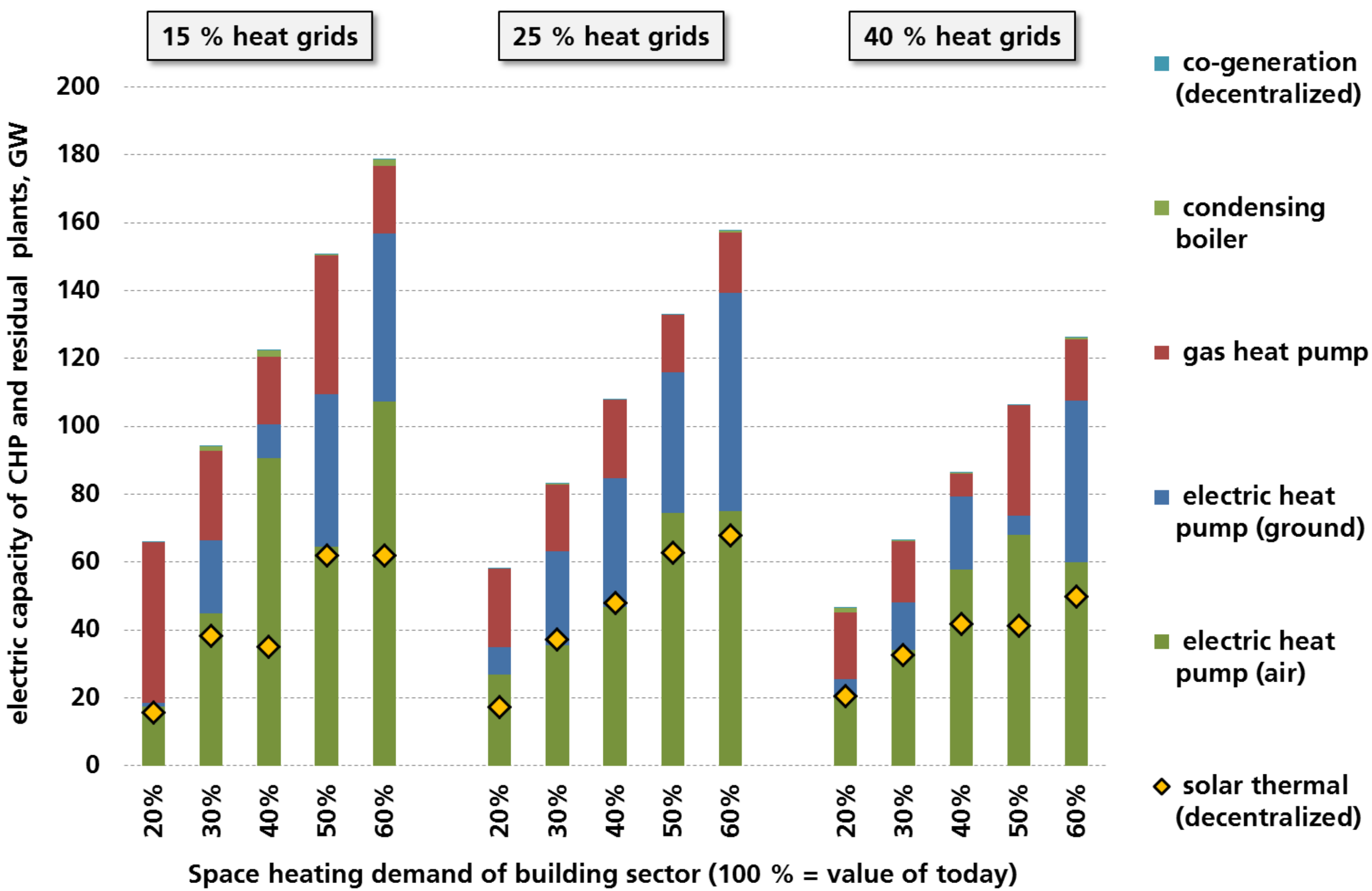
Composition of decentralized heating systems



Major findings of sensitivity analysis

- Deep building energy retrofit not cost competitive, although a higher space heating demand leads to higher needed capacity of flucutuating renewable energy sources (wind, PV)
- The fraction of heat covered by district heating has no significant impact on total annual cost
- Installed capacity for solar district heating (SDH) depends on expansion level of district heating
- Medium and large scale CHP is able to cover residual electricity generation in case that district heating networks are moderately increased
- Heat pumps (gas, electric) become the main technologies for heat supply in buildings which are not connected to district heating networks

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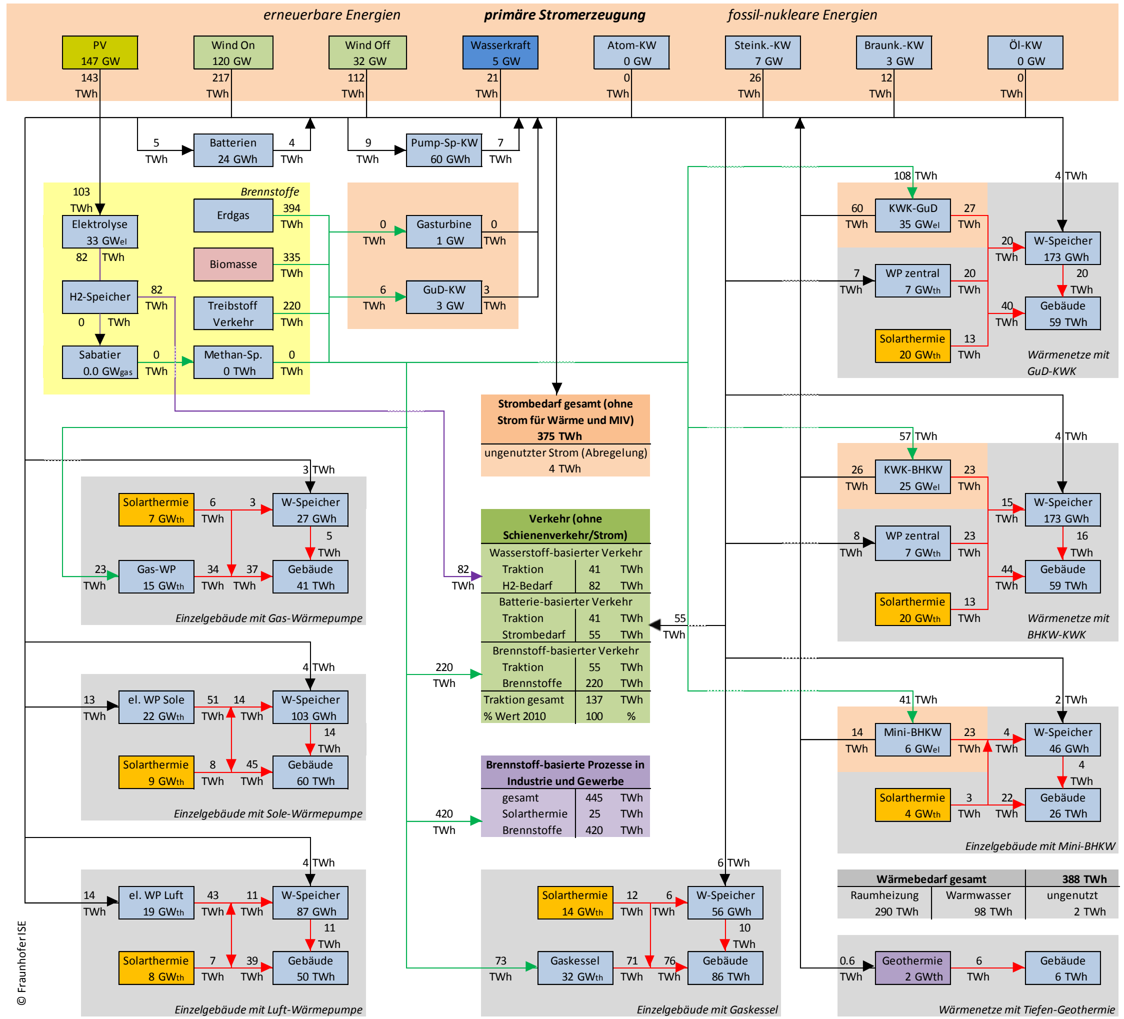
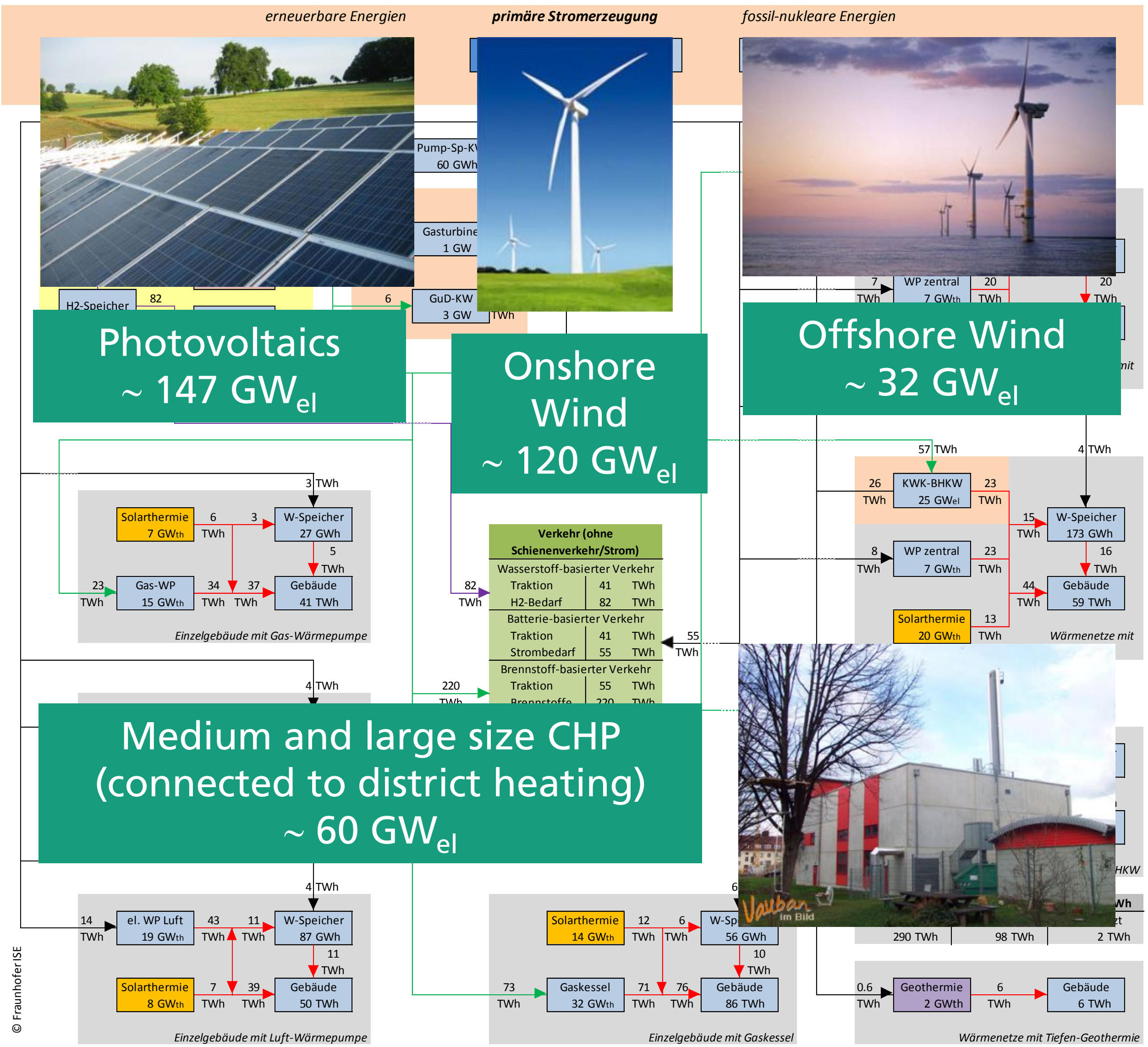
Analysis of a selected system

- Cost optimized system for a reduction of energy-related CO_2 emissions by 81 % (compared to Kyoto reference)
- Moderate expansion of district heating networks



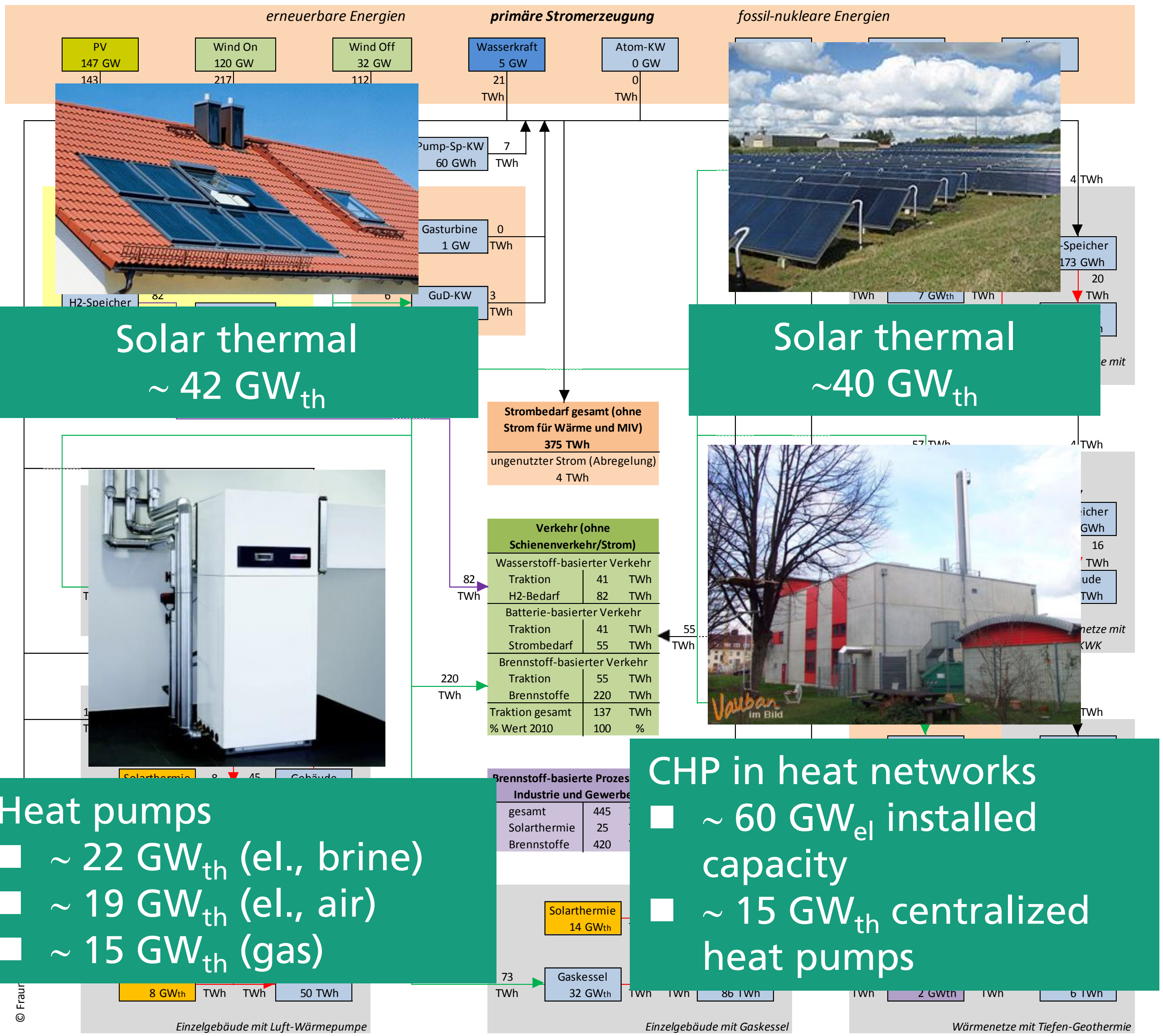
Electricity generation



Heat

decentralized

centralized



Solar thermal
~ 42 GW$_{th}$

Solar thermal
~40 GW$_{th}$

Heat pumps
- ~ 22 GW$_{th}$ (el., brine)
- ~ 19 GW$_{th}$ (el., air)
- ~ 15 GW$_{th}$ (gas)

CHP in heat networks
- ~ 60 GW$_{el}$ installed capacity
- ~ 15 GW$_{th}$ centralized heat pumps

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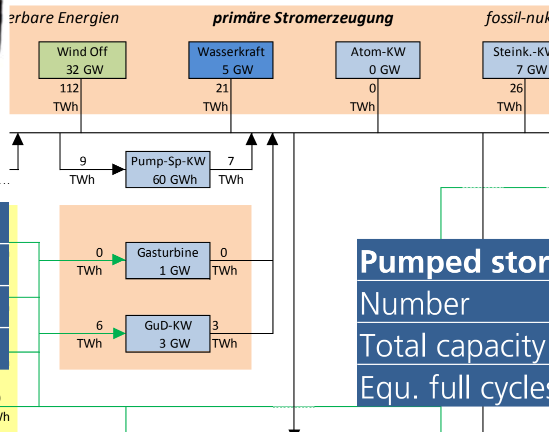
Storage



Battery storage (3 kWh)		
Number	Appr.8 Mio	Units
Total capacity	24	GWh
Equ. full cycles	167	-

Pumped storage power plants		
Number	42	Units
Total capacity	60	GWh
Equ. full cycles	117	-

Electrolysers		
Total capacity	33	GW_{el}
Full load hours	2485	h
Only needed for mobility (not for electricity and heat sector)		

Decentralized heat storage (800 Liter)		
Number	Appr.7 Mio	Units
Total capacity	319	GWh
Equ. full cycles	138	-

Centralized heat storage (50.000 m³)		
Number	Appr.150	Units
Total capacity	346	GWh
Equ. full cycles	104	-

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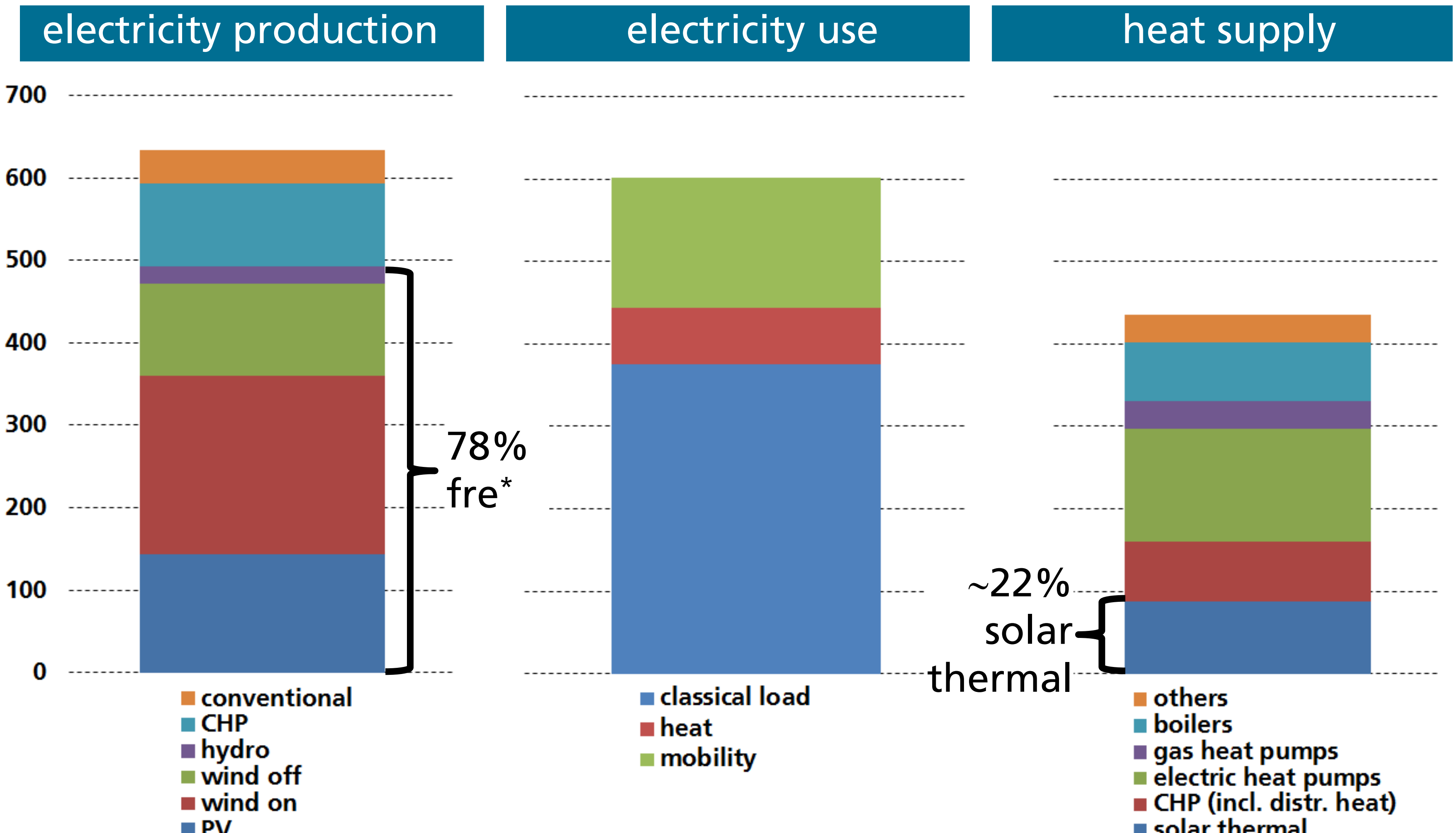
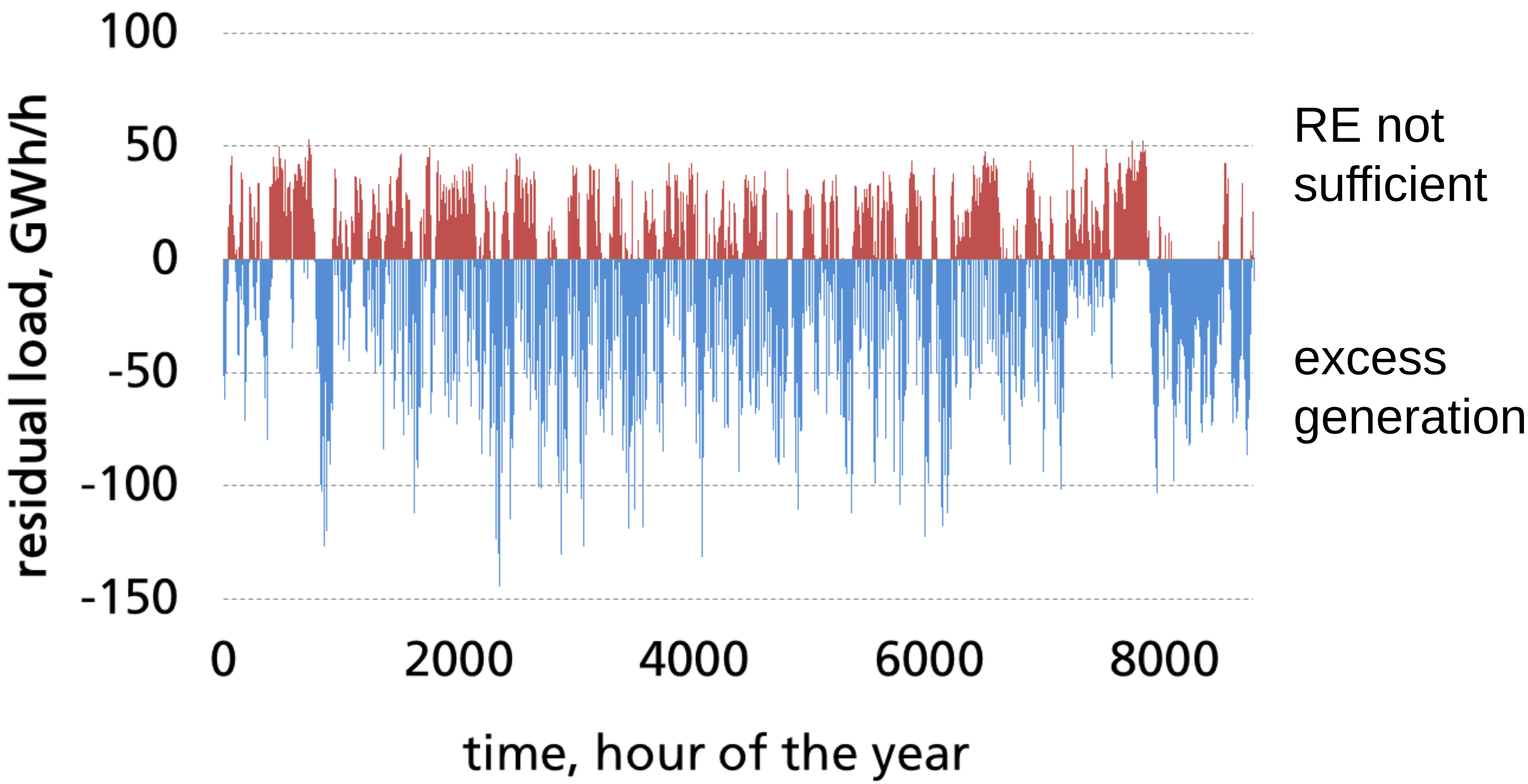
Annual energy balance (TWh)



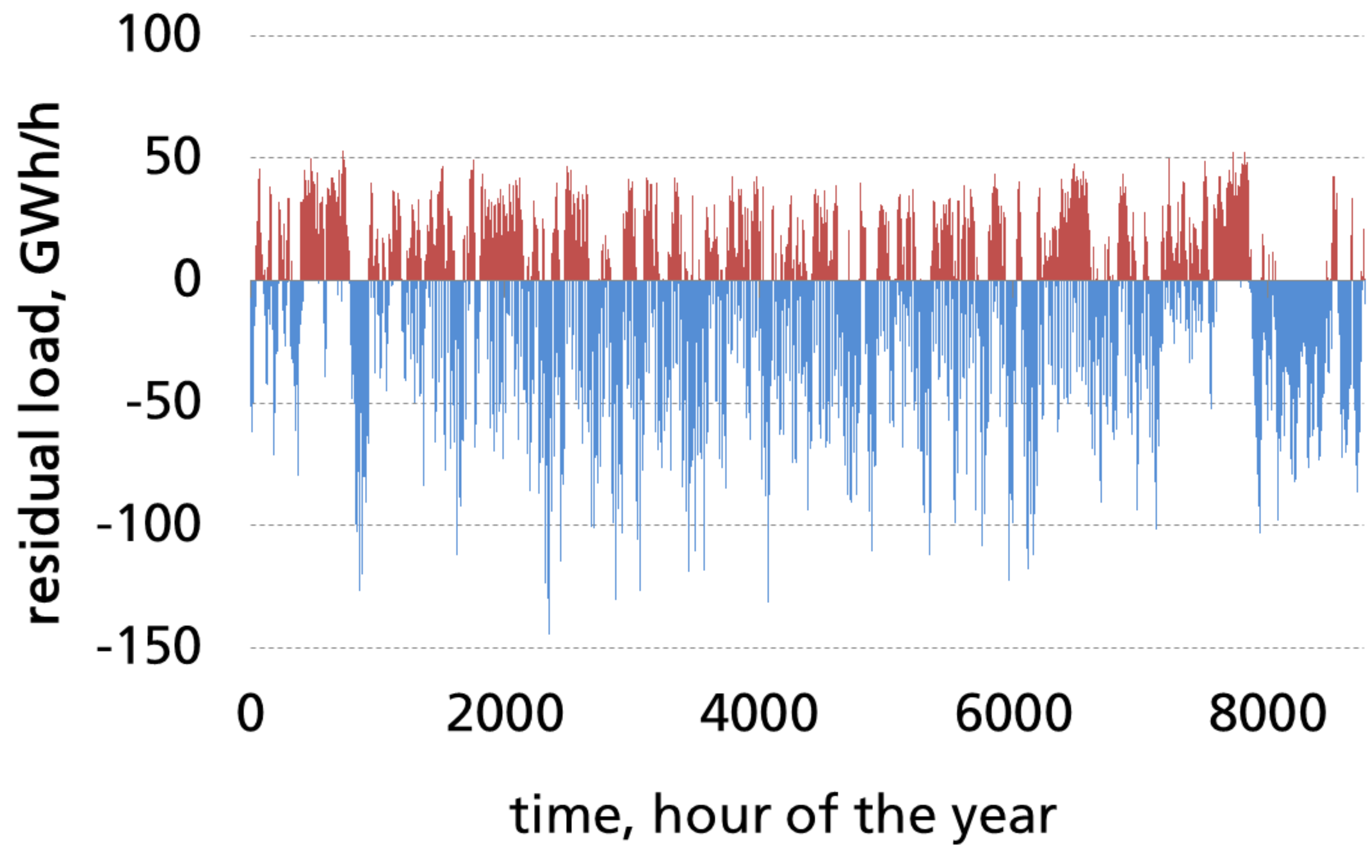
* fre = fluctuating renewable energies

Residual load 2050

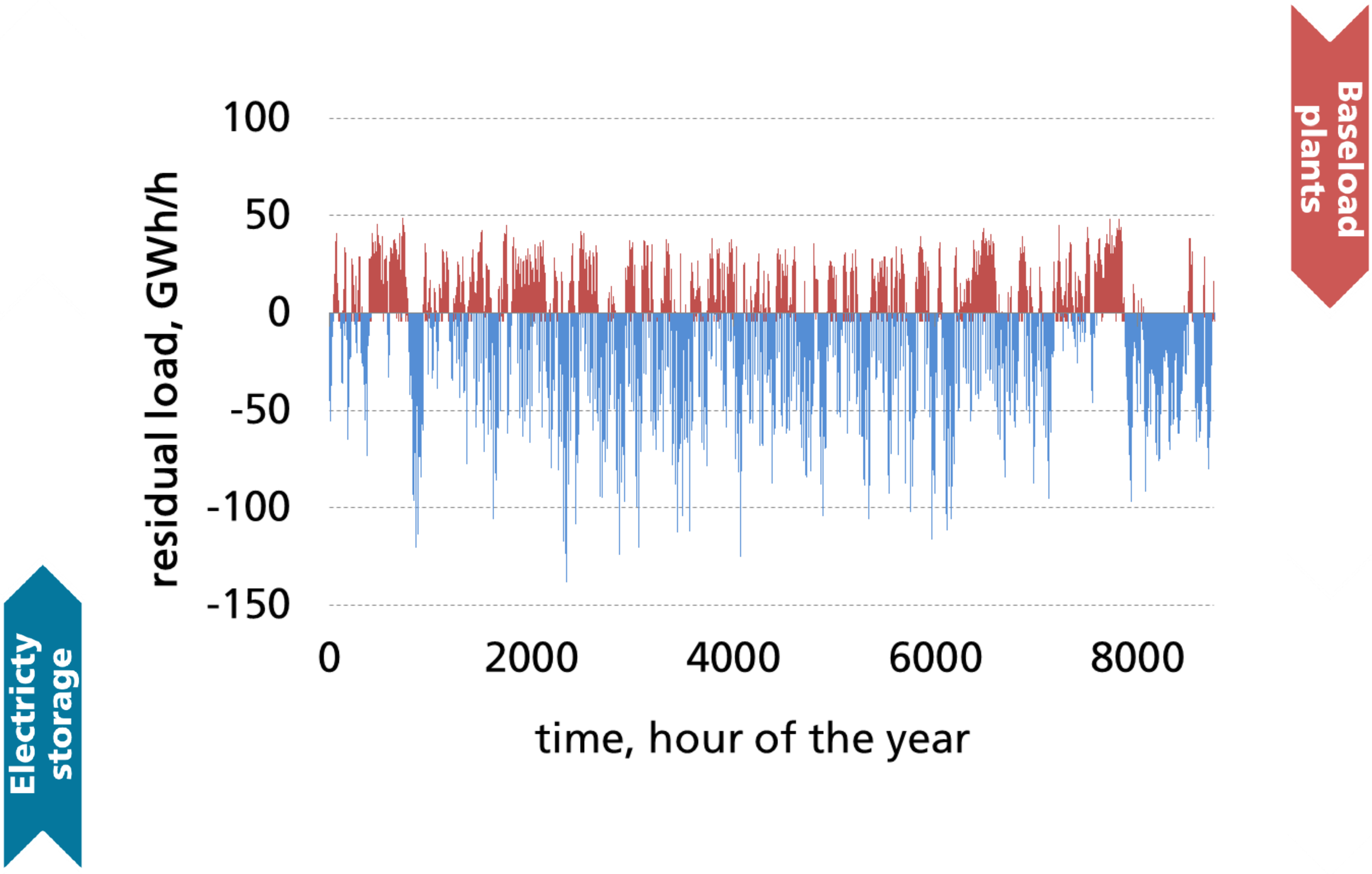
Base load minus production from fluctuating RE



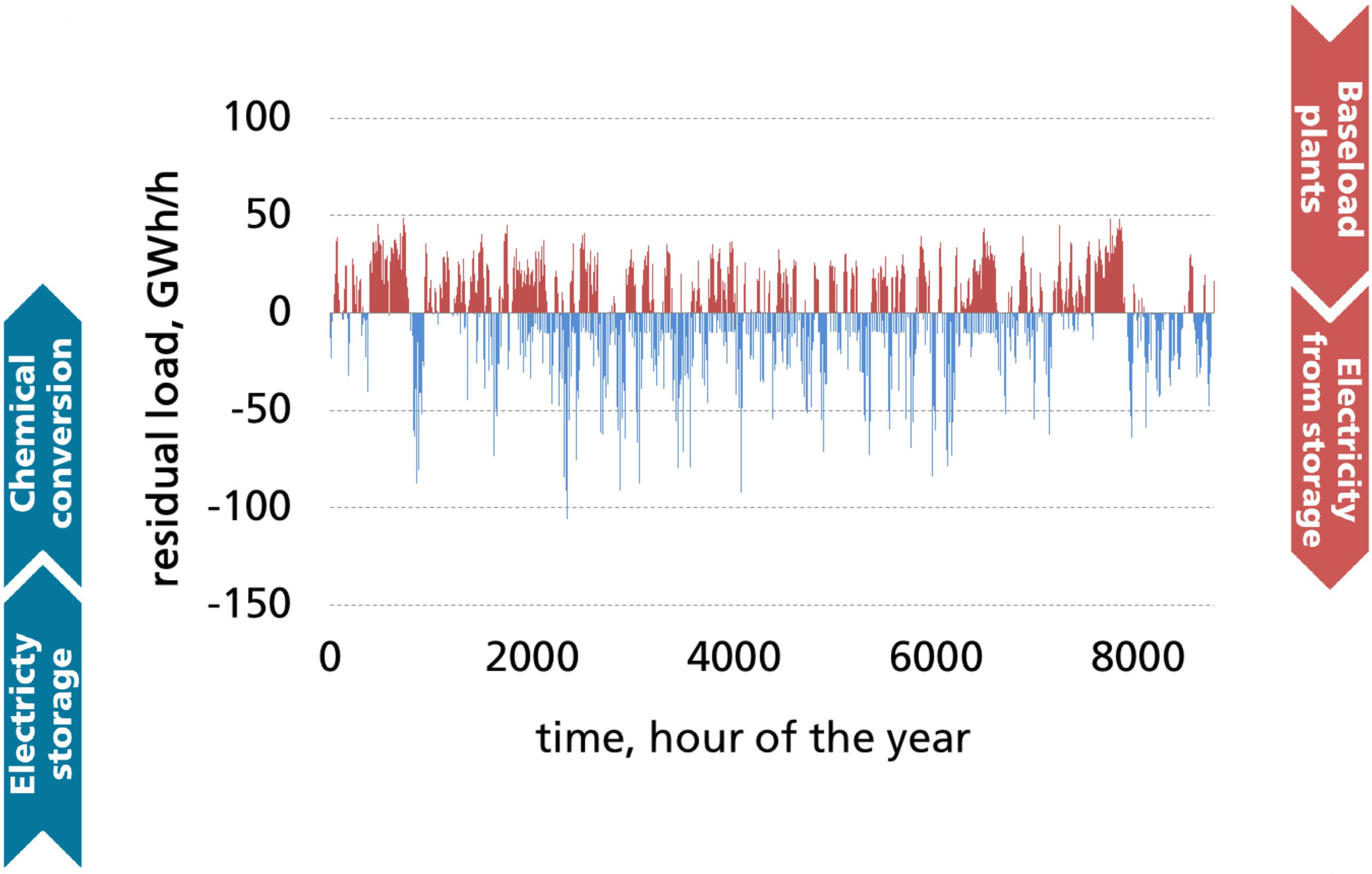
Reduction of the residual load



Reduction of the residual load



Reduction of the residual load



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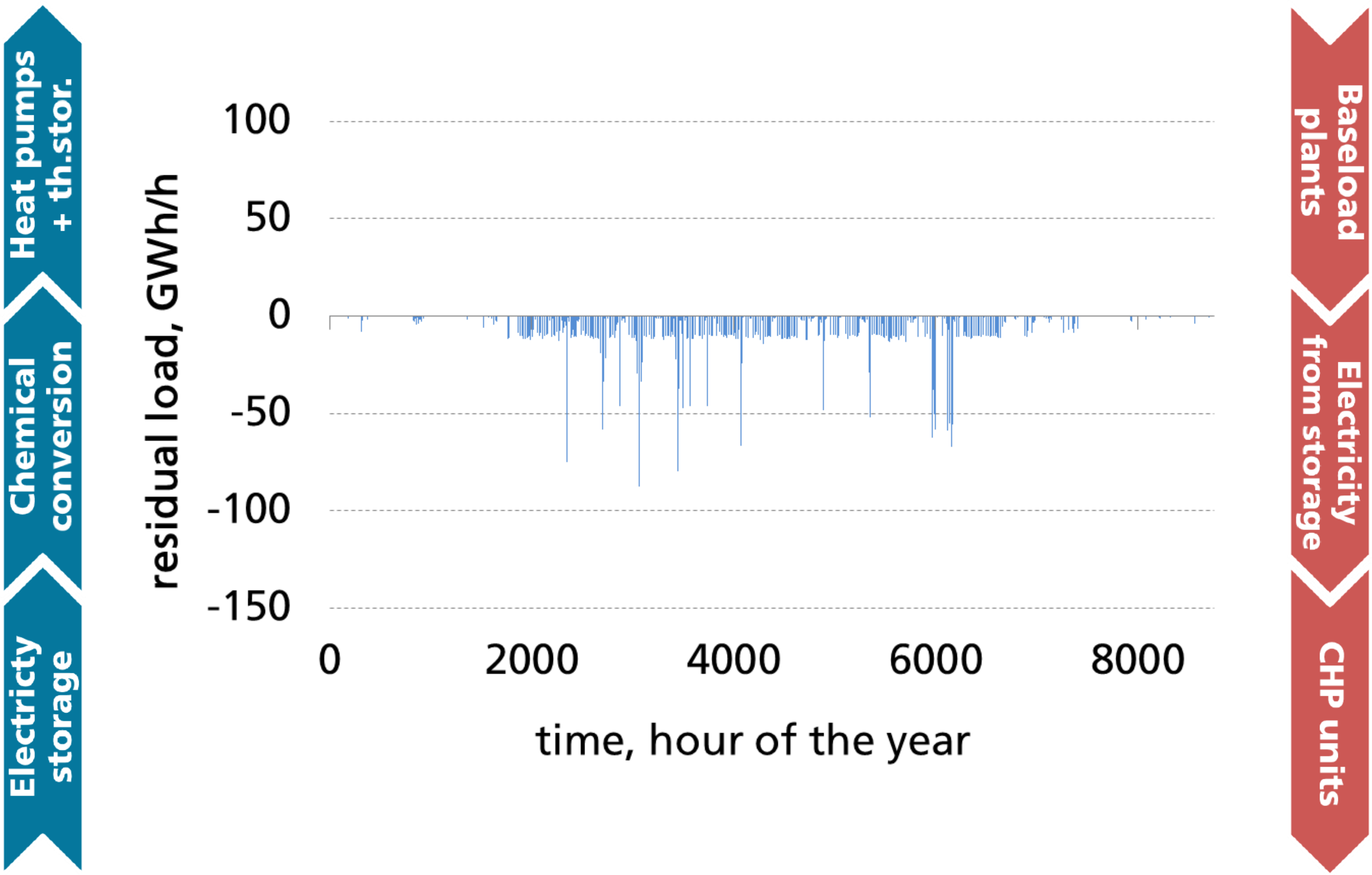
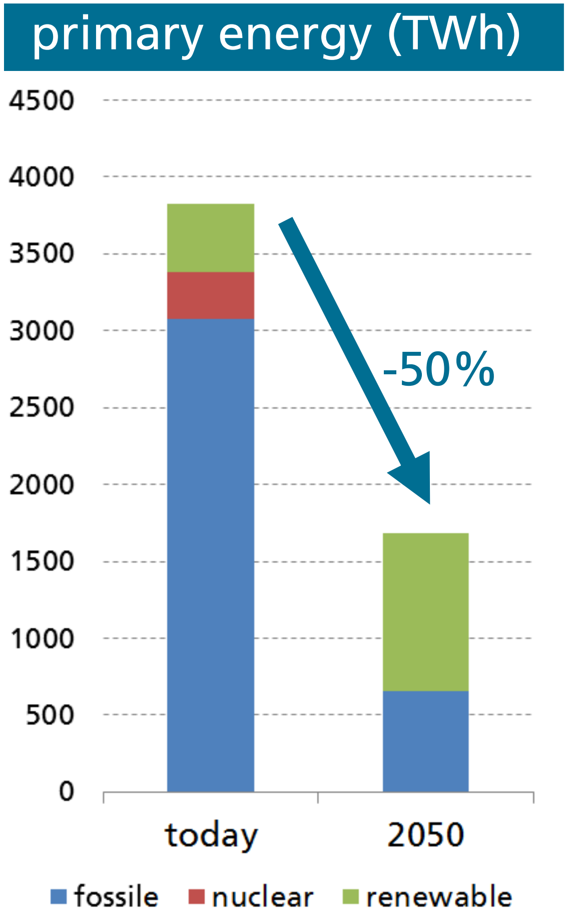


Overall comparison
Today vs. 2050 optimized system



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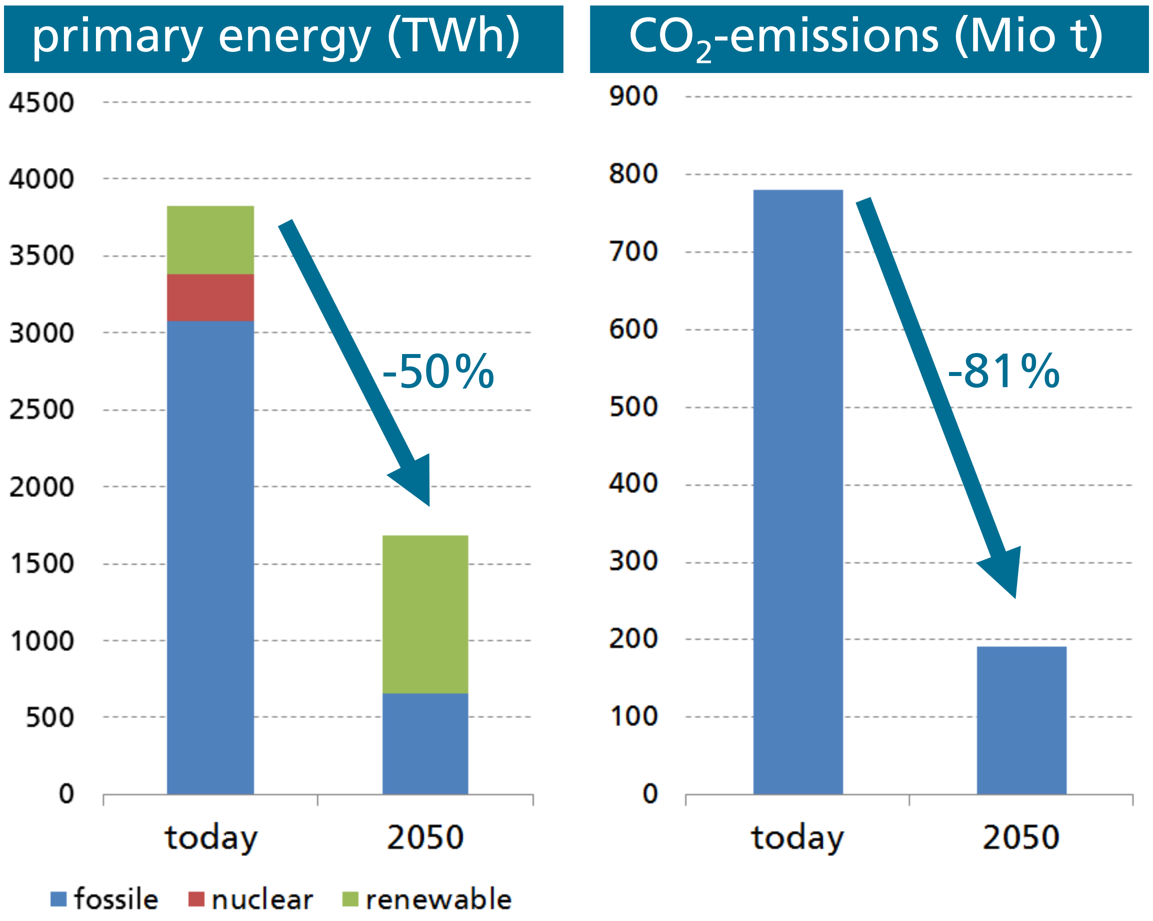

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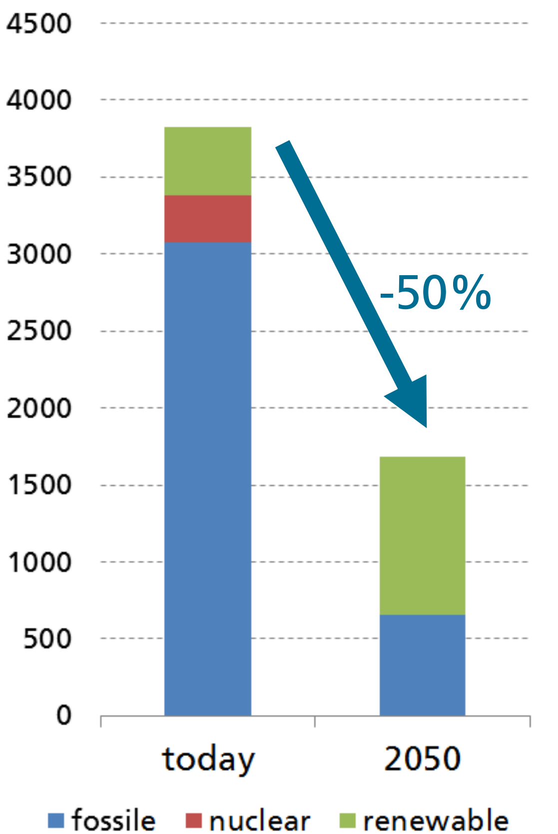
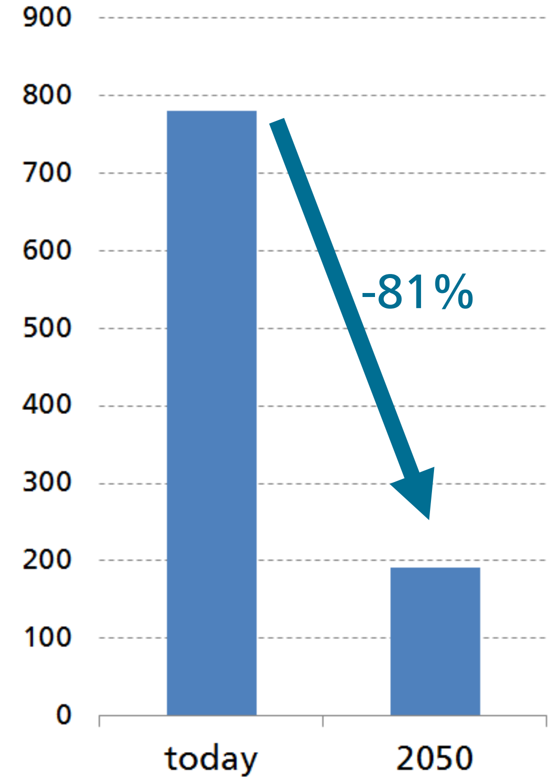
Overall comparison

Today vs. 2050 optimized system

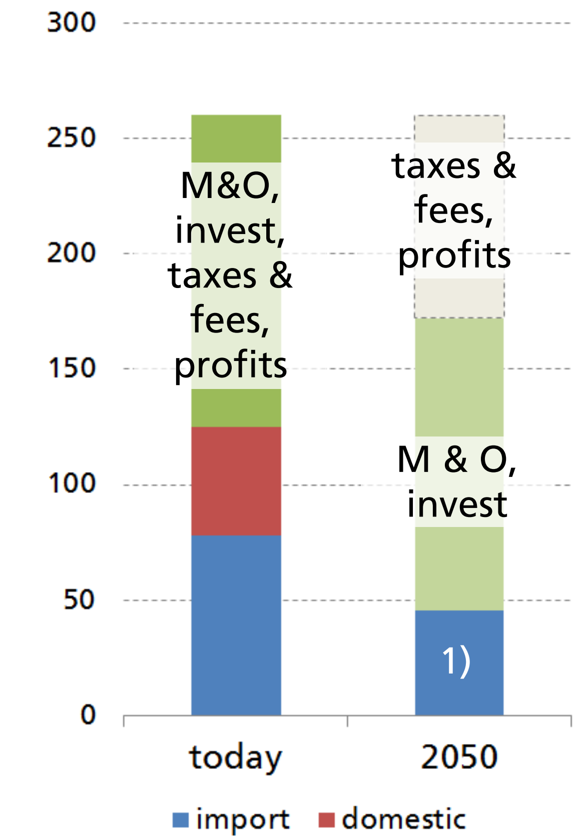
primary energy (TWh)



CO_2-emissions (Mio t)



annual cost (bill. €)



1) Assumed doubling of fossil energy prices until 2050

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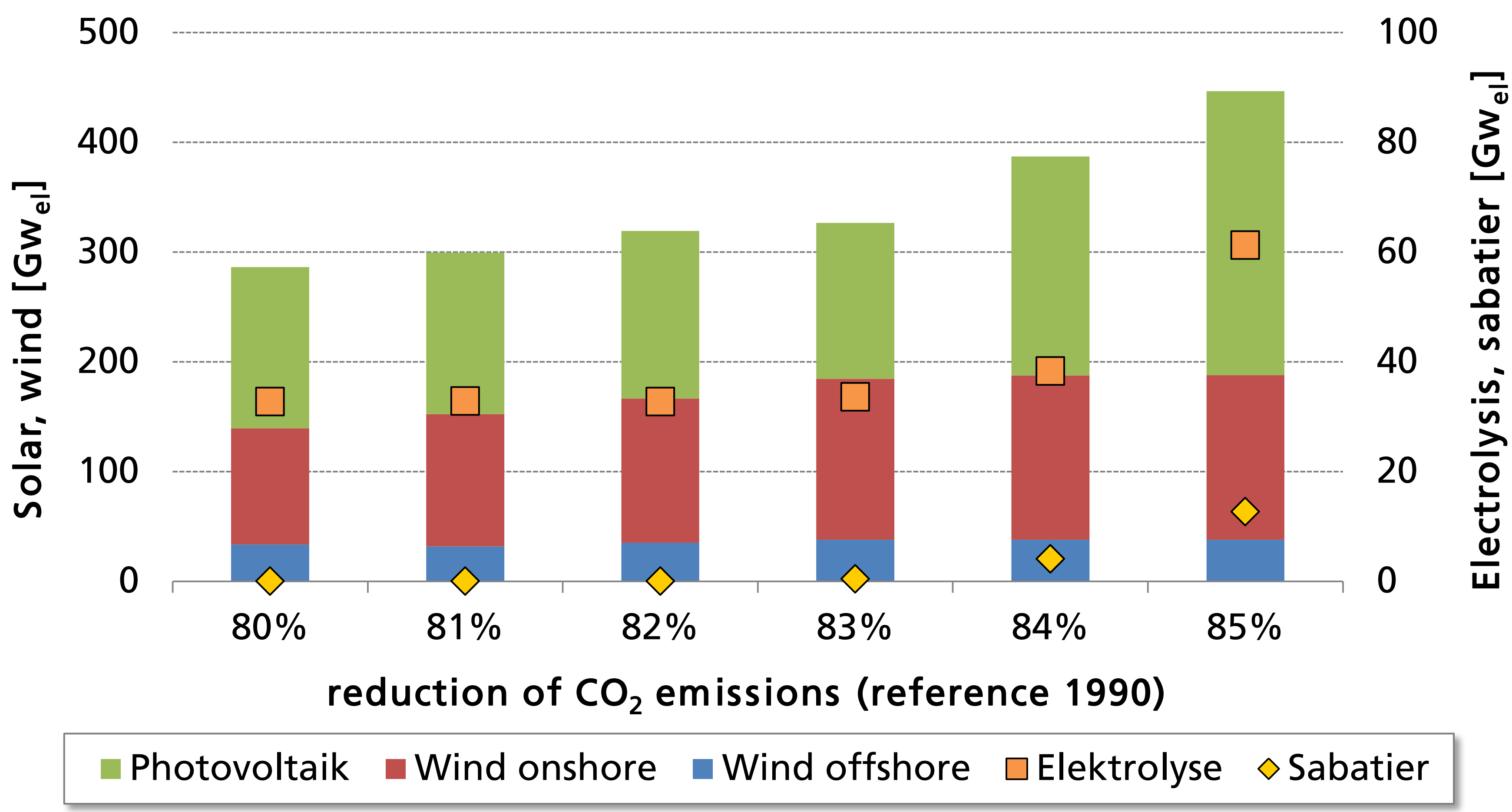
Capacity of solar and wind versus CO_2 reduction target



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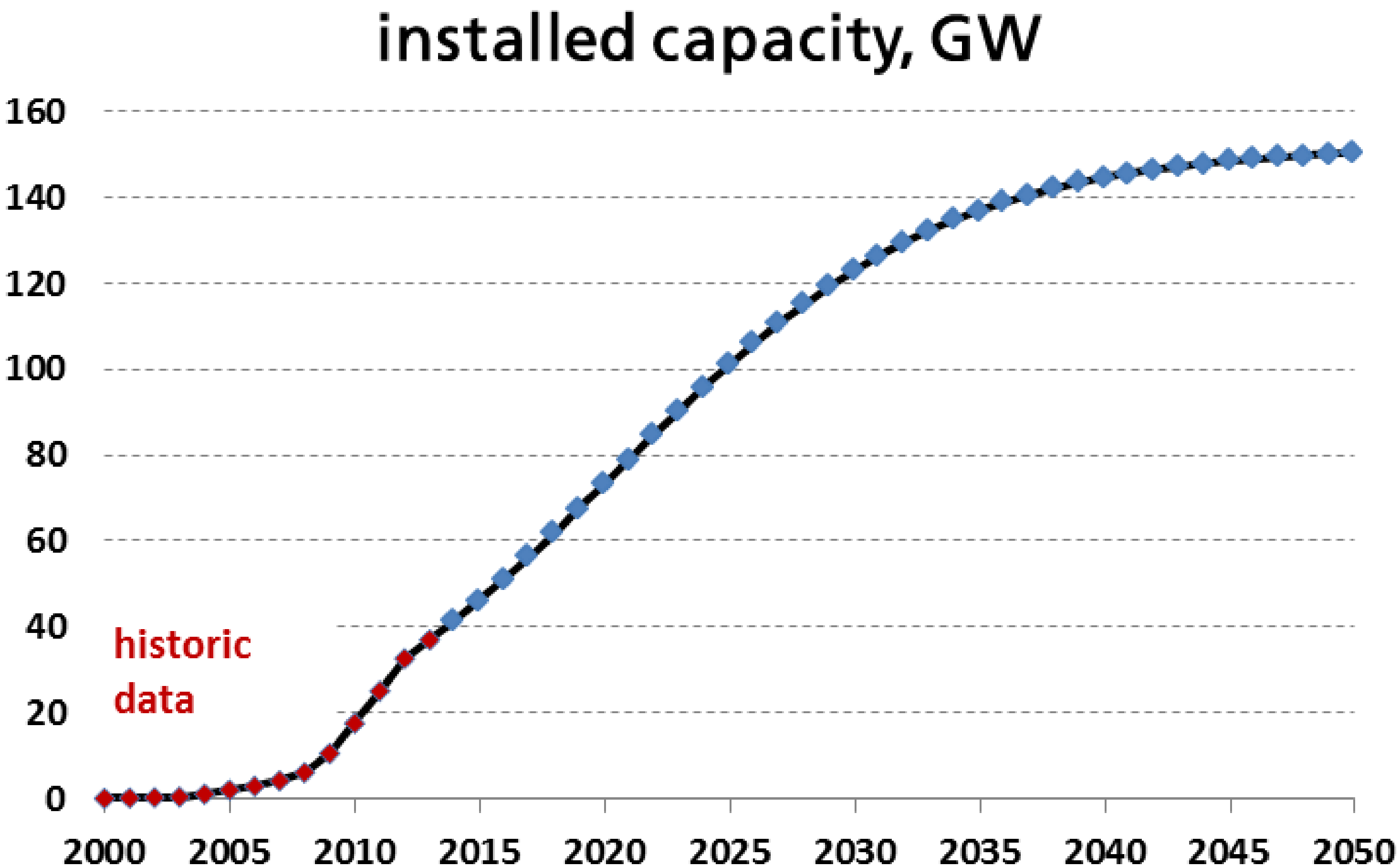
Analysis of investments from today until 2050

Example photovoltaics



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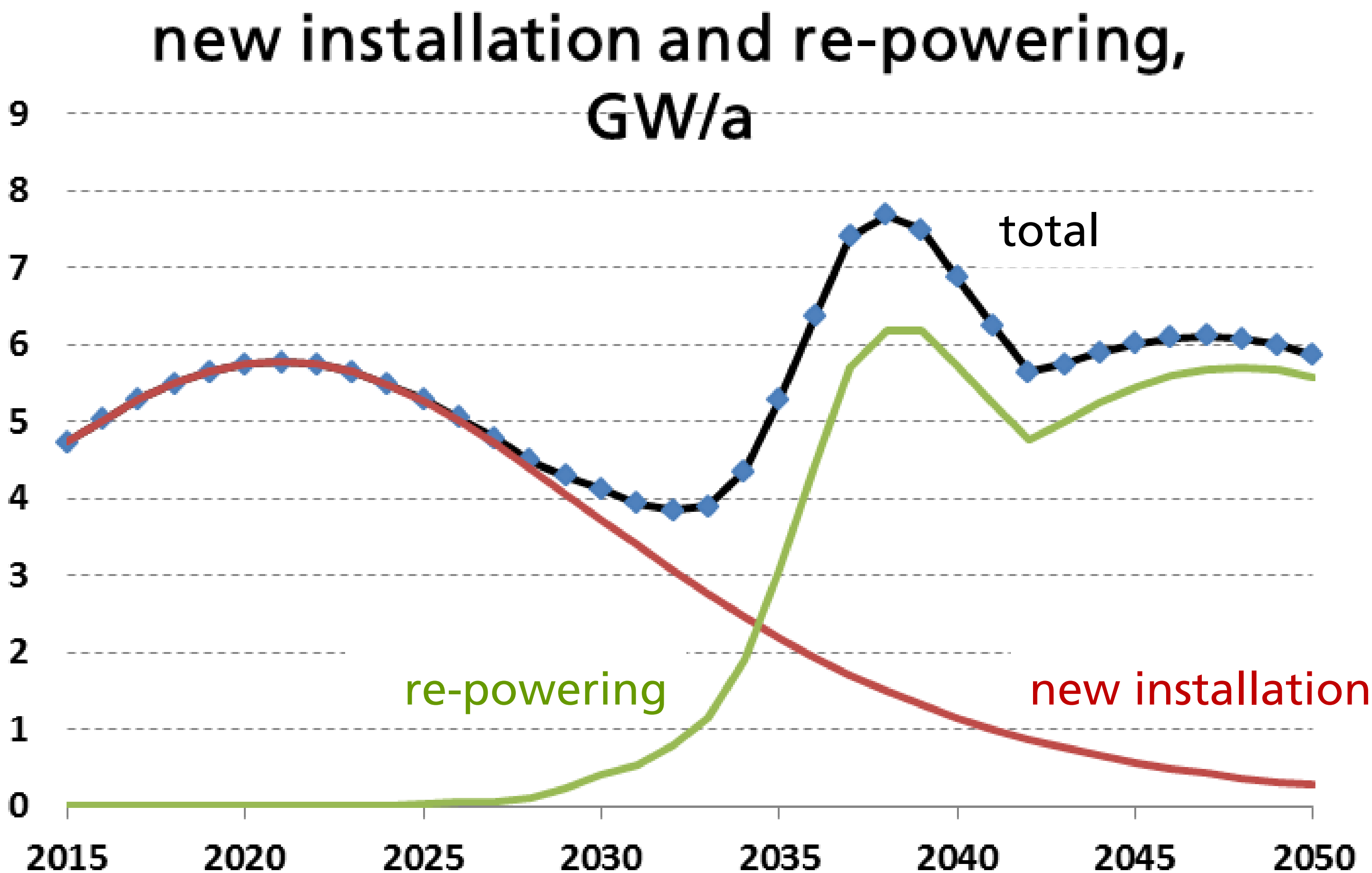
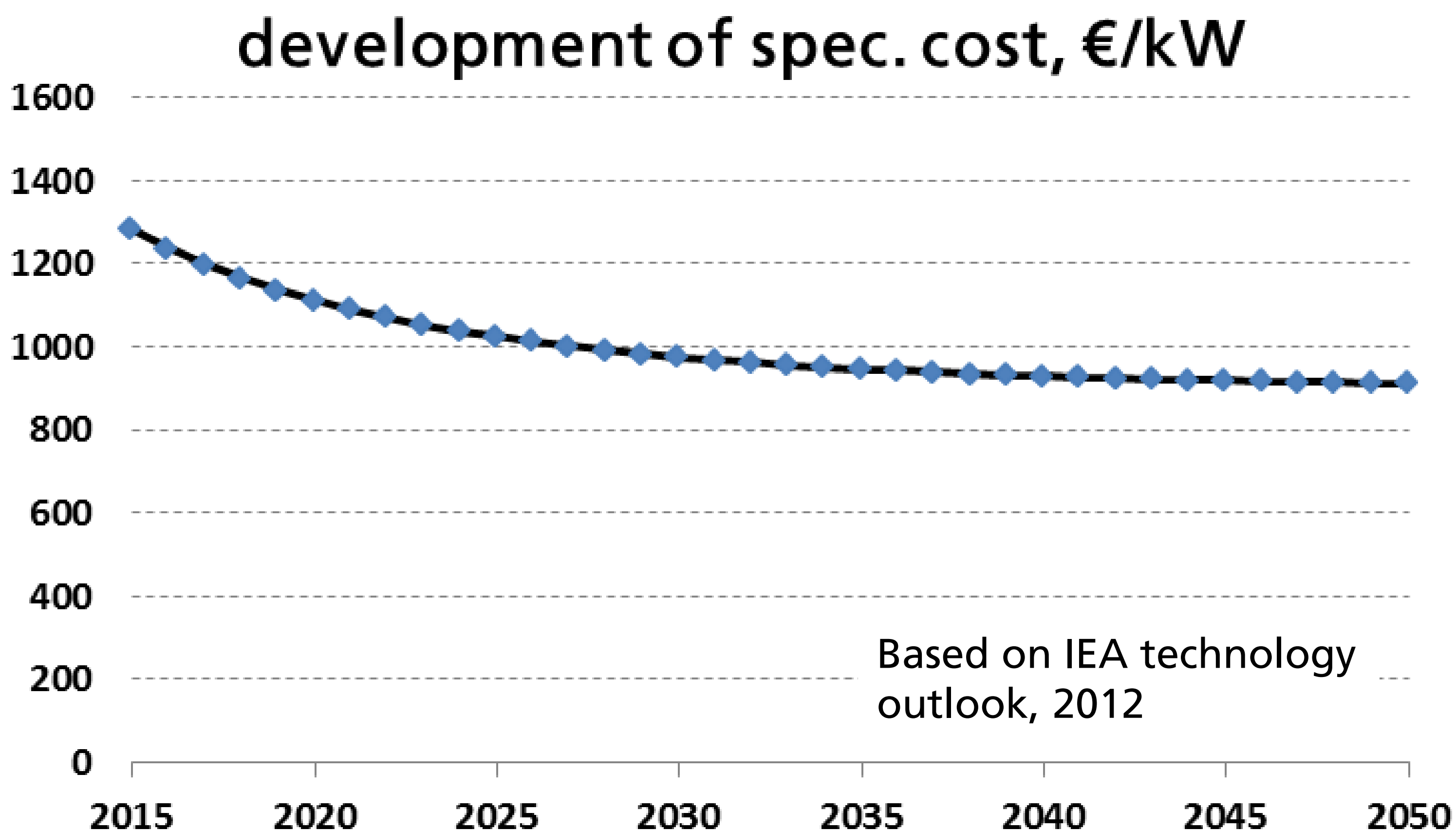
Analysis of investments from today until 2050
Example photovoltaics



Analysis of investments from today until 2050

Example photovoltaics



Analysis of investments from today until 2050

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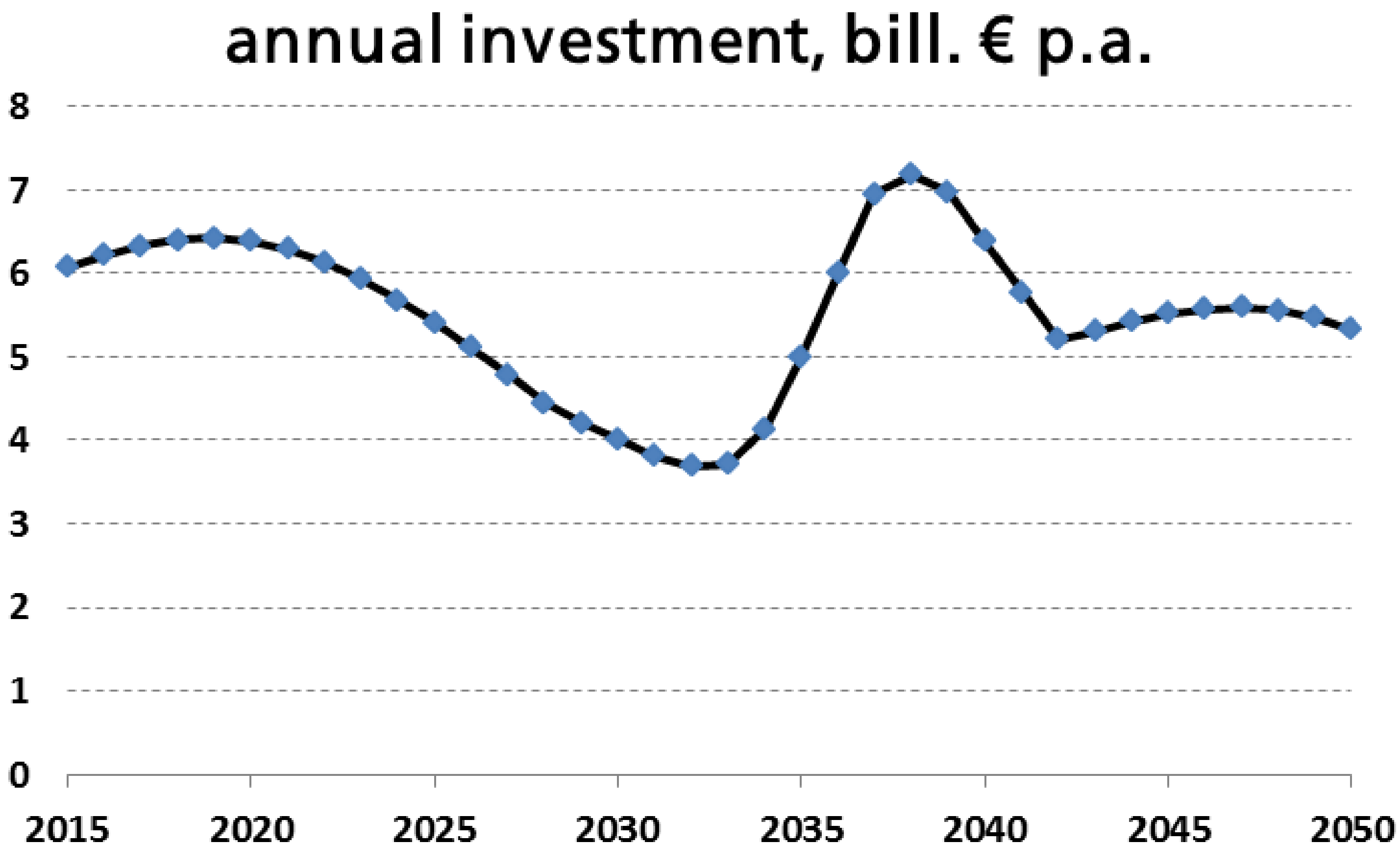
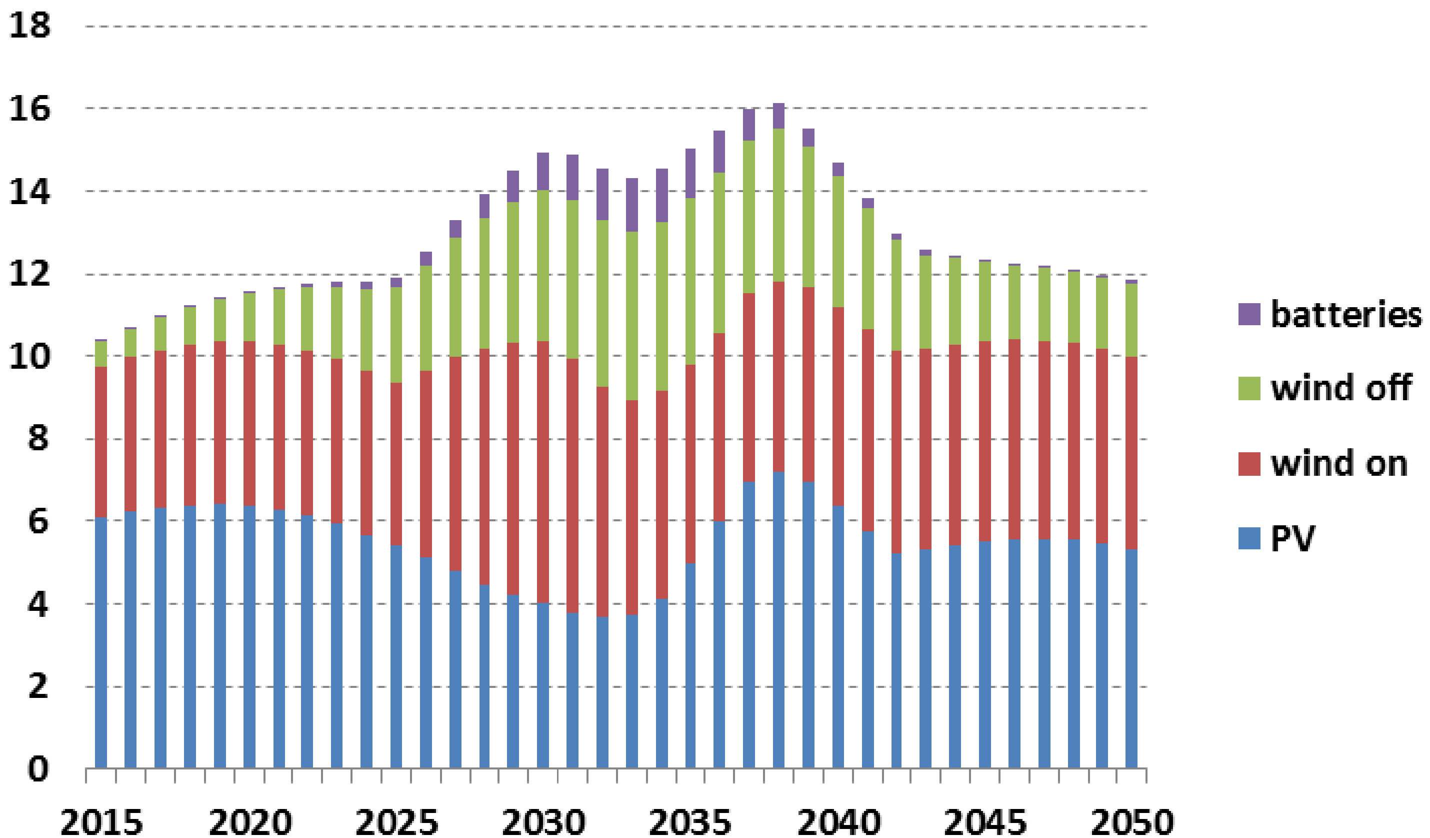


Investments for RE (wind, solar PV) and battery storage

Bill € p.a.



Total investments (w/o capital cost, incl. re-powering) from 2015 to 2050: 470 bill. $€_{2014}$

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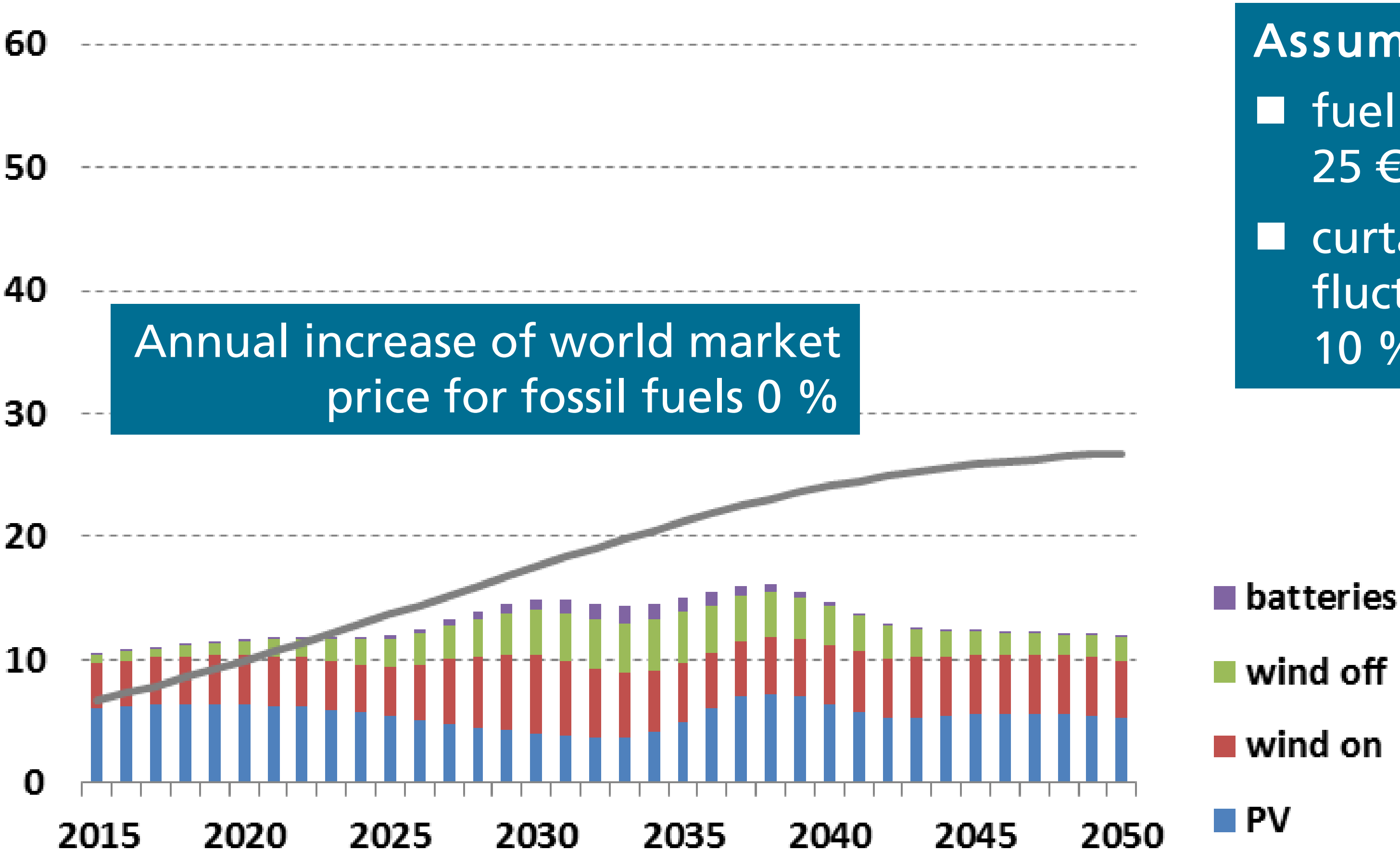
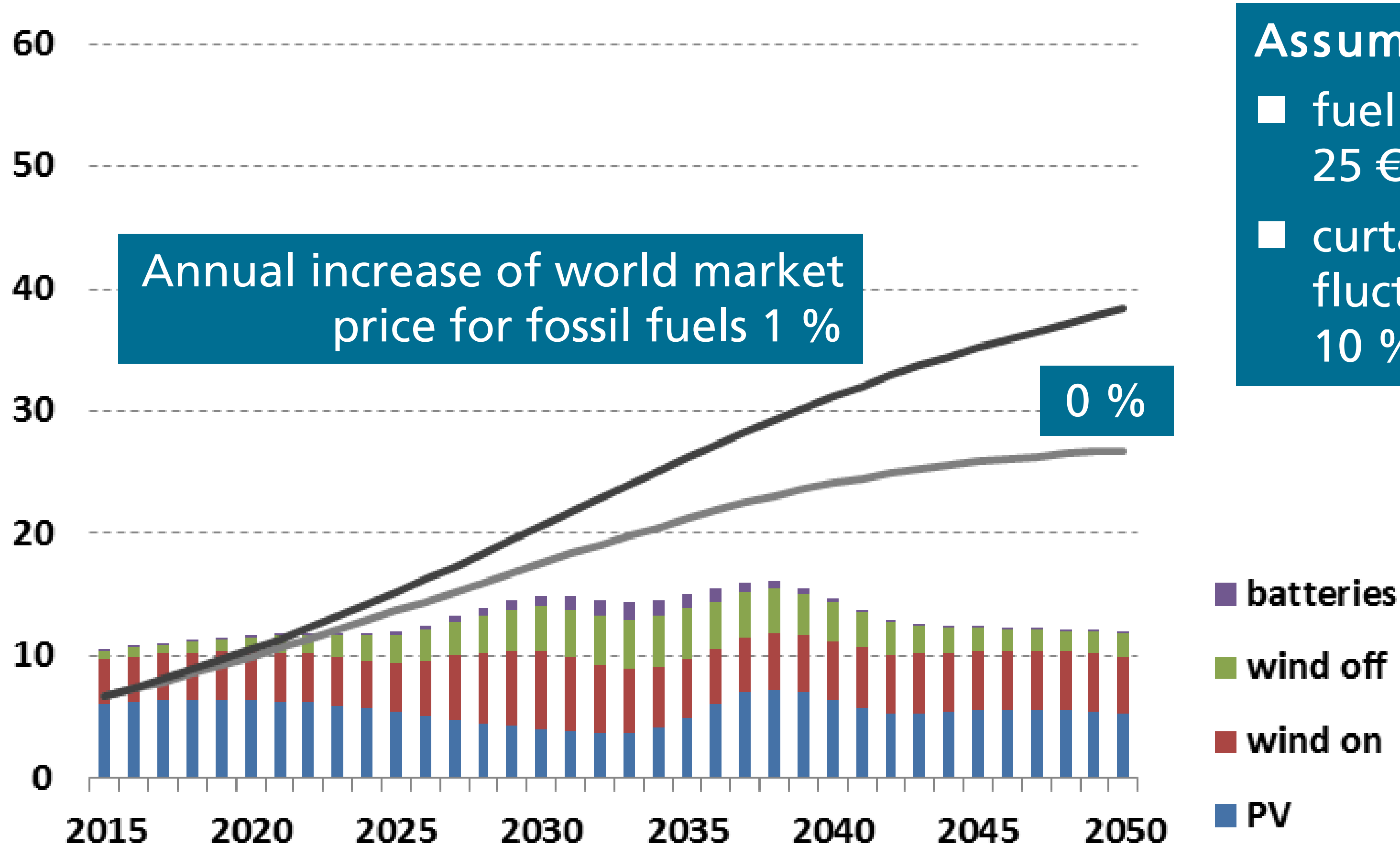
Investments vs. saved fuel cost in bill. € p.a.



Assumptions

- fuel cost today 25 €/MWh
- curtailment of fluctuating RE 10 % of energy

Investments vs. saved fuel cost in bill. € p.a.



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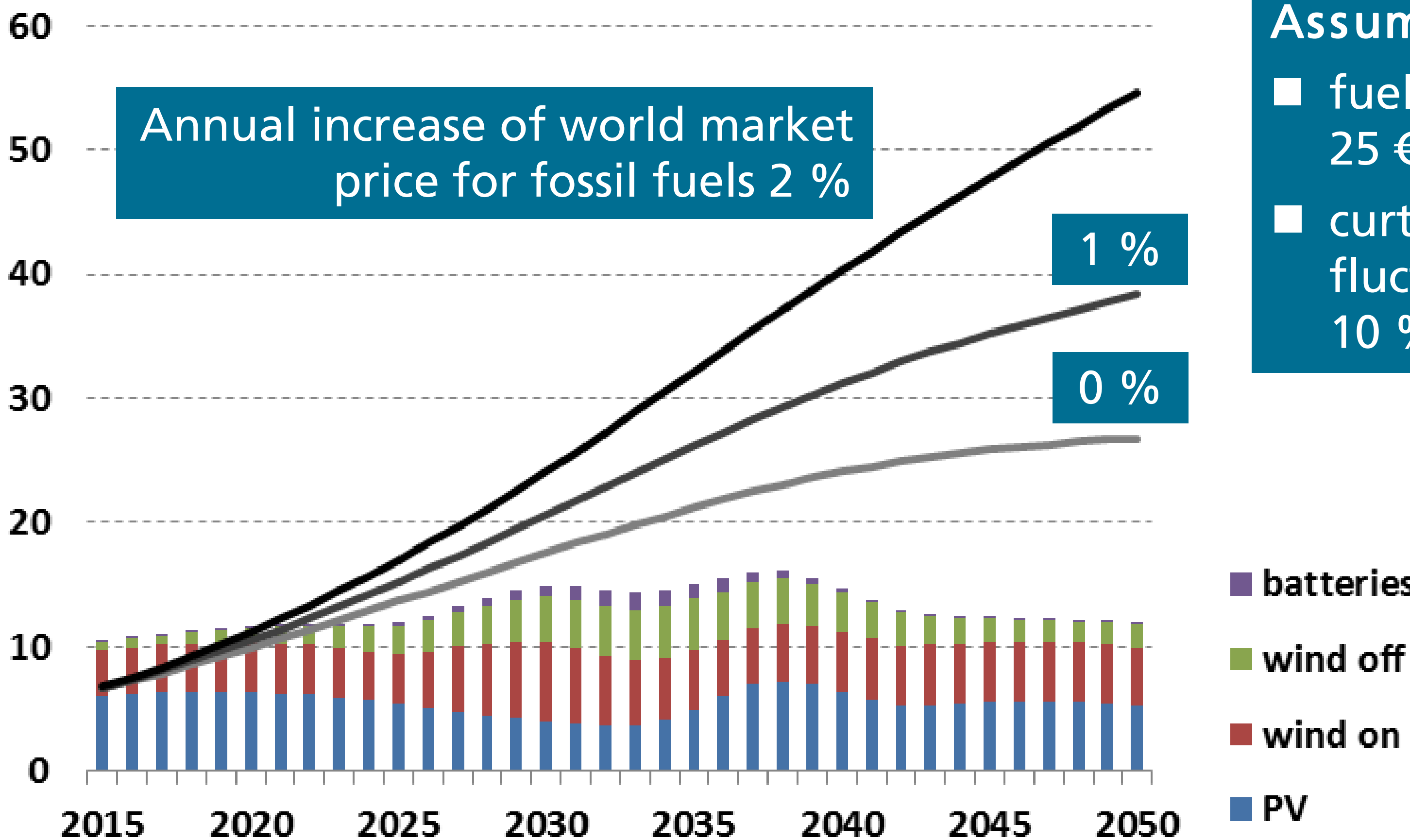

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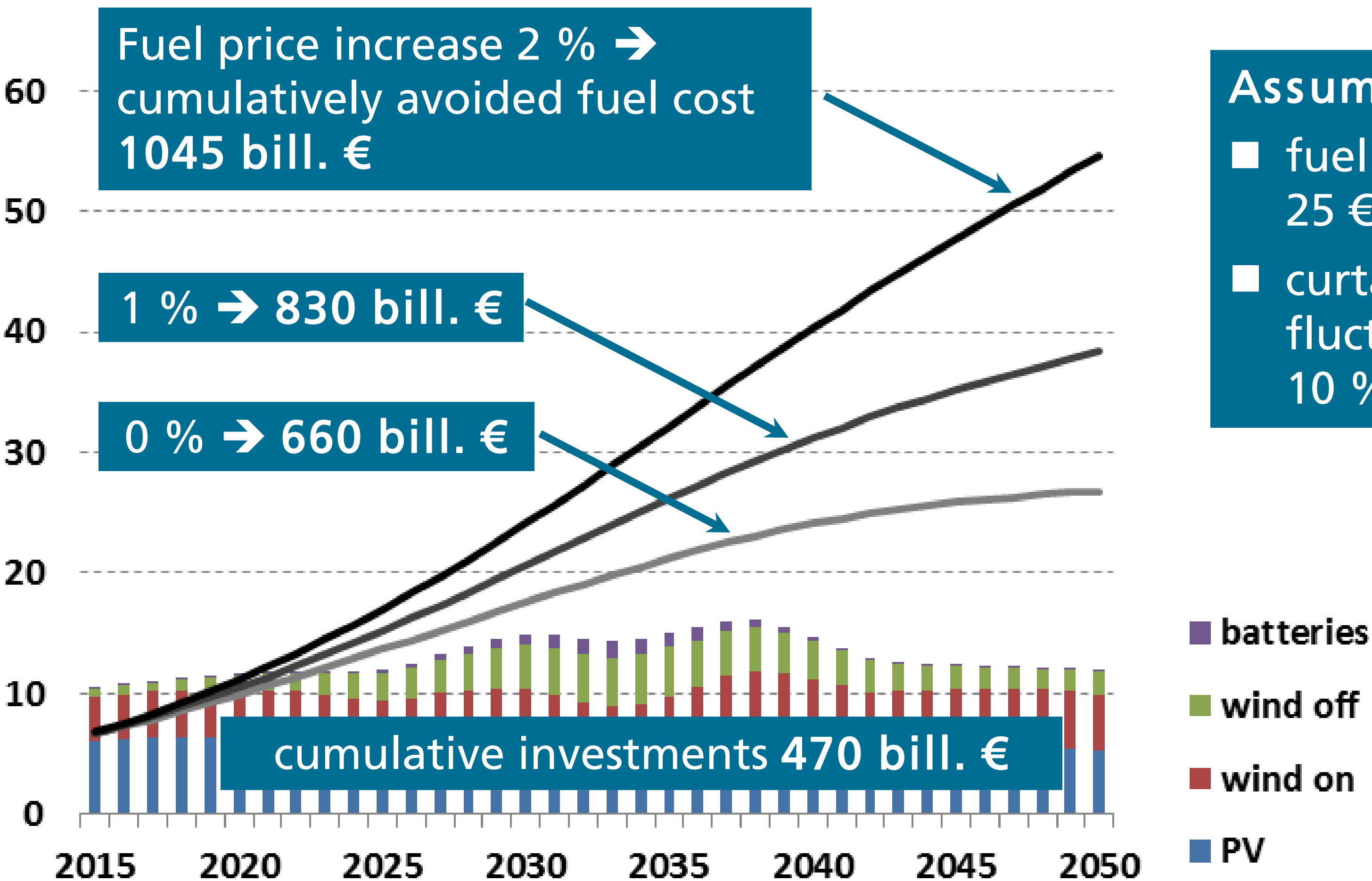

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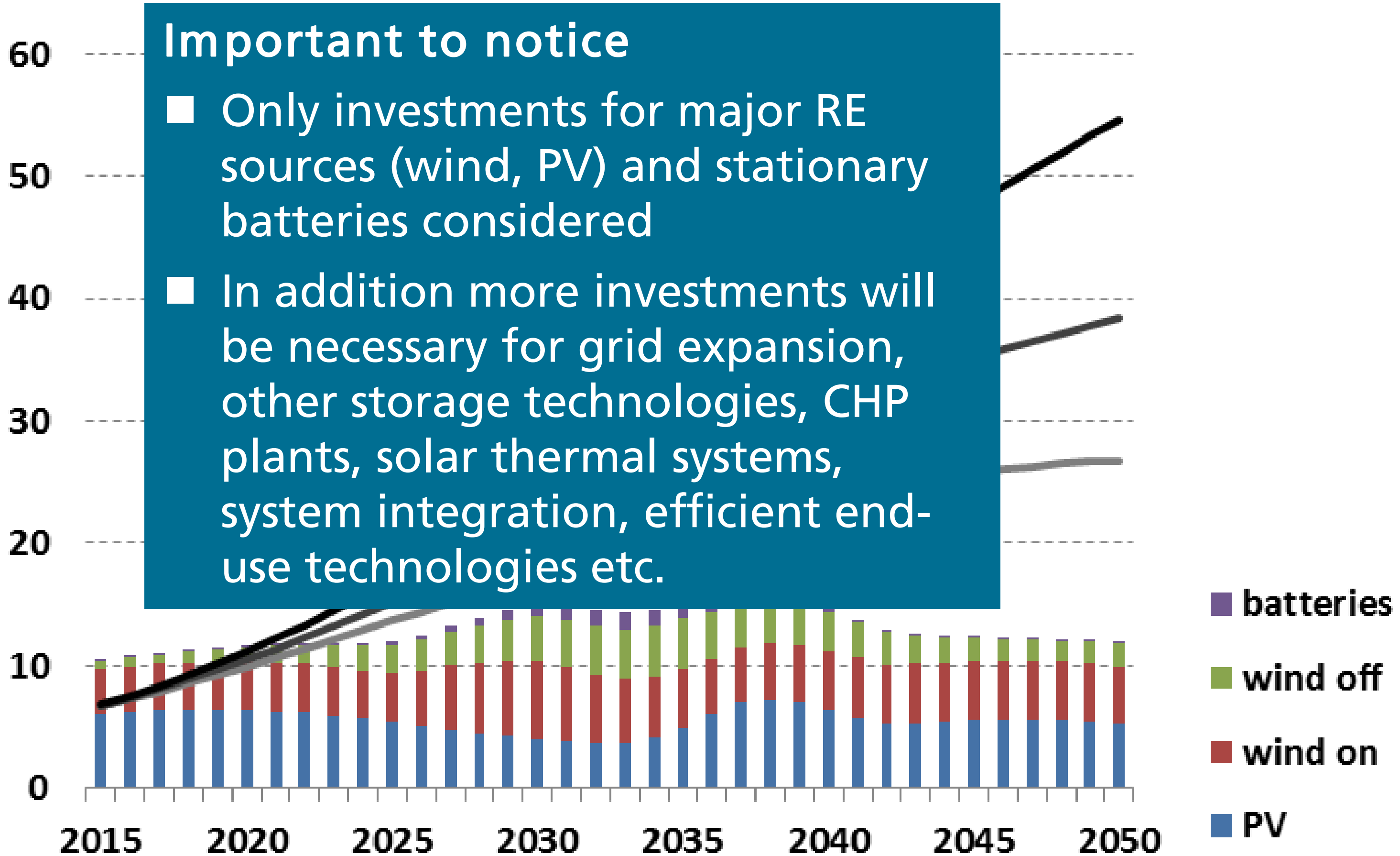

Important to notice

- Only investments for major RE sources (wind, PV) and stationary batteries considered
- In addition more investments will be necessary for grid expansion, other storage technologies, CHP plants, solar thermal systems, system integration, efficient end-use technologies etc.

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Summary (1/2)

- Reduction of energy-related CO_2 emissions by 80 % and above is possible and will in the long term lead to lower cost compared to the energy system of today
- The dependence on energy imports will be significantly reduced
- This strategy is linked to significant local value and employment creation due to installation of many thousands components and systems in all energy conversion and end-use sectors
- Key elements of the transformation are reduction consumption (classical electricity consumption, space heat), efficient conversion chains (electric engines, heat pumps replacing combustion processes) and renewable energies (electricity, heat)

Summary 2/2

- Flucutuaing renewable energies (wind, solar PV) will become the backbone of the electricity generation and dominate the overall system
- This calls for flexibilization of residual electricity production and electricity use in all end-use sectors in order to make use of negative residual load
- About one quarter of the total low temperature heat demand will be covered by solar thermal
- Depending on the level of expansion of district heating networks an installed capacity of 20 GW to 80 GW of centralized solar thermal systems seems reasonable

Outlook – next steps of model development

- Include electricity export/import
- Disaggregation/diversification of the model in various sectors, e.g.
  - mobility
  - fuel conversion chains (e.g. biomass)
  - introduction of a simple building typology (residential: SFH, MFH; commercial)
- Adjustment of the model to describe and optimize transformation pathways ➔ inclusion of diffusion/exchange rates and learning curves for all relevant technologies
- Country studies (e.g. Italy, California, South Africa, …)

References

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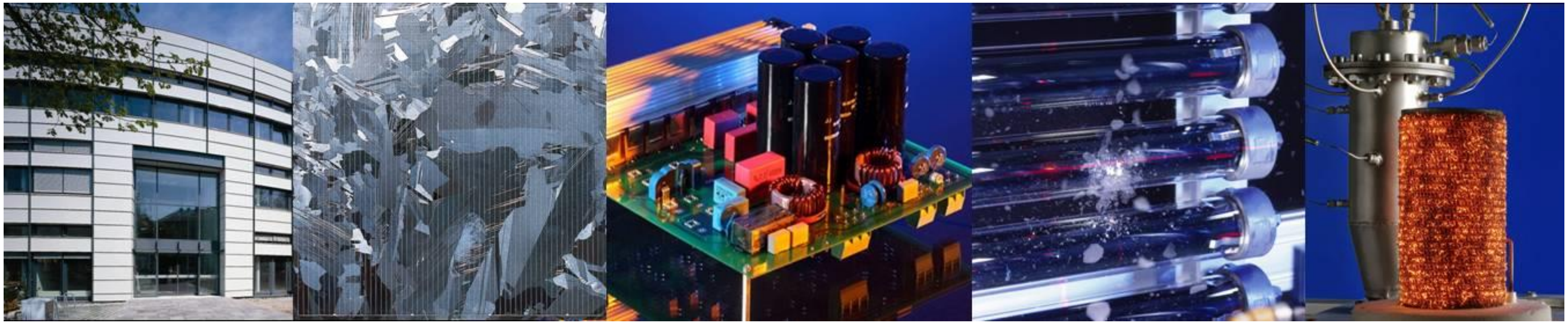

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