Holistic modeling and analysis of a future German energy system – Integration of renewables and energy efficiency solutions

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Outline

- Overall targets of the German climate protection policy
- Analysis of a renewable German energy system in 2050
  - Methodology
  - Results
  - Investments
- Conclusions & outlook

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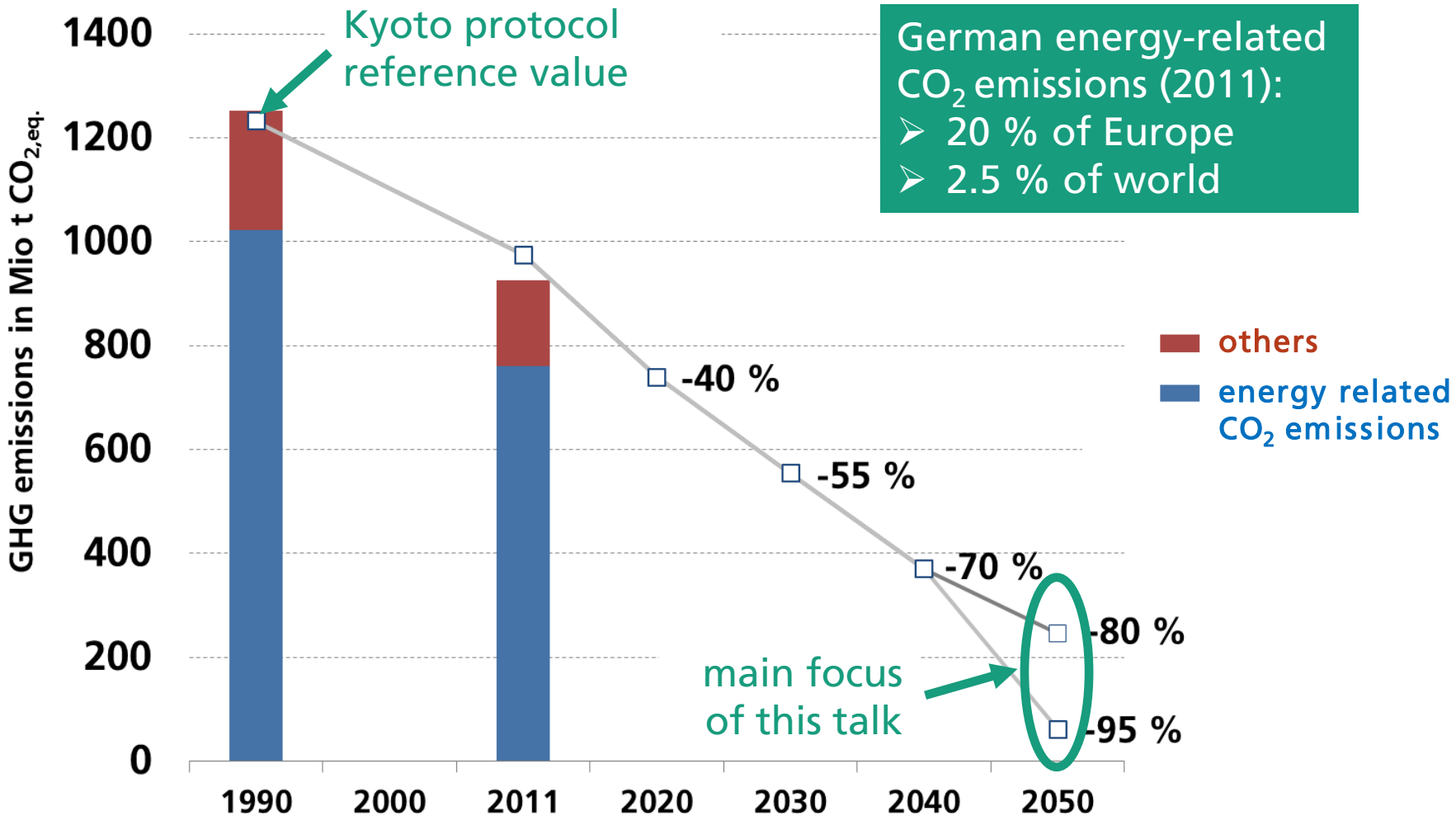
German greenhouse gas emissions – history and targets



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Motivation for this work

Guiding questions

- Is it possible to achieve Germany's CO_2 emission reduction targets by using large shares of renewable energies (no nuclear, no CCS)?
- If yes: what is the „best" composition of such energy system?
- And what is its cost?

➔ Long term perspective on macro-economic level

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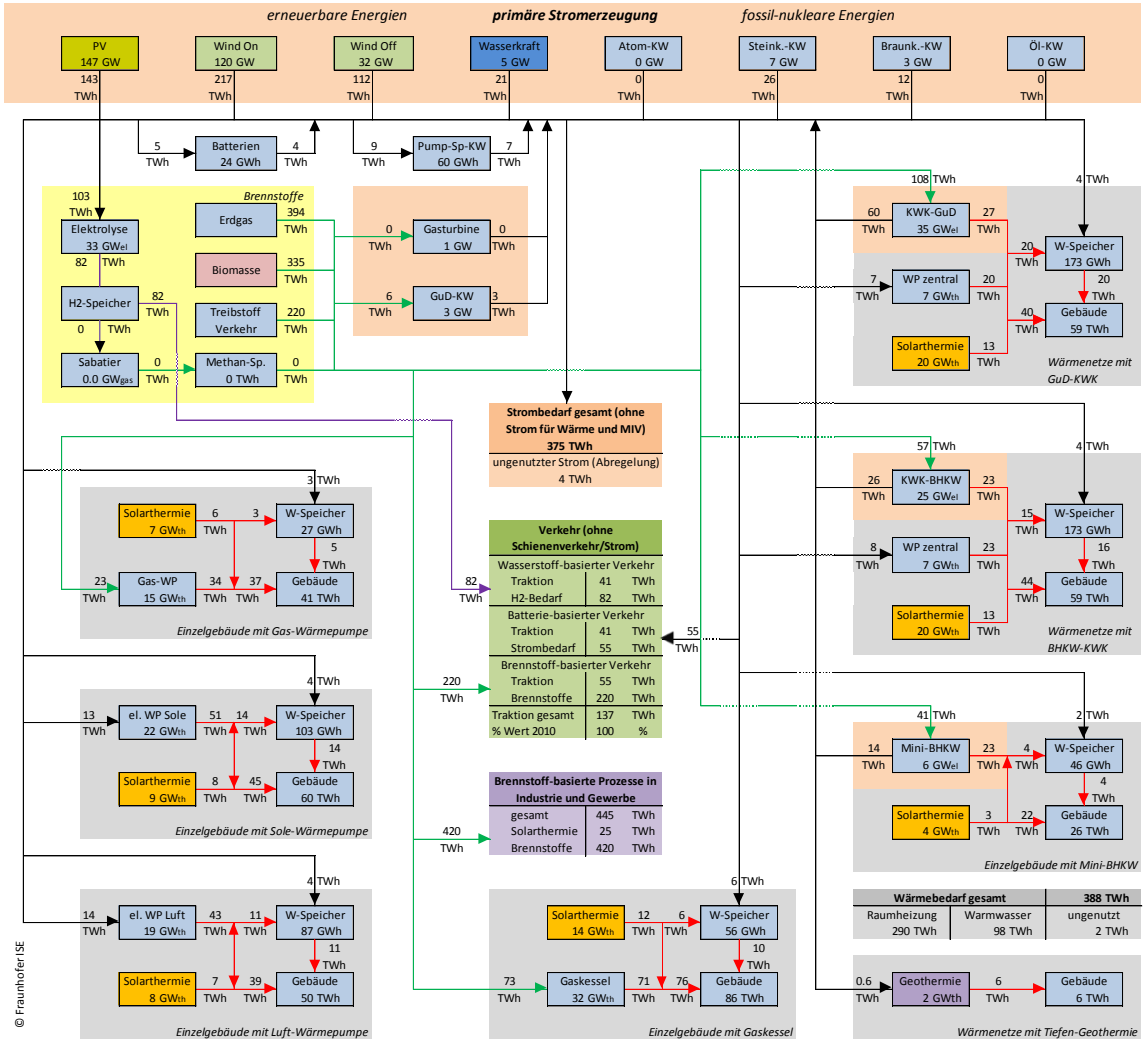
Holistic model of the German energy system
Inter-sectorial analysis of the overall system

Approach

- Comprehensive model of the overall system with all energy fluxes (for all conversion chains and end-use sectors) based on hourly energy balance
- Generic optimizer ➔ optimum composition and sizing of all components including energy retrofit of the building stock
- Goal function: minimum of total annual cost (re-investment, maintenance, operation, financing)

➔ Appropriate treatment of a highly complex system with many interdependencies

Optimization of Germany's future energy system based on hourly modeling



REMod-D

Renewable Energy Model – Deutschland

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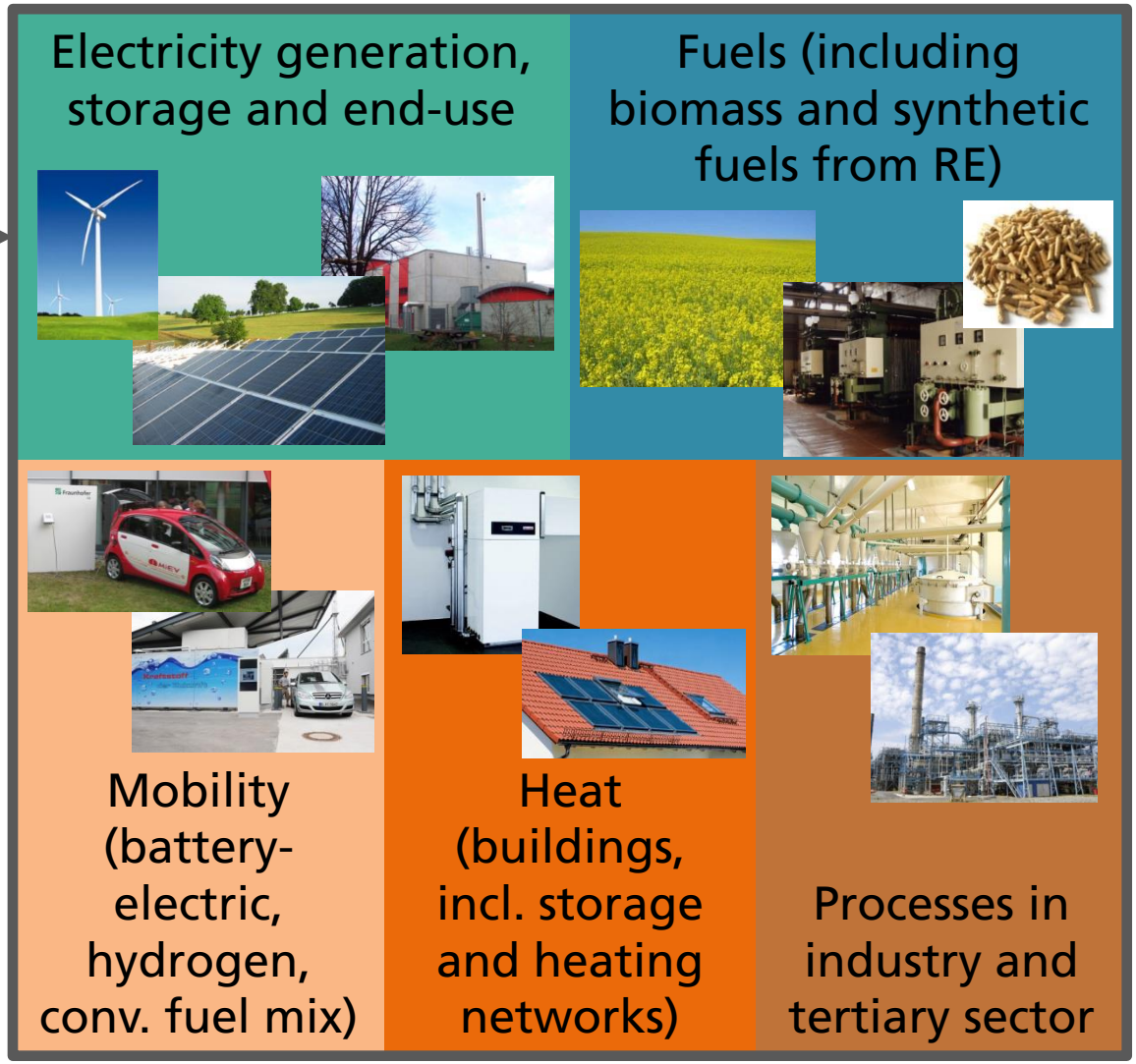
Optimization of Germany's future energy system based on hourly modeling

Comprehensive analysis of the overall system



REMod-D

Renewable Energy Model – Deutschland

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Optimization approach

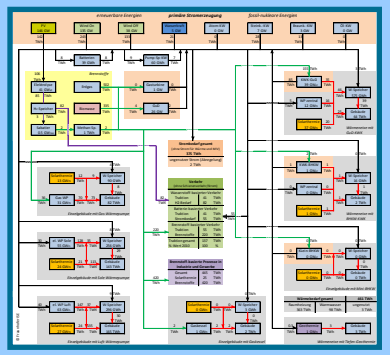
Assumptions

CO_2 emissions ➔ available amount of fossil energy sources

Other assumptions (e.g. available biomass resources for energy use)

Optimizer

minimize total annual cost



Results: optimized values for

- installed capacity of energy converters
- size of storages
- range of building energy retrofit
- heating technology mix (including district heating networks)

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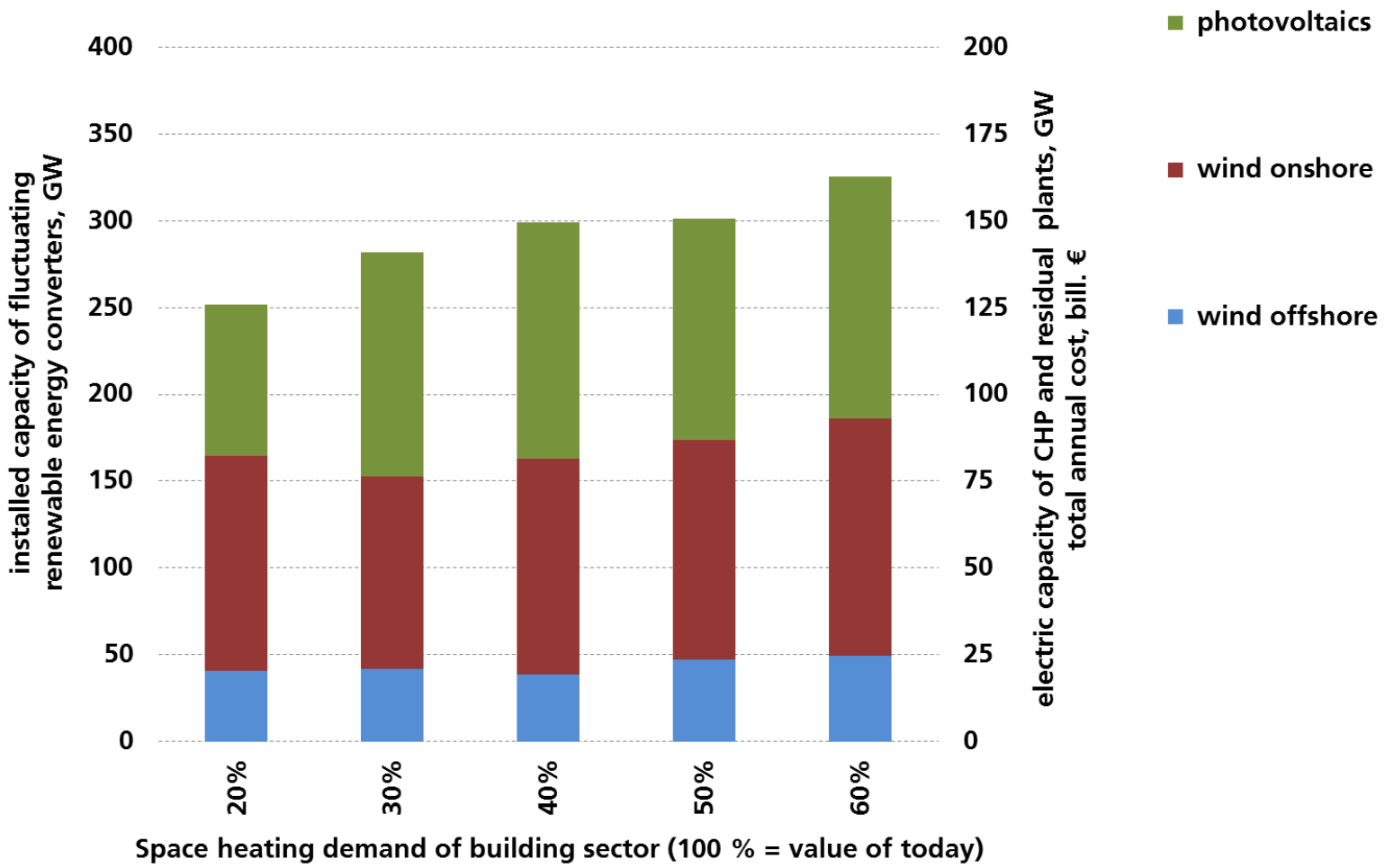
Fluctuating renewable energy sources

Installed capacity in GW_{el}



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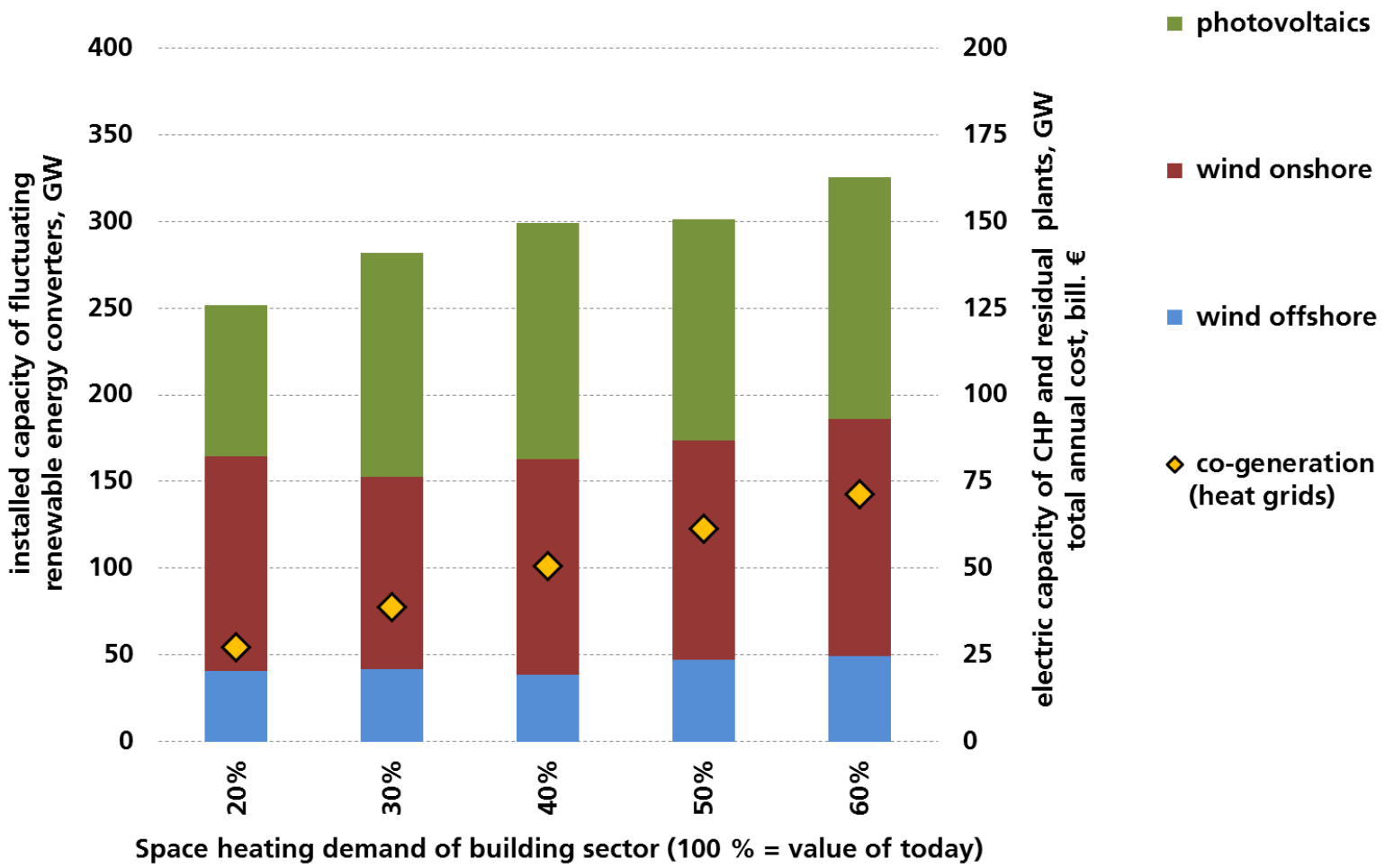
Medium and large scale CHP systems (district heating)

Installed capacity in GW_{el}



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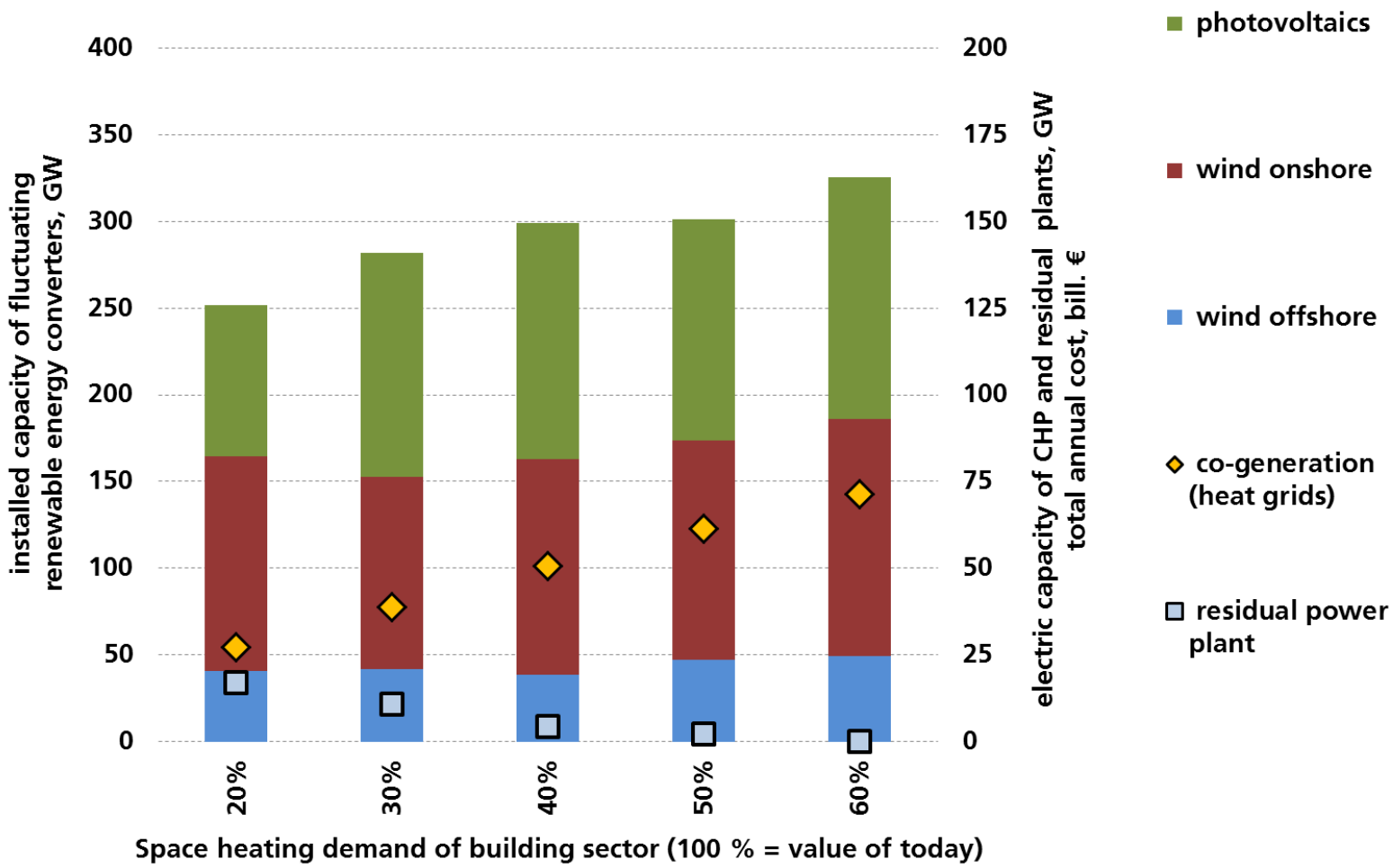
Backup power plants

Installed capacity in GW_{el}



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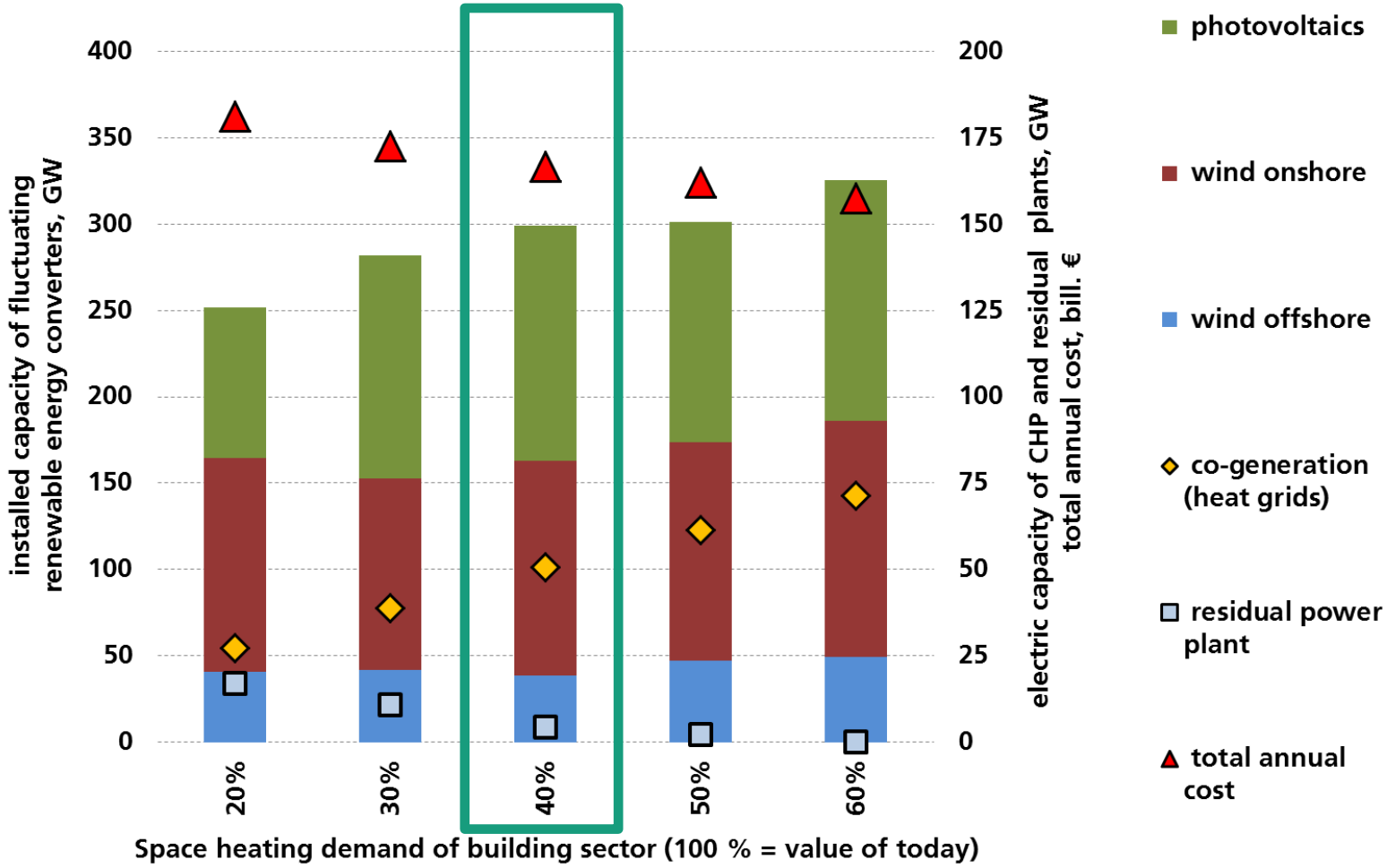
Total annual cost

Bill. €

Analysis of a selected system (next slides)



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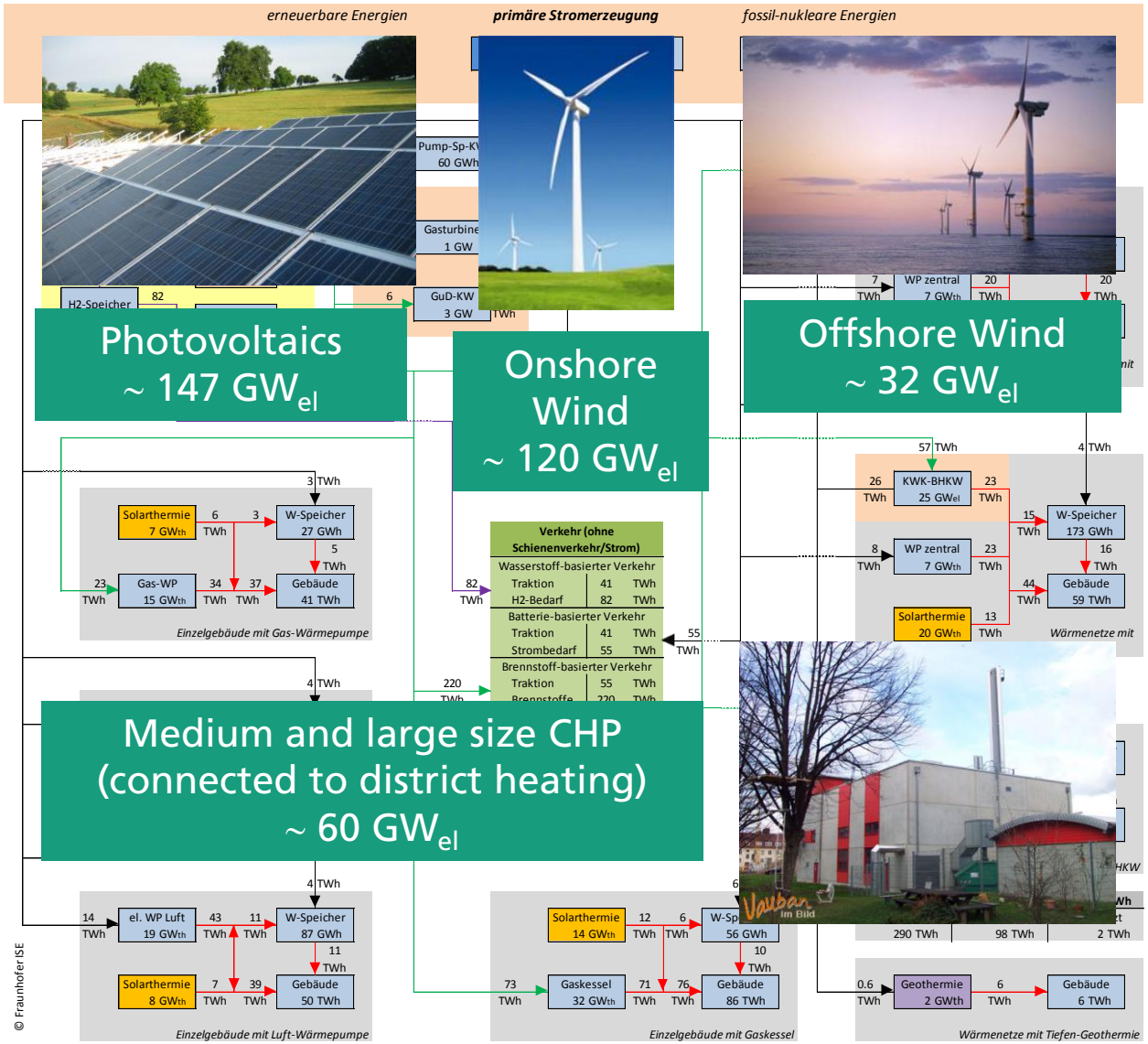
Electricity generation



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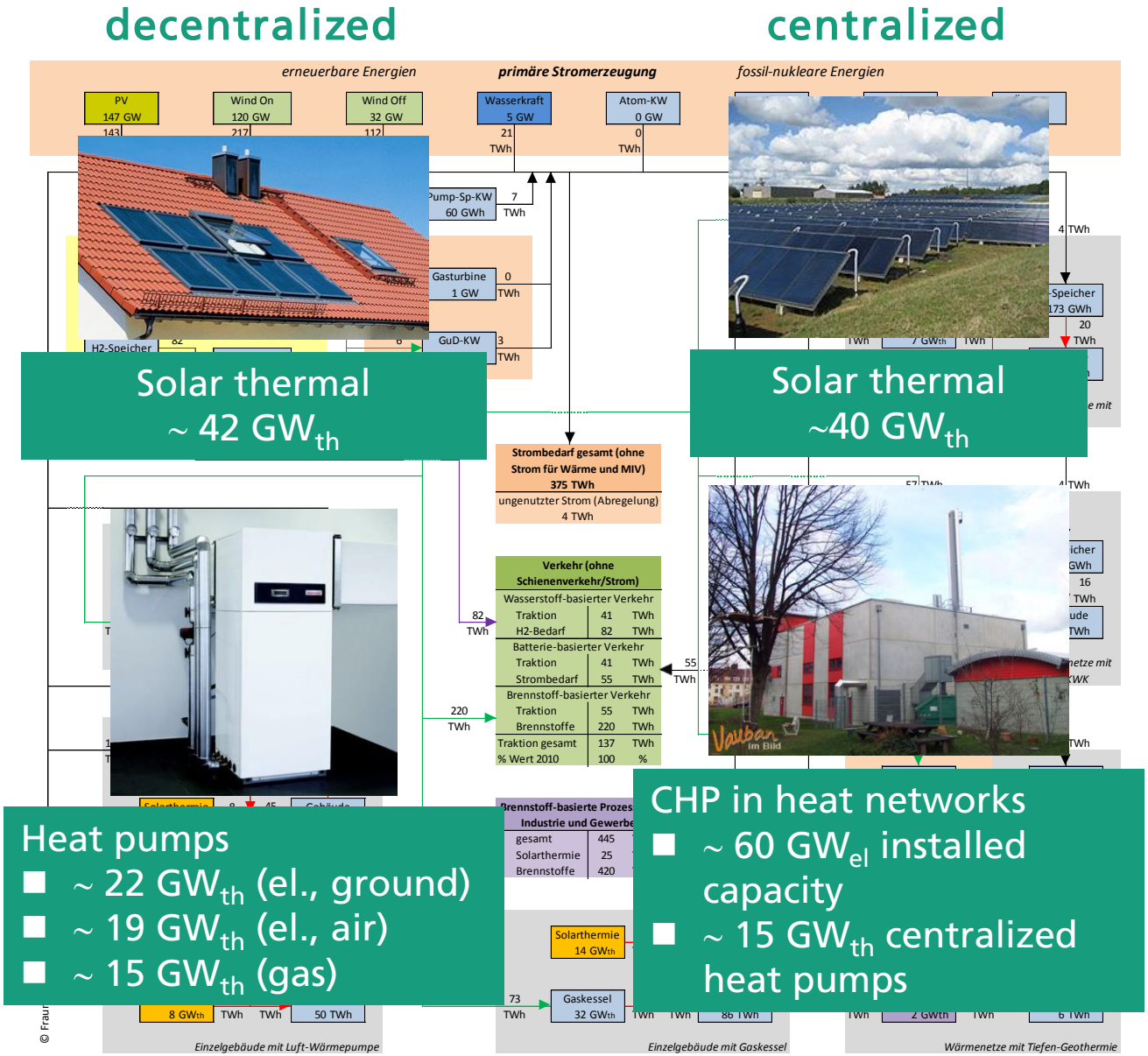
Heat



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Storage

Stationary batteries
Total ~24 GWh (e.g. 8 Mio units with 3 kWh each)

Pumped storage power plants
42 units with a total of 60 GWh

Electrolysers with total capacity of 33 GW_{el} (needed for mobility)

Heat buffers in buildings
Total ~320 GWh (e.g. 7 Mio units with 800 Litres each)

Large scale heat storage in district heating systems
Total ~350 GWh (e.g. 150 units with 50.000 m³ each)

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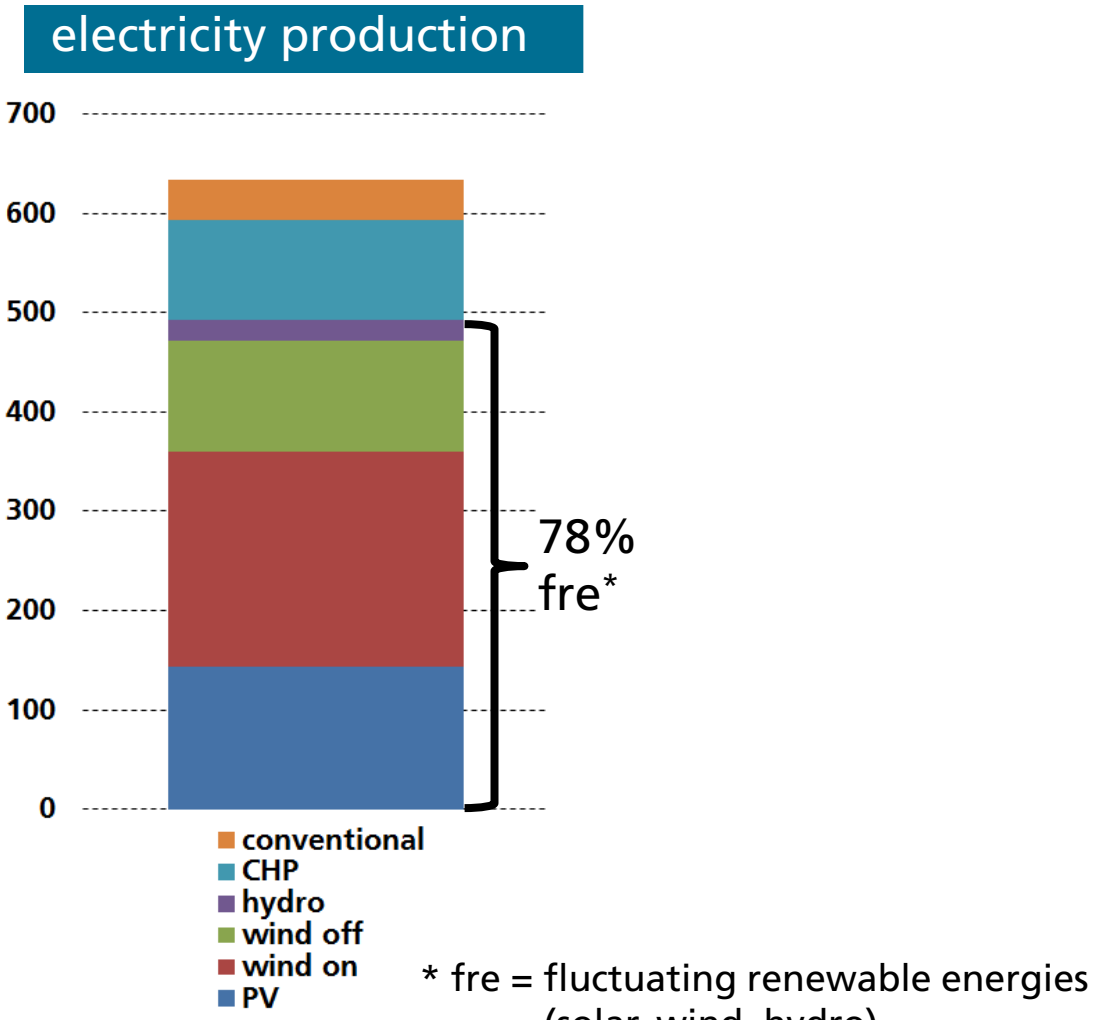
Annual energy balance (TWh)



* fre = fluctuating renewable energies (solar, wind, hydro)

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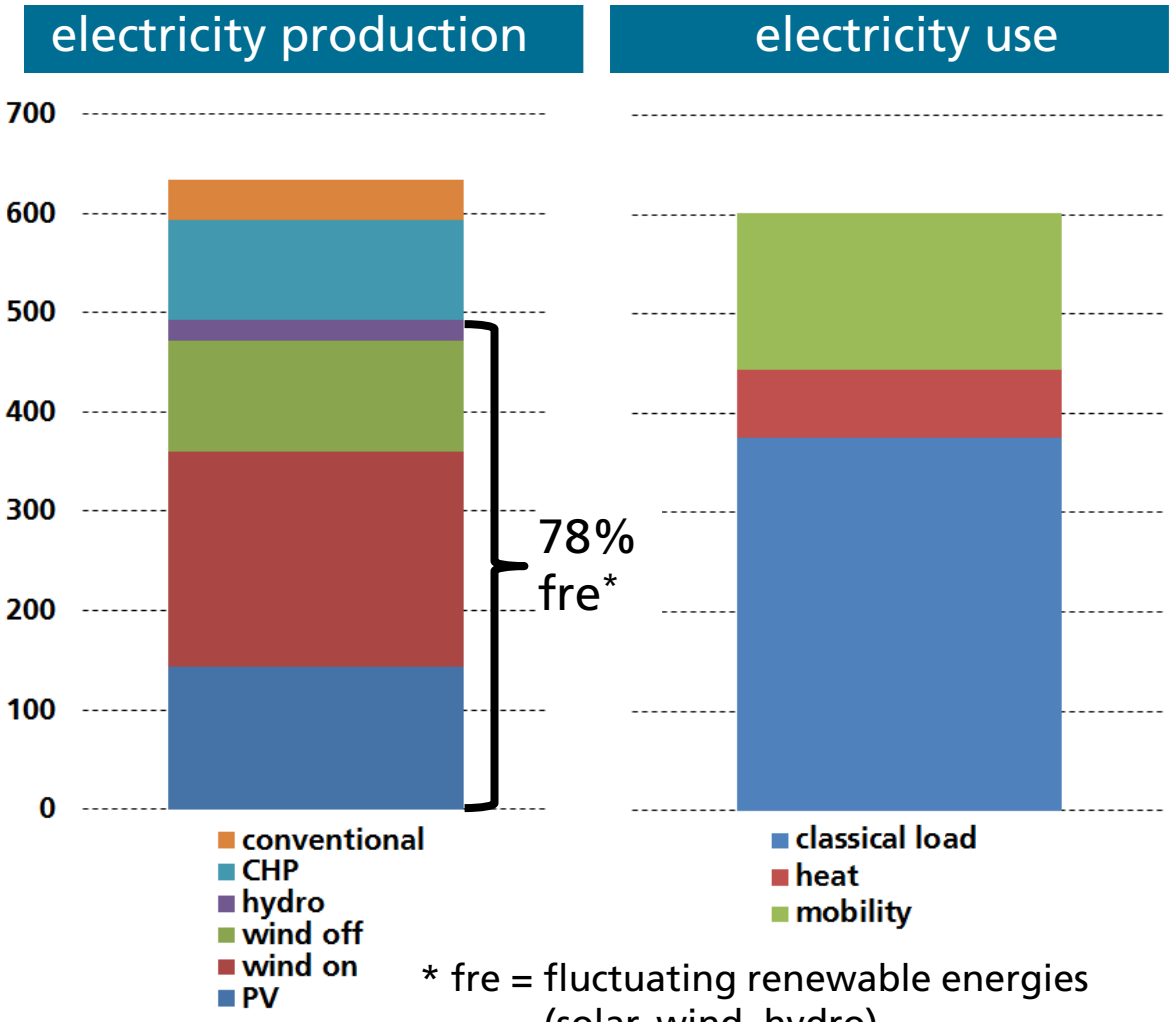

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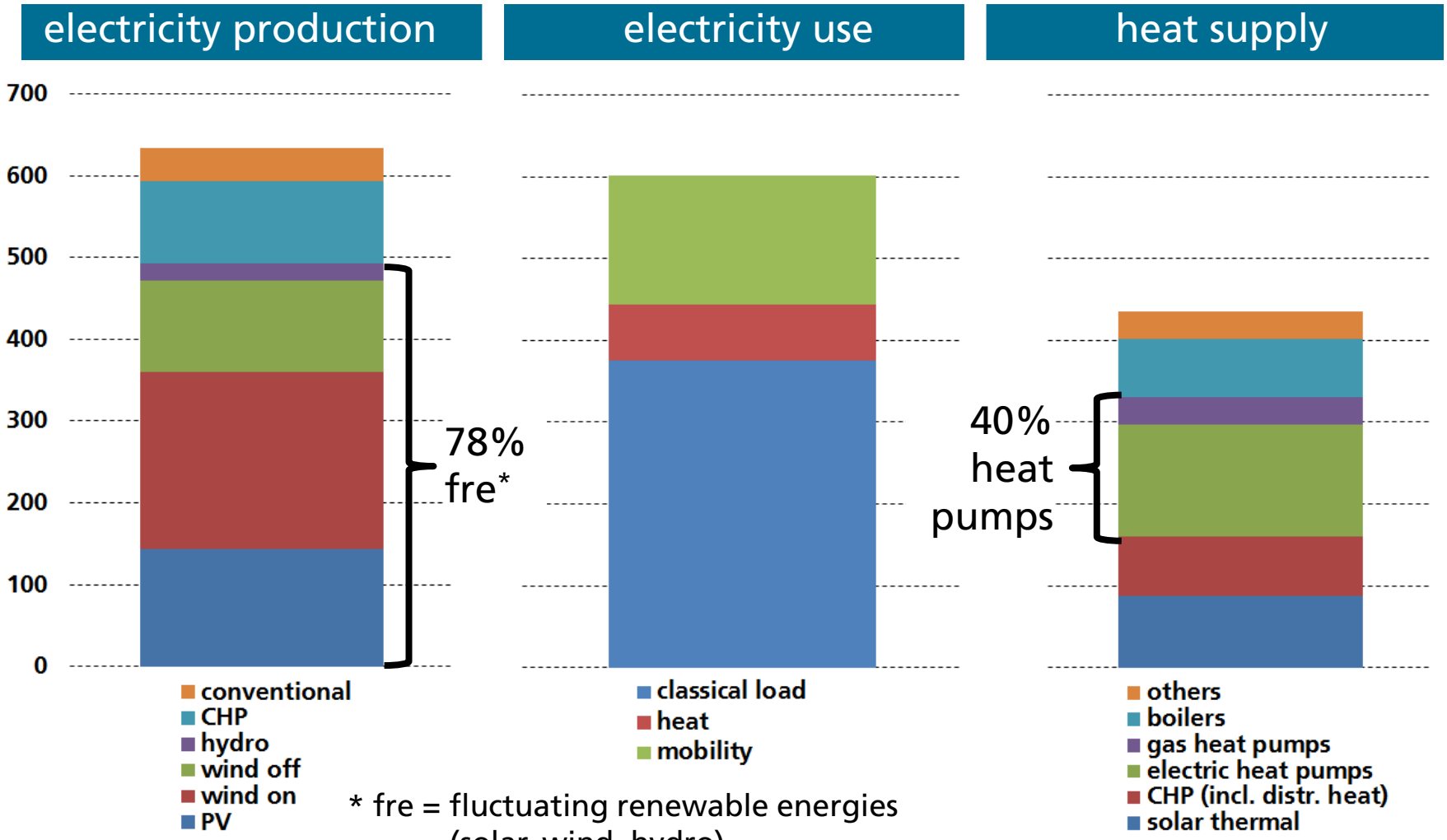

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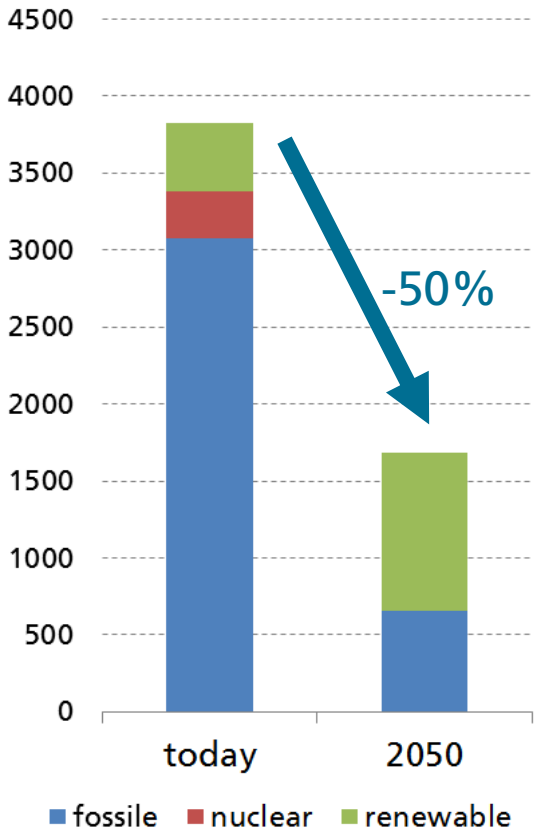
Overall comparison

Today vs. 2050 optimized system

primary energy (TWh)



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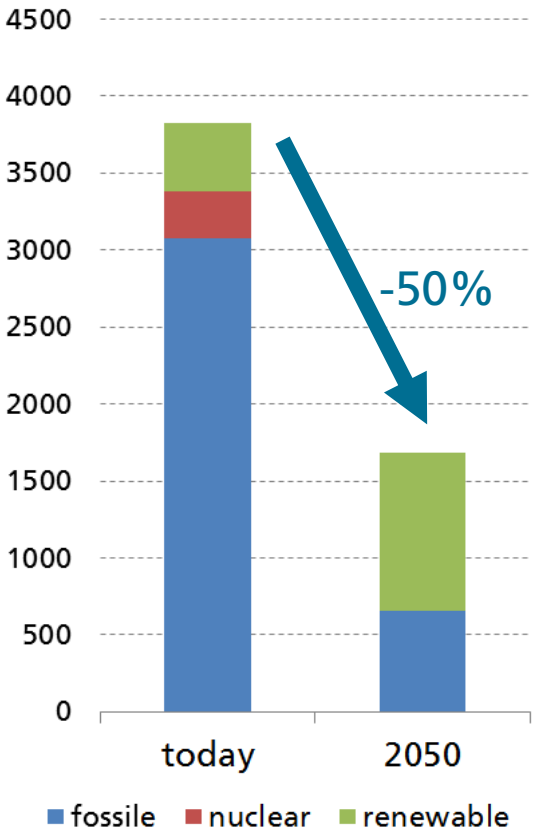
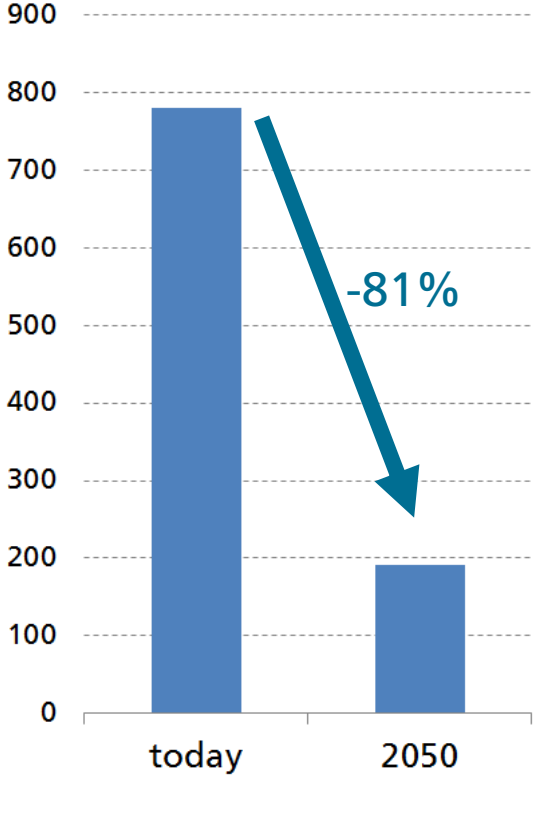


CO_2-emissions (Mio t)



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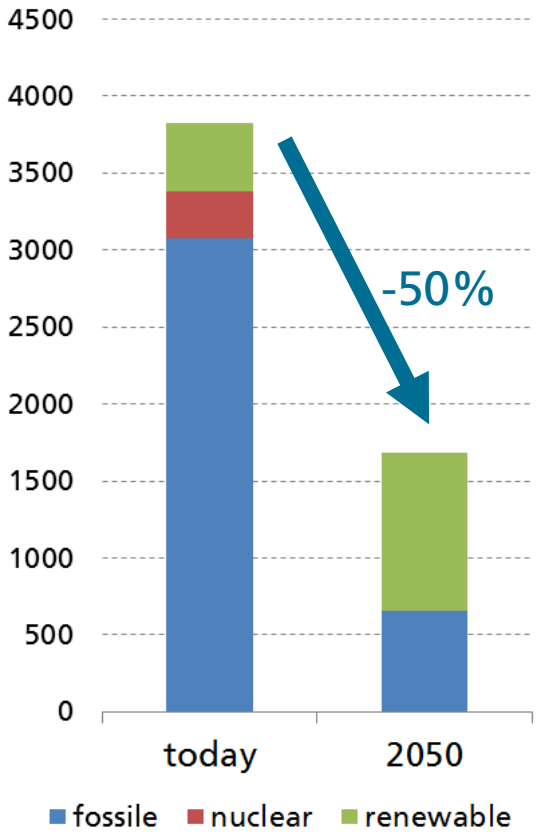

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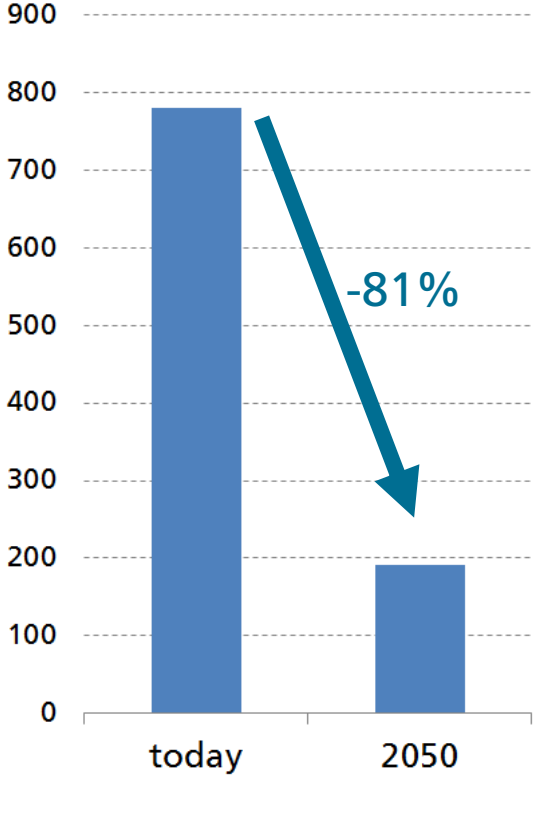
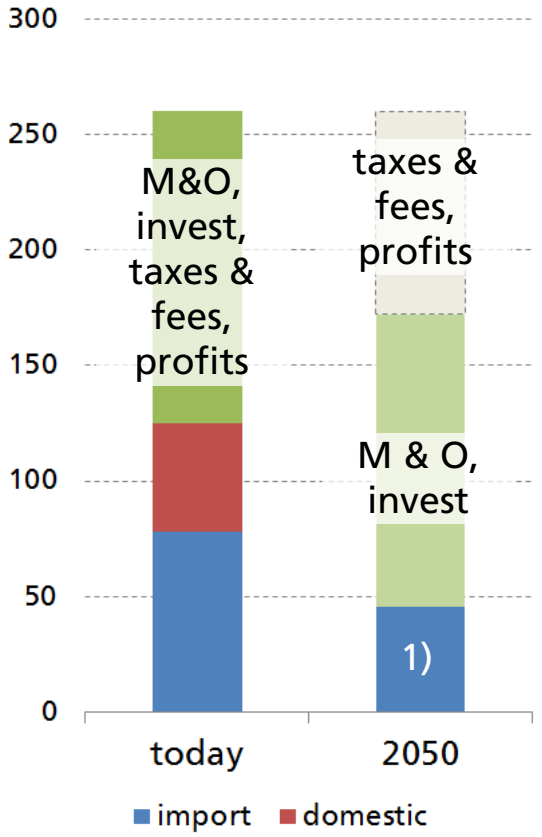


annual cost (bill. €$_{2014}$)



1) Assumed doubling of fossil energy prices until 2050

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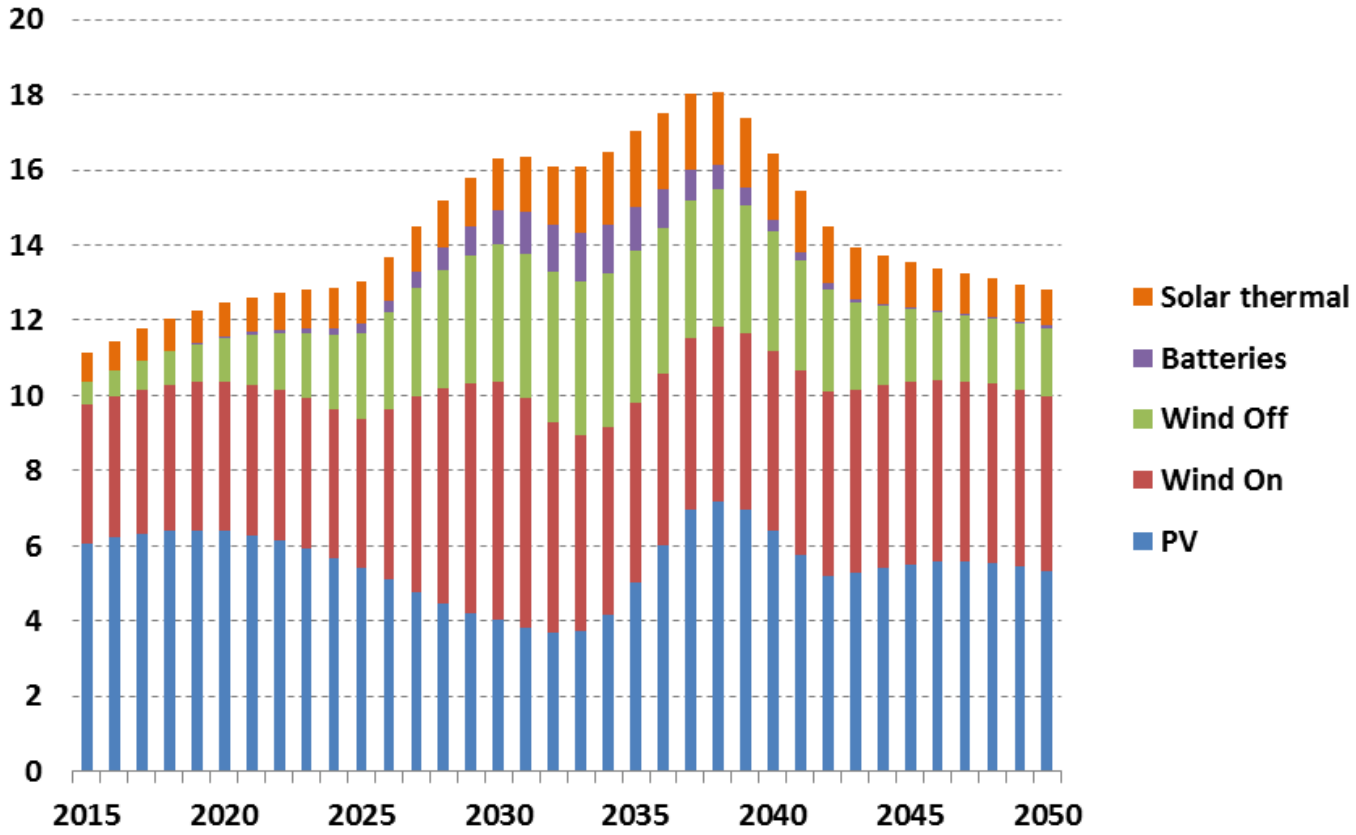
Investments for RE (wind, solar) and stationary batteries

Bill € p.a. (incl. repowering)



Total investments (w/o capital cost, incl. re-powering) from 2015 to 2050: 515 bill. $€_{2014}$

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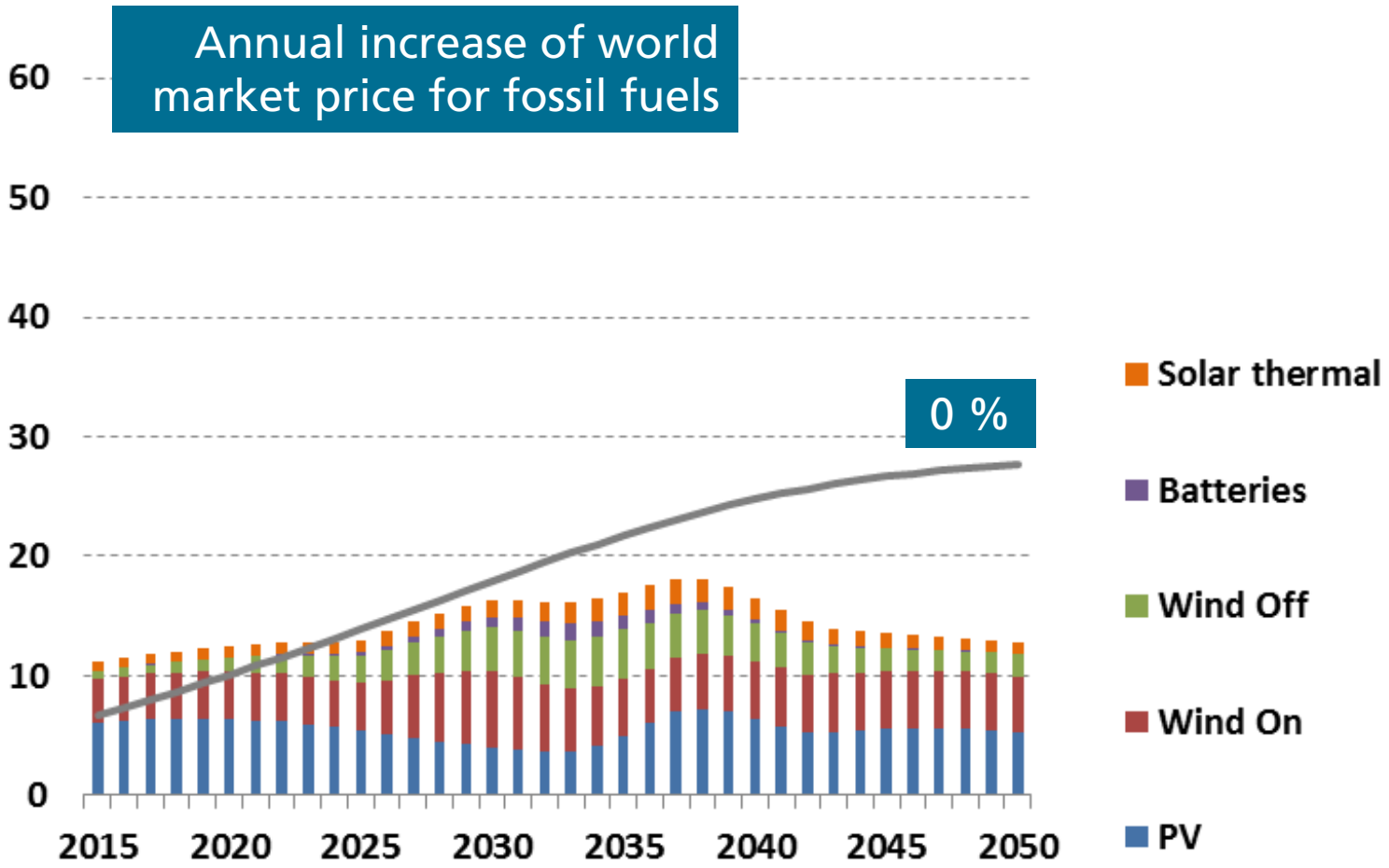
Investments vs. saved fuel cost in bill. € p.a.



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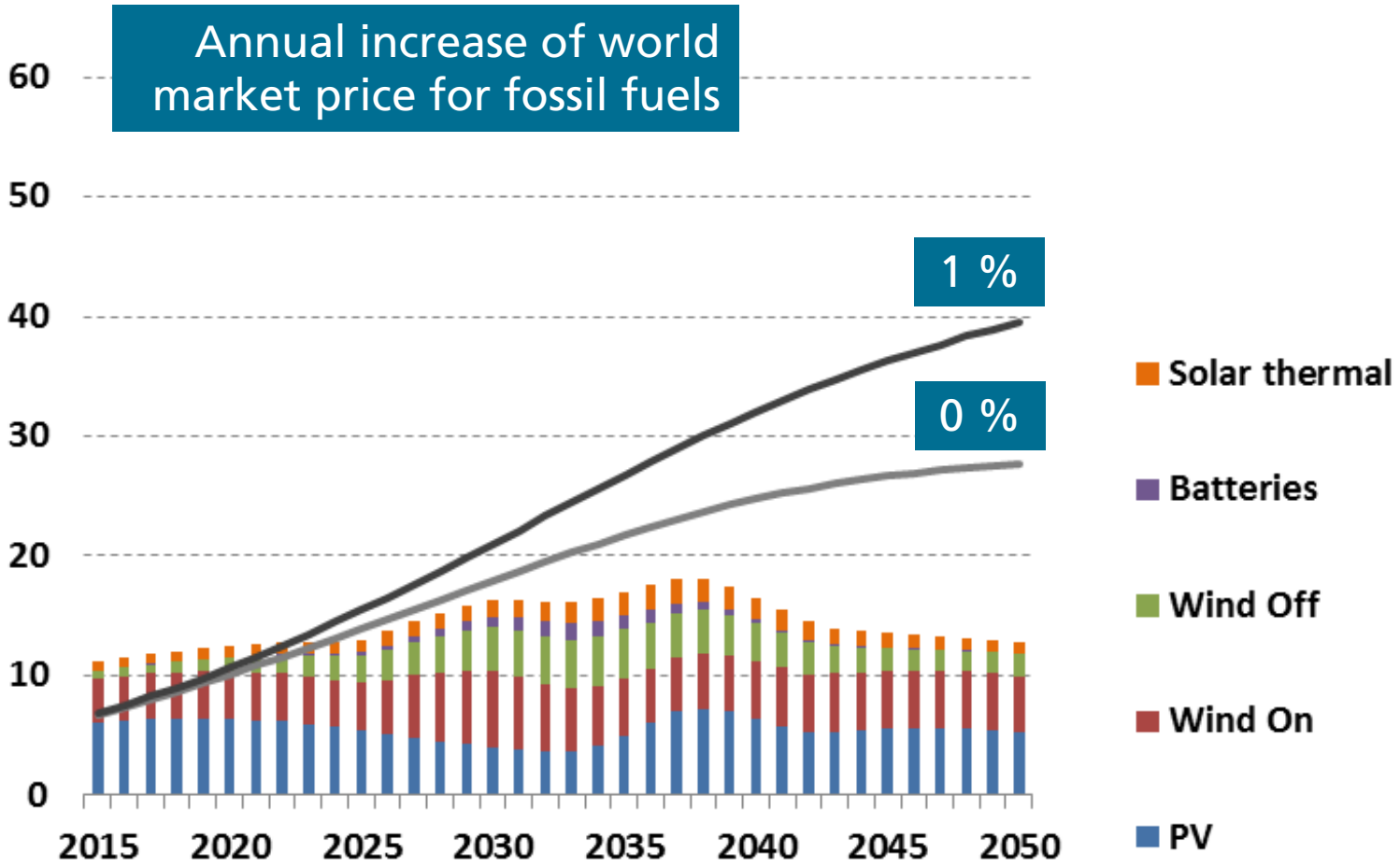

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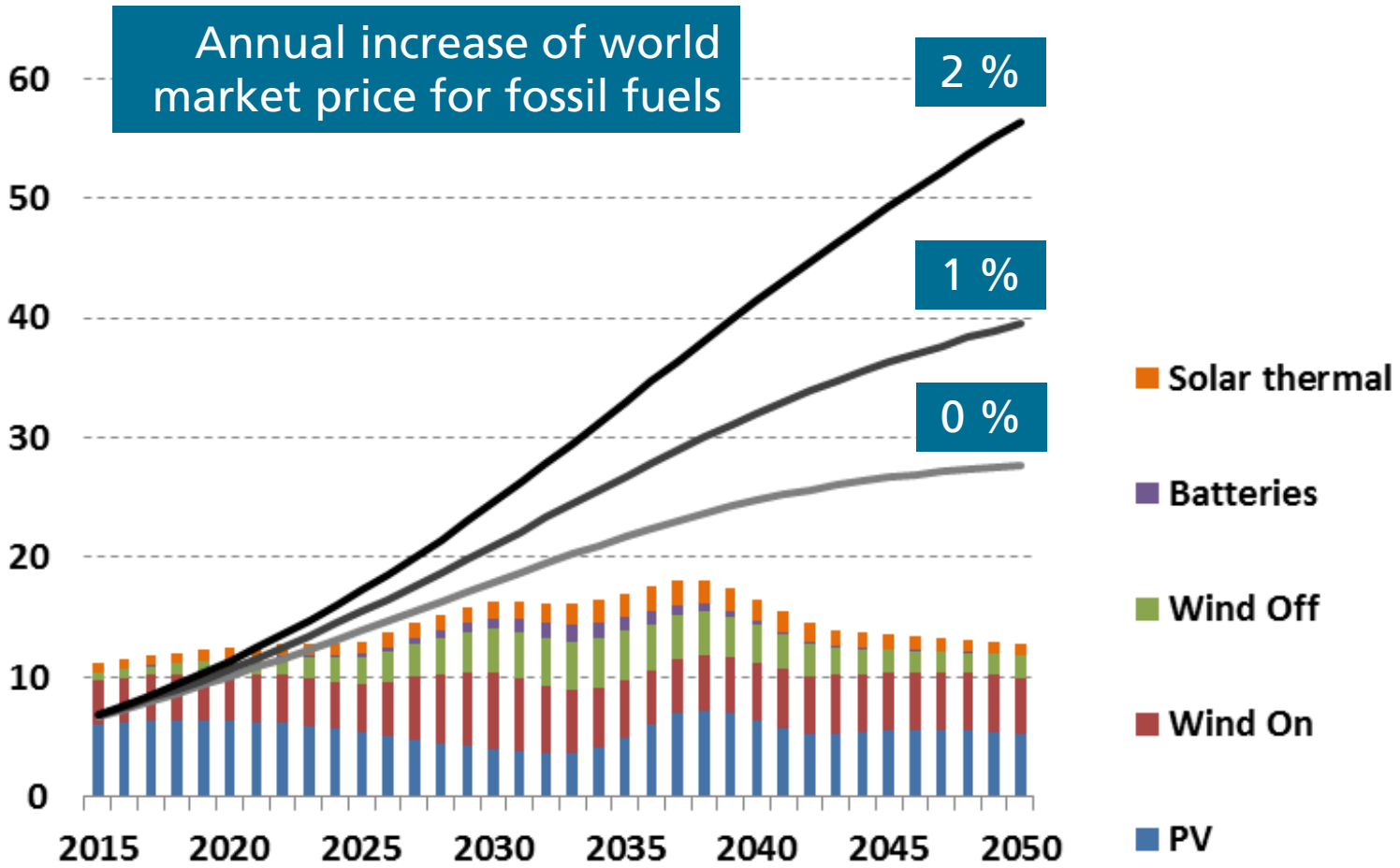

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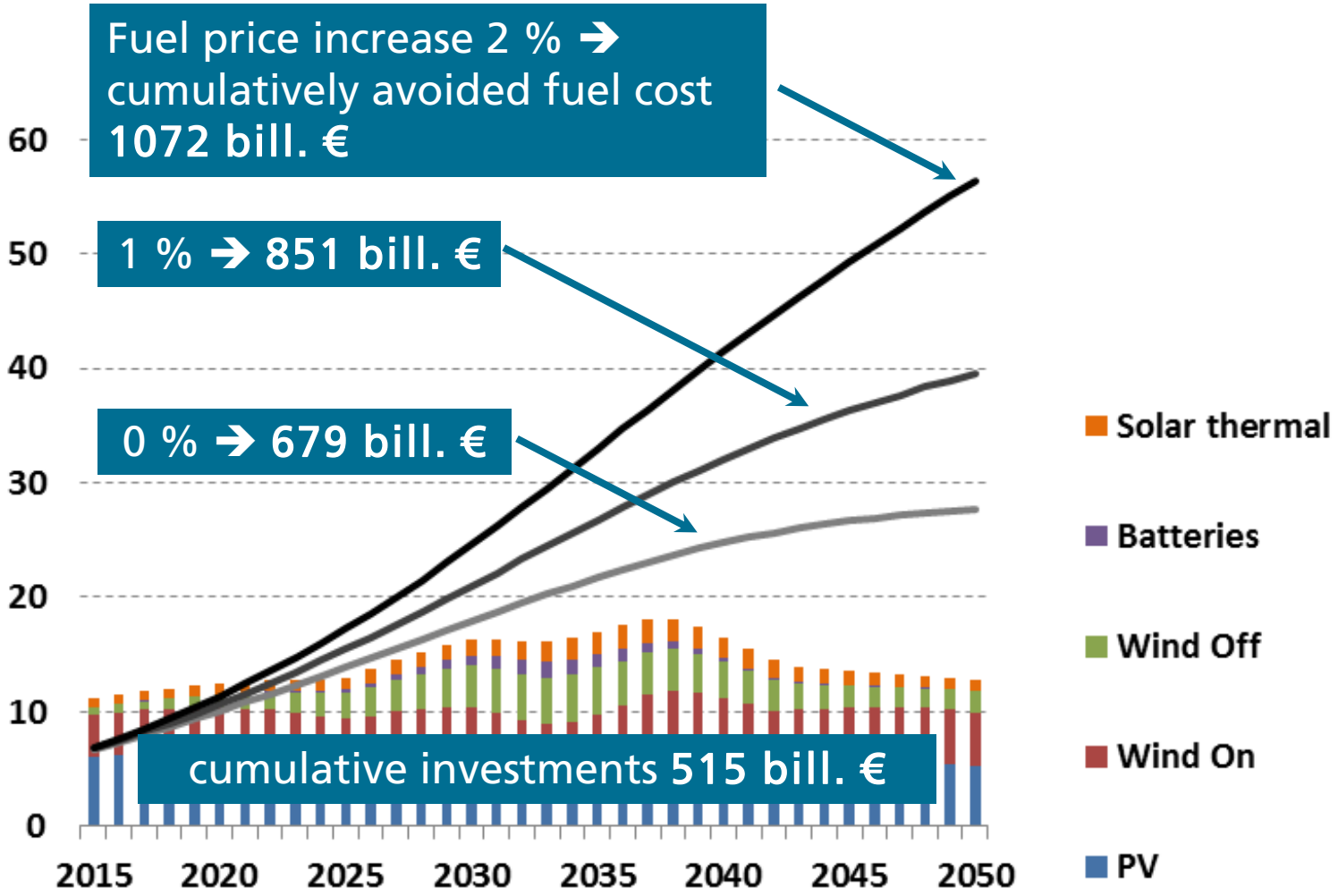

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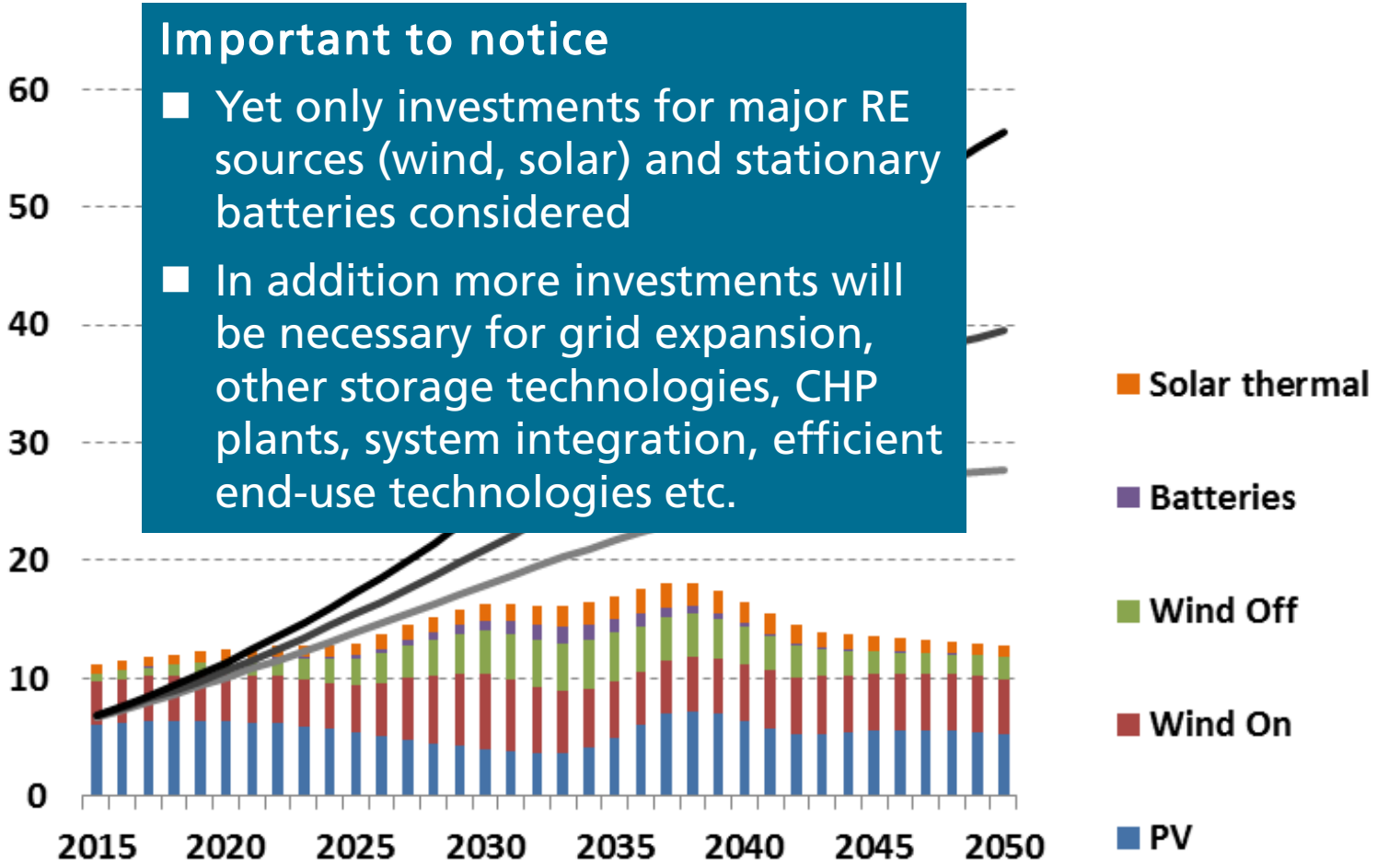

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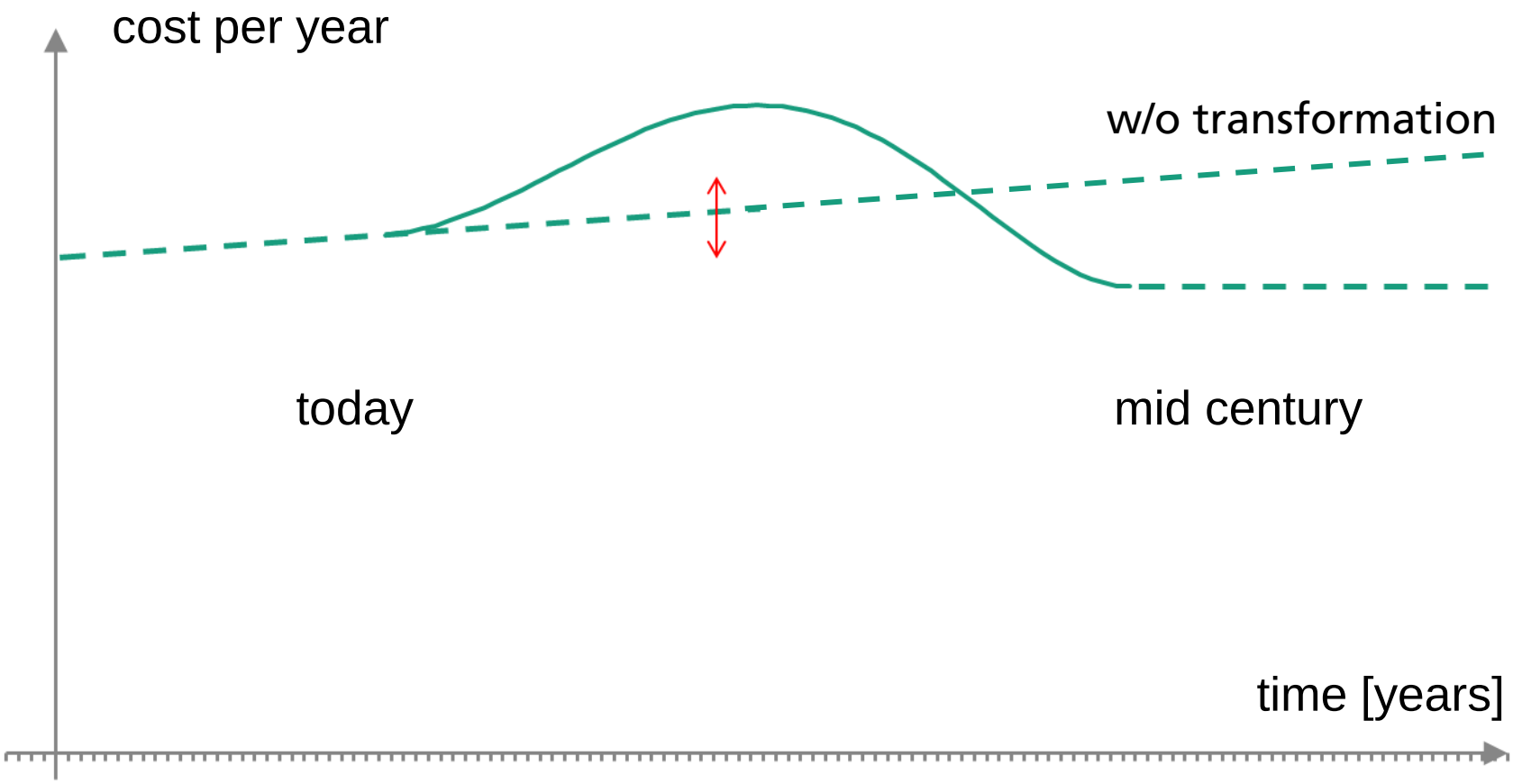
Transformation of the energy system

Qualitative trend of total annual cost



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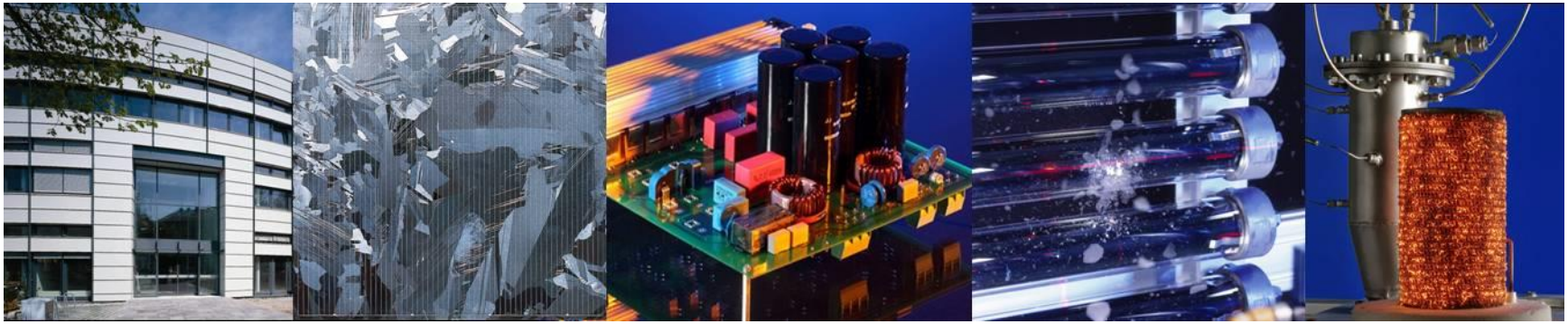
Summary 1/2

- Reduction of energy-related CO_2 emissions by 80 % and above possible
- Lower cost at least on long term
- Significantly reduced dependence on imports of energy resources
- Key elements of the transformation
  - Reduction of consumption (e.g. classical electricity consumption, space heating)
  - Efficient conversion chains (e.g. electric engines and heat pumps replacing combustion processes)
  - Renewable energies (electricity, heat)
  - New overall system design with high level of integration

Summary 2/2

- Flucutuaing renewable energies (wind, solar PV) become backbone of electricity generation and dominate the overall system
- Flexibilization of residual electricity production and electricity use in all end-use sectors (mobility, heating) needed
- Investments needed for components and systems in all energy conversion and end-use sectors ➔ Many groups of investors including citizens
- Significant local value and employment creation
- Results can be transferred to other industrialized regions or countries

Thank you for your attention…



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